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Analysis

The value of cooperation for biodiversity conservation policies

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ABSTRACT

Collective schemes are promising tools for improving biodiversity conservation policies within rural landscapes. Yet, despite being at the core of their design, cooperation and its underlying mechanisms have seldom been addressed explicitly by the literature on the topic. Our paper addresses this gap in the case of the agglomeration bonus (AB), by assessing the benefits of landowners' cooperation in conserving biodiversity through ABs with varying degrees of "collectiveness" (i.e., differing in terms of the "rules" governing landowners' enrollment into the AB). Methodologically, we couple an ecological-economic model with a group formation game to endogenize both landowners' cooperation and conservation responses to ABs characterized by different *landowner-level* enrollment rules and *plot-level* payments. Solving the model numerically on fictitious landscapes, we show that larger groups conserve biodiversity more cost-effectively. Findings indicate that the "value of cooperation" – defined as the difference in biodiversity achieved through collective vs. individual responses to the same plot-level payments – amounts to between 10 and 45 percent. As it leads to the highest degree of cooperation, we show that "open-list ABs" are generally the most cost-effective schemes, followed by "closed-list ABs" (where, contrary to open-list ABs, landowners can exclude someone from the group), "individual ABs" (where "groups" are limited to one landowner), and, finally, standard homogeneous payments (where bonuses are null). These results stress the importance of the very design of collective schemes to boost the effectiveness of conservation policies.

1. Introduction

Biodiversity conservation requires not only to conserve natural habitats, but also to arrange them in suitable landscape-level configurations, such as in agglomerated patches or specific networks (Fahrig, 2003; Bennett et al., 2006). The challenge for policymakers is that landscape ownership is fragmented across many landowners (Drechsler, 2023), which limits the ability of traditional voluntary schemes targeting individual holdings to deliver such favorable configurations, as they only induce uncoordinated conservation responses (Nguyen et al., 2022). In contrast, collective schemes – encouraging landowners to cooperatively decide on their conservation efforts – are increasingly seen as promising tools to overcome this limitation (Westerink et al., 2017; Kotchen and Segerson, 2019, 2020). Reflecting this trend, collective approaches are now being implemented in a growing number of countries (Kaiser et al., 2023), including the U.S. (Grout, 2009), Japan (Shimada, 2020), Switzerland (Häusler and Zabel, 2024), France (Limbach and Rozan, 2023), or the Netherlands (Barghusen et al., 2021).

The literature on collective schemes is also rapidly expanding (Kaiser et al., 2023), especially focusing on the so-called "*agglomeration bonus*" (Nguyen et al., 2022). First proposed by Parkhurst et al. (2002), the agglomeration bonus (AB) encourages landowners to agglomerate their conservation efforts by adding a bonus for adjacent conserved plots on top of a flat homogeneous payment (HP). An increasing number of theoretical (Albers et al., 2008; Wätzold and Drechsler, 2014; Bareille et al., 2023; Bareille and Soubeyran, 2025), experimental (Liu et al., 2019; Banerjee et al., 2021; Kuhfuss et al., 2022) and empirical (Krämer and Wätzold, 2018; Huber et al., 2021) analyses show that collective schemes – beyond the special case of the AB – are overall more cost-effective for biodiversity conservation than pure HPs. Yet, even though the notion of "collective schemes" recalls the idea of *group decision-making*, with few exceptions (e.g., Banerjee et al., 2021; Bareille et al., 2023), the collective dimension of the problem has not been explicitly taken into account. Questions like "*what are the gains in conservation arising from cooperation*?" and, if any, "*how schemes should*

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be designed to boost them?" have indeed received little attention from the literature.

The objective of this paper is to fill this gap in the particular case of the AB, by characterizing the benefits of landowners' cooperation in conserving biodiversity through schemes with varying degrees of "collectiveness". In practice, we compare the performance of four schemes implemented in reality. In collective schemes, the common idea is that landowners voluntarily form groups and collectively contract with the regulator; yet, they differ in the way cooperation is achieved as it depends on the "*enrollment rules*" set by the regulator. In the first collective scheme considered, group formation is based on landowners' autonomous initiative ("*closed-list AB*" henceforth): landowners join groups only if they are accepted by all of the group members.[1] In the second, cooperation is managed through open lists ("*open-list AB*"): landowners can freely join existing groups, with no possibility for group members to exclude newcomers.[2] We compare these two collective schemes with two individual schemes, namely: (i) an AB where landowners can only apply individually ("*individual AB*"),[3] and (ii) pure (standard) HPs.[4]

We compare these four schemes in two ways. First, we assess the "*value of cooperation*" – defined as the biodiversity gains achieved from collective vs. individual responses to the same pair of flat and bonus payments. Second, we evaluate the "*scheme cost-effectiveness*" – defined as the amount of biodiversity achieved per level of total public expenditure. These two complementary metrics allow us to highlight the benefits of collective schemes, but also those of the different enrollment rules designed by the regulator. Indeed, different enrollment rules – designed at the *landowner-level* – may affect the composition of cooperating groups formed in response to the same pair of payments (designed at the *plot-level*), ultimately affecting both conservation and public expenditure at the *landscape-level* – and thus the overall scheme cost-effectiveness.[5] Intuitively, two landowners are likely to agglomerate their conservation efforts to a greater extent when they cooperate than when they act individually, as it allows them to obtain additional bonuses at the borders of their respective landholdings. Thus, biodiversity conservation is presumably higher when landowners cooperate in larger groups. Yet, the additional bonuses to reward landowners' cooperation generate larger expenditures for the regulator, such that the effects of cooperation on scheme cost-effectiveness remain an open question.

To tackle this issue, we use an abstract spatially-explicit ecological-economic model simulating landowners' response to the different schemes. We frame the two collective schemes by introducing the ecological-economic model into a two-stage *group formation game* where landowners first decide individually with whom to cooperate (a landowner-level decision), before cooperatively choosing their conservation efforts (a plot-level decision). This allows us to endogenize both group formation and conservation decisions in any collective scheme (notably by changing the enrollment rules; i.e., *closed-* vs. *open-list ABs*).[6] In contrast, we model individual ABs and HPs by assuming that landowners act as singletons and cannot cooperate. We accordingly compute, for each scheme, both (i) the resulting biodiversity and (ii) total public expenditure, whose ratio measures (iii) scheme cost-effectiveness.

Numerically solving the model for a set of fictitious landscapes made of several multi-plot landholdings, we find that the extent of landowners' cooperation does affect their conservation decisions. All of our results actually point to a positive (conservation) value of cooperation. For the same pair of flat and bonus payments, bigger groups leads to (i) more landowners choosing to conserve habitat (the "*extensive margin*" of conservation henceforth), (ii) greater habitat provision per landowner ("*intensive margin*"), and (iii) more spatially clustered habitat patterns ("*agglomeration margin*"). As a result, we find that the two collective ABs provide more biodiversity than the individual AB under identical plot-level payments. On average across our preferred simulations, we find that the value of cooperation is between 10 and 45 percent over a wide range of bonuses.

The advantage of collective schemes also appears when looking at the scheme's cost-effectiveness. The higher cost-effectiveness of collective ABs means that the additional conservation achieved by cooperating groups – compared to independent landowners in individual ABs – is relatively greater than the additional budget required to do so. The two contrasted enrollment rules have however different impacts on the collective schemes' cost-effectiveness. For sufficiently large budgets (i.e., for large public expenditure from regulators to landowners), open-list ABs are more cost-effective than closed-list ABs as they lead to larger cooperating groups (the possibility of rejecting new members constrains group size in closed-list ABs). Despite being less cost-effective than the two collective ABs, we find that individual ABs lead to more cost-effectively conserved landscapes than those reached with pure HPs.

We make multiple contributions. The first one relates to the AB literature, which has mostly focused on the design of payments to encourage the spatial agglomeration of conservation efforts, but largely setting aside the challenges raised by cooperation. Most studies indeed either assumes individual enrollments (Parkhurst et al., 2002; Parkhurst and Shogren, 2007; Banerjee, 2018) or full cooperation (Wätzold and Drechsler, 2014; Drechsler, 2023) – two limiting cases that fail to capture how cooperation actually emerges in collective ABs. Only a few studies – namely Banerjee et al., 2021, Bareille et al., 2023, and Bareille and Soubeyran, 2025 – have endogenized group formation within ABs. Building on these works, we consider two new enrollment rules that shape how cooperation unfolds: the *open-list* and *individual* ABs, which complement the previously studied *closed-list* ABs. Comparing these three rules shows that the way groups form critically determines both the stability of cooperation and AB cost-effectiveness, therefore showing that the governance of cooperation – far from being neutral – is a key design dimension for the success or failure of ABs.

Second, building directly on the previous contribution, we move from the mere *design* of cooperation to quantify its *value*, introducing the concept of the "value of cooperation for conservation". This concept

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[1] This corresponds to the case examined by Bareille et al. (2023) and implemented in reality in Switzerland (Krämer and Wätzold, 2018; Huber et al., 2021; Häusler and Zabel, 2024).

[2] This case has not been studied by the literature, though it aligns with real-world schemes (Barghusen et al., 2021). The only difference between closed- and open-list ABs is the ability to refuse members.

