






Perspective

Using Forest Compensation Funds to Reverse Biodiversity Loss: A Case Study of Turin–Lyon High-Speed Railway Line

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Abstract: Megaprojects radically change the landscape due to their large-scale and high investments. Forests are often one of the most affected habitats, as they are frequently included in megaproject construction sites. These habitats support rich animal communities that the new settlement may threaten. Among all species present in any construction site, those listed in the Habitats Directive (92/43/CEE) deserve particular attention as they are protected throughout Europe. Here, we present a case study related to the expansion of an industrial site, part of the megaproject Turin–Lyon high-speed railway, where forest compensations were used to reverse biodiversity loss. The site expansion scheduled for 2020 included mature forests and clearings that used to host a butterfly species and at least 15 bat species protected by the Habitats Directive and other taxa of conservation concern. Forest compensations are usually used to finance tree plantations and forest improvements. In this case study, for the first time, we used them to maintain local biodiversity, which otherwise would have been severely compromised by the site expansion. Indeed, our approach has made it possible to allocate forest compensation funding to restore or improve habitats to favor biodiversity. This approach may be exported to other megaprojects to support local biodiversity.

Keywords: bats; butterflies; Chiroptera; Coleoptera; Habitats Directive; Lepidoptera; megaprojects; multi-taxa approach; protected species; saproxylic beetles



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1. Introduction

Megaprojects can be defined as large-scale projects lasting several decades, which rapidly and radically change the landscape, and require coordinated flows of international finance capital, typically USD 1 billion or more [1,2]. They involve a long-term perspective for future needs, a high level of management complexity and a high degree of stakeholder involvement. Megaprojects may include infrastructures, industrial sites, and planned cities. Infrastructure is one of the sectors in which megaprojects have mostly been developed. In recent years, most of the investments in infrastructures have involved the construction of high-speed railways, especially in China and Europe [2].

Megaprojects can have a high environmental impact. One of the habitats frequently impacted by construction and infrastructures is forests. For example, 80% of the project area of the third airport in Istanbul was a forest [3]. To construct the Panama Canal, a large forest area was destroyed and, as a consequence, surrounding forested areas are also being degraded, even today [4]. The third bridge over the Bosphorus in Turkey passes through

the Belgrade Conservation Forest and the Bosphorus Key Biodiversity Area, which includes different habitats, including forests [5]. In order to avoid any unwanted and irreparable damage to the environment, in Europe, both megaprojects and small projects are subject to strict control by the local authorities (Directive 2001/42/CE; Directive 2011/92/UE). Italian laws have transposed these European Directives (Decree 190/2002; Decree 152/2006). For megaprojects, these Decrees prescribe the development of the so-called 'Environmental Impact Assessment, a mandatory instrument for monitoring habitats and species before, during, and after the implementation of the project.

Despite efforts to mitigate or reduce adverse impacts on natural habitats, it is practically impossible to completely avoid the negative effects of megaprojects. This awareness has led to the concept of environmental compensation [6,7], which is defined as the creation, restoration or improvement of nature qualities in order to offset the ecological damage caused by infrastructure development [8]. In Europe, this concept has been transposed into Directive 2004/35/EC dealing with "environmental liability with regard to the prevention and remedying of environmental damage". This directive is innovative as it introduces, for the first time in the European Community, a concept of environmental responsibility. The "polluter pays" principle is placed at the basis of liability, which means that the author of environmental damage must bear the related costs of repairing it. The concepts of this Directive have firstly been transferred to national regulations and then to regional regulations, taking into account the different territorial and political contexts. For example, in Italy the Forest Act 34/2018 implements the principles of the Directive 2004/35/EC by ensuring that compensation for the transformation of the forest can be achieved, for instance, with the improvement and restoration of existing forests, afforestation and creation of new forests through the use of native species and the realization of hydraulic-forestry systems. However, in Italy, forest compensations only provide actions focused on the forest system, completely neglecting other components linked to animal species and, more generally, to the conservation and/or restoration of local biodiversity.

Traditionally, compensation measures have been decided during negotiation tables among proponents, stakeholders and regional authorities, without any local biodiversity monitoring. In the Piedmont region (NW Italy), since 2017 forest compensations can be monetary or physical. Physical compensation involves reforestation or forest improvement projects [9]. Fauna and ecological interactions are usually not considered. Most forest compensations in Piedmont have been monetary and directed to the regional authority (Piedmont Region). In Piedmont, no forest improvements were devoted to reversing animal biodiversity loss. In 2018, monetary compensation was used to implement hydrogeological rebalancing interventions [10]. Indeed, in Italy, due to its geomorphological context, 87% of the forest area should be managed in order to prevent soil erosion and regulate the water cycle (National Forest Act n. 3267/1923) [11,12]. In EU countries, 12% of forests are reported to be managed for soil and/or water protection with special regard to the Alps as emphasized by the Alpine Convention (1991). While all over the world, about 25% of the forests are managed to protect soil and/or water [13].

