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Preserving natural habitat quality and/or recreational attractiveness? Spatial tools for management planning

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Abstract

The concept of ecosystem services (ESs) remains underused in supporting practical decisions in conservation/development plans and programmes. One of the most important knowledge gaps for a better consideration is related to ESs spatial assessment and mapping. In this paper, we assess and map two major ES in a regional park: recreational attractiveness and natural habitat quality. Because the area under study is a large territory, primary valuation techniques would have been difficult to apply. Thus, we develop a methodology to characterise the recreation attractiveness on a part of the area under study that is further transferred in the whole study area. Predictions are based on a function of biophysical (Lancasterian) characteristics and a travel cost model. To the best of our knowledge, this study constitutes one of the first attempts at function benefit transfer based on a travel cost model. Habitat quality is computed with the InVEST module. The results call for a better accounting of site characteristics in travel cost methods that principally focus on individual characteristics. From a policy guidance perspective, we show that spatial statistical analysis of the created indicators helps in evaluating management planning strategy by locating areas that need further conservation efforts.

Keywords: Forest recreational attractiveness, Habitat quality, InVEST, Travel cost method, Function benefit transfer, Regional park.

JEL codes: Q26, Q51, R12, R58

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1. INTRODUCTION

Despite the growing political attention paid to ecosystem services (ESs), the concept remains underused in supporting practical decisions with regard to conservation and development programmes (Laurans et al., 2013). One of the most important knowledge gaps for a better consideration of ESs in territorial decision-making is related to the accounting for spatial variability in environmental and economic analyses. However, from a planning perspective, knowledge of the non-market benefits derived from ESs combined with geographic information systems (GISs) is a potentially powerful analytical tool for public land managers. By providing spatially explicit representations of ESs, land managers have the possibility to broaden the goals that can be pursued when evaluating land management scenarios (Geneletti, 2016).

However, ES modelling and mapping in the context of planning have received much attention in environmental and economic research (Bateman et al. 2014, Burkhard and Maes, 2017). Refined techniques either to quantify or to map the supply side (representing ES flows produced by the ecological functioning of ecosystems), the demand side (flows to beneficiaries) and different values associated with ESs have been developed (Tardieu, 2017). Nevertheless, ES modelling and mapping exercises are not always readily feasible in local contexts because they require a large amount of georeferenced data on ecosystems and beneficiaries, which are not necessarily available for times and places.

In this paper, our primary focus is on the modelling and mapping of natural habitat quality and the recreational attractiveness of forest ecosystems. However, the developed methods can be applied to any other ecosystem type. Several tools and models to spatially assess natural habitat quality are already available; they are usually based on ecological indicators (Maes et al., 2012) or on ecological modelling, such as Globio and Marxan (Alkemade et al., 2009; Chan et al., 2011) or InVEST[3] (Kareiva et al., 2011; Terrado et al., 2016; Sallustio et al., 2017; Salata et al., 2017). However, this topic is less investigated in the case of outdoor recreation services. In contrast to other ESs, in the literature, the modelling of the demand side is much more developed than that of the supply side. Recreation demand is commonly assessed by modelling visits carried out in a site with a particular land cover, such as woodlands (*e.g.,* Jones et al., 2010; Binner et al., 2017) or wetlands (*e.g.,* Shresta et al., 2002), or benefiting from a specific protection status, such as national parks (Martínez-Espiñeira and Amoako-Tuffour, 2008; Schägner et al., 2016) or regional parks (Bujosa Bestard and Riera Font, 2010). Modelling is usually performed with the travel cost revealed preference method or with the choice experiment declared preference method, which are both based on surveys of individuals. The advantage of travel cost methods is that they rely on real behaviours and allow the assessment of the actual benefits derived from existing managed ecosystems (in an ex post analysis). In this method, recreational values are estimated based on individuals' consumer surplus derived from a recreation demand function, describing the number of trips undertaken to the site per year. Demand is determined by an implicit price (the travel cost) and a set of other variables (distance, time

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[3] Integrated valuation of ecosystem services and tradeoffs from the Natural Capital Project. InVEST is an open-source software available at: https://www.naturalcapitalproject.org/invest/.

available, income, other available sites as substitutes, visitors' socio-economic characteristics, etc.) (Hotelling, 1947; Parsons, 2003). However, the results often produced are (1) aggregated values that do not allow for a spatial differentiation of recreation trips within the destination site and (2) driven by individuals, not enabling the specification of preferences for the biophysical characteristics of different sites.

Some exceptions can be cited from the literature. Sen et al. (2014)[4] developed a model to predict visits, obtained from a national recreation survey, according to destination site characteristics, the attributes of outset locations and the distance travelled by visitors to reach the site. They further apply the estimated model at the national scale (the United Kingdom territory). Nevertheless, whether these types of models are applicable to more local territories, requiring more precise output data to develop accurate strategies at the local scale, remains an open question. Termansen et al. (2013) and De Valck et al. (2017), respectively, mapped recreational values and site quality scores by site characteristics by transferring a function derived from a choice experiment study. In our case, we would like to rely on existing and observed (not declared) data to derive recreation demand functions. Finally, volunteered geographic information such as self-geotagged photographs on web applications directly completed by visitors (*e.g.,* Flickr©, Instagram©) may allow the development of spatially sensitive recreation maps. However, to the best of our knowledge, this type of information has not been used in this way to date, and papers mostly produce aggregated predictions (*e.g.,* Wood et al. 2013). Furthermore, it is questionable whether such data may be usable in a local context holding potentially few observations and whether they could be subject to sample selection biases because social media are more likely to be used by young and well connected people.