[3] This case closely matches those in Malawi (Ward et al., 2021) or those investigated by most experimental papers (Parkhurst et al., 2002; Parkhurst and Shogren, 2007; Banerjee et al., 2017).

[4] Existing in most countries, HPs serve as benchmark in this paper. Unlike previous schemes, their incentives do not target habitat agglomeration but are based solely on a flat per-hectare basis.

[5] Total expenditure from the regulator towards the landowners may differ in the alternative schemes *even for the same payment structure* (i.e., the same pair of flat and bonus payments). Indeed, given that *only* the between-plot connections declared *within the same conservation project* are rewarded (Krämer and Wätzold, 2018), different landowner enrollment rules can lead to different total expenditures via their differentiating effect on group formation.

[6] We model the *open-* and *closed-list* ABs by respectively assuming *open-* and *exclusive membership* rules for group formation. Already used in the literature on international environmental agreements (e.g., Barrett, 1994; Carraro and Marchiori, 2002), these two rules state that, in the open-membership case, landowners are allowed to become members of any group while, in exclusive membership, landowners can enter a group only if they are accepted by the existing members. Note that if we did not endogenize group formation, the differences implied by the two collective AB schemes would collapse. On this aspect, the group formation game proposed by Bareille et al. (2023) allows us to depart from the standard assumption that all of the landowners fully cooperate together within the grand coalition (see below).

provides a unifying lens through which the reader can interpret how different levels of *endogenously-decided cooperation* in collective schemes (here, open- and closed-list ABs) shape both landowners' behavior and biodiversity outcomes in comparison to the same pair of flat and bonus payments in an individual scheme (here, individual ABs). While we do it for the AB, our framework contributes to the wider literature on the performance of collective conservation schemes (e.g., Westerink et al., 2017; Kotchen and Segerson, 2019; Huber et al., 2021; Limbach and Rozan, 2023) by offering a generalizable approach to assess their performance when groups form endogenously rather than being assumed exogenously (as it is almost always the case).

Our third contribution is more applied and policy-oriented. Building on the conceptual and modeling advances described above, we use our simulation framework to derive practical insights for the design of cost-effective collective conservation schemes, whether within or beyond existing ABs. Specifically, our results indicate that open-list ABs tend to be the most cost-effective option. This finding carries important policy implications: it suggests that regulators can substantially improve the cost-effectiveness of existing ABs by relaxing overly restrictive enrollment rules – a reform that would require minimal institutional changes. This result complements those of Bareille and Soubeyran (2025) on the role of bonus differentiation (*within* vs. *between* landholdings) in standard closed-list ABs with endogenous group formation: while they highlight how fine-tuning *plot-level* incentives can improve AB cost-effectiveness, we show that adjusting *landowner-level* enrollment rules offers a powerful and complementary lever.

The paper is structured as follows. Section 2 presents the ecological-economic model, the group formation game, and the alternative enrollment rules underlying it. Section 3 develops the numerical implementation, and Section 4 reports the main outcomes of our simulations. Finally, Section 5 concludes by discussing the implications of our findings and outlining remaining limitations.

2. Framework

2.1. Ecological module

Consider a landscape made of J contiguous plots that are subdivided between I landowners. Each landowner i ($i \in \mathbf{I}$) owns several contiguous plots $\mathbf{F}_i$ (with $j(i) \in \mathbf{F}_i$, $\cap_{i=1}^{I} \mathbf{F}_i = \varnothing$ and $\cup_{i=1}^{I} \mathbf{F}_i = \mathbf{J}$), on which they can either undertake productive activities ($x_{j(i)} = 0$, e.g., agricultural production) or conservation activities ($x_{j(i)} = 1$, e.g., natural habitats).[7]

Denoted $B(\mathbf{x})$, biodiversity depends on the whole landscape land-use pattern $\mathbf{x} = \cup_{i \in \mathbf{I}} \cup_{j \in \mathbf{F}_i} x_{j(i)}$. Both the total number of conserved plots and the distance between them are important drivers of biodiversity conservation, regardless of who owns the plots (the subscripts are adjusted accordingly below). Although not entirely ineffective, conserved habitats that are localized far apart provide limited benefits to species with low dispersal abilities. Following Wätzold and Drechsler (2014), we specify that biodiversity depends on the landscape structure and species' dispersion ability such that:

$$B(\mathbf{x}) = \sum_{j=1}^{J} x_j \sum_{k=1,\ k \neq j}^{J} x_k \mathrm{e}^{-d_{jk}/D}, \tag{1}$$

where d_{jk} is the distance between the centroids of two different plots j and k, and D is the dispersal parameter of the species considered. It is common in this literature to consider a positive D, i.e., to focus on species that benefit from habitat agglomeration (like some butterfly species).[8] Low (positive) D implies that the species finds it difficult to disperse, i.e., that they need more spatially clustered habitats to survive.

2.2. Scheme description

2.2.1. Definition of scheme incentives and constraints

Scheme incentives. The distinctive feature of AB schemes lies in their payment structure, explicitly designed to foster habitat connectivity. Specifically, ABs reward each plot allocated to habitat by a flat payment p, plus a bonus q for each neighboring conserved plot – provided that the two plots belong to the same "conservation project" (i.e., to the same group of landowners enrolling together in the scheme; see, e.g., Krämer and Wätzold, 2018). Denoting by $\mathbf{N}_{j(i)}$ the set of neighboring plots of plot $j(i)$ within the same conservation project, the plot-level benefit $P_{j(i)}$ is:

$$P_{j(i)} = c_{j(i)}(1 - x_{j(i)}) + p x_{j(i)} + q x_{j(i)} \sum_{k \in \mathbf{N}_{j(i)}} x_k, \tag{2}$$

where $c_{j(i)}$ is the opportunity cost of habitat for plot $j(i)$. The plot-level benefit $P_{j(i)}$ therefore includes both the income from non-conservation land use (first term) and the additional payments obtained under the AB scheme (subsequent terms). In particular, the bonuses can accumulate for the same plot if $\mathbf{1}^{\top}(\mathbf{N}_{j(i)}) > 1$ (i.e., if there are several neighboring conserved plots within the same project). Note that $q = 0$ in Eq. (2) describes the problem of participation in a pure HP scheme.

Landowner-level land-use constraint. As in the experimental literature (e.g., Parkhurst et al., 2002) and in most real-world implementations of conservation schemes (e.g., Limbach and Rozan, 2023), we introduce a constraint on the maximum area per landholding that can be enrolled in the scheme. Denoted by $\overline{\mathrm{X}}$, it translates as an additional constraint on landowners' programs, such that:

$$\sum_{j \in \mathbf{F}_i} x_{j(i)} \leq \overline{\mathrm{X}}. \tag{3}$$

This constraint applies to both AB and HP schemes.[9] In addition to increasing the realism of the four schemes considered in the paper, such a constraint – absent from Bareille et al. (2023) and Bareille and Soubeyran (2025) – provides the secondary benefit of steering the differences across the conservation outcomes from the different schemes. In its absence, agglomeration of conservation efforts could arise spontaneously as more and more plots become enrolled in the scheme (see Section 4.1), hiding potential systematic differences between the alternative schemes.

2.2.2. Collective enrollment

We model collective ABs by formulating a *two-stage group formation game* where each landowner decides which group to join in the *first stage* (based on non-cooperative game principles), and members jointly decide on conservation efforts to maximize the aggregate utility of the group they belong to in the *second stage* (based on cooperative game principles). While the overall logic of our model closely follows Bareille

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[7] Note that the notation x_j indicates the same plot as in the notation $x_{j(i)}$. The difference is that land ownership is not indicated in the first notation, while it is in the second. Additionally, note that bold elements indicate vectors, while italic terms indicate scalars. For example, $\mathbf{I}$ is the vector of landowners, such that $\mathbf{I} = \{1, \ldots, I\}$.

[8] Bamière et al. (2013) examine similarly the merits of the "agglomeration malus", a scheme designed to conserve species benefiting from spatially dispersed habitats (e.g., the little bustard). In their case, the dispersal parameter D is negative.

[9] For example, European farmers are authorized to enroll a maximum of ten percent of their whole useful agricultural area within most agri-environmental schemes – whether or not collective – proposed within the framework of the common agricultural policy (e.g., Limbach and Rozan, 2023). For the simulations, we implement a constraint of about 50%, and test the robustness of our results with a constraint of 25% or in the absence of constraints. Section 4.3 shows that our main conclusions are robust to the level of constraints used in the model.

et al. (2023) and Bareille and Soubeyran (2025), we relax their assumption of a unique *exclusive membership* rule governing group formation in the first stage, and introduce alternative enrollment rules instead. We analyze the game by reasoning backward – that is, starting with the second-stage decision.