In Europe, generally, it is difficult to obtain information on how forest compensations related to megaproject construction have been spent [14]. Our understanding to date is that there have been no forest compensations used to reverse local animal biodiversity degradation. On the other hand, some studies analyzed the ecological compensation (i.e., compensations related to disadvantages incurred separately from forest damages) of megaproject construction due to habitat disturbance/loss and negative impacts on animal species (e.g., [15]). However, in most cases, compensation measures are based on previous knowledge and literature reviews and not on local studies [16–18].

Here, we present a new multi-taxa approach to use forest compensation, related to the construction of an industrial site that is part of the megaproject Turin–Lyon high-speed railway, to avoid biodiversity loss. A planned expansion of the industrial site scheduled for 2020 included areas with mature forests and clearings that may potentially host several species of conservation concern. Indeed, a butterfly species and at least 15 bat species

protected by the Habitats Directive (92/43/CEE) were already known to be present in the area. In Europe, the Habitats Directive ensures the highest level of protection to species and habitats. Species listed in the Annex IV are strictly protected, while for species listed in Annex II, the core area of their habitats must also be protected as Sites of Community Importance (SCIs) included in the Natura 2000 network. However, even for these species, the protection can be derogated when megaprojects override public interest (Article 16 of Habitats Directive 92/43/CEE). In this case, mitigation or compensatory measures are envisaged, but only when the construction is considered to change the status of these species in the area (Article 12 of Habitats Directive).

Here, we present a case study in which a megaproject was considered to impact species listed in the Habitats Directive without compromising their local conservation status, therefore, without the obligation of compensatory measures (Article 12 of Habitats Directive). We then used funds deriving from forest compensation—due for the cutting of trees—to finance environmental interventions useful for these target species in the Habitats Directive. Our approach was to go beyond routine forest management, considering the interaction between forest and animal species, particularly those that are considered a conservation priority.

2. A Case Study: The Turin–Lyon High-Speed Railway

The new Turin–Lyon railway line and its central element, the 57.5 km-long Mont Cenis base tunnel, provide a fundamental link in the New Mediterranean Corridor, one of the nine corridors of the TEN-T network, the future “metropolitan railway of Europe”. The railway infrastructure for both freight and passengers starts from Settimo Torinese, near Turin in Italy, where it interconnects with the Turin–Milan railway line, to Lyon in France. At a regional level, it connects the Susa Valley in Italy with the Maurienne Valley in France. The cost of the cross-border section is estimated to be EUR 8.6 billion. In 2018, a plan to enlarge an industrial site located in the Susa Valley, NW Italy (at about 400 m, 45°08′07.6″ N 6°59′38.8″ E) to construct a tunnel connecting Italy to France, was approved by local and national authorities. The expansion area included part of a forest and some clearings and national authorities expressed concerns for the presence of species listed in the Habitats Directive.

2.1. Study Site

The study site was in NW Italy (45°08′07.7″ N 6°59′37.8″ E), at an elevation varying between 400 and 1004 m a.s.l. The study was carried out across the following three areas: the lowest one, where industrial site expansion is located (at about 670 m a.s.l.; Area A), the ecological corridor area (at about 800 m a.s.l.; Area B) and the upper area conjunct by the corridor (at about 1000 m a.s.l.; Area C). The topography, forest and herbaceous cover of the three areas are described in Table 1.

2.2. Sampling Design

To investigate which taxa were threatened by industrial site expansion and to study a specific plan to conserve them, we planned to investigate *Zerynthia polyxena* ([Denis & Schiffermüller], 1775)—a butterfly protected by the Habitats Directive—as an umbrella species for grassland and ecotonal insects; [19]), saproxylic beetles (as umbrella species for forest environment; [20]), bats and their ecological preferences.

Table 1. Topographic, forest and herbaceous cover of Area A, B and C. Forest improvements, specifically thinning and selective cutting, were conducted even in the surroundings of Area B (40 ha at about 800 m a.s.l.).

	Area A	Area B	Area C
Mean elevation (m a.s.l.)	670	800	1000
Slope (°)	8	32	25
Aspect (°N)	137	250	186.8
Size (ha)	3.6	10	10.6
Forest surface (%)	63	90	64
Grassland surface (%)	37	10	36
Habitat-type	Mixture of semi-natural grasslands and chestnut orchards	Mixture of semi-natural grasslands and chestnut orchards	Mixture of semi-natural grasslands and chestnut orchards
Main-tree species	<i>Castanea sativa</i> , <i>Fraxinus excelsior</i> , <i>Prunus avium</i>	<i>Castanea sativa</i> , <i>Quercus pubescens</i> , <i>Prunus avium</i> , <i>Fraxinus excelsior</i>	<i>Castanea sativa</i> , <i>Fraxinus excelsior</i> , <i>Prunus avium</i>
Main herbaceous-species	<i>Festuca rubra</i> s.l., <i>Brachypodium rupestre</i> , <i>Bromus erectus</i>	<i>Poa nemoralis</i> , <i>Festuca heterophylla</i> , <i>Achnatherum calamagrostis</i> , <i>Brachypodium sylvaticum</i>	<i>Bromus erectus</i> , <i>Brachypodium rupestre</i> , <i>Festuca ovina</i> s.l. and <i>Arrhenatherum elatius</i>
Study-activities	Forest improvements, butterflies, saproxylic beetles, bats	Forest improvements, butterflies, bats	Butterflies, bats

