Landscape Structure Indicators as a Key Feature in Habitat Selection: an Operational Approach to Conservation Planning

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Abstract

Landscape structure is a key factor for biodiversity conservation. We assessed the potential role of landscape-related habitat structure on Hazel Grouse (*Tetrastesbonasia*) by recording the occurrence of the species. Hazel Grouse is a widely recognized endangered species, because of the habitat loss as a direct consequence of land use change that is jeopardizing the species survival. The aim of this study is to provide a method based on habitat suitability modelling to explore and analyse hazel grouse- landscape structure and its relation to key habitat features. We evaluated landscape factors and critical threshold for monitoring the species, in order to assess the predictive power of models based on field surveys, ancillary information and high resolution infrared aerial photographs. We tested Maximum Entropy (MaxEnt) algorithm, in order to predict the distribution of Hazel Grouse species, in the complex mountain landscape within the study site. This presence-only modelling method has showed numerous advantages over many other approaches. It is based on a function that links the fitness of individuals to their environment. Our results were highly consistent with field knowledge, showing that habitat modelling generated using spatial statistics and GIS can effectively help in the characterization of habitat requirements and the localization of the species suitable habitat. We found also that key drivers of Hazel Grouse distribution are not only environmental factors, in particular linked to elevation in mountain areas, but also landscape heterogeneity is a key feature. Hence, conservation of this species will require land management practices that maintain heterogeneous landscape; in particular small forest openings are essential for the species. The approach developed seem to be a promising operational tool for local and regional managers interested in species monitoring and management within the long term.

Keywords: Biodiversity conservation; Hazel Grouse; Landscape structure; Habitat suitability models; Management decision

Introduction

Within the current context of rapid landscape change [1-5], habitat loss is widely regarded as a major factor contributing to the decline of biodiversity [6-11]. Alpine ecosystems have been less modified by human activities than other lowland ecosystems. Nevertheless, current pressures of tourism and other forms of development in mountain areas, are significantly changing landscape structure due to growing human pressures over the last decades [12,13]. Such subtle changes in the landscape matrix is increasingly making habitat unsuitable for many life form, especially for specialist's species habitats [14-16]. Therefore, we face the challenge to monitor not just changes in natural systems but also the impact of these changes on the health and persistence of the species that depend on these environments. At present, still ecologists, conservation practitioners, and managers require modern specific tools essential for an effective landscape planning to face the increasing threats to biodiversity [17]. In order to reintroduce and rehabilitate the threatened species and to understand environmental and landscape determination of species distribution [18-21], a detailed knowledge about spatial distribution of their potential habitat [22] is a crucial challenge for planning biological conservation priorities [23-28].

Species distribution models SDMs [29] have shown great potential to help achieve conservation goals by refiningour knowledge of species distribution [30]. SDMs are referred as habitat suitability models [22]. These niche models identify areas that are ecologically suitable for the presence of species [22,29,31]. Extensive use of SDMs has broad important applications to support management decisions with regard to biodiversity [29,32-34]. Many examples can be cited that have made such an extensive use of different applications using SDMs approaches, for assessing global impacts, prioritizing or targeting areas for protected status, assessing threats to those areas, predicting distribution in unsurveyed areas and designing reserves [35-42].

These models are created on the bases of statistical relationships between landscape or/and environmental characteristics and species data [43]. Actually, the species location information from specimen records and other source are widely available due to the development of digital databases for natural history collection [44]. Hence, SDMs provide an alternative approach that can help extend the usefulness of direct observation and improve interpretation and understanding of species distributions [29]. Many methods are used to fit SDMs that may be more or less applicable depending on the type of biological and environmental data available, the species of interest and the aim of the model. Using presence/absence species data is very popular to model species distribution [43,45,46]. Nevertheless, the rarity and heterogeneity of scarce or endangered species limit the use of these conventional methods to model their habitats. The rarity and low reliability of absence data also limit the use of this method [47,48]. Therefore, new methods have been developed to improve prediction of species distribution from presence data only [32,40,49], which are often

valuable resources [41]. This approach is particularly useful to model rare species and species with low detectability.