Accordingly, we formulate several methodological questions:

(i) How can we model and map recreational attractiveness and habitat quality, in a spatially explicit way, at the local scale and from existing data?
(ii) By which method can we analyse the articulation between the supply and demand sides in the case of recreation services?
(iii) Finally, by what means can we evaluate the accuracy of a conservation or development strategy in a territory from the produced indexes?

This article presents objective GIS-based methods using readily available data and discusses their potential in guiding land managers at the local scale. We develop a methodology to predict, in a spatially sensitive way, the recreation supply and demand in a case study on a French regional park. The predictions are based on a hedonic function of biophysical supply and a travel cost method for visitor demand. We further transfer the supply and demand functions in the whole territory covered by the park, allowing for the mapping of a recreational attractiveness index. To the best of our knowledge, this study constitutes one of the first attempts at a function benefit transfer with a travel cost method. Habitat quality is computed with the InVEST module based on natural habitat suitability and pressures. Therefore, the contribution of this paper is twofold. The first contribution is

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[4] The paper by Sen et al. (2014) is mostly based on various seminal papers developing the use of GISs in travel cost techniques: Jones et al. (2010), Brainard et al. (1997 and 1999) and Lovett et al. (1997).

methodological, as we develop a clear and original method to transfer the function of a travel cost model adjusted for the biophysical attributes of destination sites and for the geographical context of beneficiaries. This method allows for the analysis of the articulation between the demand and supply of ESs, which is rarely performed in the ES literature (Termansen et al., 2013). In this way, we show that site attractiveness is principally driven by the biophysical attributes of forests rather than by the socio-economic characteristics of individuals. This finding calls for a better accounting of these attributes in travel cost methods that consequently tend to ignore key factors of recreational attractiveness. Second, we show that the created indicators can provide policy guidance for the orientation of conservation/development strategies, which often require spatial information for better management planning.

2. MATERIALS AND METHOD

2.1. Case study: The Ballons des Vosges Regional Park, France

The Ballons des Vosges regional Park (BVRP) is a 2700 km^2 territory situated in two regions of eastern France: Grand Est and Bourgogne Franche-Comté. The forest covers approximately 61% of the total area of the BVRP, and the remaining territory is covered by wetlands, lakes, agricultural areas and meadows (Figure 1). The mountainous relief gives a high diversity of natural habitats governed by different bioclimatic stages. The *High Vosges* are obstacles to oceanic disturbances that come from the west, producing heavy rains in the western part of the BVRP (more than 2m/year) to the crest line and, conversely, approximately 50 cm/year in the eastern part, making this side of the area one of the driest regions in France. One-third of the area of the BVRP is placed under remarkable natural site status and 22% under Natura 2000 conservation commitments. A few remarkable species are present in the site, such as the *Tetrao urogallus* or the *Lynx*, which are subject to particular conservation programmes. In terms of recreation, the BVRP is a landmark for skiing and hiking activities. Finally, it is one of the largest and most populated French regional parks, as it borders and includes several urban units, such as Colmar, Mulhouse and Belfort.

Natural regional park is a protection status in France. Such parks are governed by a charter approved by the states and municipalities composing the area. The charter sets the development strategy in terms of the maintenance/improvement of environmental and cultural heritage and the means to implement it over a 15-year period. According to the charter, the environmental strategy must be focused on three principal activities: (1) the forest production of wood and non-wood products, (2) recreational attractiveness, and (3) habitat and biodiversity conservation. To that end, land managers have developed a management strategy, specified in the charter by 2024, for three different territories (Figure 1). First, in the *High Vosges* territory, the objective is to conciliate habitat conservation while maintaining good recreational attractiveness. More specifically, managers rely on the European Charter for Sustainable Tourism in Protected Areas[5] and try to define tourist attendance strategies. Second, the key challenge in the *Valleys and Piedmont* is to control

