The impact of landslide stabilization on birds: insights from an Alpine valley

Mattia Brambilla
Fondazione Lombardia per l'Ambiente, Largo 10 Luglio 1976 1, I-20822 Seveso (MB), Italy
brambilla.mattia@gmail.com

Abstract

Landslides are a common issue in mountains and other areas with slopes, and their frequency is increasing because of climate change. Interventions aiming at stabilizing slopes are thus common worldwide. The environmental monitoring of consequences of such interventions rarely consider the potential impacts on wild species, and especially on animal taxa. Birds are widely adopted as biological indicators thanks to their ecology and high sensitivity to environmental changes, and could represent an ideal subject also for monitoring the impacts of landslide stabilization. By monitoring birds for 8 years in a complex restoration intervention in the Italian Alps, I investigate their potential use for understanding the impacts of landslide rehabilitation at different scales, in a 350 ha-area. A BACI protocol was adopted, with bird data collected by means of point counts. Generalized linear mixed models were used to evaluate the potential impacts of restoration phases and intervention sites; analyses were developed for the breeding period and for the whole year, and for the local vs. large scale.

I found evidence for different type of impacts, including the local impact of construction sites (e.g. negative for chaffinch), of *in operam* phase (negative for mistle thrush, Eurasian treecreeper and crested tit, positive for grey wagtail and rock bunting), as well as for disturbance effect on species' detectability and for independent trends. The general species richness was not (or very scarcely) affected by restoration works. This 8 yr-work provides an example of the potential efficacy of birds as indicators of the environmental impacts caused by landslide rehabilitation, which will likely become increasingly common in the next decades. Avian monitoring could helpfully be integrated within standard monitoring of environmental impacts of landslide stabilization/restoration.

Keywords

Alps; bioindicator; breeding birds; environmental impact; landslide rehabilitation; mountains

Introduction

Landslides are among the commonest environmental issues in mountains and other areas with important slopes or rugged topography. They represent a major problem for people living in unstable areas and are therefore a frequent target of interventions aiming at stabilizing slopes and preventing further slides and erosion. Their impact will likely exacerbate in the future, because of climate change and increasing human impacts (Clague, 2008; Crozier, 2010). As a consequence, also stabilization and rehabilitation of landslides will become increasingly frequent. The monitoring of environmental consequences of stabilizing landslides has been traditionally focused on plant (and secondarily arthropod) species and assemblages (Calle et al., 2013). However, (other) animal groups could also provide useful insights into the broader consequences of restoration or stabilization interventions on slopes subject to landslides.

Birds are likely the animal group most frequently selected as a biological indicator to evaluate the potential impacts of environmental changes or transformations. The widespread use of birds as indicators of environmental impacts is due to multiple reasons, including the well established species-habitat relationships (Keast, 1990), the frequent association of bird species with rich and diverse biological communities (Bibby et al., 1992; Sergio et al., 2005), and the correlation with the impacts on other taxa (Tuck et al., 2014). They are therefore effective indicators of ecological quality and functionality of terrestrial ecosystems in many contexts (Padoa-Schioppa et al., 2006). In addition, birds occupy several trophic levels, and quickly respond to environmental modifications, even within the same season (Brambilla and Rubolini, 2009), thus qualifying as ideal indicators of the environment state and its relative variations (Canterbury et al., 2000). Last, but not least, their populations and distributions are relatively easy to asses over varying spatial scales (Wiens, 1989).

(Brambilla et al., 2017; Scridel et al., 2018).

Considering the high sensitivity and indicator value of birds, avian species and communities represent an ideal target also for monitoring the potential impacts of landslide restoration on animal species. However, avian monitoring in relation to landslide restoration is far from being routinely adopted as expected. To the best of my knowledge, no study has explicitly assessed the potential effect of landslide restoration on birds, and a literature search (performed on 31st July 2019) in Google Scholar with “birds” AND “landslide remediation” (or “landslide rehabilitation”, “landslide restoration”, “landslide stabilization”) did not identify any paper explicitly assessing the potential effect of landslide restoration on birds.

