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# Interactions between outdoor recreation and iconic terrestrial vertebrates in two French alpine national parks

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ABSTRACT

Protected areas manage synergies and trade-offs associated with core missions of nature protection while supporting education, recreation and tourism. In this paper we demonstrate how spatial modelling co-produced with managers can support the assessment of interactions between two cultural services: outdoor recreation and iconic terrestrial vertebrates. In two French national parks (Ecrins and Vanoise) we showed clear seasonal differentiation in spatial patterns for potential iconic vertebrate diversity, recreation opportunities and their interactions. Our first hypothesis that limited access and mobility of recreationists during winter would increase potential wildlife refugia was largely validated for Ecrins. Our second hypothesis that lower but spatially diffuse pressure from recreationists in Ecrins would increase potential interference as compared to more intense but directed activity in Vanoise was consistent with patterns in summer. For winter the spatial concentration of recreation around ski resorts of Vanoise was highly impactful. Across both parks concerns about the expansion of winter activities are legitimate, especially for climate-sensitive species. We also showed the critical role of refuge areas in high valleys (summer) and lower slopes away from tracks (winter), highlighting threats from off-track practices. Beyond regulation our results will support dialogue with the public and professionals based on communication and education.

## 1. Introduction

One third of the world's protected areas are submitted to intense human pressure especially from land use or direct exploitation of plants and animals, and pressure has increased for half of protected areas since 1992 (Jones et al., 2018). The missions of protected areas are nature protection, with additional goals of access and education to nature. As such they are hotspots of non-material contributions to people (Diaz et al., 2018), or cultural ecosystem services (Millennium Ecosystem Assessment, 2003). Protected areas have indeed been found to be more attractive for nature-based tourism when they have more biodiversity (Arbieu et al., 2018; Chung et al., 2018; Siikamäki et al., 2015). This attraction is mostly linked to iconic plant and animal species: species which are important to cultural identity through existence, aesthetic or spiritual values. They include some but not all protected species (many protected species are poorly known to the public), symbolic species used for communication or identity and charismatic species used as an umbrella to support the biodiversity cause. Iconic species provide important non-material contributions to people of learning and inspiration, physical and psychological experiences through recreation and other nature activities and to supporting identities (Cox and Gaston, 2018; Diaz et al., 2018; Rüdisser et al., 2019; Subroy et al., 2019). As such they are considered as part of fulfilling protected areas goals of biodiversity conservation, psychological experiences and education and supporting identities. At the same time, recreation and tourism can have detrimental impacts on protected ecosystems and biodiversity including iconic species, especially through physical damage to soils and vegetation and through interference with fauna (Baker and Leberg, 2018; Geffroy et al., 2015; Monz et al., 2013). The two missions of nature protection and supporting education, recreation and tourism are thus complementary but can also be conflictual, creating synergies and trade-offs addressed by zoning and management plans. These tensions can be particularly acute given the economic weight of tourism in regions with highly demanded natural assets such as mountains.

Addressing the challenge of co-managing multiple cultural ecosystem services requires understanding these interactions and their management implications. For this, we need evidence of the spatial distribution of their overlaps (Lautenbach et al., 2019; Plieninger et al.,

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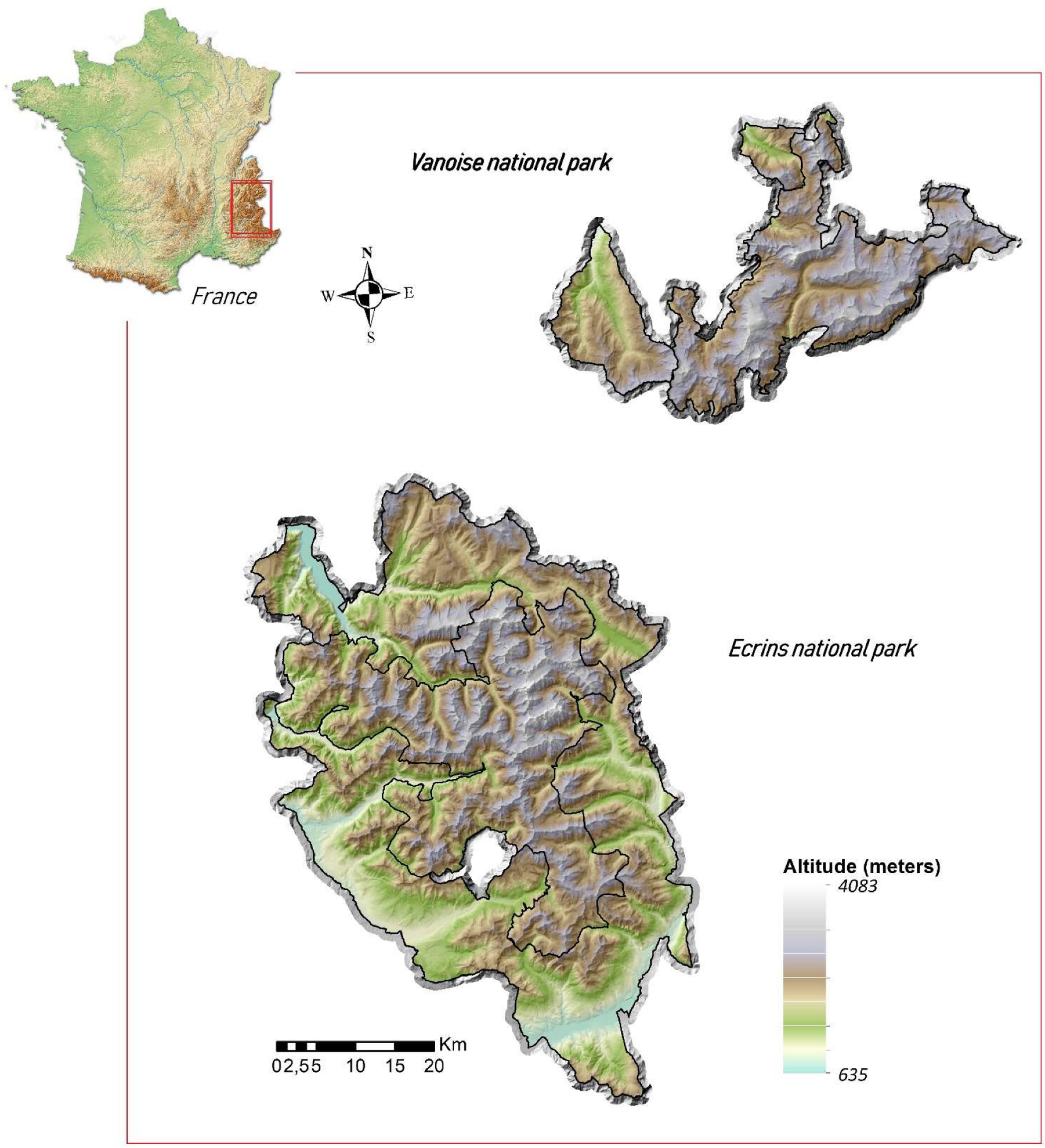