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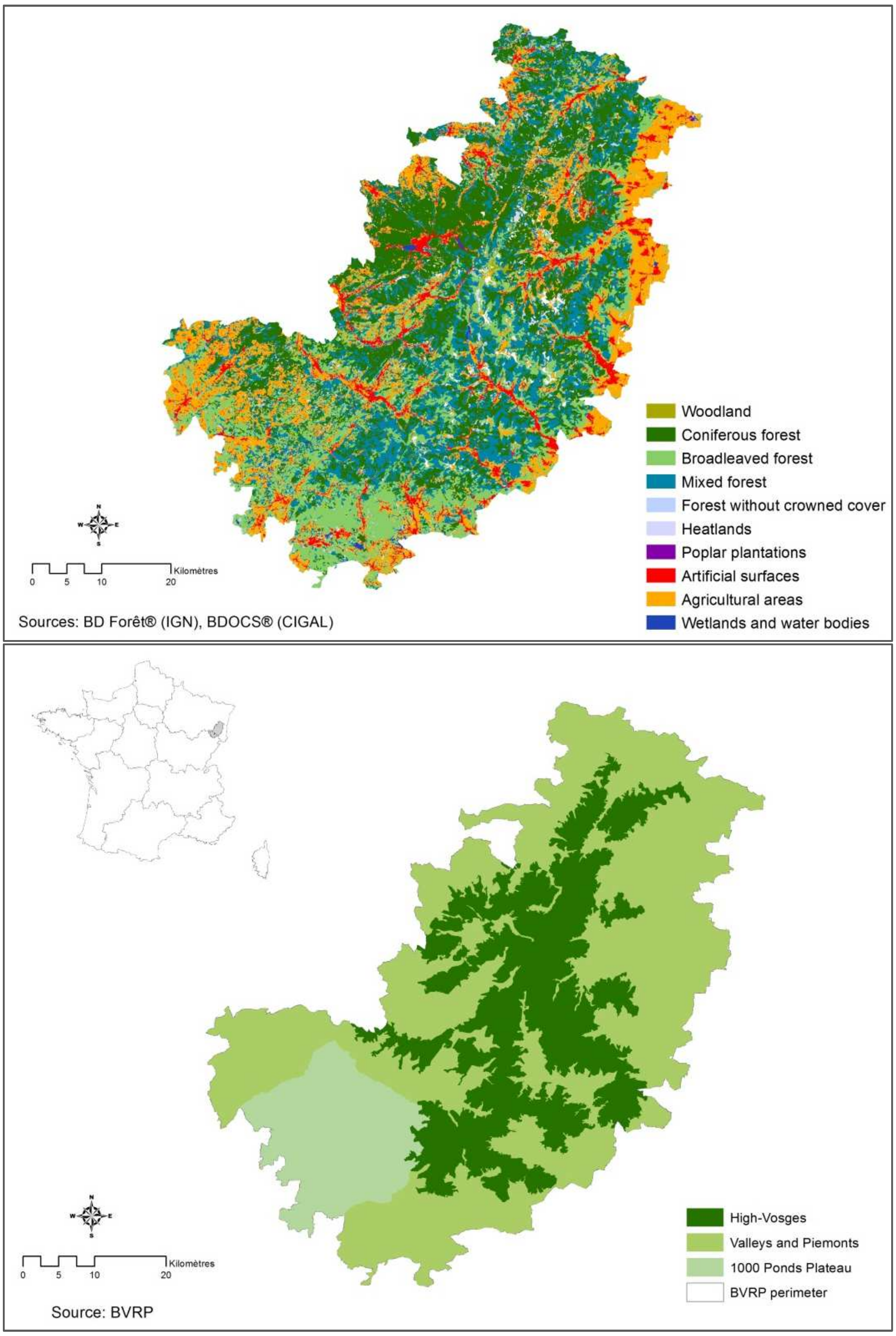
[5] http://www.europarc.org/library/europarc-events-and-programmes/european-charter-for-sustainable-tourism/

urbanisation and habitat fragmentation. Finally, the *1000 Ponds Plateau* benefits from exceptional habitat richness; however, decline from industrial and farmland activities is weakening the attractiveness of this area. Thus, the objective in this area is to sustain its vitality.



Sources: BD Forêt® (IGN), BDOCS® (CIGAL)

Source: BVRP

Figure 1: The land cover types and the three main territories of the Ballons des Vosges Regional Park (France)

2.2. Snapshot of the methodological framework

The methodological framework can be divided into three steps (Figure 2). The first step is a recreation model, described in section 2.3. This model is based on an initial survey conducted in the Lorraine region (section 2.3.1), further combined with spatial data. A hedonic function of supply attractiveness and a travel cost model are estimated to derive a combined attractiveness index. Simultaneously, a habitat quality model is computed using the InVEST software (section 2.4). The results of the two models are detailed in section 3. Finally, in section 4, the two indexes are analysed with regard to the BVRP orientation strategy to assess whether it is accurate and efficient.