With this work, using bird monitoring in a complex restoration intervention as a study case, I investigate the potential use of birds as indicator organisms for the potential impacts of landslide rehabilitation on the short term, considering both local and large-scale impacts. I also suggest possible ways to evaluate the potential impacts of restoration works on observer's ability to contact bird species, and point out what species could be particularly suited as indicators of impacts for European mountains, selecting taxa representative of different habitats on the basis of their response to restoration works.

2. Methods

2.1 Study area

The study was carried out in Val Torreggio, in the Italian Alps (Lombardy region; Fig. 1), covering an area of c. 350 ha. This is a valley with an east-west orientation, characterized by the occurrence of several landslides of different age and extent, with a variety of natural and semi-natural habitats interspersed among each others. The lowest elevation belt (800-1000 m asl) is dominated by broadleaved woodland, which include both mature stands and coppices or recent, secondary forest over abandoned grassland; small open (grassland) or semi-open habitats (shrubland) and built-up areas (small villages and isolated buildings) also occur. The upper areas (1400-1800 m asl) are dominated by coniferous forests, mixed with mown grassland, seasonal pastures and shrubland. Rocky cliffs and outcrops and paleo-landslides (old landslides, currently inactive and often colonized by vegetation) occur mostly at intermediate elevations; paleo-landslides are partly restored and partly untreated; in some parts they are covered by trees (forested paleo-landslides). A large, 30yr-old and largely unvegetated landslide occupies a large portion of the southern part of the area (Fig. 1). Some areas with sparse trees over once grazed areas occur along grassland patches and at the upper margin of the larger landslide. The valley floor is occupied by a main stream, flowing eastwards, with several small streams reaching it from the slopes. Restoration activities involved the lowest parts of the main landslide, parts of the paleo-landslides (including the one that already underwent a past restoration), a large part of the main stream course, and some of the minor streams in the valley sides. Other sites were concerned with the creation of new roads (or the re-shaping of existing tracks) and construction sites, or with minor interventions (removal of small tree patches or boulders, new ditches to reduce superficial water runoff, creation of new tracks). The main intervention features and approximate extent (as estimated by field observations carried out by the author) are summarized in Table 1 and shown in Fig. 2 and Appendix S1. The overall area directly concerned by interventions covers c. 20 ha. Interventions started between 2014 and 2017 according to site, and all ended in 2017.