**Fig. 1.** Location and topographic maps of the Vanoise and Ecrins national parks.

2013). This is not yet a common approach among protected areas, if only because they lack the necessary capabilities and resources. Along with each park's own monitoring systems, field studies document wildlife-recreation interactions and help refine the understanding of underpinning processes. However direct observations are necessarily spatially limited due to the time and expense required. Modelling is an alternative method which can afford the spatial extensiveness needed for understanding patterns of interactions and for supporting management plans (Geneletti and van Duren, 2008; Schirpke et al., 2018).

Spatial modelling of cultural services is challenging because they are those for which spatial information is sparsest as they include some non-material, intangible and subjective dimensions (Daniel et al., 2012; Plieninger et al., 2013). Additionally, the scarcity of studies combining spatial modelling of multiple cultural services limits ability to operationalise ecosystem services for management and decision (Lautenbach et al., 2019). Nevertheless, in the last few years there has been substantial progress in assessing cultural services, especially in protected areas and mountains (Martín-López et al., 2019). Spatial distributions of iconic species can be assessed by direct observations, which is a core mission of protected areas, and by habitat modelling (Guisan et al., 2017), although few protected areas have the knowledge, resources or collaborations for such modelling. Recreation is by far the most commonly modelled cultural service (Hermes et al., 2018; Schägner et al., 2018). A variety of approaches have been developed to map its different facets. Broadly, they target three facets rarely combined in a single study (Schägner et al., 2018; Schirpke et al., 2018; van Berkel and Verburg, 2014; Verhagen et al., 2017): (i) objective landscape, ecosystem (including species identity and diversity), cultural and infrastructure indicators that underpin recreation service supply capacity, (ii) social demand as described through social elicitation methods and empirical indicators (e.g. population density, social profiles, cost distance), and (iii) benefit flows assessed through visitor numbers, economic analyses or social media.

As an additional challenge, for assessing potential interactions between protection of iconic species and recreation, seasonality needs to be considered since it affects both wildlife habitat requirements and recreation activities (e.g. (Aiba et al., 2019; Graves et al., 2019; Gundersen et al., 2019; Santarém et al., 2015; Schirpke et al., 2018).

Nevertheless, seasonality stands as a major gap in spatial modelling of both iconic species and recreation.

There is therefore a significant gap between the needs of protected areas and emerging capabilities in ecosystem service modelling. In this paper we show how potential interactions between two cultural services, outdoor recreation and iconic terrestrial vertebrates can be assessed by spatial modelling, using two French mountain national parks (Parc National des Ecrins and Parc National de la Vanoise) with contrasting geography and tourism activities as case studies. Our research was initiated with the national parks' scientific and management teams who were challenged by managing interactions between their iconic vertebrates and outdoor recreation. We asked: Where are key areas of interactions and potential refugia for iconic vertebrates? How do these differ across seasons? These research questions were co-designed, models were co-produced with important implications for methodological choices and results were co-evaluated. We hypothesised that: (1) Limited access and mobility of recreationists during winter increases potential refugia for wildlife. Conversely there is greater potential for interactions in summer due to greater spatial spread of activities, (2) Lower but spatially diffuse pressure from recreationists in Ecrins increases potential interference as compared to more intense but directed activity in Vanoise.

## 2. Methods

### 2.1. Study sites

The Ecrins (PNE) and Vanoise (PNV) national parks are both located in the French Alps (Fig. 1). Both parks are highly biodiverse, with for instance one third of the national vascular plant species list represented in PNE and half in PNV (Inventaire du Patrimoine Naturel, INPN). Their communication and activities are also highly linked to their rich iconic fauna, with vertebrate themes and pictures abundantly used in documentation, web sites and education material. The two parks have differing geographies and histories, especially regarding their relationships with winter tourism, which have largely determined the most recent revision of the areas directly managed by each park. Under French biodiversity legislation (LOI n° 2006-436 du 14 avril, 2006), national parks comprise a 'core area' of public land where biodiversity protection is the primary objective and is solely managed by the state, and a 'boundary area' where multiple objectives of sustainable social and economic development based on environmental quality are pursued jointly by the park and local governments. Municipalities join the boundary area on a voluntary basis. Our study thus focused on the core and boundary areas of PNE (1,606 km2, of which a 92 km2 core area; altitude: 710–4102 m a.s.l.) and the core area of PNV (528 $km^2$; altitude: 650–3855 m a.s.l.), for which the parks influence management.

PNV was declared a national park in 1963 and is bounded by 19 ski resorts (1825 km of ski runs) in the Maurienne and Tarentaise valleys, and its core area includes some commercial skiing activities. Tensions between the economic development of the resorts and the park have prevailed since its creation, resulting in long-term tensions and culminating in a very limited boundary area (only two municipalities out of the 28 potential ones). As a result, only ca. 15% of the park area lies below 1500 m, as compared to 31% for PNE. In contrast, PNE which was declared a national park in 1973 comprises 15 ski resorts but with a much smaller area (776 km of ski runs), and the park is known for its highly preserved nature and focus on outdoor activities outside of resorts.

### 2.2. Prioritising iconic vertebrate species

First, iconic vertebrate species lists for modelling favourable habitats were identified jointly with each park's scientific staff. In PNV, a total of 29 species were selected based on an internal score for conservation priority of 3–5 (Vanoise, 2016). In PNE, 30 species were identified as those most common in public communication based on a census of web material (number of images or articles naming a given species; (Lyonnard et al., 2016)) and identified by scientific staff as specific to the park. This resulted in a combined list of 43 unique species comprising 6 amphibians or reptiles, 24 birds and 13 mammals. Of these 14 were common to both parks, 16 present in PNE only and 13 present in PNV only. From the total 43 species 21 species were present and active in winter (excluding hibernating species) including 1 amphibian, 15 birds and 5 mammals. Of these, 12 were common to both parks, 6 present in PNE only and 3 present in PNV only (Supplementary Table A1).