Some species can be useful indicators for determining the quality of ecosystems or for developing management strategies to restore and conserve biodiversity [24,50,51]. Hazel Grouse (*Tetrastes bonasia*) is considered as habitat specialist [52,53], and its indicator function makes it a suitable flagship species to promote the conservation of its habitat and biodiversity in general [54-56]. It has been listed in Appendix I of European Birds Directive (CEE/79/409) and in Appendices I, II, IV and V of the Habitat Directive of the European Union. Thus, at the large scale, the conservation of forest habitats in the Alps contributes significantly to the viability, of Hazel Grouse and other habitat specialists or threatened species. Even though its critical population decline has been documented [52,56], Hazel Grouse is not yet taken into account as a target species within a conservation objective. Despite that, habitat modification is the principal cause of decline for Hazel Grouse because it creates unsuitable landscape structure that affects critical habitat characteristics [57,58]. As a result, within this work we attemptto answer questions raised by Hazel Grouse conservation targets that should be considered within the strategy of the CBD towards 2020 [59]. The problem with current distribution data of Hazel Grouse and for other threatened and endangered species is that they are sparse and clustered making it difficult to model their suitable habitat distribution using commonly used modeling approaches. We then introduce an innovative operational approach to support conservation and management decisions by using a method that responds well when only small number of occurrence records exists. The aims of this study are (i) to identify the spatial distribution of Hazel Grouse in order to provide insights for conservation planning (highlighting the specific areas of high habitat suitability) (ii) to evaluate the effect of current landscape composition and structure on Hazel Grouse distribution and (iii) to derive key habitat features for protected areas having different status that can provide useful information for practical recommendation and management guidelines.

Hazel Grouse is a cryptic species with discrete behaviour, and therefore difficult to detect, only presence modelling methods seem to be appropriate to model its habitat quality as a function of both environmental and landscape variables in particular in complex mountain landscapes. We used a maximum entropy algorithm available in MaxEnt, designed specifically for species distribution models [49,60]. This method is known to have a highest predictive performance compared to others, in particular when applying "presence-only" species occurrence data [40,61,62].

Methods

Study area

The study site is a land dominated by forest. This forestland is an anchor in the heart of a Regional Natural Park (Chartreuse) with arising objectives of sustainable development and conservation, including a Natura 2000 site. Nevertheless, the area is located in the middle of an axe between Grenoble and Chambery, two important urban centres in the Alps facing an accelerating suburban sprawl. In addition the area is undergoing an important tourism development associated to relatively small ski resorts in winter and other sports like VTT in summer. These activities constitute an important income for a region that is losing traditional activities but increases the impact and pressures for the flora and fauna. Our study was confined to the State Forest of Grand Chartreuse within an area of 6637 hectares (Figure 1), of a complex landscape mosaic (Lat. 45°23'20" N Long 5°47'47" E).
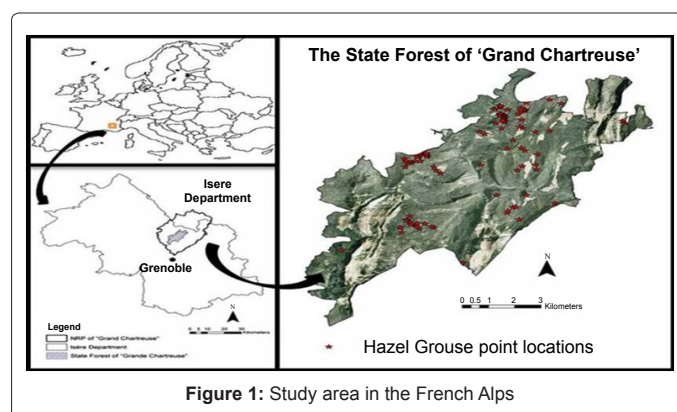

Figure 1: Study area in the French Alps

The site is part of "the state forest of the Grand Chartreuse", located at the heart of the massif of the same name. Following the objectives of the European Habitat Directive, a sustainable forest management is within the agenda of the Park, in tandem with a participatory approach launched with local actors to maintain the area biodiversity. Forestry activities are still important but with aims to balance conservation actions. There is also a plan for the creation of a biological reserve on the site that is nowadays a Natura 2000 area. In this regard, there are regional interests to develop appropriate legislative, financial and contractual instruments towards a better implementation of conservation actions.

The physical framework

Elevation within the study area ranges from 400 to 2000 m. The mountainous area is covered mainly by coniferous forest stands including also open land, expose rocky areas and other open habitats such as pastures and meadows. The dominant tree species are Fir (*Abiesalba*), Spruce (*Piceaabies*) and Beech (*Fagussylvatica*). These dominant species form a complex forest landscape matrixof a typically mixed beech-fir-spruce, with variations in the proportions of the dominant species depending on elevation. Beech is dominant at lower elevations (below 600 m), while fir, beech and spruce are mixed in the mountain range (600–1200 m). Spruce becomes dominant in the subalpine range above 1200 m. The area is managed by the National Forest Office (NFO) of the French Isere Department.