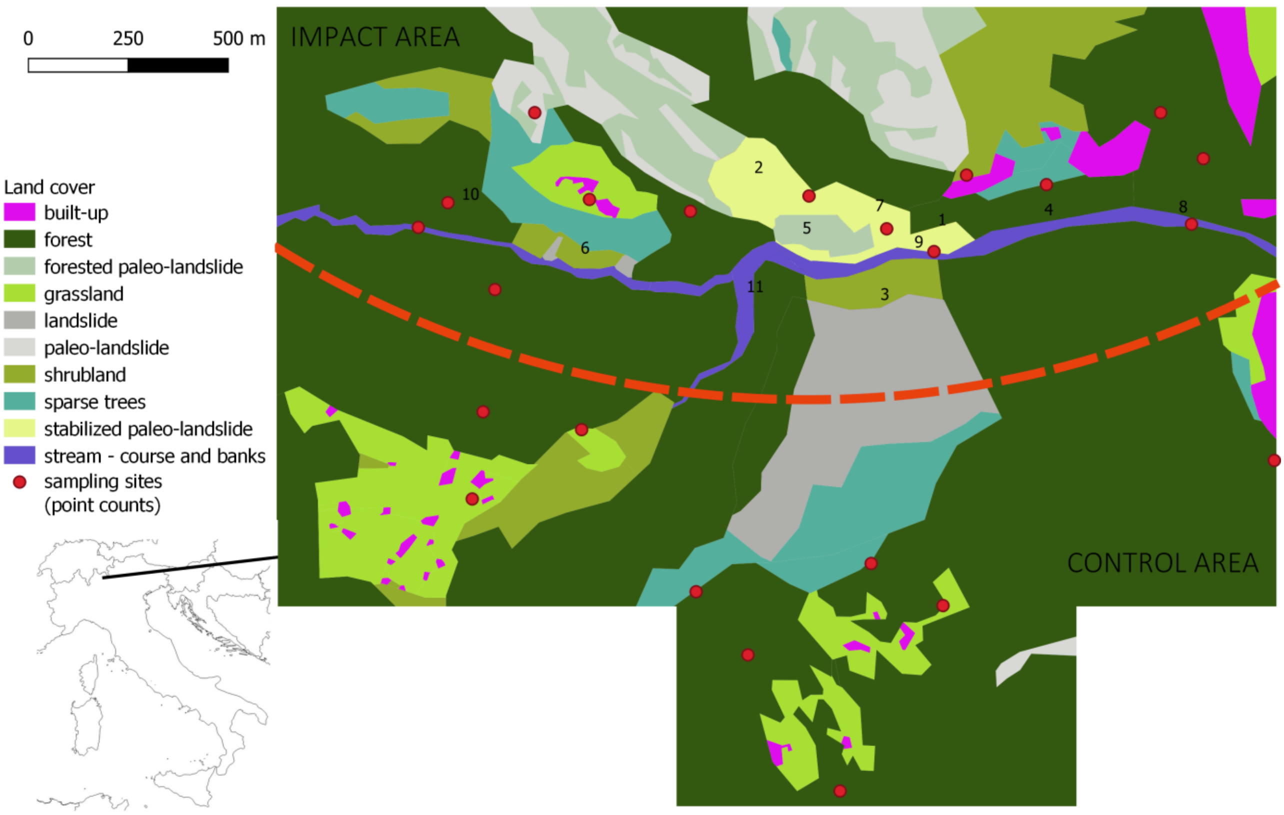

Figure 1. Dedicated land cover map (realized by combining detailed aerial ortophotographs and field observations) of the study area and spatial distribution of sampling sites (point counts; sites shown as red dots). The main stream flows eastwards, and elevation is highest at southern and northern margins. The dashed red line separates the impact and control areas. The inset on the left shows the position of the study area within Italy.

Table 1. Characteristics of the main interventions carried out within the study area. "Code" refers to the identification code (number) associated to each intervention in Fig. 2 and in Appendix S1.

Code	Brief description	Approx. extent
1	construction site (machine repository, material preparation)	0.27 ha
2	construction site, partial paleo-landslide restoration	2.82 ha
3	stabilization of the main landslide	6.70 ha
4	new road	1.26 ha
5	new roads and reshaping of existing ones	1.67 ha

6	new road	0.60 ha
7	paleo-landslide restoration (removal of stones and small trees, reshaping to reduce slope)	1.73 ha
8	stream reshaping (mostly stone removal)	0.48 ha
9	stream reshaping	1.96 ha
10	stream reshaping	0.15 ha
11	stream reshaping and paleo-landslide restoration	0.78 ha