2.2.1. *Zerynthia polyxena*

To count *Z. polyxena* butterflies, we periodically patrolled Areas A and B every other day, from 10:00 to 16:00 from March to June 2019 (57 total days of captures), capturing, marking, releasing and recapturing butterflies [19].

From March to June 2021, we regularly checked the presence of *Z. polyxena* along the ecological corridor through Pollard transect for adults (five replicates) and actively searched for eggs and larvae in the host plants *Aristolochia pallida*.

2.2.2. Saproxylic Beetles

To collect saproxylic entomological fauna, we used an interception window activated with ethanol [21]. The traps were placed on mature trees with evident necrosis or with large dead trunks, both erect or partially on the ground. They were hung up on branches close to the trunk and near the cavity or dead parts [22]. We placed seven traps from July to October 2019 in Area A and checked them every month to collect beetles and refill them.

2.2.3. Bats

Bats were acoustically monitored from May to September 2019 in Areas A–C, to study habitat selection and quantify the importance of forest habitats for the species hanging out in the expansion area and surroundings. A total of 12 sampling sites were selected (6 in Area A, 3 in Area B and 3 in Area C), where automatic bat detectors (Wildlife Acoustics Song Meter SM4BAT FS) were left to record for a whole night every 20 days. Sampling sites differed from each other in the degree of tree cover.

Species identification was carried out at the first step using an automatic classifier (TADARIDA; [23]), and subsequently this was performed manually for recordings with low correct identification probability, following methods described by Barataud [23]. Bat activity (expressed in bat passes per hour) was then used to compare habitat preferences of different species [24].

3. Forest Compensations to Reverse Biodiversity Loss

In the Piedmont region, the Regional Law 4/2009 “Gestione e promozione economica delle foreste” (Management and economic promotion of forests) implements the Legislative Decree 34/2018 principles and recognizes that a legal entity that intends to transform a forest, or a part of it, into another land use is required to compensate for the forest surface transformation and, if necessary, mitigate the impacts on the environment. When the surface area subject to transformation is greater than 1 hectare, a physical compensation can be made, either by forest restoration or forest improvements. These interventions must be carried out within the same hydrographic basin in which the transformation of the forest has been authorized. The priority for compensatory interventions is given to public terrains.

Considering that the Upper Susa Valley—the valley where the industrial site is developed—has 41% its surface covered by forests [25], afforestation is not a priority. However, being a mountainous territory characterized by the presence of steep slopes, the problem of hydrogeological instability is rather marked. Moreover, to enhance the economic resources used for forest compensation, our approach was not limited to the forest structure, but we also had the intention of improving habitats for animal species damaged by the site expansion.

We developed a new approach focused on some target taxa considered as a priority for conservation, and impacted locally by the expansion of the industrial site, by means of three phases (Figure 1): (1) monitoring species of conservation concern present in the forest area; (2) studying their local habitat preferences; and (3) developing an ad hoc local plan to reverse habitat degradation and likely biodiversity loss, using forest compensation. An additional phase (4), planned for the future, can be added to monitor target taxa and assess the success of the conservation plan.