Second stage: conservation decisions. A key feature of collective schemes is that landowners are allowed (and encouraged) to cooperate. To introduce this element, we model conservation decisions as if landowners aim to maximize the utility of the groups (or *coalitions*) they belong to (determined in the first stage, see below).[10] We also assume that cooperation involves some coordination costs $K(|\mathbf{S}_k|)$, that depend only on the size of the group $|\mathbf{S}_k|$ – which adds to the opportunity costs of conservation. Denoting the composition of any of such a group by $\mathbf{S}_k$ (i.e., the subset of landowners within the particular group denoted k),[11] we assume that the group solves the following program:

$$\max_{\mathbf{x}^{\mathbf{S}_k}} \sum_{i \in \mathbf{S}_k} U_i^{\mathbf{S}_k}(\mathbf{x}^{\mathbf{S}_k}, |\mathbf{S}_k|) = \sum_{i \in \mathbf{S}_k} \sum_{j(i) \in \mathbf{F}_i} P_{j(i)} - K(|\mathbf{S}_k|), \tag{4}$$

where $U_i^{\mathbf{S}_k}$ is the utility of landowner i in group $\mathbf{S}_k$, and $\mathbf{x}^{\mathbf{S}_k}$ is the vector of conservation decisions on the subset of plots owned by the members of $\mathbf{S}_k$. Vector $\mathbf{x}^{\mathbf{S}_k^*}$ is the solution of Eq. (4) for any pair of flat and bonus payments (p and q) in any of the two collective schemes – that also respects Eq. (3). Determined by $\mathbf{x}^{\mathbf{S}_k^*}$ and $|\mathbf{S}_k|$, the utility $U_i^{\mathbf{S}_k^*}$ of each landowner in each group formally constitutes the outcome of the second stage of the game.

First stage: cooperation decisions. Now that we know each landowner's utility in each group, we can solve the first stage of the game: that is, for each landowner, whether and with whom to cooperate in the considered collective scheme. Formally, group formation decisions depend on the comparison of each landowner's utility across all potential groups,[12] up to a grouping where no landowners can or want to change group membership (Bareille et al., 2023). These outcomes depend obviously on the pair of *plot-level* flat and bonus payments that shape landowners' conservation decisions (indirectly, via the second stage), but also on the *landowner-level* rules governing group enrollment within the scheme (directly, via this very first stage).

Denoted $\boldsymbol{\pi}$ a particular grouping (with $\boldsymbol{\pi} = \{\mathbf{S}_k, \dots \mathbf{S}_l\}$ with $\mathbf{S}_k \cap \mathbf{S}_l = \emptyset$ and $\cup_{\mathbf{S}_k \in \boldsymbol{\pi}} \mathbf{S}_k = \mathbf{I}$), the outcome of the first stage consists formally in determining, among all possible groupings (or "*group structures*"), which are the ones that are "*stable*". To determine such an outcome, we use the *internal* and *external stability conditions* as a solution concept (Barrett, 1994). These stability conditions allow us to mimic how landowners form stable groups of cooperating landowners, by systematizing the comparison of landowners' utilities in one group structure to any "marginal deviation" of this group structure.[13]

Formally, a group structure $\boldsymbol{\pi}$ is internally stable if no landowner wants to leave the group. That is, the internal stability condition states that $\forall \mathbf{S}_k \in \boldsymbol{\pi}$ and $\forall i \in \mathbf{S}_k$:

$$U_i^{\mathbf{S}_k^*}\left(\mathbf{x}^*_{\mathbf{S}_k}, |\mathbf{S}_k|\right) > U_i^{\{i\}^*}\left(\mathbf{x}^*_{\{i\}}, |\{i\}|\right). \tag{5}$$

This condition applies identically for both open- and closed-list ABs.

The property upon which open- and closed-list ABs differ relates to the external stability condition. Starting with the former, the external stability condition states that, for any group and any landowner external to it, the external landowner is unwilling to join the existing group. This formulation corresponds to the case of "*open membership*" in the coalition formation literature (Brau and Carraro, 2011). Formally, the external stability condition in open-list AB states that $\forall \mathbf{S}_k, \mathbf{S}_l \in \boldsymbol{\pi},\ \mathbf{S}_l \neq \mathbf{S}_k,\ \forall i \in \mathbf{S}_l$:

$$U_i^{\mathbf{S}_l^*}\left(\mathbf{x}^*_{\mathbf{S}_l}, |\mathbf{S}_l|\right) > U_i^{\mathbf{S}_k \cup \{i\}^*}\left(\mathbf{x}^*_{\mathbf{S}_k \cup \{i\}}, |\mathbf{S}_k \cup \{i\}|\right). \tag{6}$$

The external stability condition is more restrictive in the case of closed-ABs. It formally states that, for any group and any landowner external to it, either the external landowner is unwilling to join (as in open-list ABs), or at least one member of the group is unwilling to accept them. This formulation corresponds to the case of "*closed membership*" in the coalition formation literature (Carraro and Marchiori, 2002). On top of respecting Eq. (6), the external stability condition in closed-list AB thus additionally states that $\forall \mathbf{S}_k, \mathbf{S}_l \in \boldsymbol{\pi},\ \mathbf{S}_l \neq \mathbf{S}_k,\ \forall i \in \mathbf{S}_l,\ \exists\ j \in \mathbf{S}_k$ such that:

$$U_j^{\mathbf{S}_k^*}\left(\mathbf{x}^*_{\mathbf{S}_k}, |\mathbf{S}_k|\right) > U_j^{\mathbf{S}_k \cup \{i\}^*}\left(\mathbf{x}^*_{\mathbf{S}_k \cup \{i\}}, |\mathbf{S}_k \cup \{i\}|\right). \tag{7}$$

Solving Eqs. (5) and (6) provides the set of stable group structures resulting from open-list ABs. Similarly, the solution of Eqs. (5) to (7) provides the set of stable group structures resulting from closed-list ABs. Given Eq. (7), these two distinct algorithms provide two different sets of stable groupings of landowners applying to the open- and closed-list ABs, even for the same pair of flat and bonus payments (p and q). These two sets consist of the outcome of the first stage (see Appendix A1 in Supplementary Materials to see the resolution of the first stage on a fictitious example). The corresponding conservation decisions taken in the second stage – i.e., problem (4) – yield the biodiversity index (1) and regulator's total payments (or budget) for each stable group structure.

2.2.3. Individual enrollment

The outcomes of the two collective ABs are compared to those of two individual schemes.

Individual AB. The first one is an AB where groups are prevented from forming and only individual enrollment in the scheme is allowed. Mathematically, the landowners' conservation decisions in individual ABs are described by Eq. (4), where the groups considered are the singletons only. Eqs. (2) and (3) also apply here. Hence, in this case, the AB encourages the agglomeration of conservation efforts, but only within the borders of each landholding.

Homogeneous payments. The second individual scheme is the pure HP, a standard benchmark in the literature (e.g., Wätzold and Drechsler, 2014). Here, there is no interdependence in the plot-level payments, nor in the total landowners' payments. The landowners' conservation decisions in pure HPs are assessed by solving Eq. (4) with $q = 0$ (still limiting the evaluation to the singletons).

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[10] Such an assumption has been proposed to study the endogenous coalition formation of countries co-signing international environmental agreements with endogenously chosen features (e.g., Barrett, 1994; Carraro and Marchiori, 2002). These features are thought to be decided in order to maximize the aggregated utility of the signing countries (e.g., carbon emission reduction objectives are set to compensate individual production reduction with global growth). A similar assumption has been applied by Bareille et al. (2023) to model collective conservation decisions within closed-list ABs.

[11] Note that $\mathbf{S}_k$ formally defines the identity of the landowners contracting together within the same conservation project. $\mathbf{S}_k$ thus determines which of the neighboring plots of $j(i)$ is included within $\mathbf{N}_{j(i)}$ in Eq. (2).

[12] Each landowner's utility in each group solved in the second stage is pre-determined in the first stage. We assume in particular that conservation decisions in the second stage are taken by "myopic" landowners (as opposed to "farsighted" landowners), as commonly done in the coalition formation literature (e.g., Barrett, 1994). We further assume that no side payments occur between group members. Indeed, modeling the distribution of such transfers among landowners within the same group presents several methodological challenges, and, in any case, formal side payments in real-world implementations of collective schemes have never been observed (Nguyen et al., 2022).

[13] A "marginal deviation" of a particular group structure means any addition or deletion in group membership from one landowner's grouping (either a collective group or a singleton) to another.

2.3. Intuitions

The high degrees of heterogeneity and non-linearity of the problem described by Eqs. (1) to (7) prevent the analytical determination of the set of optimal conservation and cooperation decisions – and thus concluding on the relative performance of the alternative schemes algebraically. Although the actual results can only be checked through numerical simulations (see Section 3), several qualitative expectations can be derived from the presentations above.[14]

First, the three AB schemes are expected to create more clustered habitats than pure HPs, such that HPs are expected to be the least cost-effective of the four schemes.[15] Commonly found in the literature (e.g., Wätzold and Drechsler, 2014; Bareille et al., 2023), such a result stems from the fact that, even if the HPs target the cheapest plots, the resulting conservation efforts are often too sparse to be of relevance for species movement across space. Because all three ABs encourage the agglomeration of the conservation efforts (within or between landholdings), they are likely to be more cost-effective than HPs.[16]

Second, collective ABs are expected to create more clustered habitats than individual ABs, as cooperation favors the aggregate utility of the groups over that of the individuals. Such coordination tends to encourage the agglomeration of conservation efforts at the borders of the landholdings enrolling jointly in any of the two collective ABs. Accordingly, when cooperation effectively occurs – that is, when the benefits from coordination exceed its cooperation costs – collective ABs are likely to deliver higher biodiversity outcomes than individual ABs for the same pair of flat and bonus payments (p and q).[17]