The Natural Park of Chartreuse forests is committed to maintaining biodiversity as it has been selected as a reintroduction area for certain species and is part of the Alps hot spot for European biodiversity [63]. More than any other in the French Alps, the massif of Chartreuse is committed to the maintenance of its forests[64]. The monks from Chartreuse, started their activities during the 11th century, the Church of Saint-Hugues county and recently the seat of the Natural Regional Park of Chartre use provided to these forests a particular patrimonial value that historically helped on the protection of the forests [65-67]. These forests that were part of the church patrimonial value, benefited throughout the centuries of a particular protection status. During the nineteenth century, however, the use of forests becomes more important [65]. Consequently, these alpine ecosystems are nowadays rapidly changing on structure due to the presence of a ski resort in mid-mountain and several other related tourist attractions that jeopardize conservation objectives[13]. Protecting this natural and cultural landscape against degradation and pressures of any kind is the great challenge for biodiversity conservation targets which demands sound scientific analysis based on data and information [68]. In particular an adaptive management that can respond to increasing economic demands while still planning for conservation objectives it should be

possible in the region. We used Hazel Grouse, a declining key indicator species of the Alpine ecosystems [54] to provide insights towards balanced conservation objectives.

Hazel Grouse *(TetrastesBonasia)*: A target species

Hazel Grouse is known for being strongly affected by forest dynamics, and populations in many areas within Europe are declining. The French Alps is one of the important reserves in central Europe that hold Hazel Grouse population, their density varies locally [56]. This focal species is known as forest-dwelling bird species, sedentary (adult) and strictly linked to its habitat [52,69]. It is highly secretive and notoriously difficult to census [70]. Hazel Grouse is known to be more territorial in spring [71]. Previous research confirms that Hazel Grouse has highly-specific habitat requirements in terms of structure and composition that are in most cases best met by vertically and horizontally richly structured forest [57,71-73]. The juveniles of Hazel Grouse feed mainly on insects which are more available in a forest with characteristics patterns of openings. Moderate dense shrub cover is a fundamental element for food and for hiding from predators [71,73,74]. In particular, Open-sparse forests (small gaps in the overstorey) are required [72], whereas, open area are avoided because of high predation risk [75-77]. Remaining populations of the species are patchily distributed in mountain areas [70,78], and as lowland became unsuitable because of changes in forest use and subsequent fragmentation[79], the remaining suitable habitats are restraint [54,74]. Therefore, identification of habitat and landscape factors restricting the distribution of Hazel Grouse in forest is crucial for protecting the species.

Hazel Grouse paths

We applied a random transect survey method that standardized the effort for every transect [74,80]. Therein, we followed 51 random transects with an average length 1. 23 ± 0. 4 km. Sampling carried out during 2010 spring [71], just after snow melt but before the grass growth of underbrush mask the ground, between 600 and 1600 m of elevation (Figure 2).

Indirect evidence such as droppings, feathers, footprints and snow caves, was thoroughly searched for, on each selected track (following the selected tracks) within a 15m wide band, and then we established a plot and recorded vegetation and other data around each sampling

Figure 2: Schematic illustration of the shape of the transect line that was used to search for evidence of Hazel Grouse occurrence

point. In order to avoid or minimize the risk of sampling bias presented during field work [81], using GIS tools, we plotted (registered) all Hazel Grouse track paths with mandatory checkpoints on the GPS, which helped orienting in the field.

Droppings accounted for 99% of the species data and they were generally found in the proximity of understory plants preferred by Hazel Grouse diet and below coniferous trees (sleeping and resting sites). The field sampling done within the life if this study was oriented to enhance the existing presence data already collected by the naturalist network of the National Forest office (NFO, Isère Department) during the last ten years [29,82]. In total, 85 presence locations of Hazel Grouse collected in the study area were selected for further analysis.

Explanatory variables as candidate predictors

Environmental variable: Elevation variable (source: 50 m resolution digital elevation model DEM (French National Geographic Institute) was used in this study as independent environmental descriptor. This variable is considered as an effective surrogate of heterogeneity and provides a reasonable explanation on the role of other environmental factors such as vegetation distribution and temperature [83,84]. Potential predictor's selection is motivated by their hypothesized effects on focal species distribution and also by their availability in digital format for the study area [17,29,85,86].

Landscape Metric Indicators: Six landscape metrics (Table 1) were also evaluated, corresponding to the most commonly used landscape variables, as potential descriptors of Hazel Grouse occurrence [72-74,87,88]. Aerial photography (pixel size 0. 5m, National Geographic institute, 2003) of the study area was digitized on screen to produce a forest continuum and forest openings vector map. This binary map was then converted to 20 grain raster map (Figure 3). This map was the background for calculating landscape metrics. Ultimately, all digital information had a resolution of 20 m and to make sure that all raster layers have the same dimensions, a single raster mask delimiting the study area was used.

Using the Moving Window approach [89-91] in Visual Basic program, we computed landscape level indicators over all the study area. Because changes in the map extent can produce unpredictable behaviour of landscape metrics e. g. [92,93], we chose a specific extent of 12. 5 hectares (circle of 200m radius) (Figure 2). This extent was chosen because it seemed to be relevant for Hazel Grouse ecology and biology and survival spatial requirements based on expert knowledge and references [73,94]. It is also nearly in accordance with Hazel Grouse's territory reported by Swenson [69]. Species' point of view or "perception" is an important feature to be considered in order to better understand the ways in which species interact with the spatial arrangements of its environment [95,96].