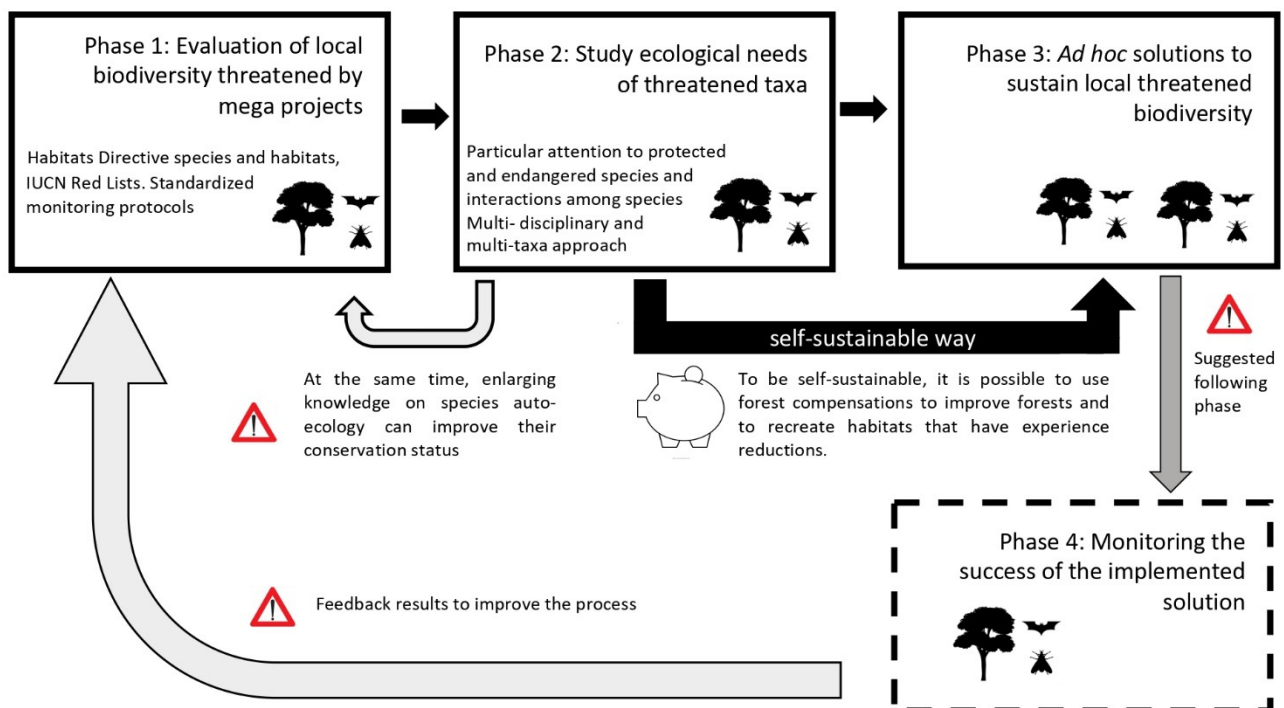


Figure 1. Innovative approach to reduce megaproject impacts on biodiversity; this is divided into three phases that have the aim (phase 1) to identify which biodiversity components would be locally threatened by the megaproject expansion; (phase 2) to study ecological preferences of species with particular attention to those identified as priorities (e.g., species listed in the Habitats Directive); and (phase 3) to develop local solutions to sustain biodiversity (e.g., recreating habitats that have been lost). Monitoring the success of the implemented plan is a suggested fourth phase.

3.1. Phase 1: Evaluation of Animal Taxa Threatened by the Megaproject

Considering the data collected for the PMA and other information provided thereafter, the Italian government requested further information on some taxa that could be impacted by planned deforestation in the expansion site. One of the target species was *Zerynthia polyxena*, which was present in the expansion area and surroundings with some subpopulations for which we did not record any individual exchanges. A particular concern was also expressed for the planned cutting of old trees, rich in cavities considered potential roosting sites for bats (Chiroptera) and suitable habitats for saproxylic beetles (Coleoptera). Therefore, we planned 1 year of monitoring activities on these taxa.

3.1.1. Ecology of *Zerynthia polyxena*

In 2019, we selected a study area surrounding the Turin–Lyon High-Speed railway expansion site [19] where *Z. polyxena* was found. We confirmed the presence of *Z. polyxena* in the area and found that the species is locally monophagous and only lays eggs on its host plant, *Aristolochia pallida* L. [26], also present in the area. The main threats for this species are the proceeding natural succession, agricultural practice and reforestation [27]. Considering that the expansion site included both the protected butterfly species and its host plant, it was considered as a breeding site that should not be compromised in accordance with Habitats Directive indications, although the site is not included in a Natura 2000 European Network. However, since the Turin–Lyon High-Speed railway is considered a priority at the national and European levels for its public utility, it would have been possible to derogate this protection.

Considering the limitation of the expansion area, compensation measures were not mandatory because degradation of the site would not have affected the species conservation status, which is driven by all subpopulations in the surrounding area of the industrial site (max 2.5 km distance). However, the local subpopulation of *Z. polyxena* in the expansion site was estimated to be rather small (104 individuals, from Mark-Recapture-Release) and, more worryingly, 62% of the area where the subpopulation was present would have been included in the expansion of the construction site. Therefore, the species was locally doomed to extinction. Considering this situation, the regional authority (Piedmont Region), i.e., the relevant authority under national provisions, demanded local solutions to avoid the complete loss of *Z. polyxena* subpopulation in the expansion site.