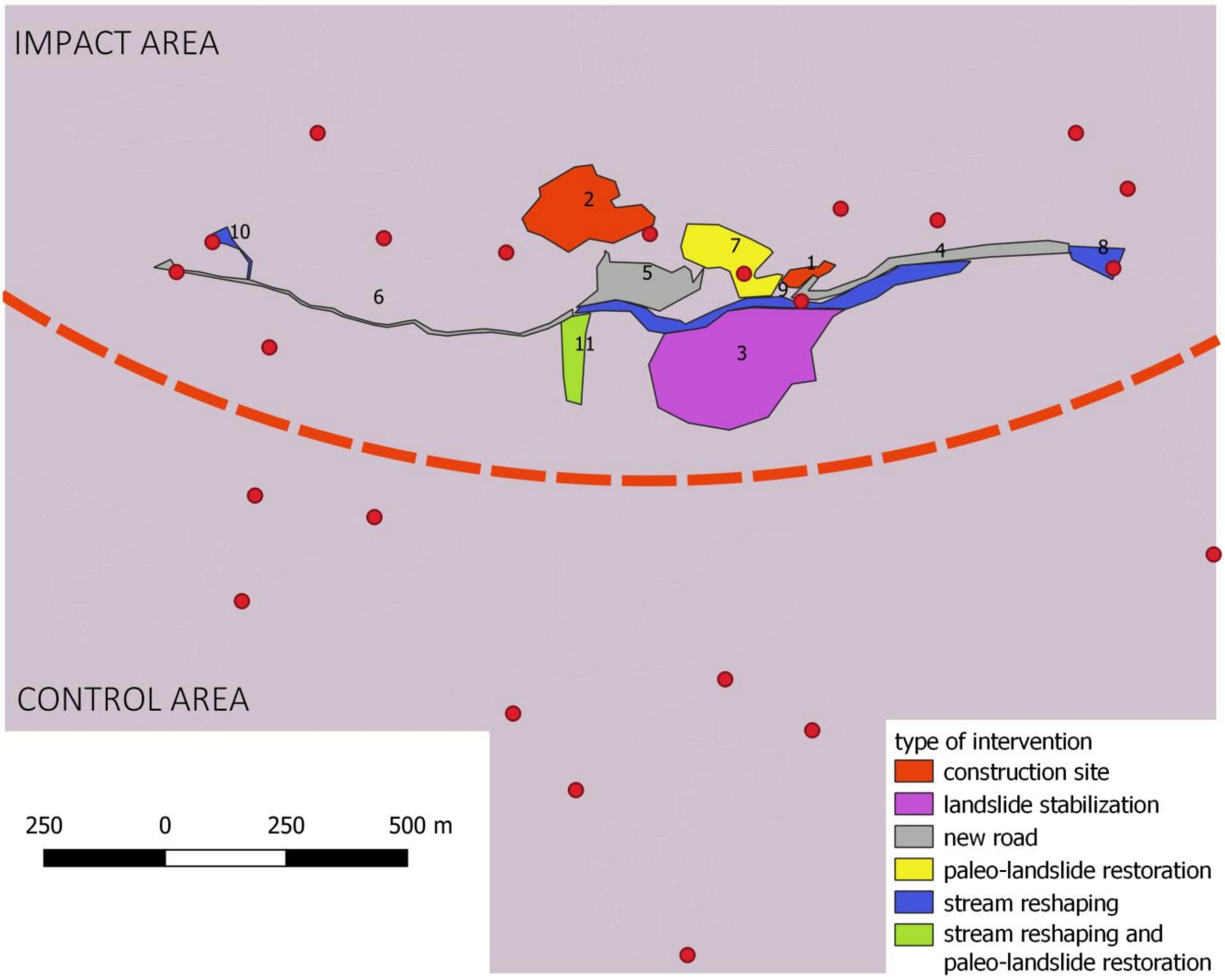

Figure 2. Spatial distribution of the main interventions and approximate area covered by each one (see Table 1 for individual characteristics). Dark red dots represent the sampling sites (point counts). The dashed red line separates the impact and control areas.

In addition to the landslide-related interventions, other potentially impacting activities carried out during the study period were tree logging in some portions of coniferous forests, and renovation of old buildings in the southern part of the valley.

2.2 Monitoring protocol

I opted for a BACI (before-after control-impact) protocol for the collection of field data and for the analysis of impacts (Battisti and Marini, 2018; Stewart-Oaten et al., 1986), thus including sites with and without interventions (and at varying distances), and monitoring them before, during and after the restoration activities. 23 sampling locations were selected and surveyed by means of 10 minutes-point counts. Part of them were located at intervention sites or close to them (within 250 m) in the northern sector of the study valley (‘impact area’, north of the dashed red line in Figs. 1-2); other sites were located relatively far (>400 m) from the interventions in the southern sector (‘control area’, south of the dashed red line in Figs. 1-2). The minimum distance between neighbouring points was >200 m (except for points located on the stream, which were sometimes closer to other points, as the detection distance at such points was limited to a very few tens of meters) to reduce the risk of double census of the same individuals. A network of point counts was thus set to cover all portions and habitats of the area (but with some non-sampled areas due to accessibility constraints), as well as the gradient of interventions and related disturbance (Fig. 1). At seven points, interventions were performed (starting in 2014 at five sites, in 2017 at two sites, ending in 2017 at all points).