As a second step within each park's list, we calculated species priority scores using seven of the eight top criteria from the French Pyrenees National Park prioritisation framework and their associated methods (Thirion and Vollette, 2016): endemicity, geographic rarity, phylogenetic originality, population decline, demographic vulnerabilty, ecological role, and national conservation responsibility (Supplementary Table A2). We excluded the climate sensitivity criterion from the original framework due to lack of strong evidence for expected changes in habitat availability. Detailed scores for each criterion and species, standardised from 0 to 4, are presented in Supplementary Table A1. Species final scores were calculated by summing scores across the seven criteria, and expressed as a % of a maximum possible score of 28.

### 2.3. Modelling species habitats and potential diversity (PD)

Each park's diversity in iconic vertebrates in winter and summer was mapped as the sum in a given 10 × 10 m pixel of an img format raster of potential presence of individual species based on nationally-described habitat requirements. Park staff expressed strong preference for this method as compared to using their expert opinion or park-specific observation data bases in order to first account for species overall distributions across the Alps, and second to reserve observation data for validating model predictions. Habitat requirements were preferred to using species distribution models to reflect fine-scale effects of land cover / use and to enable the later replication of analyses by park staff. For each species and each season, habitat suitability was modelled using habitat criteria and associated rules following (Byczek, 2017), adapted from (Maiorano et al., 2013) (Supplementary Fig. A1a).

First, in each pixel habitat suitability for each species was determined according to suitability of land cover types of the Sentinel 2 data base (https://sentinel.esa.int) to support its reproduction, raising offspring, feeding, resting and movement, with a score of 0/1 for each land cover type and thus a score of 0–5 for each species (Supplementary Table 3). We note that glaciers were thereby excluded as habitat. Second, the pixel's suitability was moderated by the species land cover breadth described by the ratio of suitable land cover types for the five vital functions to the total number of land cover types commonly visited by the species. Data was sourced from the national biodiversity data base (Inventaire National du Patrimoine Naturel, INPN). Third, land cover suitability was weighted by the species priority score in order to reflect the importance of that pixel for iconic vertebrates.

The resulting land cover suitability index was then combined with species altitudinal range (from the INPN data base), avoidance of built-up land (filtering out pixels within 500 m), distance to roads (with negative impacts depending on road type and increasing habitat suitability within a 5 km buffer away from roads) and proximity to water (with a 600 m threshold). These five variables were averaged with equal weights in summer, whereas for winter roads were down-weighted to 0.5 due to limited traffic within park boundaries, and the weight of (often frozen) rivers and water bodies reduced to 0.25. These weights were established with park scientific staff. An exploration of sensitivities to weightings was considered out of the scope of the present study, even if that would obviously be required for further research. Species preferences for these individual habitat suitability factors were further confirmed by experts from the two PNs and from the national Ligue de Protection des Oiseaux NGO.

Habitat suitability maps for each species and each season were validated within PNE using the absolute validation index (Hirzel and Arlettaz, 2003), calculated as the ratio of pixels with observed presence (from 2010 to 2019) in the Biodiv'Ecrins data base (https://biodiversite.ecrins-parcnational.fr/) to predicted presence. The case of presence observations only as here precludes the use of indices based on confusion matrices (Guisan et al., 2017). Available data allowed validation for 34 species in summer and 19 in winter. For each observation we applied a radius of 100 m to account for potential location uncertainty.

Finally, each pixel's potential diversity (PD) was calculated by averaging suitability across the summer/winter species pool within each park. PD thus represents a dimensionless index for comparison across pixels.

### 2.4. Modelling recreation opportunities

Each park's recreation opportunities in winter or summer were mapped following an original adaptation of the Recreation Opportunity Spectrum for the French Alps using crowd-sourced itinerary data (Byczek et al., 2018). This method assesses recreation opportunities based on ecosystem attractiveness, avoidance of human disturbance and accessibility (Supplementary Fig. A1b).

Briefly, we assessed the potential of an area for recreation (*PRI* = Potential recreation index) as a product of an environmental attractiveness module (*EA* = environmental attractiveness) and that of an avoidance of human disturbance factors module (*DA* = avoidance of human disturbance). A third module quantified the accessibility of areas for recreation (*AI* = accessibility index). The product of *AI* and *PRI* produced a final surface termed the ROS (recreation opportunities spectrum) which reflects the capacity of different parts of the national parks to provide recreation services.

We estimated environmental attractiveness as a composite sum of 1) the proximity to natural landscapes (*PNL*); 2) the degree of nature conservation (*DNC*); 3) the proximity of watercourses and lakes (*PAA*) within a 200 m buffer; and 4) a scenic beauty factor (*SB*) to quantify the attractiveness of mountain panoramas based on view-shed size.

Under the assumption of increasing attractiveness with increasing remoteness the degree of avoidance of human disturbances was estimated using a composite factor of the maximum of either increasing distance to major roads (*RA*) due to increasing noise and visual pollution, and of increasing distance from built-up areas including buildings and infrastructure (*UAA*). Disturbance was modelled as a linearly decreasing function within a 500 m buffer from built-up areas, whereas for roads buffer sizes varied from 250 m; to 100 m and 30 m according to French legislation on noise impact from different road types (http://georhonalpes.fr).

Accessibility of the national parks for recreation was assessed by the product of areas reachable by hiking trails and routes, mountain bike trails and ski touring itineraries (*sports_summer* and *sports_winter* respectively for summer and winter), and the proximity of an area to a major road, with accessibility scores increasing with decreasing Euclidian distance to public roads. Note that for winter we discounted seasonally-closed roads. As an original method which we developed for an earlier application in the French Alps (Byczek et al., 2018), the hiking, mountain biking and ski touring routes were compiled from crowd-sourced GPS tracks recovered from social media sites dedicated to mountain activities (skitour.fr, vttour.fr, visugpx.com and camptocamp.org). These tracks represent unique presence/absence values rather than quantitative use data for which crowd-sourcing would necessarily produce a biased subset. Their representativeness of user