3.1.2. Saproxylic Beetles

Considering that the expansion site included a forest rich in cavities and deadwood, we planned to investigate if saproxylic beetles listed in the Habitats Directive were present in the area. We followed the ISPRA guidelines for monitoring species listed in the Habitats Directive [28], using visual encounter survey and windows traps searching for *Osmoderma eremita*, *Rosalia alpina*, *Lucanus cervus* and *Cerambyx cerdo*. In 2019, we did not find any individuals belonging to any of these species. However, using window traps, we collected 2656 saproxylic beetles belonging to 78 species, of which four species are considered threatened according to the Italian Red List [29]: *Elater ferrugineus*, *Gnorimus variabilis*, *Brachygonus megerlei* and *Megathous nigerrimus* (Piccini et al. in prep.). These species are also considered to be Near Threatened in Europe, except for *M. nigerrimus*, which is of least concern [30]. Moreover, we found another rare species that has recently been evaluated as Vulnerable according to IUCN criteria, namely *Gerandryus aetnensis* [31].

3.1.3. Bats

Many bat species, including most of the rarest and endangered, are linked to forest environments. Forest habitats perform three fundamental functions for bats, in that they offer roosting opportunities to many species, produce a wide variety of prey (insects) [32], and can be used as a spatial reference for commuting, also due to higher insect densities and the chance of shelter from predators and wind [33]. Tree roosts can be abandoned woodpecker holes, hollows produced by xylophagous insects, flaking bark, broken and

cracked branches and trunks [34]. Based on data collected through surveys for PMA, at least 13 bat species are known to be present in the area, of which eight (*Barbastella barbastellus*, *Pipistrellus pipistrellus*, *Pipistrellus pygmaeus*, *Nyctalus leisleri*, *Nyctalus noctula*, *Myotis myotis*/*Myotis blythii*, small *Myotis* species, *Plecotus* spp.) are linked to forest habitats. However, it should be noted that some species (*Myotis* spp. and *Plecotus* spp.) have been treated at the genus level because of limits in acoustic identification used for these surveys [35,36]. Therefore, the actual number of species is likely to be greater. In the expansion area of the industrial site, at least 31 large chestnut trees (*Castanea sativa*) with potential bat roost features were identified. Although not native and planted, chestnut trees are the oldest and largest trees in the wood. They have cavities and cracks offering shelter opportunities to different bat species and, therefore, play a fundamental ecological role for conserving local bat communities. Their role is not compensated for by the presence of trees of other species, which are generally much younger and with fewer cavities. For these reasons, the loss of large chestnut trees could represent a significant limitation for some forest bats.

3.2. Phase 2: Study Ecological Needs of Threatened Taxa

We had just 1 year to establish which parameters are important for conserving the target species. In 2019, the ecological preferences of *Z. polyxena* and its host plant *A. pallida* were investigated by collecting data on the butterfly abundance, tree cover, litter plant features and by surveying herbaceous vegetation [19]. We found that *Z. polyxena* has subnemoral (forest-edge) preferences, generally feeds in open areas (in accordance with [37,38]) and uses forest-edge and ecotones as an oviposition site. The species prefers small clearings (<1 ha) with a high number of *A. pallida* (in accordance with [39]). These data were used to suggest conservation actions supporting both *Z. polyxena* and other butterfly species. Specifically, management measures should prevent afforestation (e.g., through irregular either mowing or grazing) and favor the presence of small clearings and ecotonal habitats.

Acoustic bat monitoring, carried out in 2019, focused on understanding habitat preferences by bats in a forest-dominant environment, where ecotones, clearings and pastures were present to a lesser extent. It is known that habitat complexity and heterogeneity can increase bat activity and species richness [40]. We recorded at least 15 bat species belonging to nine genera (Table 2). Differences in bat activity showed a general need for high habitat variability and preference for ecotones for most species [41,42], whereas *Myotis* species showed a strong selection for closed forests [43]. A moderate selection for forest habitats was also shown by *Pipistrellus* and *Nyctalus* species [34].

3.3. Phase 3: Ad Hoc Solution to Reverse Habitat Loss

Nowadays, one of the major threats for biodiversity in Alpine environments is land-use change ([44,45]—specifically afforestation [46], which is linked to land abandonment [47]. On the other hand, forests rich in cavities, necrosis and deadwood support higher species richness both in terms of saproxylic beetles [48] and bats [49,50]. Species richness and abundance of saproxylic beetles is not only linked to deadwood volume [51], but also to clearing presence [52]. A delicate equilibrium therefore exists between forest cover, tree ages, and the presence of open areas within the forest.

Table 2. Species and groups of species detected in 2019. For each species, the Annexes of the Habitats Directive where it is listed and the category according to the IUCN Red List (LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; DD = Data Deficient) are reported. Species or genera that mainly roost in trees are in bold.