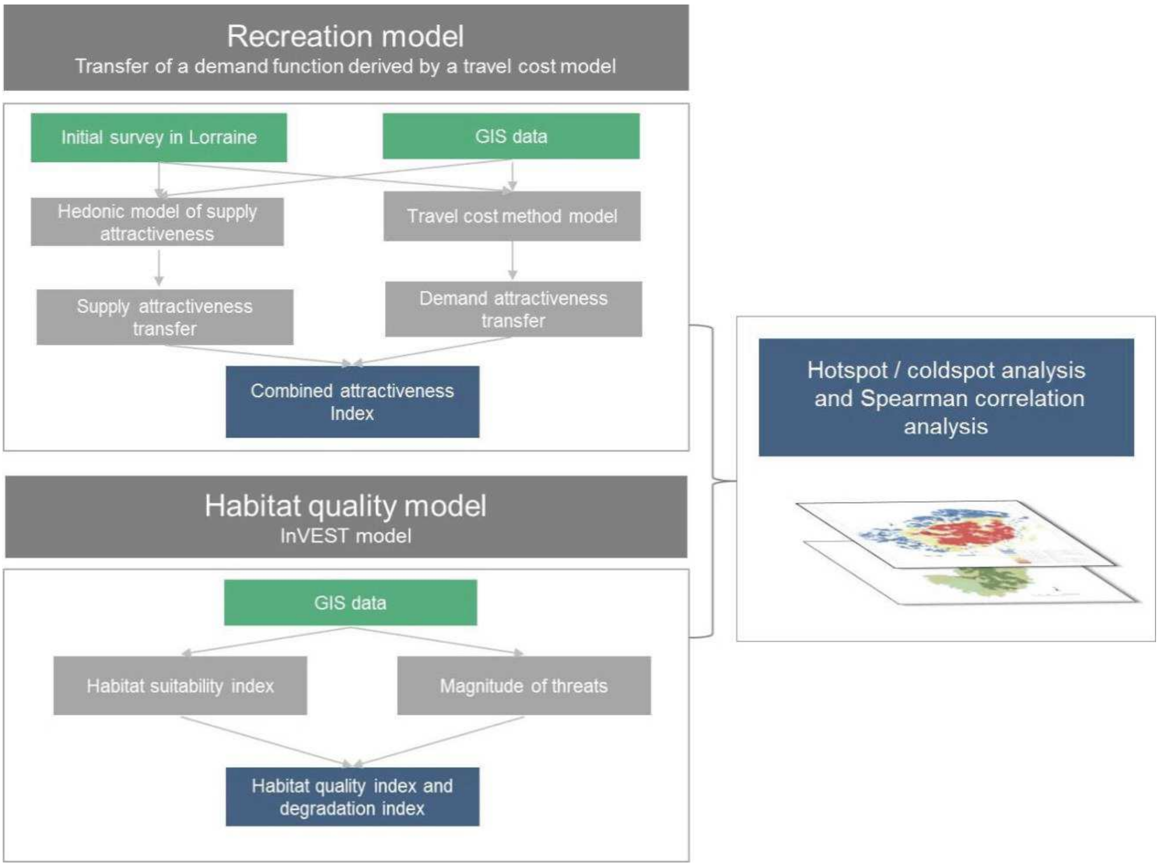


Figure 2: Snapshot of the methodological framework

2.3. Recreation model

2.3.1. Original survey and scales of analysis

We rely on an online survey initially conducted in the former Lorraine region (now the Grand Est region), covering one-third of BVRP territory (Figure 3). This survey had been used in different application cases to study local recreation: Abildtrup et al. (2015a and 2015b). It was carried out between July and August 2010 by email surveys in the former Lorraine region. A total of 1144 respondents completed the questionnaire, and 526 had visited a forest and provided information about which specific forest they had visited in the last 12 months. All of the survey details are reported in Abildtrup et al. (2015a and 2015b).

In the initial survey, Lorraine’s forests were divided into “forest units" representing relevant recreational units greater than or equal to 5 ha. A total of 5568 forest units were delineated in the initial survey. From this total sample, we selected the forest units included in the BVRP, which are in the Vosges department in the Lorraine region, resulting in 256 forest units. In total, 1236 visits were recorded in 94 forest units, over 256, and distributed throughout the entire area of the BVRP, surrounded by a 10 km[6] buffer zone (Figure 3). Our recreation model is thus developed based on those forest units. However, because we had no clear rules to define forest units in the rest of the BVRP area, we defined recreational units through a raster distributed homogeneously according to a kilometric mesh. Based on the forest French database (BD Forêt®, IGN), we assign the surface of forest areas to each mesh. Only the meshes including at least 50% of closed forest are considered as forest recreational units in this work. Meshes cover the entire area of the park, increased by a 10 km buffer zone around its perimeter to take into account possible visitors leaving outside and, therefore, to avoid border effects. Ultimately, we obtained 3774 forest recreational units over the entire BVRP (Figure 3). These recreational units are used for the transfer of the recreational functions.