Each point was surveyed by the author with the aid of 10x42 binoculars. All contacts with birds were distinguished according to the distance from the points (within and beyond 100 m).

All points had been surveyed more times each year during the period June 2011 – September 2018. In most years, counts were performed in spring (three surveys in April/May – June, according to weather and snow cover), summer (one survey in July-August) and winter (one survey in December-February), with limited variation among years. Some winter surveys did not include all points because of access constraints due to snow and ice cover. One autumn survey (September) was performed in 2013 and 2018.

2.3 Analyses

To obtain a quantitative evaluation of the effects of restoration interventions and of work-associated disturbance, I focused on overall species richness per point and on single indicator species (occurrence or abundance per point). Indicator species have been selected for different habitats, according to the following requisites: i) a certain degree of ecological specialization and ‘representativeness’ for a given habitat (at least, within the study area; based on literature and personal experience), excluding thus species adapted to different or degraded habitats; ii) species regularly occurring within the area and with a good sample size; iii) species for which point counts represent a reliable survey method (excluding e.g. raptors). The following species (for the following habitats) were thus selected: grey wagtail *Motacilla cinerea* and dipper *Cinclus cinclus* (watercourses); mistle thrush *Turdus viscivorus*, tree pipit *Anthus trivialis* and rock bunting *Emberiza cia* (open and semi-open habitats); nuthatch *Sitta europaea* and marsh tit *Poecile palustris* (broadleaved forests); willow tit *Poecile montanus*, crested tit *Lophophanes cristatus*, Eurasian treecreeper *Certhia familiaris*, nutcracker *Nucifraga caryocatactes*, bullfinch *Pyrrhula pyrrhula* and crossbill *Loxia curvirostra* (coniferous forests). In addition, I selected four species found across most habitats and sites: robin *Erithacus rubecula*, blackcap *Sylvia atricapilla*, chiffchaff *Phylloscopus collybita*, coal tit *Periparus ater* and chaffinch *Fringilla coelebs.*

In order to assess the impact of restoration works, I developed GLMMs (Generalized Linear Mixed Models). For each species, different models were built considering breeding vs. all data, and data within the 100 m-radius vs. all data, to explore potential effects on general species status vs. local breeding population, and on site-level vs. broader scale. Therefore, the following combinations were tested: all-year abundance (occurrence) within the 100 m-radius; breeding abundance (occurrence) within the 100 m-radius; overall all-year abundance (occurrence) (within and outside the 100 m-radius); overall breeding abundance (occurrence) (within and outside the 100 m-radius).

The need for such distinction is due i) to the particular importance of the breeding assemblage, which includes the populations with the strongest link to the area, and the most interesting species for the Alpine region; ii) to the potential evaluation of local vs. large scale impacts, thanks to the collection of data separating those within and outside the 100 m-radius. In addition, possible impacts on observer’s ability in locating the species could also be highlighted (negative effects outside the 100 m-radius, because of noise precluding contacts with ‘far’ individuals belonging to species mostly/partly located by calls).

Models were built with occurrence or abundance of the target species at a point as the dependent variable, and the following predictors: i) season (categorical: breeding (April-July), autumn (August-September), winter (December-February); included in models with all-year data, but not in that focusing on the breeding season only); ii) phase (categorical: *ante operam*, *in operam* (2014-2017), *post operam*; for sites in the control area, phase was set to *ante operam* for all years); iii) intervention site (0: no intervention site, 1: active site; varying from point to point according to the local timing of restoration works). Point count identity was entered as a random factor to take into account the non-independent data collected at the same site. Models have been developed either with Poisson (abundance) or binomial (occurrence) error. Models were checked for convergence and overdispersion; in that case, models were re-run using a negative binomial error. If models did not converge, or resulted overdispersed, even after such correction, they were rejected.