Species	Annex in Habitats Directive	Red List Category
<i>Pipistrellus kuhlii</i>	IV	LC
<i>Pipistrellus nathusii</i>	IV	NT
<i>Pipistrellus pipistrellus</i>	IV	LC
<i>Pipistrellus pygmaeus</i>	IV	DD
<i>Hypsugo savii</i>	IV	LC
<i>Nyctalus leisleri</i>	IV	NT
<i>Nyctalus noctula</i>	IV	VU
<i>Eptesicus serotinus</i>	IV	NT
<i>Barbastella barbastellus</i>	II–IV	EN
<i>Plecotus</i> spp.	IV	
Small <i>Myotis</i> (<i>Myotis</i> spp.)		
<i>Myotis crypticus</i>	IV	VU
<i>Myotis daubentonii</i>	IV	LC
Large <i>Myotis</i> (<i>M. myotis</i> / <i>M. blythii</i>)	II–IV	VU
<i>Tadarida teniotis</i>	IV	LC
<i>Rhinolophus ferrumequinum</i>	II–IV	VU

We used the data collected during surveys and inputs from the literature to develop an action plan that could be implemented using forest compensation funds, respecting the indication provided by regional law, but directing interventions for conserving a more significant number of species. We proposed a complex and diversified solution to favor the maintenance of those species that would have suffered from habitat loss. Our proposal was to make clearings for butterflies, leaving cut trees on the ground (within the limits provided by law) so as to increase deadwood for saproxylic beetles—and many other species that would benefit from dead wood on the ground—and to create artificial holes in tree trunks to provide bats with artificial roosts.

We proposed an ecological corridor composed of ten stepping stone clearings (overall 10 ha) to recreate suitable habitats for the *Z. polyxena*—and other butterfly species—and to possibly conjunct the subpopulation at risk with another recently separated subpopulation at about 1 km (Figure 2). Moreover, to facilitate *Z. polyxena* colonizations, host plants and larvae were translocated to new clearings (Figure 3). Clearings were produced by cutting young trees and leaving branches, tops and other small woody material on the ground as deadwood. This practice is regulated by the Piedmont Region to maintain fertility and protect soil from erosion, but also supports forest biodiversity, e.g., saproxylic species [53,54], small mammals [55,56] and reptiles [57].