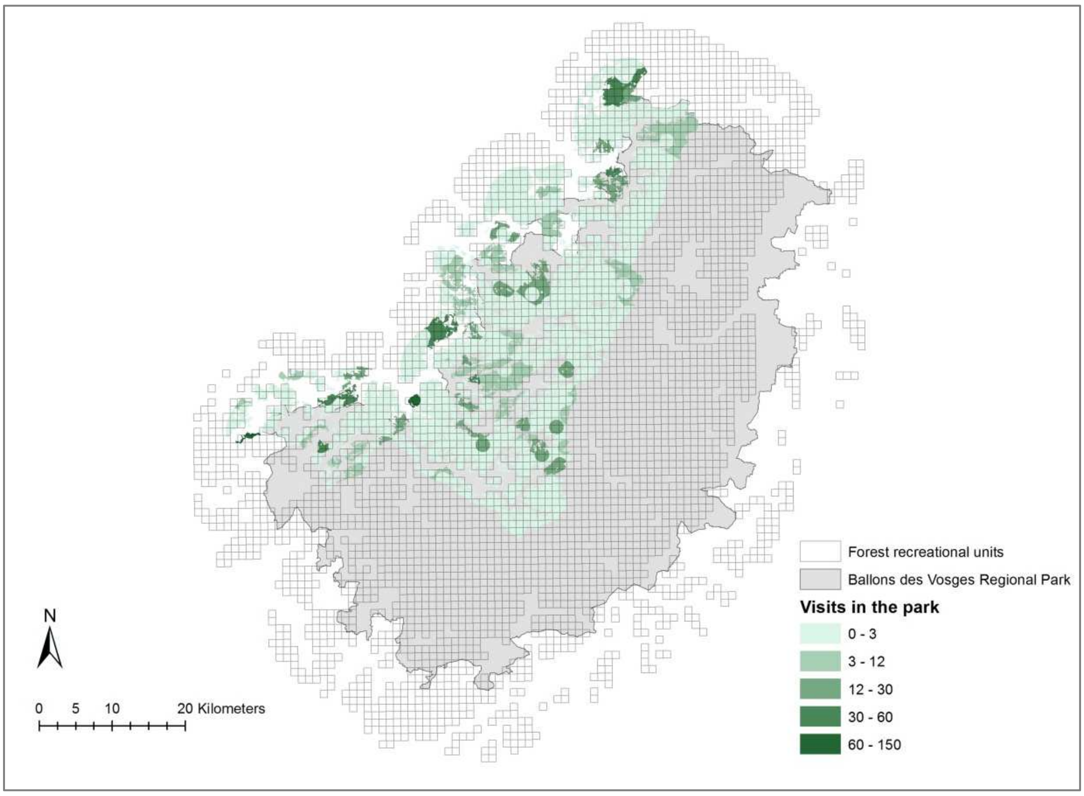


Figure 3: Area covered by the initial survey in the BVRP, the forest units visited, and the kilometric mesh used for the benefit transfer

2.3.2. Supply attractiveness model

In a typical travel cost model, the visited sites are directly revealed by visitors during the survey. However, in this paper, such locations are unknown in a large part of the BVRP and have to be predicted. The supply attractiveness model characterises the supply of recreational forests in the area with a hedonic function of biophysical characteristics and forecasts the most interesting characteristics. The prediction model do so by taking

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[6] We considered this buffer zone because forest units are sometimes juxtaposed with BVRP territory or are very close to the limits of the BVRP.

information on the number of visits to destination sites from the initial survey and observes how this information is related to (i) the forest structure characteristics, (ii) the amenities available at the site, and (iii) the distribution of the population around the site (Table 1). The expectations concerning these variables are that elevation, coniferous, broadleaved and mixed forests, and water surfaces are more attractive, as well as sites strongly endowed with amenities. The population living 2 km around the forest represents the forest recreational pressure. We expect that when the pressure is important, the forest is less attractive. These variables were not present in the initial survey and have been reconstituted for the purposes of the paper.

Table 1: Description of the variables for the supply attractiveness model

Variable	Description	Data source	Descriptive statistics		
			Mean	Median	Std. err.
Population at 2 km	Population included in a 2 km buffer zone of the mesh	Census data, INSEE	2165	1827	1472
Share of forest types	Share of coniferous forests at the site	GIS calculation from the Forest French database (BD Forêt®, IGN)	0.41	0.43	0.22
	Share of broadleaved forest at the site		0.17	0.09	0.15
	Share of mixed forests at the site		0.27	0.25	0.14
Hiking path	Hiking path density (in m) including biking paths	BDTOPO®, IGN – paths, roads	11369	6998	14781
Natural and cultural points of interest	Number of natural and cultural points of interest in the mesh	BDTOPO®, IGN – nature and culture	0.3	0	0.86
Water courses, water surfaces	Share of water courses in the mesh with a buffer zone of 200 m around the courses	BDTOPO®, IGN – water surfaces	0.09	0.06	0.14
Elevation	Altitude (in m)	BD Alti®, IGN	669	630	177

The supply attractiveness of each recreational unit is predicted with a count data model. These models are particularly accurate when the dependent variable is an integer taking few values than the visitors' trips taken to a destination site (Shaw, 1988; Englin and Shonkwiler, 1995; Baerenklau et al., 2010, Roussel et al., 2016).

Many pixels, however, are not visited. We addressed this issue by using a zero-inflated count data model, where the probability of participation is estimated simultaneously with the visit function (Gurmu and Trivedi, 1996). Zero-inflated count data models are more general than typical count model in that they relax the restriction that an identical process generates both zeros and positive integers. Moreover, as Englin et al. (2003) argue and as is the case in our dataset, zero trips can be generated by both a binomial process (for people not in the market *i.e.,* not visiting any forests) and a Poisson process (for people in the market *i.e.,* surveyed visitors who did not take any trips in the specific forest in question). In contrast to simple-hurdle models, zero-inflated models account for both types of zeros by estimating a two-step procedure. First, a participation model determines whether the zero observation belongs to the group where the dependent variable is always null (*i.e.,* non-visitors) or whether it belongs to the group in which the dependent variable can be positive or null (*i.e.,* visitors).

Furthermore, a Poisson or a negative binomial regression estimates the visit function. Thus, the density function with a Poisson distribution for each forest *i* is as follows:

$$P\left(v_j = k|X_j\right) = \begin{cases} \pi_i + \left(1 - \pi_j\right)\mathrm{e}^{-\mathrm{j}} & si\ k = 0 \\ \left(1 - \pi_i\right)\mathrm{e}^{-\lambda_\mathrm{j}} \dfrac{\lambda_j^k}{k\,!} & si\ k > 0 \end{cases} \tag{1}$$

where π_j: the probability that a visitor coming from an outset location j will take no trip to forest *i;* and

$\left(1 - \pi_j\right)$: the probability that v_j follow a Poisson law with a λ_j parameter (see Roussel et al., 2016 for more explanations on the standard Poisson model).

For the λ_i parameter representing the average number of visits, π_i is dependent on a vector of explanatory variables that can be different from X_i, the vector of the explanatory variables for λ_i. Participation can be either assessed with a logit or a probit model, depending on the distribution we assume.