Third, characterized by different enrollment rules, the two collective ABs are expected to have different impacts on landowners' cooperation, and thus on (i) biodiversity conservation, (ii) total expenditure, and (iii) AB cost-effectiveness. The main difference between the performance of the two collective schemes is expected to be caused by the differential size of the groups spontaneously arising from the two. Intuitively, if the bonuses are big enough, singletons will find it more profitable to join pre-existing groups (at least if the additional bonuses obtained via cooperation are greater than the incurred coordination costs). However, pre-existing group members may have already allocated large habitat areas, such that a new member will likely bring little additional benefit to them – while surely entailing higher coordination costs. If they have such an option, pre-existing group members could thus prefer to exclude newcomers from joining their groups. In other words, we expect that closed-list ABs will generate stable group structures characterized by *more* and *smaller* groups than open-list ABs. Because they likely lead to the emergence of larger groups, open-list ABs are also expected to provide more biodiversity than closed-list ABs (for the same pair of flat and bonus payments p and q).[18]

Fourth, the relative cost-effectiveness of the four schemes does not only depend on their ability to generate clustered habitats (through cooperation or not), but also on several structural parameters underlying the studied problem. In particular, (i) the dispersal range of the species of interest, (ii) the land-enrollment constraint, and (iii) the magnitude of coordination costs – respectively appearing in Eqs. (1), (3) and (4) – may each alter the comparative advantages and limitations of the schemes. For example, when the species' dispersal capacity is very high, additional agglomeration may no longer yield sufficient biodiversity benefits to outweigh its higher cost, making HP schemes potentially more cost-effective than ABs (Wätzold and Drechsler, 2014). Conversely, when dispersal is very limited, only highly clustered landscapes – typically induced by AB schemes – generate meaningful ecological gains. Thus, while the qualitative intuitions described in the three points above are expected to hold in general, the relative performance of the schemes may vary depending on these parameters. We therefore investigate their influence through various sensitivity analyses in Section 4.3.

3. Numerical implementation

We numerically solve the model described by Eqs. (1) to (7) with mathematical programming.[19] The model is applied to a set of abstract landscapes of about one square kilometer, composed of 133 hexagonal plots of one hectare (ha), and seven landowners owning 19 plots each.[20] To account for the heterogeneous fertility across landscape, we randomize plot-level opportunity costs. We create 50 cost-randomization landscapes, starting from a plot-level cost $c_{j(i)}$ drawn from a uniform distribution between €50/ha and €150/ha, additionally constraining the spatial cost auto-correlation to a Moran's index of 0.5. Such an algorithm creates landscapes composed of clusters of low and high soil fertility that resemble real ones. In the particular example of Fig. 1, landowners A and B have plots mostly characterized by low opportunity costs (e.g., marginal land), while E has plots with high opportunity costs (e.g., cash crops).

We use an illustrative dispersal rate of $D = 5$ in our preferred analyses, assuming that the targeted species can spread with a 10% survival probability between two conserved plots located at two landscape extremes in Fig. 1 (while they can only do so over one third of the landscape when $D = 2$).[21] We also consider a land constraint $\overline{\mathrm{X}} = 10$ ha, which represents roughly 50% of each landholding area. Finally, we assume that coordination costs are a quadratic function of group

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[14] This section does not aim to report empirical or simulation results. Instead, it provides qualitative expectations based on the model's structure, which serve to guide the interpretation of the numerical simulations and their results (see Sections 3 and 4).

[15] We formally define cost-effectiveness of a particular conservation landscape $\mathbf{x}$ as the ratio of biodiversity $B(\mathbf{x})$ to the scheme's total expenditure (equal to $\sum_{i=1}^{I} \sum_{j=1}^{J} \{px_{j(i)} + qx_{j(i)} \sum_{k \in \mathbf{N}_{j(i)}} x_k\}$), which also reflects the regulator's budget. We empirically measure cost-effectiveness as averages over all of the stable group structures from all of the generated fictitious landscapes. The difference in total expenditure between the three AB schemes stem from the formation of different cooperating groups, which differently translate via the set of eligible plots to be rewarded in the alternative conservation projects.

[16] Bareille et al. (2023) found that HPs could be more cost-effective than closed-list ABs when the regulator's budget is large enough to enroll almost all of the plots (because connectivity among conserved plots spontaneously arises). We do not expect such a result to arise here, given the additional land-use constraint that we introduced in Eq. (3).

[17] If cooperation becomes too costly, landowners opt out and behave individually, so that the outcome converges to that of an individual AB. In both cases, yet, the relative cost-effectiveness of collective vs. individual ABs remains ambiguous as higher rewarded agglomeration also increases the schemes' total expenditure (i.e., the regulator's budget).

[18] Yet, because they also increase the schemes' total expenditure (i.e., the regulator's budget), the relative cost-effectiveness of the two collective ABs is ambiguous.

[19] We solve the program with the CPLEX 22.1.2.0 version on GAMS STUDIO 1.20.6 64 on a computer with Apple M3 (24 GB of RAM).

[20] We limit the application of our models to seven landowners, given the explosion of the (exponential) number of group structures to consider otherwise. For example, there are $Bell(9) = 21{,}147$ group structures to consider with nine landowners, but only $Bell(7) = 877$ with seven landowners – reducing by the same proportion the already long calculation times needed to establish stable group structures numerically (see Bareille et al., 2023, for more details). Obviously, one could try to work on more fragmented landholdings (see Drechsler, 2023, for example), but we expect our results to be qualitatively similar. Such a structure, made of 7 × 19 plots, is purely illustrative.

[21] Such a dispersal rate ($D = 5$) typically corresponds to those applying to some sedentary butterfly species, e.g., *Gonepteryx rhamni*, *Papilio machaon* and *Aglais io*, three common species found in European rural landscapes (e.g., Gutiérrez and Thomas, 2000; Ehl et al., 2019). *Papilio machaon* is one of the species typically targeted by the AB implemented in Switzerland (Wermeille et al., 2014).

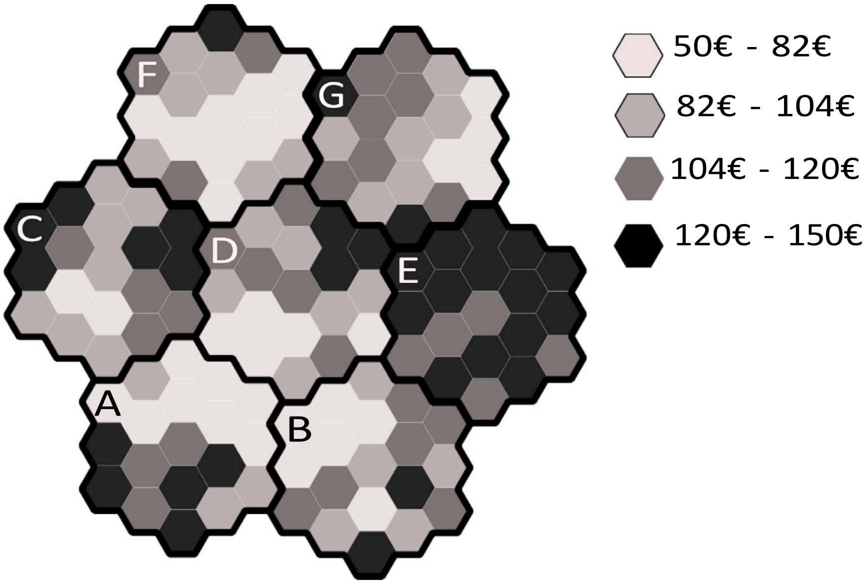

Fig. 1. Example of opportunity cost distribution across the landscape.
Note. The figure shows the distribution of the opportunity costs (from €50/ha to €150/ha) in one of the 50 cost-randomized generated landscapes (with Moran's I equal to 0.5). The letters are the landowner identifiers. The black lines are the borders of the landholdings. Colors indicate the deciles of the cost distribution for the different plots. The darker the color, the higher the cost.

size such that $K(|\mathbf{S}|) = cS^2$ (with $c = 10$ in our preferred analyses). In the robustness checks (Section 4.3), we test the sensitivity of our main results to changes in these three parameters (i.e., dispersal rate, land constraint, and coordination costs).

With these elements in mind, our simulations increase the agglomeration bonuses from $q = €0$/ha to €40/ha, combined with a fixed flat payment of $p = €20$/ha, for each of the three types of AB schemes (open-list, closed-list, and individual ABs). Because landowners can accumulate bonuses on the same plot (up to six times in our setting; see Fig. 1 and Eq. (2)), we expect only limited changes in conservation decisions when bonuses exceed $q = €25$/ha – this property follows from the fact that $6 \times q + p = 6 \times 25 + 20 > \max(\mathbf{c})$, meaning that all opportunity costs are already covered at this threshold.

For the pure HP scheme, we set $q = €0$/ha and vary p from €0/ha to €150/ha. Hence, in the AB simulations, p is fixed and q varies, while in the HP simulations, q is fixed and p varies – ensuring that all schemes are compared under an equivalent total budget constraint.

4. Simulation results

This section presents the results of our model simulating the landowners' responses to the four schemes, namely: open-list AB, closed-list AB, individual AB, and HP. Section 4.1 examines the conservation and cooperation outcomes across schemes when reasoning at a given pair of flat and bonus payments (p and q). Section 4.2 investigates their cost-effectiveness when translating these (plot-level) payments into total (landscape-level) public expenditures. Section 4.3 shows the sensitivity of our results.