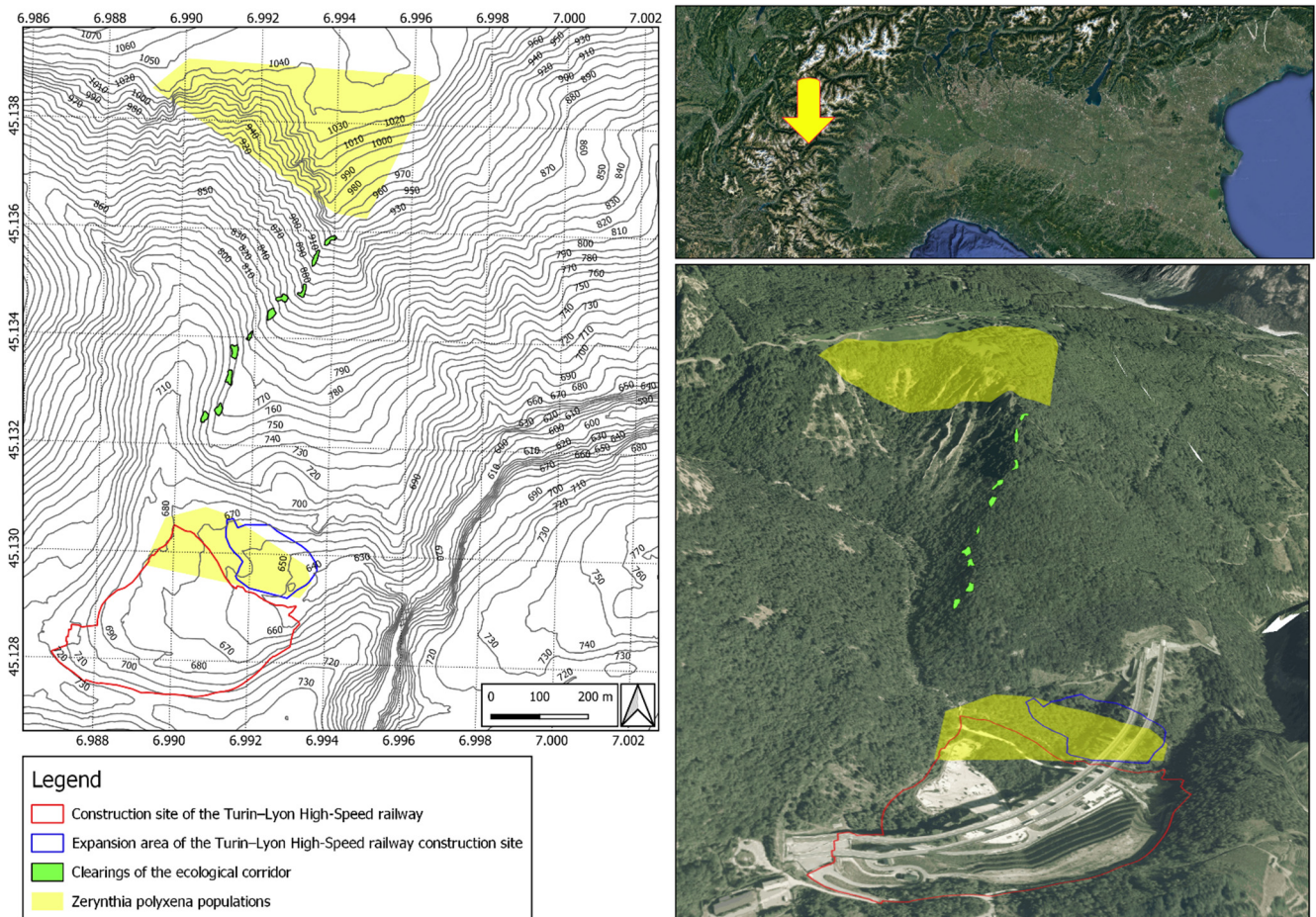


Figure 2. Map of the ecological corridor composed of ten forest clearings (ten stepping stones areas) realized to favor the connection of two subpopulations of *Z. polyxena* (areas in yellow). The expansion of the industrial site threatens one of these subpopulations.

In addition to creating the clearings, the plan included forest improvements, such as thinning and selective cutting in about 40 ha in the surrounding area of the corridor. In order to compensate for the loss of old trees, forest aging interventions and artificial bat roost installations were planned for at least 30 trees in forest and forest margins surrounding the expansion site. In particular, two artificial holes were produced in the trunk of broad-leaved trees—and also some conifers—with a diameter of greater than 40 cm (Figure 4). Bat boxes (a wooden Kent double-chambered box and a Schwegler 2F woodcrate box) were installed in the same trees to increase roosting sites—and to compare the usefulness of artificial holes in respect to bat boxes; and a black corrugated fiberglass panel was fixed around the trunk to produce artificial cavities similar to cracks in the cortex. While wooden bat boxes are known to be mostly used by *Pipistrellus* species [58,59], Schwegler bat boxes can also be occupied by *Myotis*, *Nyctalus*, and *Plecotus* species [60–63]. Artificial roost orientation was varied in order to ensure greater heterogeneity, also based on thermodynamic conditions [64]. By differentiating artificial roost type and orientation, we therefore aimed at improving suitability for different bat species. In 2020, 30 trees were provided with artificial cavities and nest-boxes.



Figure 3. Images of the ecological corridor, and the translocation of host plants (*A. pallida*) and *Z. polyxena* larvae. The map shows the area where the ecological corridor was located (Strip 1; 10 ha), and an area with thinning and selective cutting (Strip 2; 40 ha).



Figure 4. Successive phases of making artificial holes for bats in tree trunks. An experienced forest climber drills a large hole with the help of a chainsaw. The opening is then narrowed with a wooden rod to create a smaller entrance favorable to bats.

3.4. Phase 4: Monitoring Success of the Applied Plan

Within an adaptive forest management framework, we plan to monitor the results of our interventions over the next 3 years, in order to evaluate the outcome for the target species and collect information that is useful to improve our protocol. Monitoring is especially important to assess if the two subpopulations of *Z. polyxena* will connect and to evaluate if artificial cavities will be used by bats.

4. Discussion

This case study used forest compensation from a megaproject to plan management actions to protect bats, butterfly species and other insects. The approach that we developed is a proposal to use forest economic compensation to reduce biodiversity threats due to habitat degradation and loss induced by megaprojects when other compensation funds are not available. Without forest compensation, there would not be funds allocated to restore habitat degradation and biodiversity loss, even for species listed in the Habitats Directive and found in the industrial site expansion area. Megaprojects derogate the Habitats Directive due to their economic and social relevance, and compensations and mitigation actions may be applied for those infrastructures that pass through or are very near to Sites of Community Importance. However, in our case study, even if a breeding site of *Z. polyxena* was threatened by the expansion of the industrial site, according to the Habitats Directive, compensations and mitigations would not have been considered necessary. Indeed, the presence of other subpopulations a few kilometers from the study area means the industrial site expansion does not compromise the survival of the *Z. polyxena* population in the area. Our approach was to create an ecological corridor consisting of a sequence of clearings in the woods, to connect the threatened subpopulation with another subpopulation for which we did not record exchanges of individuals. The opportunity to connect these two subpopulations will increase their chances of survival in the long term.