Habitat distribution modelling

MaxEnt ecological niche modelling [49,97] uses known occurrences and background data resampled from the set of pixels where the species is known to occur. The modelling approach is used then to make inferences about probability of geographical distribution of species based on environmental variables and to reconstruct the boundaries of the ecological niche [49]. The resulting model represents the relative probability of the species' distribution over all grid cells in the defined geographic space, where a high probability indicates that the space is predicted to have suitable environmental conditions for the species
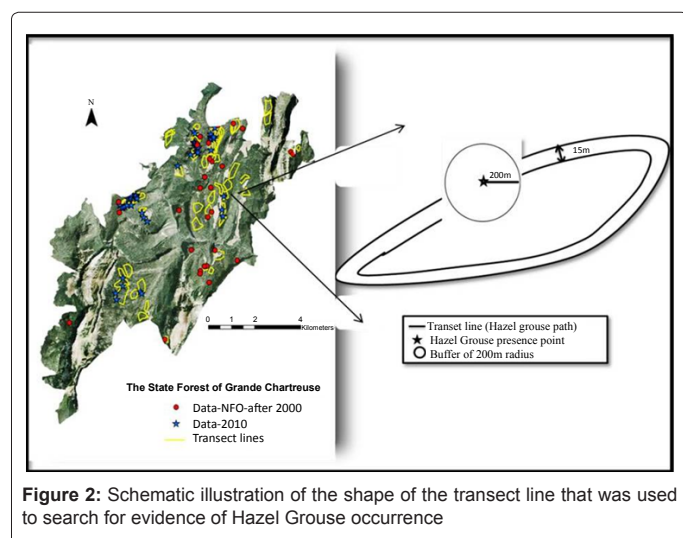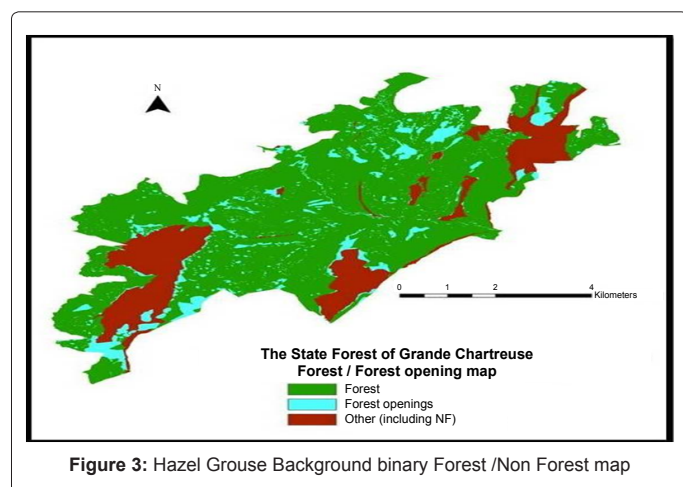
Figure 3: Hazel Grouse Background binary Forest /Non Forest map

[41,49]. This algorithm has been shown to perform well even with scarce and noisy presence data subsets collected by different researchers and methodologies [29,40]. The model can easily be updated with new specific occurrences for the target species.

We used MaxEnt software because of its strong attributes such as its algorithm constraints predicted species ranges and thus reduces and avoids commission error that could lead to erroneous conservation decisions[41,98,99]. It can investigate variable importance through jacknife procedure, in which model performance is assessed based on its ability to predict the single locality that is excluded from the 'training' dataset [99]. It permits to show relative suitability rather than the occurrence probability [100]. Globally its properties have several implications for how it should be used in this study [41,86]. We used default setting [60], except for iteration number; we executed 100 replicated model runs. We configured the machine-learning algorithm to use 80% of the species records for training dataset and 20% for testing the model [101]. We determined the heuristic of the relative contribution of each variable to species' distribution. MaxEnt estimates the importance of variables' contribution, representing the percentage of the variable contribution to the model based on path selected for a particular run. In addition, the permutation importance values were obtained by changing the predictors' value between presence and background points and evaluating how that affects the AUC value.

Model evaluation and threshold selection

The Model quality was evaluated based on the Area Under Curve (AUC) value [39,97,101] as it is part of MaxEnt output [49]. High AUC value indicates a high capacity of models to discriminate the presence and absence species [39,102]. We compared AUC values for 100 models replicates, and chose the best model (the model with ROC value closet to 1). According to Phillips et al [60] and Pearson and Dudik [99], we used a fixed threshold to reject only the lowest 10% of possible predicted values at each run. This threshold value, based on a logistic threshold of 10 percentile training presence, was used to reclassify our model (binary building reclassifying).