4.1. Conservation, group formation and the value of cooperation

We outline below the key intuitions on how the alternative schemes function, focusing on conservation decisions (second stage of the group formation game) and cooperation decisions (first stage of the game). Using the illustrative landscape in Fig. 1 (one of the 50 generated), we first present the landowners' conservation responses to a similar pair of flat and bonus payments in different groupings (where we expect only differences between ABs vs. HPs), before questioning these groupings' stability (where we expect differences between the three ABs).

4.1.1. Conservation decisions

Fig. 2 shows landowners' conservation decisions in different illustrative groupings – from no cooperation (top row), to full cooperation (last row) – in response to increasing bonuses (from $q = €10$/ha to $q = €20$/ha) with a fixed flat payment of $p = €20$/ha. Depicted land-use patterns (habitat in green, agriculture in gray) allow us to characterize landowners' conservation decisions along three margins: "*extensive*" (whether to conserve or not), "*intensive*" (how much to conserve), and "*agglomeration*" (how conservation is spatially clustered). These conservation responses depend on three key drivers: (i) the spatial distribution of opportunity costs, (ii) the bonus levels, and (iii) the extent of cooperation between landowners. To deepen the role of these drivers, we detail below the landowners' responses to alternative bonuses in the different groupings shown in Fig. 2.

First, without cooperation, conservation efforts remain spatially fragmented. Indeed, we find that only landowners A, B, and F respond at the extensive margin to an increase in the bonus from $q = €10$/ha to €15/ha in $\boldsymbol{\pi} = \{A, B, C, D, E, F, G\}$. The three landowners respond differently at the intensive margin, with landowner F implementing the most habitats. Regarding the agglomeration margin, the number and location of the conserved habitats within $\{A, B, C, D, E, F, G\}$ are highly affected by the distribution of the opportunity costs across the landscape.

Second, compared to individual decision-making, cooperation leads to more conservation at the extensive, intensive, and agglomeration margins. Indeed, Fig. 2 shows that different groupings differently respond to a similar bonus increase from $q = €10$/ha to €15/ha. For example, conservation decisions when all landowners cooperate together in $\{ABCDEFG\}$ are characterized by the largest and most clustered habitats (lowest row of Fig. 2). Full cooperation leads five out of the seven landowners to allocate land to habitats, and only landowners G and E – for which the opportunity costs are the highest – to not provide any. As such, compared to $\{A, B, C, D, E, F, G\}$, two more landowners provide habitats for the same pair (p, q) in $\{ABCDEFG\}$. The responses at the intensive margin also change, with landowners A, B and F all adjusting their conservation decisions when cooperating within $\{ABCDEFG\}$ – now involving the maximum allowed number of plots within the scheme ($\overline{\text{X}} = 10$ ha). Finally, the agglomeration margin also changes from $\{A, B, C, D, E, F, G\}$ to $\{ABCDEFG\}$, with

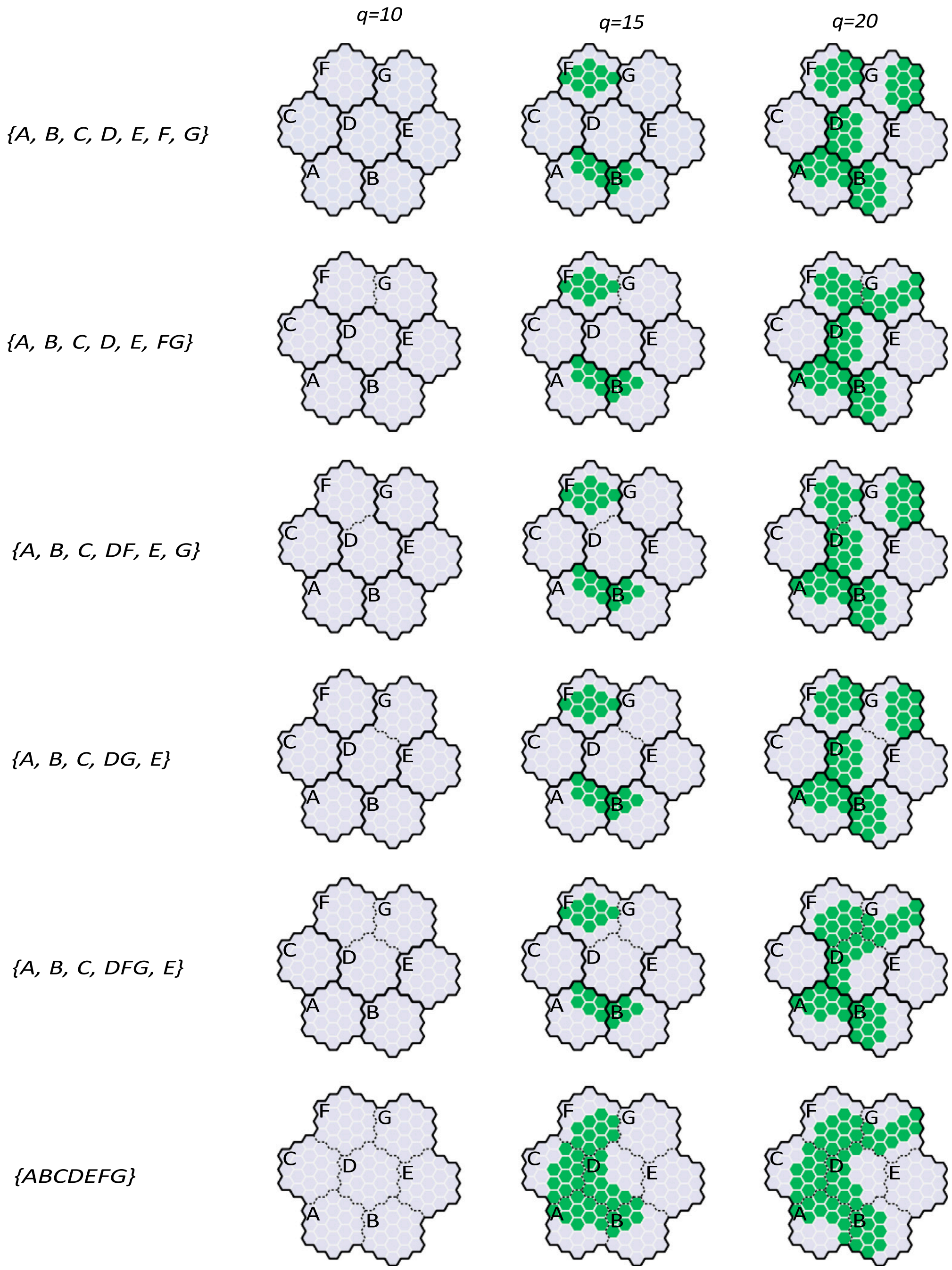

Fig. 2. Conservation decisions in alternative group structures for different bonuses.

Note. The figure shows the optimal land-use allocation decisions – green vs. gray for conserved vs. productive plots – made by landowners within alternative group structures in response to bonuses from q = €10 to q = €20. Cooperation entails coordination costs of $K(|\mathbf{S}|) = cS^2$, with $c = 10$. Bonuses are associated with a flat payment of p = €20/ha, and the land enrollment constraint is $\overline{\mathrm{X}} = 10$ ha. The composition of the alternative group structures considered is shown at the beginning of each line. To facilitate presentation, conservation decisions correspond to those associated with the landscape shown in Fig. 1. Black letters are landowner identifiers. Black lines are landholding boundaries. Gray lines between landholdings indicate coalitions.

landowners A, B, and F adjusting conservation location to benefit from additional bonuses with their neighbors at the border of their landholdings, ultimately resulting in higher habitat agglomeration within the landscape.

Third, ABs reduce the importance of the spatial distribution of opportunity costs as the primary driver of conservation – especially when landowners cooperate. This pattern becomes evident when comparing conservation decisions in Fig. 2 with those under pure HPs (varying p, with q = €0/ha) in Fig. 3, where opportunity costs alone determine habitat locations (see Fig. 1).[22]

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[22] Even though pure HPs are not designed to do so, they can lead to habitat agglomeration given the spatial auto-correlation of those plot-level opportunity costs at the landscape scale (though less than for the AB, see Fig. 2). As noted by the literature (e.g., Wätzold and Drechsler, 2014), this feature is even more

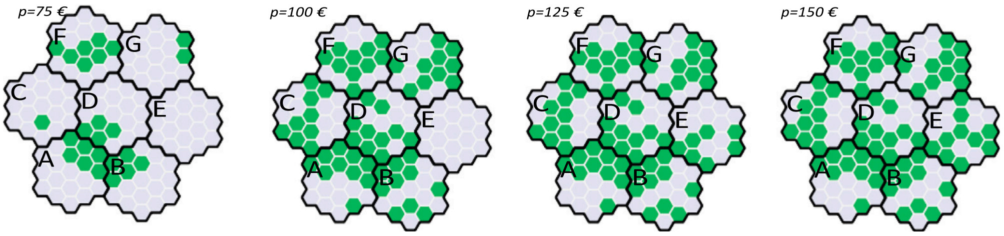

Fig. 3. Conservation decisions in response to HPs.