Different procedures were used to build GLMMs, as different estimates are sometimes obtained using slightly different approaches (Zuur et al., 2009). I used the *packages* nlme, lme4 and glmmADMB (Bates et al., 2015; Pinheiro and Bates, 2010; Skaug et al., 2018) in R (R Development Core Team, 2016); the package *sjstats* was used to check for overdispersion. Different approaches generally led to similar results (not shown), for all non-rejected models. I considered the significance of phase and construction site in the model (which included also season), discriminating between non-significant ($P>0.1$), marginally significant ($0.1 < P < 0.05$) and significant ($P<0.05$) effects.

A few possible outcomes were a priori defined as representing different potential impacts of restoration works, including i) broader-scale impacts of *in operam* phase (which mean large-scale effects of disturbance/habitat alteration) ii) long-lasting impacts (impacts of *in operam* and *post operam* phases and construction sites), iii) disturbance effects on detectability (disturbance effects on observer due to the noise produced by the intervention sites, which should result in fewer contacts especially with far birds), iv) local impacts of intervention sites (when the impact is circumscribed to the area modified by stabilization works), and v) potentially independent trends with respect to restoration activities (Table 2).

Table 2. Possible main types of impact and related patterns expected in modelling bird data according to restoration activities. “(yes)” means that an impact could be expected but is not strictly required to attribute a trend to a given category. This is not an exhaustive description of potential effects, as other patterns may also be found (see text).

broad-scale impacts of *in operam* phase		
	only within 100	all data
intervention site		
phase *in operam*	yes	yes
phase *post operam*	no	no
long-lasting impacts		
	only within 100	all data
intervention site	yes	
phase *in operam*	(yes)	
phase *post operam*	yes	
disturbance effects on detectability		
	only within 100	all data
intervention site	no	yes
phase *in operam*		
phase *post operam*		
local impact of intervention sites		
	only within 100	all data
intervention site	yes	(yes)
phase *in operam*	no	no
phase *post operam*	no	no
potentially independent trend		
	only within 100	all data
intervention site	no	no

phase *in operam*	yes
phase *post operam*	yes

Given that the *post operam* phase covered only one year (2018), and that many species may show inter-annual variation in abundance and distribution patterns (Maron et al., 2005), in this specific example potential effects specifically due to the *post operam* phase could not be distinguished from possible year effects. For the same reason, potential large-scale and long-lasting impacts could be hard to disentangle from independent trends; however, the lack of effects of intervention sites and on local data (within 100 m) would point towards the latter rather than the former. As the monitoring finished, the area was opened to recreation with the construction of new car parks and other tourist facilities, thus potentially creating new impacts, different from those associated with the landslide stabilization.

3. Results

3.1 Species richness

Almost no impact at all was found on the number of species per point; the only effect found by models was a positive effect of *in operam* phase on the overall number of species (including all seasons and all records irrespective of distance).

3.2 Single species

Almost all models for crossbills did not converge and thus this species was left out from the analyses. I found evidence for all the preliminary defined possible patterns with the only exception of long-lasting impacts (Table 3), both for breeding and/or whole-year data, with a slight prevalence of effects for the breeding season (Table3 and Appendix S2). In addition, some species showed patterns which were not clearly attributable to any of the previously defined ones, or were intermediate between expected ones. In particular, dipper showed evidence of increase after the completion of restoration activities (*post operam*), while no other significant effects were detected; outcomes for robin fall between an effect of *in operam* and an independent trend.. Results are summarized in Table 3 and the single-species models are reported in Appendix S2.