2.3.3. Demand attractiveness model

Demand attractiveness is derived from the initial survey by applying a travel cost model. This model aims to predict the trips taken in each forest recreational unit from any given outset area. To allow the trip function to be transferable, we limited the number of variables to those that can be reconstituted in the entire area covered by the BVRP. Moreover, as Bateman et al. (2011) suggest, this type of parameterisation is recommended because of the multiplicative role of coefficients resulting in major transfer errors in over-parametrised models. We derive a recreation demand function from the travel cost model determined by an implicit price (the trip cost) and a set of independent variables (the socio-economic and demographic characteristics of the individual and the availability of potential substitute sites).

The trip cost is a combined cost between trip costs for individuals using motorised means of travel and an opportunity cost of time. The trip cost is computed as follows:

$$TC = 2 \times \left(\frac{(D \times KMC)}{P} + OCT\right) \tag{2}$$

where *TC* is the trip cost and *D* is the distance between the outset location and the site in km[7]. *KMC* is a km cost based on the vehicle fiscal power published annually by the fiscal administration. Because we do not have this information, we made the assumption that vehicles have a mean fiscal power of 4 fiscal horsepower, corresponding to a 0.493/km cost[8]. This cost takes into account vehicle depreciation, maintenance costs, tire expenses, fuel consumption and insurance premiums. *P* is the number of individuals in the group. The costs

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[7] In many cases, D is computed for the purpose. To do so, we used the osrmtime command from Stata (Huber and Rust, 2016).

[8] KMC takes into account vehicle depreciation, maintenance, fuel and insurance costs and is published annually by the fiscal administration in France:
https://www3.impots.gouv.fr/simulateur/calcul_impot/2017/pdf/baremekm.pdf.
This inclusion of vehicle depreciation is typical in the TCM (see Parsons, 2003). However, this inclusion has been discussed in the literature (see Earnhart, 2003) because individuals may not explicitly perceive these types of costs.

are multiplied by two to consider the entire round trip. We did not consider foot and cycle travels, even though some studies considered material depreciation in terms of cycle or trekking shoes (*e.g.*, Bertram et al., 2017). OCT is the opportunity cost of time. An individual who visits a recreation site has an opportunity to use his time differently (working, for example) and is therefore subject to an opportunity cost. This cost relies on the assumption of an individual's trade-off between labour and leisure. The OCT characterises the cost of time while travelling to and from the site and eventually the time spent at the site[9]. However, we chose not to consider an OCT for two reasons: (i) because we rely on very local recreation, implying short trips to forests, and (ii) because this approach assumes that individuals have flexible jobs and are able to substitute work for leisure time at the margin, and this assumption is rarely verified.

As in the supply attractiveness model, visits are predicted with a count data model where the dependent variable is the number of observed visits in each forest unit *i*. The observations come from the initial survey. The dependent variables are recomputed to serve our trip function transfer and are described in Table 2. The expectations regarding these variables are that the trip cost between the respondent outset location and the visited site decreases visit demand as well as the availability of substitutes around the outset location and that the income increases recreation demand.

Table 2: Variables used in the demand attractiveness model and in the transfer

Variables	Description	Data source	Descriptive statistics		
			Mean	Median	Std. err.
Visits	Declared visits by visitors in the year preceding the survey	Survey	15.63	6	23.5
TC (Trip cost)	*Initial survey*				
	Calculated from the centroid of the visitor's IRIS[10] to the recreational unit centroid	GIS calculation, ESRI ArcGIS	16.20	10.46	23.93
	Reconstituted variable in the transfer Calculated from each IRIS centroid to each recreational unit centroid with equation 1				
Income	*Initial survey*				
	Median income in different income classes	Census data INSEE	33007	33750	14581
	Reconstituted variable in the transfer Median income at the IRIS level				
Availability of substitutes	*Initial survey* Share of other land use types around a 5 km[11] buffer around the visitor's IRIS centroid	GIS calculation (ESRI ArcGIS) from Corine Land Cover (2012)			
	% Urban areas (CLC1)		0.38	0.25	0.34
	% Agricultural areas (CLC2)		0.25	0.24	0.27
	% Wetlands (CLC4)		0.001	0	0.008
	% Water bodies (CLC5)		0.008	0	0.014
	% Coniferous forests (CLC311)		0.19	0.14	0.18
	% Broadleaved forests (CLC312)		0.05	0	0.15
	% mixed forests (CLC313)		0.04	0	0.11

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[9] For a discussion regarding the OCT, refer to Roussel et al. (2016).

[10] IRIS is the smallest level of French national statistics, and it includes approximately 2000 persons.

[11] The 5 km buffer was chosen following Sen et al. (2014), who tested different radiuses (1 km, 2.5 km, 5 km, and 10 km). The 5 km radius had the best fit according to the Akaike information criterion (AIC).

Reconstituted variable in the transfer
Share of other land use types around a 5 km buffer around the IRIS centroid

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2.3.4. Benefit transfer and construction of the combined attractiveness index

Two transfer functions are completed to map the combined attractiveness indicator (CAI) of BVRP forests:

(1) A transfer of the function developed in the supply attractiveness model that leads to the development of a supply attractiveness index (SAI); and
(2) A trip transfer function predicting the visits in BVRP territory, allowing the development of the demand attractiveness index (DAI).