Note. The figure shows the optimal land-use allocation decisions – green vs. gray for conserved vs. productive plot – made by landowners responding to pure HPs from p = €75/ha to p = €150/ha. The flat payments are associated with a bonus of q = €0 and a land enrollment constraint of $\overline{X} = 10$ ha. To facilitate presentation, the conservation decisions correspond to those associated with the landscape shown in Fig. 1. Black letters are landowner identifiers. Black lines are landholding boundaries.

One of the key insights of Fig. 2 is that, for a given pair of flat and bonus payments (p, q), landowners conserve more plots – and more clustered ones – when they cooperate within larger groups. While only commented for one cost-randomized landscape (based on Fig. 1), we observe this pattern in our 50 generated landscapes. Depicting how total habitat area (left panel) and connectivity per plot (right panel) vary depending on the average size of the landowner's groups over our 50 landscapes, Fig. 4 clearly indicates that *bigger groups conserve larger and more connected habitats* for the same pair of payments (p, q).[23] In the illustrative case of $p = q =$ €20/ha, the total habitat area is on average 15% larger if landowners form groups with, on average, about three members (e.g., $\{ABCD, EFG\}$) compared to the non-cooperative grouping structure $\{A, B, C, D, E, F, G\}$ – and even 30% greater in $\{ABCDEFG\}$ than in $\{A, B, C, D, E, F, G\}$. The average connectivity of conserved plots is even more responsive to cooperation, with a difference amounting to more than 50% between $\{ABCDEFG\}$ and $\{A, B, C, D, E, F, G\}$. In other words, landowners' cooperation affects the responses at the agglomeration margin even more than those at the intensive and extensive margins. These effects become less pronounced when bonuses increase. For example, the difference of total habitat area between $\{ABCDEFG\}$ and $\{A, B, C, D, E, F, G\}$ limits to about 5% on average when q = €25/ha. In this particular case, most of the landowners now enroll the maximum amount of habitats allowed within the scheme ($\overline{X} = 10$ ha). Though smaller than for q = €20/ha, the difference of connectivity between $\{ABCDEFG\}$ and $\{A, B, C, D, E, F, G\}$ still amounts to about 20% when q = €25/ha.

4.1.2. *Stability of group arrangements*

While previous results suggest that collective schemes perform better than individual schemes, not all possible group structures are necessarily stable. The conservation benefits that larger groups seem to trigger in Figs. 2 and 4 are only *potential*; actual conservation outcomes are conditioned by the stability of group structures. We examine below how the alternative schemes affect landowners' group enrollment in response to the same pair of flat and bonus payments (p, q).

The easiest case is the individual AB, where cooperation among landowners is impossible by design. There, only group structure $\boldsymbol{\pi} = \{A, B, C, D, E, F, G\}$ is allowed, and the resulting land-use patterns typically correspond to those shown in the first row of Fig. 2. If cooperation is allowed, the stability of the group arrangement depends on the rules governing enrollment within the two collective schemes.

To observe the difference between open- and closed-list ABs, Fig. 5 shows the average size of the stable groupings arising from the two collective AB schemes, for the same pair of flat and bonus payments (p, q). As expected (see Section 2.3), closed-list ABs constrain the group size to smaller groups than those arising in open-list ABs. The average group size within the stable group structures quickly reaches a maximum in closed-list ABs (about two landowners, similarly to Bareille et al., 2023, and Bareille and Soubeyran, 2025), at about q = €30/ha – further bonus increases do not affect average group size. On the contrary, in open-list ABs, average group size within stable group structures increases with the bonuses, up to a level that is twice that of closed-list ABs. Stable group size increases in open-list ABs because group members cannot exclude external landowners from joining.[24]

4.1.3. *The value of cooperation*

Now that we have seen both that bigger groups lead to additional conservation (Section 4.1.1), but that these latter ones do not necessarily constitute the most stable groupings (Section 4.1.2), we here ask what is the value of cooperation for conservation *once the stability of group structure is addressed* (i.e., coupling the results from both Sections 4.1.1 and 4.1.2). That is, how much more biodiversity do *stable* groups in collective ABs provide compared to individuals for the same pair of flat and bonus payments (p, q)?

Fig. 6 explores this issue, by showing the percentage difference in biodiversity outcomes resulting from the stable group structures' conservation decisions in the two collective ABs, in comparison to the individual AB, for the same pair (p, q). This figure calls for several comments.

First, Fig. 6 shows that individual AB is the poorest performing scheme, whatever the bonus payment q. Allowing cooperation increases biodiversity for all pairs of flat and bonus payments considered, in a range from about 10% to 45%. In other words, the value of cooperation for biodiversity conservation is between 10 and 45%.

Second, this improvement is particularly high for the lowest bonus levels, suggesting that cooperation is of primary importance in reaching an effective configuration when habitat area is small. When the habitat area is already large, cooperating groups yield little additional biodiversity (in comparison to individuals facing a similar pair of flat and bonus payments).

Third, the relative performance of open- and closed-list ABs changes with the bonus levels (in line with the size of the cooperating groups described before), further suggesting that the extent of cooperation determines AB outcomes. The difference between open- and closed-list ABs is marginal until about q = €20/ha. For higher bonuses, open-list AB however conserves substantially higher biodiversity than closed-list ABs, given that the former leads to higher cooperation (see Fig. 5) and more clustered habitats (see Fig. 4) than the latter.

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pronounced when landscapes present spatially auto-correlated opportunity costs, as ours do (see Fig. 1).

[23] In our simulations, all coalition structures that satisfy the stability conditions (Eqs. (5)–(7), depending on the enrollment rule) are considered equally likely to emerge. This simplifying assumption is consistent with the internal logic of our framework, in which coordination difficulties and diverging interests are already embedded in the stability criteria. Accordingly, the reported values in Fig. 4 (and for all of the following ones) are computed as averages over all stable coalition structures across all landscapes. We acknowledge, however, that in real-world settings larger coalitions may be less likely to form, and we discuss this limitation in Section 5.

[24] *A contrario*, the size of stable groups is limited in closed-list ABs because at least one landowner prefers to restrict collective enrollment in the scheme.

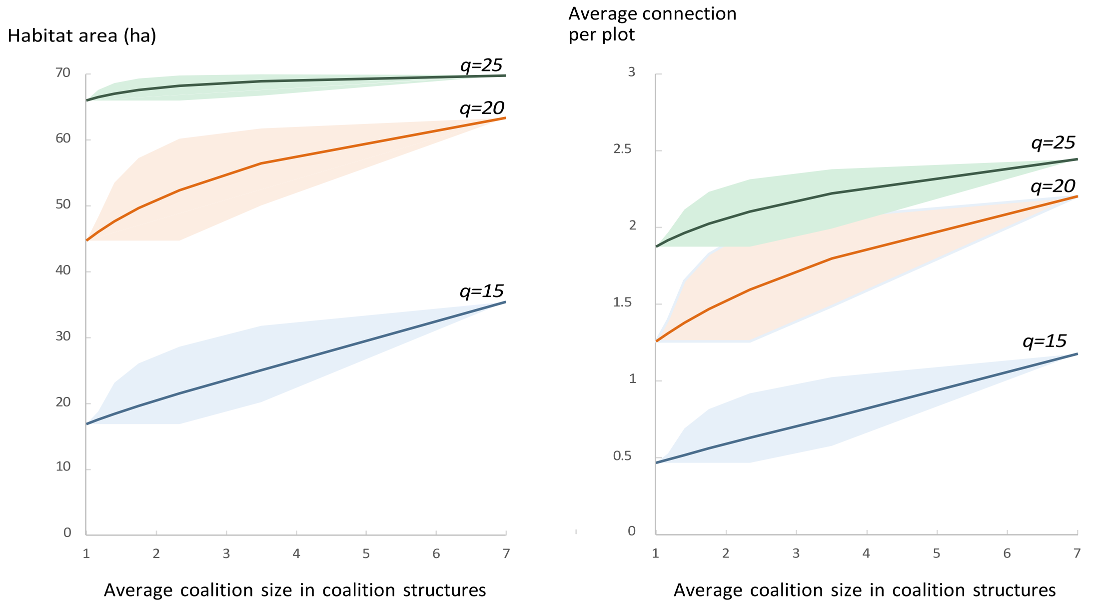

Fig. 4. Conservation decisions depending on average group size.
Note. The figure shows changes in the habitat area (left panel) and the number of connected habitats per plot reached by alternative group structures – ordered by group size – in response to different bonuses (from q = €15 to q = €25, with different color code). Cooperation entails coordination costs of $K(|\mathbf{S}|) = cS^2$, with $c = 10$. Bonuses are associated with a flat payment of p = €20/ha and a land enrollment constraint of $\overline{\mathrm{X}} = 10$ ha. Conservation decisions correspond to those taken by all group structures within our 50 generated landscapes. Thick lines correspond to averages, while shadow areas delineate the set between the minimum and the maximum.