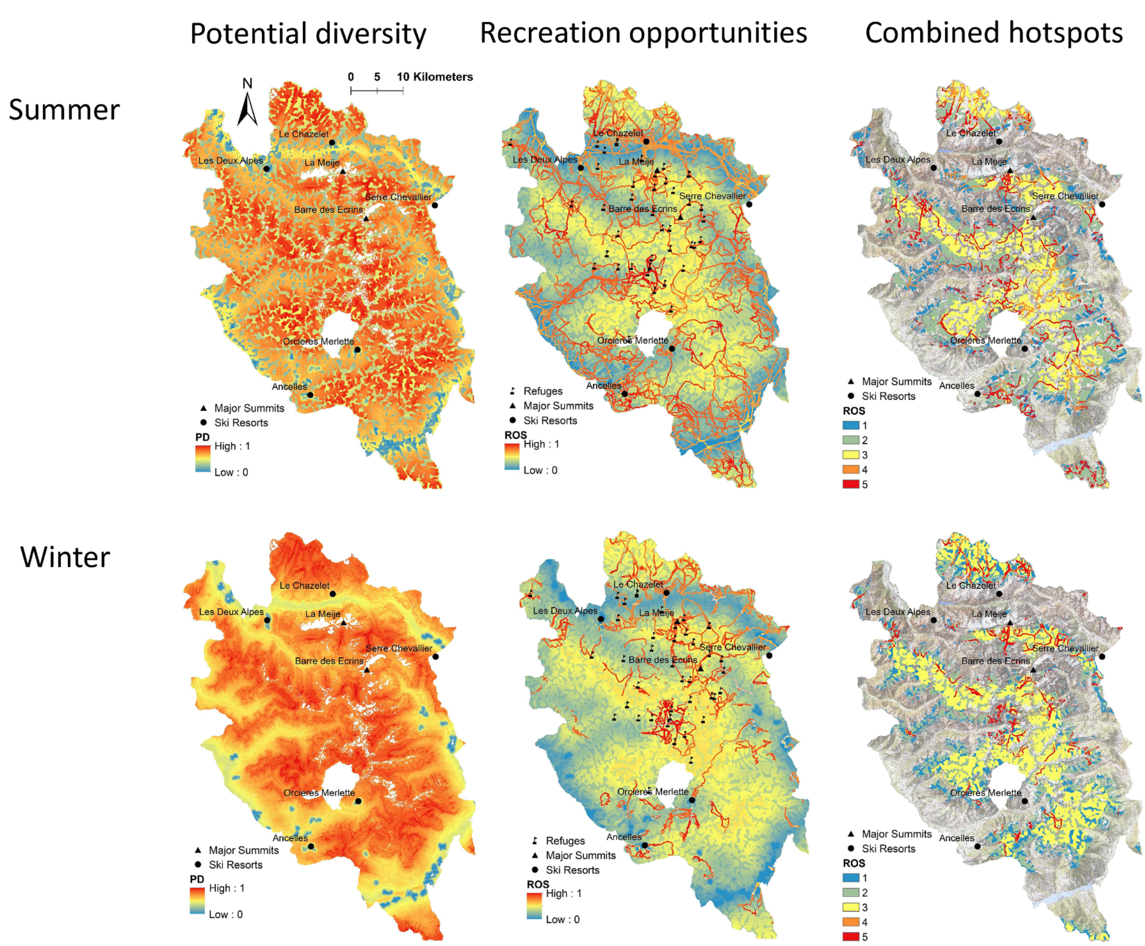


**Fig. 2.** Maps for Parc National des Ecrins of Potential Diversity (PD, left column), recreation opportunities (ROS, middle column) and overlap between higher PD and ROS levels (right column). Upper row: summer, lower row: winter.

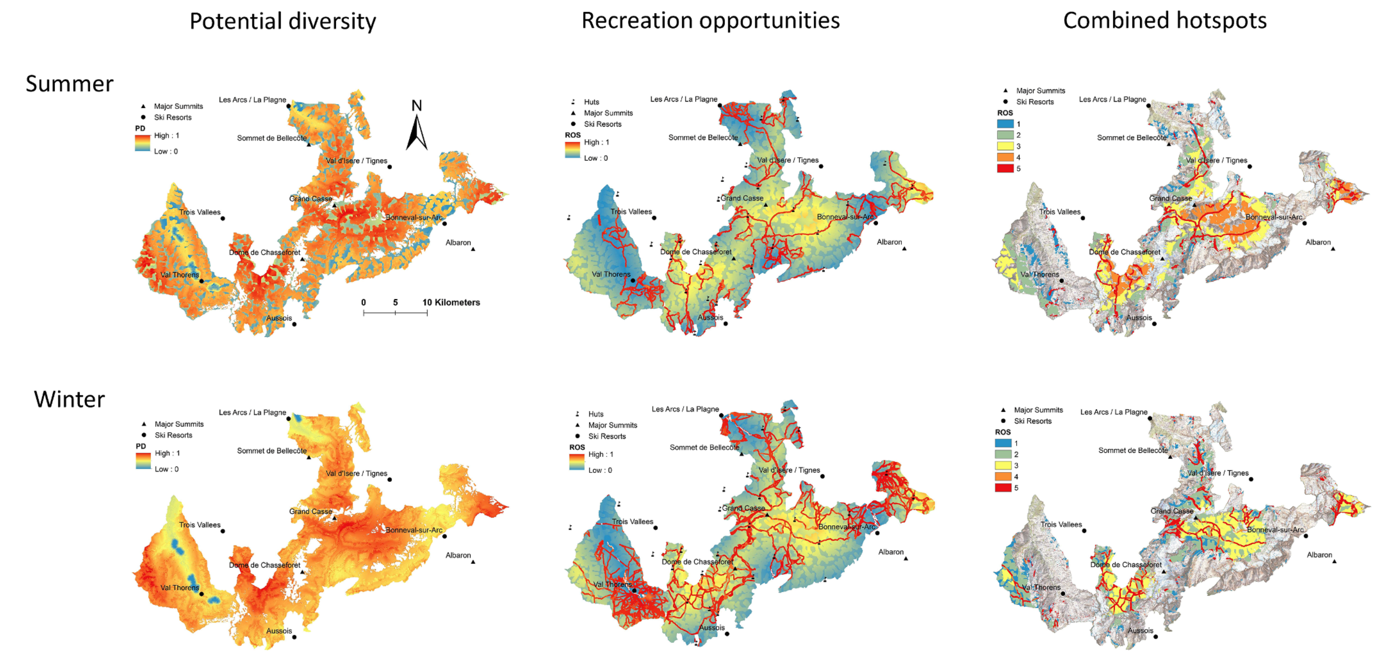


**Fig. 3.** Maps for Parc National de la Vanoise of Potential Diversity ((PD, left column), recreation opportunities (ROS, middle column) and overlap between higher PD and ROS levels (right column). Upper row: summer, lower row: winter.

practices was previously validated for the nearby Grenoble region (Byczek et al., 2018).

A more complete description of a similar model in the adjacent Grenoble region can be found in (Byczek et al., 2018) with justifications for the inclusion of each of these composite layers of attractiveness and accessibility, as well as details of their parameterisation.