Table 3. Summary of impacts found by means of Generalized Linear Mixed Models (for model significance, see Appendix S1). Please note that also further patterns have been found (see text).

species	habitat	broad-scale impacts of *in operam* phase	disturbance effects on detectability	local impact of intervention sites	potentially independent trend	period / variable
grey wagtail	watercourses	+				B, W, A, O
dipper	watercourses			no impact (see text)		
mistle thrush	open habitats	-				B, W, A
tree pipit	open habitats				-	B, W, A, O
rock bunting	open habitats	+*				B, W, A, O
nuthatch	broadleaved forest			no impact		
marsh tit	broadleaved forest					?
willow tit	coniferous forests				-	B, W, A, O
crested tit	coniferous forests	-				B, A, O
Eurasian treecreeper	coniferous forests	-				B, A, O
nutcracker	coniferous forests	+				W, A, O
bullfinch	coniferous forests		-		+	B, W, A, O
robin	generalist	+?	-?		+?	B, W, A, O
blackcap	generalist			no impact		
chiffchaff	generalist			no impact		
coal tit	generalist				+	B, W, A, O
chaffinch	generalist			-		B, W, A, O

Legend of symbols used in the Table:

*only within 100 m

? only a few marginally significant effects or unclear patterns

For period/variable: B: breeding; W: whole year; A: abundance; O: occurrence.

4. Discussion

While the effects of mass movements on biodiversity have been investigated in different geographical contexts (e.g. Alexandrowicz and Margielewski, 2010; Geertsema and Pojar, 2007), the impacts of interventions targeted at landslide restoration/stabilization on animal species have received a surprisingly limited attention. In particular, birds, despite their acknowledged role of ecological indicators (Canterbury et al., 2000), have apparently never been considered in scientific literature dedicated to such a type of environmental restorations. Despite the limitations imposed by the short *post operam* monitoring, this 8 yr-work provides a first example of the potential use and efficacy of birds as indicators of environmental impacts caused by landslide rehabilitation, and suggests potential approaches to be adopted to distinguish between temporary and longer-lasting impacts, as well as between concomitant variations not directly linked to stabilization/restoration activities. Considering the likely increasing importance of landslide impacts (Clague, 2008), stabilization actions and slope restorations will also become increasingly common, and hopefully the results of this work could contribute to inform future monitoring plans.

Some demographic or behavioural impacts are beyond those that can be detected by the approach here adopted: variations in survival or breeding success, time-budget or stress levels can not be assessed by means of field surveys like bird counts. However, this type of counts are the commonest form (and a reputedly robust approach) of environmental monitoring focused on impacts on animal (and especially on bird) populations. This kind of approach based on multi-season point counts over sites subjected to potential impacts, over several years and in combination with a BACI design, allowed an evaluation of the effects on both general and breeding populations of target species. The latter were selected in order to adequately represent the main different habitats found within the study area. In this study the *post operam* phase lasted only one year, thus making patterns potentially prone to the effect of year-specific variations in species occurrence/abundance (Maron et al., 2005). Nevertheless, this study provided a way to assess impacts over different spatial and temporal scales, enabling a distinction between different kind of variations, more or less related to restoration/stabilization activities. The latter had been considered all together in this study; although they shared some common patterns of changes (vegetation removal, ground clearing, disturbance), they also differed in terms of target habitats and interventions. Further studies focussing on single types of interventions, or evaluating the individual effects of specific activities over larger datasets, could allow insights also into the specific impacts of different intervention types contributing to landslide stabilization interventions.

Species richness showed a very limited variation in relation to stabilization works. Only the number of species found all-year round and without distance limits resulted positively associated with the *in operam* phase. This could potentially be due to an increase in detection rates of some species, thanks to the more open habitat and the sparser vegetation. Whether this could be the reason for the observed increase in species richness during the *in operam* phase or not, the lack of effect for all other combinations of data and periods suggests a very minor effect of stabilization works on species richness.

For a couple of species (bullfinch and, potentially, robin), I found evidence for a likely decrease in species detectability due to noise and disturbance determined by interventions. More precise evaluation of such effects on detectability could be obtained with occupancy or N-mixture models, which ideally would require a higher number of replicated counts than those here performed.