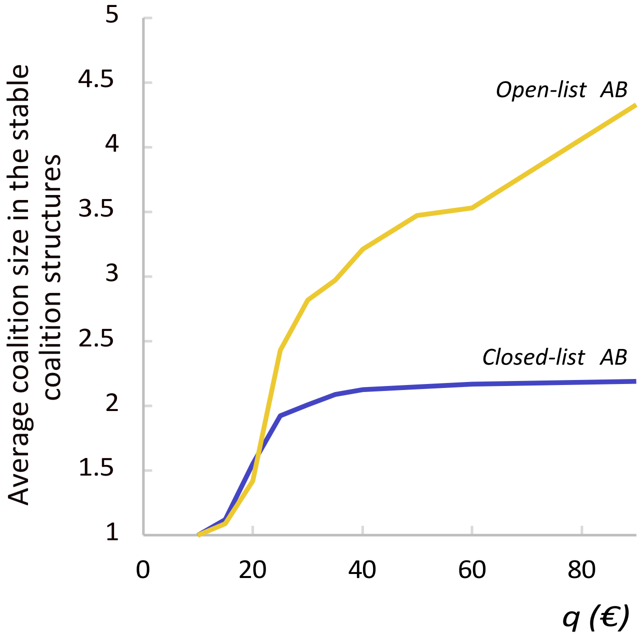

Fig. 5. Average group size in stable group structures in open- and closed-list ABs.
Note. The figure shows changes in average group size within the stable group structure formed in response to open- (yellow line) and closed-list (blue line) ABs. Cooperation entails coordination costs of $K(|\mathbf{S}|) = cS^2$, with $c = 10$. Bonuses q are associated with a flat payment of p = €20/ha, and the land enrollment constraint is $\overline{\mathrm{X}} = 10$ ha. Changes in group size within stable group structures are computed on average for all the stable group structures within our 50 generated landscapes.

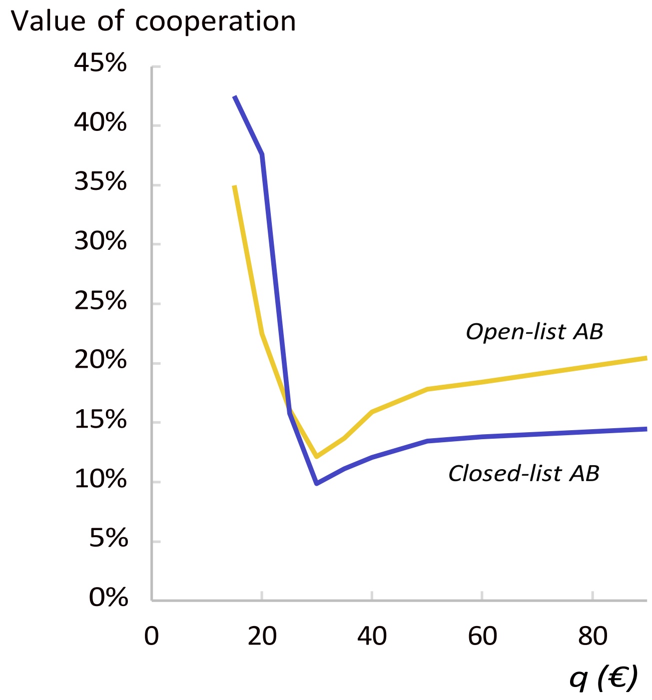

Fig. 6. Value of cooperation for biodiversity conservation.
Note. The figure shows changes in biodiversity within the stable group structure formed in response to the bonuses in the open- (yellow lines) and closed-list (blue lines) ABs. More specifically, the figure shows the relative biodiversity levels of the open- and closed-list ABs in comparison to the individual AB, where no cooperation is allowed. Cooperation entails coordination costs of $K(|\mathbf{S}|) = cS^2$, with $c = 10$. Bonuses are associated with a flat payment of p = €20 and the land enrollment constraint is $\overline{\mathrm{X}} = 10$ ha. Changes in biodiversity correspond to those on average over all the stable group structures within our 50 generated landscapes (characterized with Moran's I of 0.5 and dispersal rate of $D = 5$).

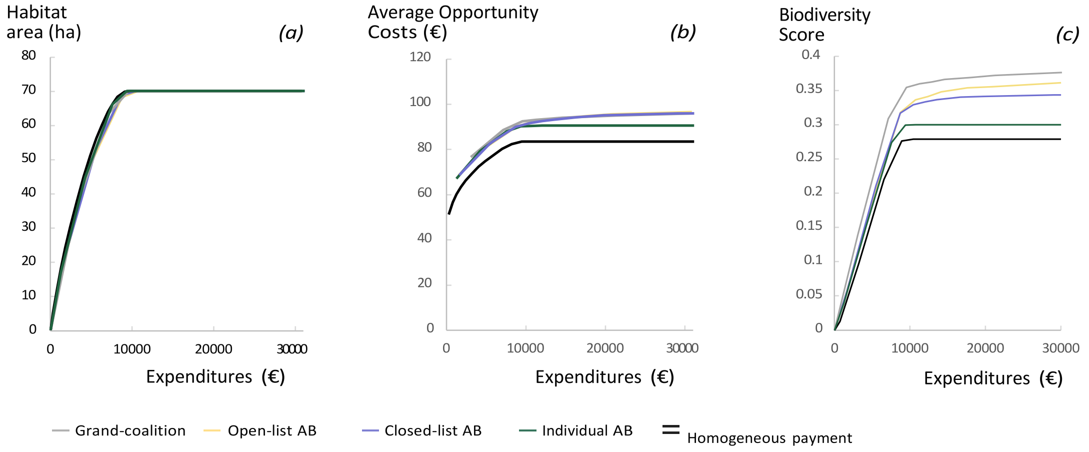

Fig. 7. Effectiveness of the schemes.

Note. The figure shows the habitat area (a), the average opportunity costs of the plots allocated to habitat (b), and the biodiversity score (c) per level of expenditure, under the grand coalition (gray), open-list AB (yellow), closed-list AB(blue), individual AB (green) and HP (black). Cooperation entails coordination costs of $K(|\mathbf{S}|) = cS^2$, with $c = 10$. Bonuses are associated with a flat payment of $p =$ €20/ha and the land enrollment constraint is $\overline{X} = 10$ ha. The indicators for the collective schemes are computed on average on all the stable group structures within our 50 generated landscapes (characterized by Moran's I equal to 0.5 and species dispersal rate of $D = 5$).

4.2. AB cost-effectiveness

We have so far reasoned in terms of conservation and cooperation outcomes *per given pair of plot-level flat and bonus payments* (p and q). If we show that open-list ABs favor the formation of larger groups that conserve more plots per bonus level, higher enrollment also implies greater total public expenditure (from the regulator to landowners). As such, Fig. 7 compares a selection of performance indicators for the four schemes when expressed our results in terms of total public expenditure instead of bonus level.[25]

Panel (a) of Fig. 7 displays the average amount of habitat per level of public expenditure across our 50 landscapes. All schemes yield roughly similar habitat levels, with no substantial differences among them, although HP seems to consistently constitute the upper bound – consistent with standard findings in the literature (e.g., Drechsler et al., 2010; Wätzold and Drechsler, 2014; Bareille et al., 2023; Bareille and Soubeyran, 2025). All schemes lead in particular to a habitat area of 70 ha for high budgets (greater than €10,000), representing the total of the maximum amount of habitats that each landowner can enroll within the scheme ($\overline{X} = 10$ ha). As discussed above, the fact that bonuses do not increase total habitat area relative to flat-rate payments – even under full cooperation in the grand coalition – is a well-established result in the AB literature (Drechsler et al., 2010; Wätzold and Drechsler, 2014; Drechsler, 2023). While Bareille et al. (2023) have already expanded this result to the closed-list AB, Panel (a) of Fig. 7 extends it to the individual and open-list ABs. Given the different cooperation patterns highlighted in Section 4.1, this implies that the extent of cooperation in the alternative schemes does not affect habitat size (at constant budget).[26]

Larger differences emerge when looking at which plots are selected under the different schemes. Panel (b) of Fig. 7 shows that the average opportunity cost of the conserved plot differs among the schemes across our 50 landscapes. The main difference lies between the AB and HP schemes, with plots enrolled under ABs exhibiting higher opportunity costs than those enrolled within HPs. As discussed in Section 4.1, this is a standard result of the AB literature, which reflects the fact that plot enrollment in HP schemes depends only on plot-level opportunity costs (Wätzold and Drechsler, 2014). On the contrary, landowners' benefits in the ABs depend on the number of connections between conserved plots, that is, on both plot *location* and *opportunity cost*. The interest of the AB is that it encourages landowners to enroll more costly plots, which are however *closer to one another*. The alternative enrollment rules do not affect the average opportunity cost of the plot enrolled within the AB.

This higher level of agglomeration generated by the ABs is clearly visible within Panel (c) of Fig. 7, where we see clear differences between the alternative schemes over our 50 landscapes – whether in the three AB schemes, within the grand coalition or within the pure HP scheme. For the same budget, we see a clear ordering where the least cost-effective scheme is the HP. The most cost-effective response occurs in ABs within the grand coalition. The greater cost-effectiveness of AB within the grand coalition compared to HPs is fully in line with the AB literature (Wätzold and Drechsler, 2014).[27] Similarly, the intermediate position of the closed-list AB between the grand coalition and the HP mirrors the previous insights of Bareille et al. (2023).