### 2.5. *Identifying potential interactions between iconic vertebrates and recreation*

Overlaps between favourable habitat for iconic vertebrates and recreation opportunities were first described by overlaying PD and ROS maps. Firstly, we classified each map (per park and per season) according to respective above vs. below median values. The resulting four combinations described broad congruence of upper and lower values across PD and ROS. Secondly, the operation was repeated using instead lower 25% and upper 75% quartiles for identifying combined hot/cold spots of PD and ROS. Thirdly, we quantified spatial correlations across the two maps for each park and each season using residual mean square errors (RMSE), calculated from the differences between identical location pixels in the differing rasters and then averaged for the whole area.

To further explore the degree to which recreation opportunities (ROS) impacted on potential habitat for iconic vertebrates (PD), we overlayed a map classifying ROS into differing degrees of attractiveness over a map of the highest quality areas for iconic vertebrate habitat for both summer and winter. The area considered as highest quality habitat was chosen as the upper third of PD values for a national park at each season. ROS values for each park at each season were classified into five Jenks natural breaks groupings ranging from ROS 1 being the least attractive for recreation, up to ROS 5 being those areas most attractive for recreation. The Jenks natural breaks classification method determines the best arrangement of values into different classes. This is done by seeking to minimize each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups thereby reducing the variance within classes and maximizing the variance between classes (Jenks, 1967). Overlay maps thus identified areas from lowest to highest potential interference with best iconic vertebrate habitat.

All maps were produced and spatial analyses conducted using ArcGIS Desktop 10.7.1 (ESRI, 2019).

## 3. Results

### 3.1. *Seasonal distributions of potential diversity of iconic vertebrates*

#### 3.1.1. *Validation of species habitat distributions*

Our habitat modelling method captured observed distributions in summer and winter with great accuracy, with a median 80% match for exact location, and a median 95% match within a 100 m buffer (Supplementary Fig. A2). Only four of 34 species (common whitethroat (*Sylvia communis*), wallcreeper (*Trychodoma muraria*), peregrine falcon (*Falconus peregrinus*), European scops owl (*Otus scops*)) had notably lower matches for summer, and two of 19 species (griffon vulture (*Gyps fulvus*), rock partridge (*Alectoris graeca*)) for winter.

#### 3.1.2. *Spatial distributions of potential diversity and seasonal variations*

Within each of the two parks there were strong spatial contrasts in PD, with highest values within the core of each park (Fig. 2a,b, Fig. 3a,b). Overall distribution patterns were similar across seasons, with most favourable habitat concentrated below 3000 m, and especially in the subalpine belt. However, in PNV the relative contribution of altitudes lower than 2500 m was less than in PNE, first because of lower representation of lower altitudes due largely to the exclusion of boundary areas of non-member municipalities, and second due to the stronger presence of ski resorts.

Distributions in both parks were largely structured by habitat assumptions of attractiveness by water and avoidance of built-up land and roads, as well as their strong co-location in valleys associated with topography in mountains. Consequently, areas of lower PD were concentrated near built-up areas and along major roads, either valleys at the edge of PNE (Fig. 2a,b), or resorts of PNV (Fig. 3a,b). In summer road traffic decreased the habitat value of valley bottoms, which in contrast were more attractive in winter.

As a result of these drivers, summer PDs were strongly bimodal in both parks, with a first mode of higher values in less accessible valleys and a second mode mid-slope. The first mode was associated with favourable habitats provided by conifer forests, aquatic ecosystems and managed grasslands, which have a lower representation in the PNV perimeter (only 3.2% of the total area) as compared to PNE (19.8%). The second and strongest mode reflected the prevalence in the parks

**Table 1**
% area in combinations of quantile values for PD and ROS using median and quartiles (25–75%), and RMSE for each park and season. HH: combined upper values, HC: upper values for PD and lower values for ROS, CH: lower values for PD and upper values for ROS, CC: combined lower values. RMSE: residual mean square error.

| PNE | Median | Summer | Winter | 25–75 | Summer | Winter | RMSE summer | RMSE winter |
|---|---|---|---|---|---|---|---|---|
| HH | | 35 | 39 | | 6.60 | 12.81 | 0.279 | 0.188 |
| HC | | 16 | 12 | | 0.07 | 0.11 | | |
| CH | | 15 | 10 | | 5.16 | 1.47 | | |
| CC | | 35 | 39 | | 11.38 | 15.78 | | |
| *Total* | | *100* | *100* | | *23.21* | *30.18* | | |
| PNV | Median | Summer | Winter | 25–75 | Summer | Winter | RMSE summer | RMSE winter |
| HH | | 35 | 33 | | 11.15 | 4.75 | 0.289 | 0.281 |
| HC | | 15 | 17 | | 0.32 | 0.48 | | |
| CH | | 14 | 15 | | 3.23 | 5.34 | | |
| CC | | 36 | 35 | | 9.74 | 12.19 | | |
| *Total* | | *100* | *100* | | *24.44* | *22.76* | | |

perimeters of the two land cover classes most favourable to parks iconic vertebrates, alpine meadows and rocky areas (with as much as 81.5% of the study area for PNV).

Winter PDs (Fig. 2b, Fig. 3b) were more spatially homogenous within park core areas due to three facts. Firstly we decreased the relative weights of water and roads in winter (see Methods), leading to reducing attractiveness of water and decreasing exclusion by roads. Secondly the restriction to species present and active in winter excluded a majority of lower altitude and/or aquatic species including amphibians and reptiles, further reducing lower altitude PD. Thirdly, of the 22 species excluded sixteen were associated with conifer forests, aquatic ecosystems or managed grasslands, resulting in the reduction of the corresponding mode of summer PD. The largely unimodal distribution was therefore centred towards higher alpine meadows and rocky areas.

### *3.2. Seasonal distributions of outdoor recreation activities*

As PD, recreation opportunities were strongly structured by topography through its multiple effects on: scenic beauty from open mountain tops with scarce or no vegetation (positive effects), built-up areas and infrastructure especially at lower elevations and in valleys (negative effects) and access tracks and itineraries preferentially following valleys and watercourses (positive effects). This resulted in highly linear, bimodally distributed opportunities with limited opportunities at the lowest altitudes, a first mode of high values along mountain valleys in summer and a second mode of higher values determined by high scenic beauty (Fig. 2c,d, Fig. 3c,d).