In the case of the supply attractiveness model, the significant coefficients derived from the supply attractiveness model are applied to each 1 km^2 mesh of recreational units in the park. The result, after normalisation, gives the SAI based on the characteristics sought by visitors. The SAI for each cell i varies between $[0;\ 1]$ and is calculated as follows:

$$SAI_i = \frac{SA_i - SA_{Min}}{SA_{Max} - SA_{Min}} \tag{3}$$

where

$$SA_i = \exp(\beta sv_i)\,, \forall i \tag{4}$$

SA_i is the recreational supply attractiveness score of recreational cell i, with $i \in \{1, \dots, I\}$ before normalisation. sv_i is a vector of the supply independent variables (the same variables as those described in Table 1) describing recreational forest unit i in the entire park, and β is a vector of the estimated parameters associated with the vector SV in the supply attractiveness model (specified as a zero-inflated Poisson (ZIP) model, which is why the functional form of the equation is a semi-logarithmic form).

Furthermore, the demand function is applied to construct the DAI applied to the variables described in Table 2.

$$DAI_i = \frac{DA_i - DA_{Min}}{DA_{Max} - DA_{Min}} \tag{5}$$

where

$$DA_{ij} = \exp\left(\gamma TC_{ij} + \sigma dv_j\right), \forall i, \forall j$$

and

$$DA_i = \sum_{j=1}^{J} DA_{ij}\,, \forall i, \forall j \tag{6}$$

DA_i is the demand attractiveness of recreational cell i from a series of outset locations present in the BVRP, with $i \in \{1, \dots, I\}$ before normalisation. As in the common travel cost, it also denotes the number of visits in cell i. DA_{ij} is the demand attractiveness for cell i from a given visitor coming from an outset location j, with $j \in \{1, \dots, J\}$. dv_j is the vector of demand independent variables describing visitors and the outset area j characteristics, *i.e.*, the percentage of various land use types within a set radius of the outset location. TC_{ij} is the travel cost between recreational cell i and outset j. All the variables are described in Table 2. σ and γ are the vector of parameters associated with the trip cost and other variables estimated in the demand attractiveness model.

Finally, the CAI is attributed to each recreational unit cell i by computing the geometric mean of the two indexes as follows:

$$CAI_i = \sqrt{SAI_i \times DAI_i} \qquad (7)$$

Using a geometric mean makes it possible to consider a non-compensation between the two indexes. That is, the SAI and the DAI cannot completely compensate each other in the CAI if the SAI is strong and the DAI is weak, or *vice versa*. Therefore, a strong combined index reveals strong supply attractiveness combined with a strong demand index (which is symmetrical for a low CAI).

2.4. Habitat quality index

We use the InVEST model of habitat quality as a proxy to represent biodiversity richness. InVEST defines habitat quality as "*the resources and conditions present in an area that produce occupancy – including survival and reproduction – by a given organism*" (Hall et al., 1997:175). Thus, the aim is to estimate the quality of habitats in spatially explicit terms by measuring the appropriate conditions for the survival and reproduction of species generally based on the potential threat and degradation of natural habitats (Tallis et al., 2013).

Land use/land cover (LULC) is composed of seven categories extracted from the Corine Land Cover database (CLC, 2012): artificial areas (CLC1), agricultural areas (CLC2), coniferous forests (CLC311), broadleaved forests (CLC312), mixed forests (CLC313), scrub and/or herbaceous vegetation associations (CLC4), and open spaces with little or no vegetation (CLC5). Thus, only forests are considered and more precisely identified (*i.e.,* three categories of forest land cover), as our analysis is based on the habitat quality of forest areas.

Habitat quality/degradation is a function of threats from different sources, *e.g.,* artificial areas, agricultural lands, main roads, secondary roads, and trails. Artificial areas and agricultural lands are included as sources of landscape fragmentation and habitat degradation (Girvetz et al., 2008). In addition, a few studies have revealed the important impact of forest roads on biodiversity and forest habitat (*e.g.,* Marcantonio et al., 2013). Consequently, analysis of road networks according to their categorisation (primary, secondary and trails, derived from the BDTOPO®) is critical to better understand the role of linear infrastructure on habitat loss, fragmentation, and degradation (Underhill and Angold, 2000; Von Der Lippe and Kowarik, 2008).

The habitat quality index depends on three factors: the impact of threats (*i.e.,* the impact of each threat on habitat quality, relative to other threats, ranging from 0 to 1), the distance between a habitat and threats (*i.e.*, maximum distance, in km, over which each threat affects habitat quality)[12], and the sensitivity of a habitat to threats.

Based on these different factors, the threat level T_{xj} is defined as follows:

$$T_{ij} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{Wr}{\sum_{r=1}^{R} w_r} \right) r_y \, x_{rxy} s_{jr} \tag{8}$$

where y is a mesh of the threat raster r, Yr are all the meshes of the raster r, Wr is the relative weight of the impact of threat r, x_{rxy} is the impact of threat r that originates in grid cell y on the habitat in grid cell i (function of the distance), and S_{jr} is the sensitivity of habitat j to threat r.

The habitat quality Q_{xj} is defined as follows:

$$Q_{ij} = H_j \, (1 - \left(\frac{T_{ij}^{z}}{T_{ij}^{z} + K^{z}} \right)) \tag{9}$$

H_j ranges from 0 to 1, where 1 indicates LULC classes with the highest suitability for species, and K is the saturation constant. Thus, the higher the degradation index T_{ij} is, the lower the quality of habitats Q_{ij}.