Despite the limited area directly interested by stabilization activities, some species showed clear signs of true impacts of interventions, mirroring the pre-defined categories of potential impacts. A negative and large-scale impact of the *in operam* phase was found for mistle thrush, crested tit and Eurasian treecreeper. Mistle thrush is a species inhabiting woodland margins, open forest, areas with sparse trees and shrubs, and probably was affected by the increased disturbance over the area due to the works; notably, in the same period the species increased at the regional scale (Brambilla and Calvi, 2019). Crested tit and Eurasian treecreeper are both forest-dwellers, tied to conifers, and the negative effect of *in operam* phase was found in both for the breeding period, the most critical part of the annual cycle, during which many species are more sensitive to disturbance and/or habitat alteration. On the opposite, the effect of *in operam* phase was generally positive for grey wagtail (commonly found along streams), which benefited from stream re-shaping and increased habitat openness ensured by restoration activities, which indeed resulted in an increase of small ditches and streams (to reduce the surface interested by water runoff), and in more open habitats. Positive effects of *in operam* phase on breeding rock bunting, which is tied to open or semi-open habitats and rocky sites, are likely due to the increase in open habitat and bare ground made available by the restoration activities, and partly reduced with the re-vegetation of several of those sites. Positive effects of *in operam* phase were found for robin and (non-breeding) nutcracker. For the former, the pattern is somewhat intermediate with that expected for an independent trend, and it is possible that such phase just coincided with a positive trend at a broader scale, something that actually happened in the same period at the regional scale (Brambilla and Calvi, 2019). The positive effect for nutcracker out of the breeding period is hard to interpret and could be due to the strong variation in productivity and abundance shown by that species, which showed a peak at the beginning of the *in operam* phase (see Appendix S2), and is coherent with the trend estimated at the European level (PECBMS, 2019); therefore, it is possible that such a positive effect is not due to a real impact of the *in operam* phase. Dipper showed an increase after the completion of works, during the *post operam* phase. Whether this could be attributed to positive impacts of stream reshaping and restoration, or to a favourable year occurring in 2018 (the only one of *post operam* included in the study), can not be unambiguously assessed. Even if not apparent from the quantitative analysis, the fine-scale patterns of occurrence suggest a temporary abandonment of stream portions during activities, quickly followed by re-occupation as soon as the activities ceased (pers. obs.).

The *post operam* monitoring period should cover a much longer time than it was possible in this specific case study to clearly understand the variations in species occurrence and/or abundance after the stabilization works. This could be particularly relevant for large-scale restoration works, where the vegetation may take several years to recover or develop and thus short-term effects may be different from long-term ones.

The results suggest that grey wagtail, mistle thrush, crested tit and Eurasian treecreeper could qualify as potential indicators for watercourse, open/semi-open habitats and coniferous forests (latter two), respectively; such habitats are indeed the ones most likely to be affected by activities linked to landslide restoration in temperate mountains. Even a generalist and highly adaptable species like the chaffinch turned out to be sensitive to the presence of active construction sites, which resulted in a negative effect on the species occurrence and abundance. Further assessments would reveal whether it could be used as a reliable indicator of local impact of construction sites.

This work thus demonstrates the potential usefulness of bird monitoring to detect some of the environmental impacts of landslide restoration: avian species occupying different habitats respond (both positively and, especially, negatively) to stabilization activities and / or construction sites, confirming the sensitivity of birds to environmental modifications, even over relatively limited extents and time.

The BACI protocol proved to be essential to distinguish between impacts related to the developed activities, and those independent from them. Tree pipit and willow tit, as examples, showed a decline likely not related to interventions, but in line with a negative trend at the European scale (PECBMS, 2019). BACI frameworks are needed to discriminate between perturbation-related and independent effects. Further improvements could integrate community occupancy models within the BACI framework (Russell et al., 2015), the use of control sites scattered over broad areas (to obtain unaffected sites also for species with larger home ranges), and the use of N-mixture models to fully evaluate the detection-related effects together with the impacts of habitat changes (Royle, 2004).

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Supplementary material

Appendix S1. Description of the main interventions considered in the monitoring.

Appendix S2. Variations in the abundance and occurrence of target species, based on point counts.

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