Overall seasonal differences reflected differences in recreation activities and in accessibility, with many roads to high valleys and passes closed in winter. Apart from the switch from snow-related activities in winter to hiking, climbing and mountaineering in summer, cycling increased the attraction of lower valleys as seen especially in PNE (Fig. 2c), and to some extent for ski resorts and high passes (e.g. Iseran) in PNV (Fig. 3c). Note however that mountain biking is forbidden in the core areas of both parks. The potential for summer activities also extended to the highest altitudes and near mountain huts in summer, especially in PNE.

There were striking differences in seasonal patterns between the two national parks. In PNE areas for recreation were as expected more widely distributed in summer than in winter especially in mountain valleys. Overall, in PNE summer ROS formed an extensive web covering much of the park (Fig. 2c), whereas in winter high ROS was concentrated around resorts, and a few popular ski touring areas around the iconic summits (La Meije, Ecrins) or closest to roads (e.g. Chazelet area) (Fig. 2d).

In contrast, in PNV ski resorts strongly concentrated winter activities with a considerable area under high ROS values, including access from ski lifts to backcountry glacial terrain (Fig. 3c). Higher ROS values in summer were much less extensive and concentrated around resorts and a number of popular longer-distance itineraries (Tour de la Vanoise) constrained by large glaciers (Fig. 3d).

### *3.3. Potential interactions between recreation and iconic vertebrates*

Whether in winter or summer, for both parks over two thirds of the area has congruent levels of PD and ROS (HH or CC, with about a third each for median classification) reflecting spatial correlation of iconic vertebrate habitat and recreation potential (RMSE values) (Table 1). This spatial correlation is largely driven by topography and its effects on key drivers of: rivers, roads/settlements, tracks, which co-determine vertebrate distributions and recreation opportunities. Areas of overlap of simultaneous highest/lowest habitat and recreation potentials (25–75% quartiles) confirm this spatial correlation with over three quarter of congruent hot/cold spots and hardly any area under combinations of high PD/low ROS (HC) or low PD/high ROS (CH). This emphasises limited opportunities for iconic vertebrates to escape interference with recreation, as shown by particularly low percent areas of most favourable habitat with least recreation opportunities (HC, 25–75% quartiles). These patterns were largely consistent across seasons, though for PNE congruent hotspots nearly doubled from summer to winter, and they were nearly divided by three for PNV.

To further investigate how recreation opportunities interact with highest habitat values for iconic vertebrates we restricted the overlap analysis to the top third of values of PD for each park and each season. This captured the upper half of the mode of higher values for summer and the upper third of the right-skewed normal distribution for winter.

In PNE (Fig. 2e,f), nearly half of the higher PD area coincided with very low (ROS1) or low (ROS2) recreation opportunities in both summer and winter, with respectively 17 and 20% for ROS1. However the area of higher PD had nearly 20% high (ROS4) or very high (ROS5) recreation potential in summer, an overlap that was halved to 10% in winter. Of these the most severe potential for interference (ROS5) was 19% in summer and 10% in winter respectively (Fig. 4a).

In PNV (Fig. 3e,f), while half of the higher PD area coincided with very low (ROS1) or low (ROS2) recreation opportunities in winter (of which 13% under ROS1), this decreased to less than 40% in summer (with 16% under ROS1). The area of higher PD had a third high (ROS4) or very high (ROS5) recreation potential in summer, an overlap that decreased to 22% in winter. Of these the most severe potential for interference (ROS5) was 15% in summer and 19% in winter (Fig. 4b).

Areas of greatest potential interference (ROS5) were concentrated along tracks in summer, with the addition of the strong imprint of popular mountaineering areas (e.g. around Pralognan-la-Vanoise and in the Upper Maurienne valley; ROS4) in PNV. For PNE in winter greatest potential interference concentrated around resorts especially in the Champsaur valley, and a few popular ski touring areas around the iconic summits (La Meije, Ecrins) and closest to roads (e.g. Chazelet resort). ROS5 areas were very extensive near the resorts of PNV (e.g. Val d'Isère, Trois Vallées, la Plagne/les Arcs) which provide off-piste access to the park's core area, along with popular ski touring access of the upper Maurienne valley.

In summer potential wildlife refugia with low interference from recreation concentrated in the mountain valleys also used by popular