Results

Model prediction analysis

The prediction map of the potential distribution of Hazel Grouseas a function of suitable habitat distribution (Figure 4) shows that the potential habitat with high suitability thresholds were distributed in the

higher elevations of the state forest of Grand Chartreuse (Table 2). The highest MaxEnt scores were located in the mountainous areas located above 1000 m.

The model was highly successful in highlighting areas that could potentially harbour this rare species as well as undersampled areas with suitable environment conditions. With 10 percentile threshold (0.24), 61% of the analysed study area classified as a potential habitat for Hazel Grouse.

Using three arbitrarily defined probability classes, the high suitability class showedonly 1%, while medium suitabilityscore 60% and low or null suitability 39%. Areas with a probability of presence greater than 70% were considered to be areas of high habitat suitability [39,40]. Thus, most of the areas fall under medium and low suitability classes, while high habitat suitability was restricted only to about 1% of the whole study area, providing evidence for territorial resources for Hazel Grouse species.

The most relevant variables

The best model calibration test for Hazel Grouse yielded satisfactory results (AUC train=0. 77 and AUC test= 1). AUC scores indicate a good to high discriminative capacity between predicted presence and absence [39]. The omission rate was null at the minimum training presence threshold. Among input variables elevation was the most influential and contributed37. 5% to MaxEnt model. Landscape layers contributed 62. 5% to the habitat model of species of which patch density 28. 3% had maximum contribution and 17% for contagion (Table 2).

Considering the permutation importance, elevation had also the maximum influence on the habitat model and contributed to 26.2% while contagion and patch density together contributed to 35% (Table2). It seems to be more pertinent to consider variables importance choice, because it allows overcoming correlations issues between indicators as it depends on the final MaxEnt model results and not on the path used
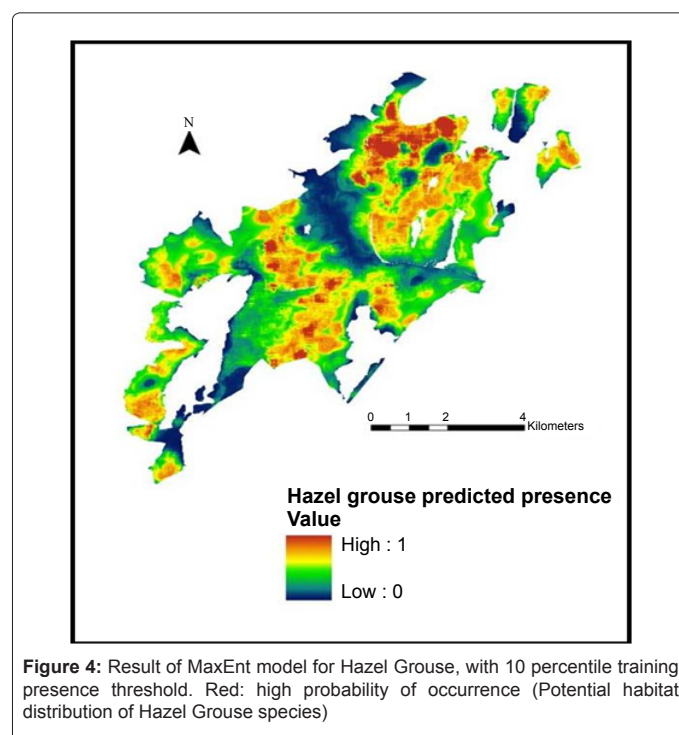

Figure 4: Result of MaxEnt model for Hazel Grouse, with 10 percentile training presence threshold. Red: high probability of occurrence (Potential habitat distribution of Hazel Grouse species)

Acronym	Metric	Description	Range value
CA	Opening Percentage (landscape percentage)	percentage of area occupied by opening $$PLAND = Pi = \frac{\sum_{j=1}^{n} aij}{A}(100)$$	$0 < CA \leq 100$
SHAPE	Mean shape index	increases with complexity of patch shapes; independent of patch size $$MN = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} Xij}{N}$$	SHAPE_MN≥1
ED	Edge density (m/ha)	Total length of edge per unit area $$ED = \frac{E}{A}(10,000)$$	$ED \leq 0$
CONTAG	Contagion index (percent)	Mesure of the aggregation of the land cover $$CONTAG = \left[1 + \frac{\sum_{i=1}^{n}\sum_{k=1}^{n}\left[(Pi)\left(\frac{gik}{\sum_{k=1}^{n}gik}\right)\right]*\left[\ln\ln(Pi)\left(\frac{gik}{\sum_{k=1}^{n}gik}\right)\right]}{2\ln\ln(m)}\right](100)$$	$0 < CONTAG \leq 100$
PD	Patch density Number per 100 hectares	Number of patch per area $$PD = \frac{N}{A}(10,000)(100)$$	$PD < 0$
Distance to gaps		Eulicdean Distance	$EuDis \geq 0$

CA: Pi = proportion of the landscape occupied by patch type (class) I; aij = area (m2) of patch ij.; A = total landscape area (m2). Shape: Aij= la surface de patchei type; N= total number of patches in the landscape. ED: E = total length (m) of edge in landscape; A = total landscape area (m2). Contagion: Pi =proportion of the landscape occupied by patch type (class); gik =number of adjacencies (joins) between pixels of patch types (classes) i and k based on the double-count method. m =number of patch types (classes) present in the landscape, including the landscape border if present. PD: N = total number of patches in the landscape; A = total landscape area (m2).