What is new relates to the respective positions of the individual and open-list ABs in Panel (c) of Fig. 7. On the one hand, Fig. 7 shows that individual ABs are in an intermediate position between HPs and closed-list ABs. That is, they are more cost-effective than the pure HP scheme, but are less cost-effective than the scheme investigated by Bareille et al. (2023). On the other hand, Fig. 7 shows that open-list ABs are in an intermediate position between closed-list ABs and the grand coalition. That is, they are still less cost-effective than the grand coalition (that does not arise), but are more cost-effective than the scheme investigated by Bareille et al. (2023). The difference between open- and closed-list ABs grows as the budget increases, illustrating the enlargement of the groups enrolling within the open-list ABs (compared to groups remaining of small size within the closed-list ABs; see Section 4.1).

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[25] For further comparison, we also add here the results of the "grand coalition" in the AB (which, in line with Bareille et al., 2023, does not spontaneously arise in this setting), the best potential aggregate outcome for the landowners as a whole by definition.

[26] More precisely, this means that the extent of cooperation does not affect the extensive and intensive margins – whereas it affects the agglomeration margin (see below).

[27] Yet, as said in footnote 25, the grand coalition is not a stable grouping in responses to collective AB (Bareille et al., 2023).

4.3. Sensitivity analyses

We investigate below whether the results presented above are due to particular empirical choices relating to (i) the dispersal capacity of the species of interest, (ii) the land-enrollment constraint, or (iii) the coordination costs.

For the dispersal capacity, we evaluate the value of cooperation for a smaller ($D = 1$) and a larger ($D = 10$) capacity of the species to disperse over space (instead of $D = 5$ in our preferred analyses). As shown in Figure A2 in the Supplementary Materials, decreasing the dispersal parameter increases the absolute differences in the effectiveness among the schemes (in particular between the ABs and HPs), but it does not affect the ranking of the schemes, nor does it affect the value of cooperation, as it simply scales the biodiversity values up and down (with no effect on landowners' conservation and cooperation decisions).

On the contrary, changes in the land-enrollment constraints greatly affect the value of cooperation. Figure A3 in the Supplementary Materials shows the results of the value of cooperation when $\bar{X} = 5$ and when $\bar{X} = 19$ (i.e., when there is no constraint). The results suggest that the value of cooperation increases when the land-enrollment constraints are strengthened. This is rather intuitive: as landowners can enroll fewer plots, cooperating with neighbors gives relatively greater value to the potential connections with neighboring plots. If landowners can enroll any plot they own, cooperating adds relatively less.

Finally, coordination costs do affect the value of cooperation. Figure A4 in the Supplementary Materials shows the result for the main model compared with the results assuming $c = 20$ and $c = 30$. Not surprisingly, the higher the coordination costs, the lower the value of cooperation. Indeed, as these costs increase the average size of the groups in the stable grouping decreases, eroding the potential value of the collective schemes.[28]

5. Discussion and concluding remarks

Collective schemes, which encourage cooperation among independent landowners, are increasingly seen as a promising tool for achieving effective landscape-scale habitat configurations for biodiversity conservation (Nguyen et al., 2022). Yet, despite an increasing interest, the literature on collective schemes has paid little attention to the challenges and possibilities associated with cooperation itself. Most models assume either no cooperation or full cooperation (e.g., Parkhurst and Shogren, 2007; Wätzold and Drechsler, 2014), overlooking the endogenous nature of group formation decisions – though recent works have begun to address this gap (Banerjee et al., 2021; Bareille et al., 2023; Bareille and Soubeyran, 2025).

Building on the framework developed by Bareille et al. (2023) and Bareille and Soubeyran (2025), we extend their analysis of endogenous coalition formation within *closed-list* ABs in two directions. First, we introduce two alternative enrollment rules – the open-list and individual ABs – which relax the assumption of exclusive group membership and allow us to capture a wider range of cooperation process among landowners (how landowners can form stable groups across the landscape). Second, we use this extended framework to quantify *the value of cooperation* for conservation. Specifically, we compare the landscape-level outcomes of these three ABs with those of a standard HP scheme – all ABs reward conservation identically at the *plot level*, but differ in how they enable or constrain cooperation at the *landowner level*. This comparison allows us to isolate the contribution of cooperation itself to biodiversity conservation and AB cost-effectiveness *at the landscape level*.

Findings from our simulations on fictitious landscapes show that there is indeed a positive value in designing incentives that foresee cooperation on conservation efforts. Compared to individual enrollment within the AB, collective enrollment yields (i) more landowners to choose to conserve habitat (the "*extensive margin*" of conservation), (ii) greater habitat provision per landowner ("*intensive margin*"), and (iii) more spatially clustered habitat patterns ("*agglomeration margin*") for the same plot-level payments. Overall, the two collective ABs improve biodiversity conservation by 10 to 45 percent with respect to individual AB over a wide range of bonuses – an advantage that additionally translates into greater scheme cost-effectiveness.

Our main conclusion is to show that the relative performance of the two collective schemes in terms of biodiversity conservation depends on their relative capacity to foster cooperation among landowners. Because open-list ABs yield larger groups of cooperating landowners than closed-list ABs (as they do not allow the refusal of new members), our analyses reveal that they are the most cost-effective schemes (at least for sufficiently large budgets). Individual ABs are always the least cost-effective AB schemes, as they prevent landowners from cooperating by design – even if they remain more cost-effective than pure HPs, as they still encourage landowners to agglomerate habitats within each holding (whereas HPs do not). Overall, our analyses thus confirm that including incentives for rewarding the spatial connectivity of habitats does improve the scheme cost-effectiveness (see results comparing individual ABs vs. HPs), *but it does this even more so if conditional on cooperation* (collective vs. individual ABs).

Our results offer several insights for the practical design of collective schemes targeting biodiversity conservation. In particular, they suggest that regulators could substantially improve the cost-effectiveness of existing ABs by revisiting the institutional rules that govern group enrollment. Allowing open-list enrollment – where membership can evolve over time as landowners join existing groups – appears to foster larger and more stable cooperation, thereby enhancing both biodiversity outcomes and AB cost-effectiveness. Importantly, such a reform would not require major institutional changes, but rather a shift in governance logic: from fixed and exclusive membership lists to more adaptive and inclusive forms of collective participation. Managing cooperation through open lists, like those implemented in the Netherlands (Barghusen et al., 2021), should therefore be favored.

While these findings provide clear guidance for policy design, they also rely on the specific methodological strengths of our *in silico* approach. Empirical evaluations of collective schemes remain limited by the scarcity and heterogeneity of real-world case studies (Krämer and Wätzold, 2018; Huber et al., 2021; Limbach and Rozan, 2023; Häusler and Zabel, 2024), and experimental approaches, although informative about behavioral responses (Banerjee et al., 2017; Villamayor-Tomas et al., 2019), struggle to capture landscape-level ecological outcomes (Banerjee et al., 2021). Against this background, our *in silico* simulation framework provides a valuable complementary perspective: by abstracting from contextual complexities, it enables systematic exploration of alternative governance designs under controlled ecological and economic conditions. As explained in Baumgärtner et al. (2008), our model adopts an intermediate epistemic stance, using idealized settings to isolate *mechanism-level* effects (rather than to reproduce context-specific outcomes).[29] In this sense, our approach complements previous qualitative analyses of collective agri-environmental approaches (Franks, 2011; Bodin, 2017; Riley et al., 2018; Prager,

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[28] Note, however, that this impact does not necessarily translate into lower cost-effectiveness at the scheme level. As highlighted by Bareille et al. (2023) and Bareille and Soubeyran (2025), coordination costs play a relatively minor role in determining the overall AB cost-effectiveness.

[29] More broadly, our model should be viewed as a conceptual device rather than a representation of any specific landscape. Its purpose is to improve our understanding of the qualitative mechanisms through which cooperation among landowners can influence biodiversity outcomes and AB cost-effectiveness, rather than to generate empirically "realistic" predictions. In this sense, the model is generic by design: it abstracts from contextual details to isolate and analyze the core ecological-economic feedbacks associated with collective action in agri-environmental schemes.

2022), by offering a quantitative tool to isolate the ecological-economic mechanisms through which cooperation shapes biodiversity outcomes and scheme performance.

Beyond these methodological considerations, our results point to several avenues for future research. First, although open-list ABs appear highly cost-effective in our setting, their practical implementation remains largely unexplored; field experiments or pilot programs would be valuable to assess the real-world feasibility of open-list ABs, initial design, and subsequent management. Second, while our analysis focuses on cooperation within ABs, similar mechanisms likely apply to other spatial incentives such as agglomeration payments (Wätzold and Drechsler, 2014) or threshold payments (Zavalloni et al., 2019). Extending our framework to these instruments would help determine whether cooperation among landowners plays a comparable role in fostering biodiversity conservation there too (beyond the AB case). Finally, a promising direction would be to relax the assumption that all stable coalition structures are equally likely to emerge. In practice, larger or more heterogeneous coalitions may indeed face higher coordination barriers (Ray, 2007), which could be represented through constrained or probabilistic stability formulations (e.g., Myerson, 1977; Laruelle and Valenciano, 2008). Incorporating such refinements, together with additional contextual features (e.g., side-payments, fragmented holdings), would help bridge the gap between the theoretical “coalition stability” concepts and the dynamics of cooperation observed in real landscapes.

CRediT authorship contribution statement

Matteo Zavalloni: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **François Bareille:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Matteo Zavalloni reports financial support was provided by Horizon Europe. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.ecolecon.2025.108901.

Data availability

No data was used for the research described in the article.

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