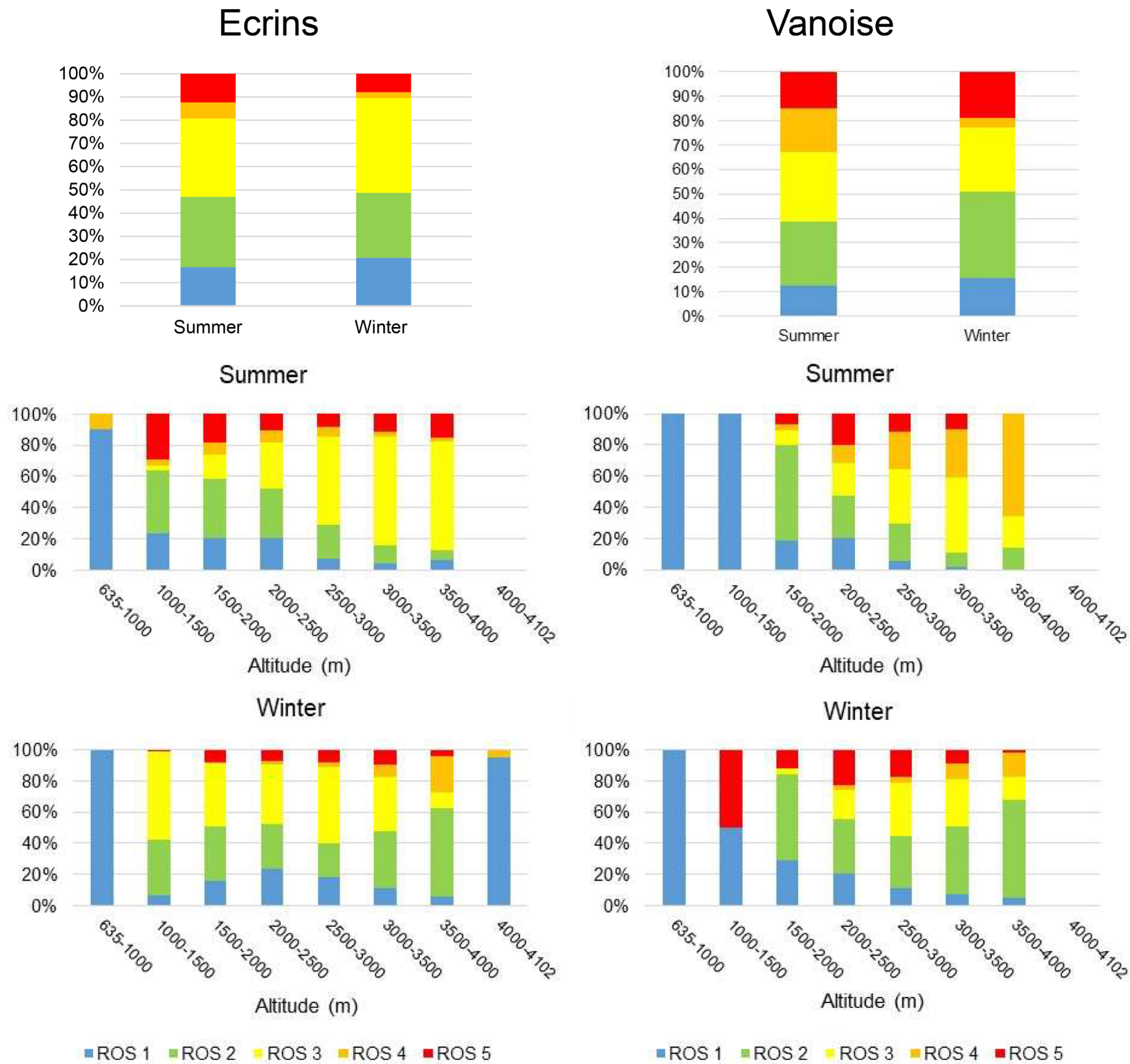


**Fig. 4.** Percentage area of different levels of recreation potential (ROS) within the upper potential diversity (PD) area. The top row presents aggregate values for each season at park level for Parc National des Ecrins (left) and Parc National de la Vanoise (right). The middle row presents values for different altitudinal slices in summer for Parc National des Ecrins (left) and Parc National de la Vanoise (right). The bottom row presents values for different altitudinal slices in winter for Parc National des Ecrins (left) and Parc National de la Vanoise (right). Within each stacked bar each colours represents a level of ROS (from 1 at the bottom to 5 on top).

itineraries, but on the slopes away from tracks and/or in valleys or bowls without track access. In winter, the potential for these was additionally located where road closure limits access.

In PNE greatest summer potential interference (ROS4,5) was in montane and subalpine ecosystems below 2500 m– where most high PD is found and most hiking / climbing activities are concentrated, with especially high values for valleys below 1500 m. In the small areas of high PD highest altitudes (> 3000 m) mountaineering potentially interferes with unique iconic vertebrates (e.g. rock ptarmigan (*Lagopus muta)*, snow hare (*Lepus timidus)*, wallcreeper (*Trychodoma muraria)*, vultures (*Gypaetus barbatus, Gyps fulvus*)). Higher potential interference in winter was also mostly concentrated at these high altitudes and for these same species. Summer potential refugia (ROS1,2) were greatest in subalpine and alpine meadows and rocky or scree slopes from 2000 to 2500 m, though their relative importance was high below 2000 m. Winter potential refugia were largely evenly distributed across altitudes below 2500 m but their presence at higher altitudes was essential for those species which are potentially exposed to high interference in summer.

In PNV summer patterns were overall similar to PNE, with the exception of the relatively large area of high potential interference (ROS4) around popular mountaineering routes above 3000 m. In contrast for winter half of the limited park areas below 1500 m had potentially very high interference (ROS5) around ski resorts, but once away from built-up areas there were considerable opportunities for refugia below 2000 m, e.g. in forests or in isolated valleys. These habitats are particularly important for carnivores (wolf (*Canis lupus*), lynx (*Lynx lynx*)) and forest birds (black grouse (*Lyrurus tetrix),* hazel grouse (*Bonasa bonasia)*, Tengmalm's owl *(Aegolius funereus)*). Additionally, similar to PNE areas of lower potential interference (ROS1,2) at altitudes beyond 3000 m can be critical for fragile high altitude iconic vertebrates.

## 4. Discussion

This research contributes to the still limited body of evidence on interactions among cultural services, and how ecosystem service mapping can contribute to that as part of a co-production process with protected area managers. In the following we discuss key results considering the benefits and constraints from the collaboration, and the implications for management of seasonal differences and how they play out across the two parks.

### *4.1. Modelling potential interactions between two cultural ES: Iconic vertebrates and recreation*

With a co-produced research process between scientists and national park managers we demonstrated how spatial modelling methods help address critical management questions by complementing core capabilities of national park teams through value adding both national parks and external data sets. In collaboration with national park's scientific staff we successfully developed and implemented models with relatively simple methods that capture and capitalise on their knowledge and which they could easily replicate. This was particularly important for ground-truthing results with park services and empowering them for pursuing their own future applications. We were thus able to map potential interactions between favourable habitat for iconic vertebrates and recreation potential and identify their key features in relation to national park management – e.g. management of tracks, huts and interference with ski resorts.

We acknowledge the limits of using potential values for both iconic vertebrates and recreation. For PD we were able to support the quality of our results by validating predicted species habitats with parks observation data. Obviously, this approach does not reflect population densities, another critical dimension for management. Likewise, recreation potential does not provide information about densities of recreationists; a strong data gap in French national parks. Whilst it could be argued that most results came as no surprise, e.g. strong attractiveness of upper valleys for both iconic vertebrates and outdoor recreation, park services strongly valued their spatially comprehensive nature, the visual support for internal and external communication provided by maps (Jacobs et al., 2016) along with a scientifically robust demonstration of critical areas for management like upper valley slopes, forests near resorts or rare inaccessible valleys. Results were presented at both parks scientific committee meetings and stimulated further inquiries in PNV. This represents a unique experience of close collaboration around a highly sensitive issue and highlights the value of co-produced ecosystem service mapping exercises for protected areas (Palomo et al., 2013; Reed et al., 2013).

Our modelling approach carries some limitations for the simplicity and some degree of circularity of models. Model component layers tend to be inherently positively or negatively correlated. First for species habitat potentials, aquatic habitats are critical habitat requirements but coincide with road disturbance in lower valleys. Secondly for the recreation opportunity spectrum, roads provide access while at the same time being perceived as disturbances to quiet experiences of nature. Especially in mountains, steep topography constrains tracks and itineraries to river valleys, leading to a form of double-counting. Conversely scenic beauty is highest from mountain tops. Nevertheless, in our previous study for the Grenoble region an online questionnaire showed very high congruence between ROS maps and respondents declared preferences and visitation patterns (Byczek et al., 2018), justifying in particular our summing approach in spite of correlations among criteria. Thirdly the PD and ROS models shared aquatic habitats and roads and built-up areas as variables, inevitably reinforcing their impacts in analyses of potential interactions. Whilst numerically trivial these effects are strong realities, and the value of our results lies beyond them as attested by park teams.