Our approach allowed us to enhance the quality of the forest for many insects: as we created small clearings in the forest using clearcutting to favor butterflies and other open-area insect colonization; by leaving the cut trees in the forest, we increased local suitability for species needing deadwood. It has already been shown that a small-scale mosaic supports the co-occurrence of diversified communities of insects, specifically favoring the coexistence of light-demanding, ecotonal and shade-tolerant species [65]. Indeed, forest disturbances (e.g., natural disturbance such as fire, the activity of wild ungulates or human-induced disturbance such as traditional practices, in particular pastoralism of small ruminant livestock, lopping, prescribed burns, branch beating), when not too intensive, create and maintain forest canopy gaps that increase species richness, habitat quality and local diversity [66–68]. Moreover, those small clearings support a higher presence of taxa when subpopulations are connected and not isolated [69]. In our case, small interconnected clearings in the forest matrix composed the stepping-stone of an ecological corridor that could conjunct two closed *Z. polyxena* subpopulations. Indeed, genetic studies suggest that subpopulations of this species in the Susa Valley may previously have been more interconnected than they are today. Open habitat fragmentation due to natural reforestation may have recently separated those subpopulations. To reverse this trend, it is crucial to connect subpopulations and locally reduce reforestation, which is one of the major threats for the species in the Alpine environment [27]. Artificial and natural corridors—especially those surrounded by forest—are generally used by insects—in particular butterflies and moths—to disperse and colonize new areas [70–72]. Indeed, there is a good chance that butterfly species will use the interconnected, newly created small-clearings as a corridor to disperse. To aid in this process for *Z. polyxena*, we also translocated both its larvae and the host plants (*A. pallida*).

Italian forests generally have a good level of naturalness—introduced species are, for example, somewhat limited, at least in the Alps—but trees are very young. Large human communities once inhabited mountainous areas, and forests were extensively cut for timber and to gain space for crops and livestock [73]. Only recently—particularly from the second

post-war period—with the abandonment of the mountain, the forest has regained most of the spaces lost in the past [74]. However, a high tree cover is inevitably associated with the presence of young trees. Forest suitability for bats depends on the availability of roosting sites and the abundance and variety of prey. Roosting sites are cavities in trees, such as woodpecker and xylophagous insect holes, flaking bark, broken and cracked branches, and trunks [34]. Hollows are found in older, mature trees, as a result of wind breakage, heat, lightning strikes, fire, the action of woodpeckers, and attacks from insects and fungi [75,76]. In young forests, the number of available trees with cavities that bats can use is generally low. Unfortunately, we could not quantify the number of trees with holes in our study area. However, the formation of cavities is a prolonged process. In *Quercus robur* forests, less than 1% of trees <100 years old formed a cavity, compared to 50% of trees aged between 200 and 300 years old, and nearly all trees older than 400 years [76]. Therefore, trees with cavities should be maintained as a priority for biodiversity conservation in young forests.

In our study area, the expansion of the industrial site was 2 hectares, characterized by a chestnut forest in a decline phase and with a natural regeneration of broad-leaved species. This area was no longer managed in the last forty years. Thirty-one trees were rich in cavities compared to the other trees in the same forest patch that have recently grown. Therefore, we planned to compensate for their cutting by creating artificial holes in the trunk of other trees, an approach already used for different taxa in lowland forest [77]. In our case, we also placed a corrugated fiberglass panel around the trunk in the same trees to produce other artificial cavities, similar to cracks in the cortex, and two bat boxes for comparison. The monitoring foreseen in the coming years will confirm the effectiveness of these interventions, which may eventually be replicated in other areas with young forests.

Forest compensations are usually applied for tree plantation, general forest improvements, or to improve hydrogeological stability (e.g., [9]). Here, we used forest compensation for the first time to favor local animal biodiversity threatened by the industrial site. The innovative approach that we have presented here is in accordance with the indication of the Habitats Directive and an effective conservation approach. We first quantified the taxa that would have been affected by the expansion of the industrial site in part of the forest; secondly, we prepared a specific plan which provides for interventions that would benefit several taxa; finally, we used the available forest compensation funding to apply this multi-taxa approach. In accordance with Habitats Directive, the realization of the new habitats—or their improvement—which started before cutting the forest, permitted animals to migrate into those new habitats.

As a caveat, we recognize the last phase of the approach (Figure 1) is still ongoing; thus, the actual results might be fully evaluated several years after the forest interventions (e.g., [78]). Indeed, this research is a perspective study, that will prove its real effectiveness over time. Indeed, we suggest to monitoring the evolution and evaluating the success of this approach by the following methods: (i) regularly counting species richness and abundance of *Z. polyxena*, butterflies, saproxylic beetles and bats; (ii) evaluating the colonization of the ecological corridor by target organisms (e.g., moths, butterflies); (iii) assessing the genetic pattern of heterozygosis of *Z. polyxena* following the remixing of individuals from two subpopulations; (iv) surveying colonization of artificial roosts by bats.

This approach requires strong expertise to understand which local components could be degraded by the industrial site, to determine priorities among those components (with particular attention to protected species), study their ecological preferences, and plan a possible local solution. In this way, it is possible to maintain already vital ecosystems with complex biodiversity using available compensation funds.

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