Table 1: Landscape metrics used in this work at a relevant scale

to obtain it. Moreover, looking to the Jackknife test for gain, we found that the variable with highest influence when used in isolation is patch density which appears to have the most information by itself followed by contagion (Figure 5). On the other hand, elevation appears to have the most useful information. But elevation is indicative of temperature and vegetation distribution variability, therefore it is reasonable to obtain this relation. In sum, patch density is one of the best explanatory variables of the predictive model but it is not the only one to explain Hazel Grouse presence. Contagion seemed to be another important indicator to be considered. Contagion refers to the tendency of patch types to be spatially aggregated; and measures the extent to which cells of similar class are aggregated. In other words, contagion reflects the overall "clumpiness" of the landscape without explicit reference to the patches.

Our results indicate that Hazel Grouse is sensitive to the type of a forest matrix characterized by openings or gaps. Also, suitable for hazel grouse presence are coppice deciduous forest and Spruce dominated multi-layered forest types. The different habitat types presented in the study area revealed that the predicted potential habitats for Hazel Grouse species were mostly located in areas of high coniferous forest presence, followed by high mixed forest, and others types. These observations are in accordance with other authors [55,71,73,103-105]. High suitability areas were found to be located mainly in spruce dominated forest where also dispersed patches with high structural heterogeneity exist. While, areas with low habitat suitability were mainly found in degraded open forest at low elevation.

Discussion

The modelling approach introduced in this study provided an operational approach for species conservation planning, in particular to inform management decision. Having information about the relationships between species presence and habitat structure is important for wildlife managers in order to plan intervention pattern on habitat for species conservation. Hence, the outputs of the model provided a spatial distribution of landscape structure while ranking at the same time habitat suitability for the species. Our habitat suitability map provides baseline information about the spatial arrangement of potentially suitable habitat for Hazel Grouse and it clearly showed areas of high suitability adjacent to areas of lower quality (Figure 2). These results are particularly important to target conservation efforts and adaptive forest management in lower quality areas that are closer to more suitable ones.

Furthermore, we identified the factors that represent resource gradients, determining species distribution at the appropriate scale [29]. Our approach demonstrated that both environmental and landscape parameters were important for determining the spatial distribution of Hazel Grouse in the current study area.
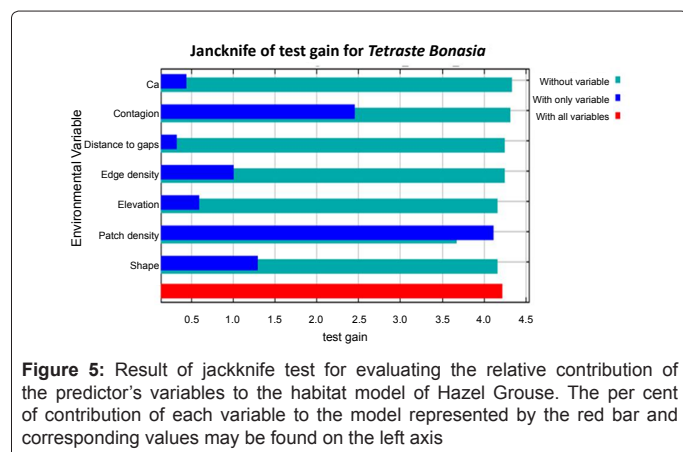
Environmental indicators

In mountain areas, the elevation, as a surrogate of temperature factor,plays a key role in determining the distribution of potential habitats of Hazel Grouse as is the case for other species as well. The restricted distribution of the highly suitable habitats of Hazel Grouse to higher elevations is in agreement with species records and published literature which indicate that the species does not occur in low areas (less than 1000 m for the French Alps) [78,79]. Effectively, elevation determines habitat suitability of the species by influencing forest type distribution and also temperature gradients. Therefore, results obtained for the mountain area where the species breeds still nowadays have demonstrated the important role of climatic parameters for species presence.

Assessments of the effects of climate typically require information at a relevant scale in agreement with the study objectives[106]. Although climatic variables are retained for their potential relevance to species ecology and spatial requirement [74,107,108], we could not include them directly in our model. As is usually the case, the available data for the study area (i. e. Seasonal mean temperatures, Annual precipitation, etc.), are regional level climate layers generated through interpolation of climate data at broad scales. Therefore, the data is not accurate enough to match their solution level and the inherent variability needed for the modelling purposes at the relevant scale in mountain regions. Thus elevation is used as a surrogate to climate predictors.