Further model developments may however consider limiting the impacts of such trade-offs and synergies by down-weighting variables by their correlations. Additionally, each of the PD and ROS models worked using equal importance across criteria in non-weighted sums. This could be improved using Multi-Criterion Decisions Analysis (MCDA), a powerful method for incorporating information on relative weights of criteria in final outcomes (Adem Esmail and Geneletti, 2018; Langemeyer et al., 2016). For ROS and its components, user relative preferences can be elicited through social methods (Getzner and Švajda, 2015; Schirpke et al., 2019b). Advanced analyses of social media data are also emerging for analysing preferences (Mancini et al., 2019), and for directly informing managers of protected areas about use patterns and their drivers (Gosal et al., 2019; Richards and Tunçer, 2018; Tew et al., 2019).

Lastly, iconic plant and animal species could be a component of ROS models, acknowledging their direct contribution to attractiveness and recreational experience (Cox and Gaston, 2018; Crouzat et al., 2016). We deliberately did not include this important component of protected areas visitors experience for assessing interactions between recreation and the distribution of favourable wildlife habitat without confounding analyses. For similar reasons, park managers preferred for huts not to be incorporated as part of the accessibility module of ROS, as assessing risks to wildlife of potential extension of hut openings for spring ski touring was a motivation for the project. Overall, the current ROS model is considered as a first iteration of a continuing collaborative process between scientists and parks.

### *4.2. Seasonal patterns in interactions*

Iconic wildlife and outdoor recreation are strongly intertwined cultural services in mountains (Crouzat et al., 2016; Schirpke et al., 2019a) and in protected areas (Chung et al., 2018). However analyses of their interactions have so far not considered seasonal variation in both species ecologies (which species are present and which habitats matter) and recreation activities (Schirpke et al., 2018). For example, their assessment for the French Alps and Pyrenees highlighted general patterns of interaction hot spots in the subalpine belt and near popular summits, especially in national parks. Potential iconic vertebrates refugia with high habitat potential but low ROS were largely in the alpine belt and in less accessible prealpine massifs with low human population density (Crouzat et al., 2018). Given expected seasonal differences in interactions and their implications for management, national parks motivated their inclusion in our study. Parks were particularly concerned about ongoing development of winter activities and the very limited knowledge of their extent and wildlife impacts in protected areas (Bielański et al., 2018). Our results show clear seasonal differentiation in spatial patterns for potential iconic vertebrate species diversity, recreation opportunities and their interactions, as well as how they vary across the two national parks.

We first hypothesised that limited access and mobility of recreationists during winter would increase potential refugia for wildlife, while conversely there would be greater potential for interactions in summer due to greater spatial spread of activities. This hypothesis was largely confirmed for Ecrins (PNE) where area of strong potential interference between higher quality habitat and recreation opportunities was halved in winter as compared to summer, and highly confined to a few specific areas. Nevertheless, the proportion of potential refugia (higher quality habitat with low ROS) was largely stable across seasons due to the simultaneous decrease in total area favourable for wintering iconic vertebrates. This situation contrasted with the more complex situation in Vanoise (PNV). First overlap between higher quality habitat and low recreation opportunities decreased somewhat from winter to summer. Second, contrary to PNE the most severe potential for interference (ROS5) was significantly greater in winter than summer.

These different seasonal patterns were largely explained by our second hypothesis that lower but physically diffuse pressure from recreationists in PNE would increase potential interference as compared to more intense but directed activity in PNV. This was definitely the case for summer. However, for winter the spatial concentration around ski resorts of PNV was highly impactful. Our analysis focused on higher quality habitat, which did not include resorts *per se*. Rather we clearly demonstrate potentially harmful interference caused by the access they provide to protected habitat of vulnerable species (Braunisch et al., 2011). PNV has an enduring history of conflict with ski resort development (Mauz, 2007), a pressure still increasing due to climate change and resulting increasing demand for higher altitude infrastructure development, and to marketing of large, connected ski areas. Overall parks concerns about the expansion of winter activities are warranted by the non-negligible areas of potentially high interactions with iconic vertebrates, especially climate-sensitive species like rock ptarmigan and snow hare. The critical knowledge gap around the magnitude of interference yet needs to be addressed using precise track data of recreationists and wildlife (Braunisch et al., 2011). Social analyses of interactions can complement these by documenting encounter patterns and understanding recreationists' perceptions of their interference with wildlife (Bielański et al., 2018).

Our results were useful to support parks assumptions on seasonal interaction patterns like joint hot spots of recreation and iconic vertebrate habitat near popular tracks and summits, or the impacts of ski resorts and popular ski touring itineraries. But we also showed unexpectedly strong evidence about the critical role of refuge areas in high valleys (summer) and lower slopes away from tracks (winter). These point to risks associated with the emergence of off-track practices (Bourdeau et al., 2018), the need to quantify them and to understand their motivations. Analyses of tracks and practices are required to reveal sensitive interactions at a finer temporal grain, for instance potential conflicts between reproduction and ski touring and opening of huts in spring.

## 5. Conclusion

This study was motivated by the tension between two core missions of protected areas: biodiversity protection and public access to nature, including recreation. Their challenge of managing for multiple cultural services is primarily addressed through planning and regulatory tools (Moreaux et al., 2018), with increasing support from spatial modelling of nature's multiple values (Geneletti and van Duren, 2008; Schröter and Remme, 2016). Our analyses of potential interactions between iconic vertebrate habitat and outdoor recreation potential demonstrated how co-production of such knowledge with park managers can inform management by highlighting critical times and places. Beyond regulatory interventions they will support dialogue based on communication and education of the public and mountain professionals. Such actions are already in place for rock ptarmigan (*Lagopus muta*) and its interactions with ski resorts (PNV) and snow sport practitioners (multiple French protected areas), and for winter practices overall (PNE).

Whilst powerful through its spatial extensiveness, spatial modelling of wildlife habitat and recreation indicators will need to be combined with other data sources including advanced analyses of social media images and trip reports, spatial tracking and social data. Further analyses also ought to incorporate climate change sensitivities, which are critical for multiple iconic high mountain vertebrates (Revermann et al., 2012; Thuiller et al., 2018; Zurell et al., 2012) and add to risks from human disturbance (Imperio et al., 2013). Likewise expected changes in outdoor recreation practices will need to be accounted for.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2020.101155.

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