Within our study area, the distribution range of Hazel Grouse was mainly limited by altitude and thus, by the availability of mixed (Fir-Beech) and coniferous forests. Spruce dominated multi-layered forest

Variable	Percent contribution	Permutation importance
Elevation	37.5	26.2
Patch density	28.3	12
Contagion	17	23
Ca	6.9	6.5
Shape	6.5	6
Distance to gaps	3.6	11.4
Edge density	0.2	15.1

Table 2: Estimate of relative contributions and permutation importance of the predictor environmental variables to the MaxEnt model

Figure 5: Result of jackknife test for evaluating the relative contribution of the predictor's variables to the habitat model of Hazel Grouse. The per cent of contribution of each variable to the model represented by the red bar and corresponding values may be found on the left axis

with a deciduous feature is restricted to areas at high altitude and it is considered as representative of Hazel Grouse living conditions in the Alps Mountains [69,72,74]. This can be explained by the feeding regime (winter habitat selection) [70,74], as the food resources are restricted and difficult to access in winter. The same stands for refuge places from preys that are limited. That is why mixed forests are increasingly used in winter [109,110], where a favourable combination of food and cover [52,71,105] can be found. Likewise, species reproduction is affected by severe weather conditions or climate changes [107], because the females are greatly dependant on exogenous nutrient and energy sources for clutch formation and adverse weather or late winter can reduce the foraging time due to rain and wet vegetation and thus decrease the reproductive success [111].

How do landscape features influence Hazel Grouse occurrence in mountain forest?

The type of data to describe predictors used in SDMs and also the need to rely on surrogates are critical issues [29]. For biodiversity estimations and monitoring, landscape metrics are highly informative and capable of interpretation [112]. Therefore, they are largely used for monitoring at different scales [113] and they have to play a considerable role in biodiversity analysis and assessment especially in local studies of species distribution (see Walz [114]. Our results confirm that Hazel Grouse habitat quality is determined by forest land scape spatial structure descriptors. In this sense the modelling tool used can be promisingly useful for assessment studies at different landscape scales and to provide a set of replicable indicators.

Habitat heterogeneity is often illustrated by spatial descriptors of the habitat [115,116] and it is characterized by several landscape indicators such as contagion, patch density and edge density [117-120]. Landscape heterogeneity features are considered as main drivers (surrogates) of habitat quality, thus of Hazel Grouse occurrence, as it was previously documented[72,74,88,121], but not explicitly tested. The present study demonstrates that contagion and patch density indices influence significantly the probability of Hazel Grouse occurrence. Nevertheless, variable contributions should be interpreted with caution when the predictor variables are correlated [122]. Therefore, the model wasre-evaluated on the bases of the permuted data; the resulting drop in training (AUC) allowed to demonstrate that edge density is more important to explain the species presence than PD. While, results from MaxEnt permutation importance indicates that the model depends heavily on contagion as a variable that reflects the degree of habitat heterogeneity. Some variables such as edge density and distance to

gaps have poorly contributed in the predicted habitat suitability map (Table2), but this can be explained because they are highly correlated with contagion [117-119,122].

Nevertheless, it must be noted that Hazel grouse is sensitive to a forest gap width and consequently preferred not to venture far from forest cover, however, it sometimes crossed gaps as large as 1km [123]. During the breeding season, openings provide important localized sources for the species in terms of food, and preferred habitat structure. Evidence suggests that such resources are more abundant, visible and accessible in forests gaps, highlighting the role of these structural features on the landscape [74,124]. Besides that, juveniles of Hazel Grouse feed mainly on insects, more available also in forests gaps. In addition, Hazel Grouse may be attracted by openings because of increased cover in lower levels which offer protection from predators. Our results suggest that the presence of gaps enhanced the presence and movement of this forest bird.

As a result, our study supports the importance of landscape structure indicators for predicting Hazel Grouse habitat quality that is introduced by heterogeneity which implies increasing, somehow, the amount of forest edge and dispersed forest gaps. These key structural forest features, improve the quality of Hazel Grouse habitat throughout a higher supply of food and refuge resources [71,73]. Eventually, our results indicate that our study area is representative of the livelihood conditions of Hazel Grouse in mountain areas and in particular in the Alps; therefore, we have to stress here the importance of the landscape structure for species suitable habitat management.

Usefulness of habitat model as an operational tool for conservation in Chartreuse Natural Park

Systematic conservation planning requires information on the spatial distribution of biodiversity. Forest managers and conservationists benefit greatly from understanding species habitat requirements and determining priority conservation needs. But in some cases, in particular in mountain areas the accessibility is difficult therefore obtaining the needed species data is costly and time consuming. Considering the difficulties in accessing some part of Chartreuse forests (i. e. rocky crests and valleys of very difficult access) [67], targeting efforts to areas of high probability of species occurrence will increase the success of future field excursions. In the current study, prioritization is based upon projected distributions generated by niche modelling of Hazel Grouse occurrence data collected from surveys in the State Forest of Grand Chartreuse. Our fitted model in this study suggests insights for further planning perspectives in favour to Hazel Grouse species as it allows defining potentially suitable areas and discovering new areas over relative coarse geographical scale. Prioritization results highlight also areas that warrant attention for future field surveys.

Comparing the actual forest management plan over the study area with our habitat suitability map, we found that 73% of the forest production sectors defined in the forest management plan represent suitable habitat for hazel grouse species (NOF Isère, management plan, 2002–2017). Accordingly, we assume that it could be relevant to keep the actual management strategy which seems to match the indicator species habitat preference. However, any increase in production or changes on the actual management will have a direct impact on biodiversity. At present forest management is not selective for a particular species habitat. As an example we remarked that the Natura 2000 site within the study area does not correspond to high habitat quality for hazel grouse. In that sense the model results can support to target management

decisions in the near future in order to maintain biodiversity while still keeping forest production standards.

This work proposed two criteria as primary instruments for monitoring Hazel Grouse habitat forests. Management decision can be made at two levels; one at *broad scale* (e. g. region) based on elevation criteria (i. e. more than 1000m) other for monitoring and managing the habitat at *finer scale* considering landscape heterogeneity indicators "fine tuning". Accordingly, habitat suitability could be improved by adopting forest measures that aimsat increasing the carrying capacity of Hazel Grouse; hence maintaining a forest structure that benefit habitat heterogeneity. In mountain areas, there are many possible management actions as the habitat quality presents a high spatial variability. Generally, alpine topography supports a mosaic of early serial stages, so we could adopt forestry measures that guarantee young serial stages required for Hazel Grouse presence. This forest strategy can benefit also other elements of biodiversity [120] within sub Alpine ecosystem.

Conclusion

Habitat heterogeneity and in particular landscape structure has been shown to be a key element for sustaining high biodiversity levels in general [125-127]. Here, we have qualitatively recognized that landscape heterogeneity in sub-Alpine ecosystem is essential for the occurrence of Hazel Grouse, an emblematic species of the Alpine fauna. This is also true for similar species like capercaillie *Tetraourogallus* in subalpine woodland [128]. Consequently, promoting optimal conditions for Hazel Grouse survival would be favourable to Alpine biodiversity in general under the assumption that Hazel Grouse plays the role of an umbrella species within such ecosystem.

Within the context of global grouse decline [56], the methodological approach used in this study could be used to acquire geographic understanding and appreciation of biodiversity. Our study is one of the few studies to use probability data on species' distribution to systematically plan the conservation of Hazel Grouse at a fine scale. This is particularly important, because Hazel Grouse is a threatened species and all EU countries, including France, must respond to the EU reporting as a need for the conservation status evaluation' of its habitat under the framework of the Habitat Directive (Article 17). The initial objective of stopping the loss of biodiversity by 2010 has not been respected. In all, following the overall failure of global CBD 2010 targets, it is, after all, very relevant to find out what the global high-ranking political community has in mind for the next decade. Nagoya [59]discussions set goals that nations must consider in terms of conservation. In order to assess progress in achieving the goals of the strategic plan of CBD 2020, we need to agree on a framework of focal areas to guide the actions. And to be effective, the implementation must occur across sectors of high potential for biodiversity (i. e. hotspots),at the same time, biodiversity issues must be integrated into national policies programs and forestry management plans. This could be used to address decision makers [36,129] with scientifically sound data to create more predicted biodiversity area. One of the main reasons of CBD 2010 failure was the lack of species spatial distribution information (i. e. actual location) and also absence of a multi scale analysis approach. Thus, the modelling approach developed within the framework of this work could be very promising to support CBD 2020 targets. As it allows to gain spatial knowledge on species distributionand recognizes major knowledge gaps [30]. Our results are consistent with previous studies on landscape structure effects on forest species (see Schindler et al [113,130]. The approach developed provides evidence to increase protection in areas with low range suitability (critical sectors) when

needed. In that way, supports planning strategies allowing a compromise in between economic needs and species distribution, ensuring levels of suitability between existing and potential target habitats.

Ultimately, we have conducted our research at small ecological scale, but at the macro-scale, there would be still some open questions: How do climate change scenarios (strong vs. moderate) influence the eco-climatic envelope of Hazel Grouse in the Alps? We provided some hints in this work but still many open questions remain to conduct further research towards the aim of balancing biodiversity targets within an adaptive forest management framework.

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