The parameters of the model are based on the literature and expert knowledge (Polasky et al., 2011; Terrado et al., 2016; Salata et al., 2017; Sallustio et al., 2017). We defined our scores based on their absolute and, more importantly, their relative values. Our scores were further validated by local managers and experts (a public forest manager, a biodiversity officer in the BVRP, and a forest officer in the National Geographic Institute). The inputs are presented in Tables 3 and 4.

Table 3: The characteristics of the threats to habitat quality in the BVRP

Type of threat r	Maximum distance *Max.D*	Impact weight Wr
Urban cover	1.5	0.9
Agricultural cover	1	0.56
Main roads	1.5	0.9
Secondary roads	1	0.7
Trails	0.3	0.35

Table 4: Habitat suitability and the sensitivity to each threat in the BVRP

	Habitat suitability	Urban	Agriculture	Road1	Road2	Trail
Forest cover	Hj			Sjr		
Broadleaved forest	0.9	0.8	0.5	0.8	0.6	0.4
Coniferous forest	0.8	0.72	0.45	0.72	0.54	0.36
Mixed forest	0.9	0.8	0.5	0.8	0.6	0.4

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[12] The distance decay is defined by the InVEST model as exponential.

3. RESULTS

3.1. Recreation model

3.1.1. Supply attractiveness model

We estimated four count data models: a Poisson model, a ZIP model, a negative binomial model and a zero-inflated negative binomial model. The likelihood ratio test on alpha, representing the dispersion parameter, showed that our dataset was not over-dispersed, justifying the use of a Poisson model over a negative binomial model. The Vuong test confirmed that the ZIP model had to be preferred over a standard Poisson model (z>2).

We tested various model specifications, including the following:

- Hiking paths as the number of paths instead of m;
- Water courses and forest surfaces instead of coverage share variables;
- Public *versus* private forests;
- The distance to the nearest forest; and
- Different variables explaining non-visited forests.

We present the best fitting model according to the Akaike information criterion (AIC) and Bayesian information criterion (BIC) model selection criteria in Table 5.

Table 5: Zero-inflated Poisson model for the supply attractiveness model based on destination sites

Variables	**ZIP coefficients**	***Std. Err.***
Trip demand		
Population 2 km around the site	-4.87e-05	(3.18e-05)
Log (% of broadleaved forests at the site)	-0.100***	(0.0287)
Log (% of mixed forest at the site)	0.0807**	(0.0390)
Natural and cultural points of interest at sites (number of points)	0.521***	(0.0457)
Water courses, water surfaces (% of the surface)	0.996**	(0.416)
Elevation	-0.00646***	(0.00138)
Squared elevation	7.88e-06**	(9.66e-07)
Hiking path density (in m)	-1.16e-05	(7.32e-06)
Squared hiking path density (in m)	0	(1.29e-10)
Constant	5.608***	(0.448)
Participation		
Hiking path density (in m)	-5.84e-05**	(2.48e-05)
Squared hiking path density (in m)	7.41e-10*	(4.02e-10)
Constant	0.917***	(0.237)
Log likelihood	-1038.1072	
LR chi^2 (9)	268.85377	
Prob>chi^2	0.000	
AIC	2098.2144	
BIC	2135.9372	
Number of zero observations	162	
Number of non-zero observations	94	
Total observations	256	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Vuong test of ZIP vs. standard Poisson: z=5.76 Pr>z=0.0000
Alpha test on ZINB=1.948269 Pr>z=0.286
Coniferous forests are set as the base case coverage share

We can observe that the most powerful predictor is elevation, followed by the presence of water and the presence of natural and cultural points of interest at the site. This result is also observed in some studies based on declared preferences (*e.g.,* Abildtrup et al., 2013; Termansen et al., 2013 and De Valck, 2017). Forest types are integrated as logarithms and can thus be interpreted as elasticities. Mixed forests exert the greatest attraction compared to coniferous and broadleaved forests. These types of forest characteristics are, to the best of our knowledge, rarely integrated in models explaining recreational visits, making comparisons difficult. However, some studies have integrated some of them in their regressions. For instance, Sen et al. (2014) found a positive relationship between visits and the presence of woodland (they do not separate forest types). Termansen et al. (2013) found a preference for broadleaved forest, and Schägner et al. (2016) found that the forest type had no effect.

Neither the presence of a population at 2 km around the site nor the density of the hiking path has an impact on site attractiveness. This result contradicts our first intuitions and the findings in the literature (*e.g.,* De Valck et al., 2017), but this result may be because the case study includes many hiking paths, so that the variable does not discriminate between different supply units. Furthermore, elevation has a negative effect on attractiveness. Nevertheless, the square of elevation has a positive impact, giving an overall non-linear effect of the elevation variables. Graphically, the effect of elevation on supply attractiveness has a convex curve; that is, elevation has a low effect on attractiveness until a certain point at which it plays a major role (823 m, in our case). This result makes sense in a mountainous environment, such as the BVRP; indeed, it shows that individuals are more attracted by forests with a low elevation and a high elevation and have lower preferences for forests situated in medium mountains. Participation is only explained by hiking path density. Sites with fewer hiking paths are more likely to be visited, however the predictor is weak.

3.1.2. Demand attractiveness model

For the supply attractiveness model, we estimated four count data models. However, for the same reasons, we ultimately relied on a ZIP model to explain demand attractiveness. The results are presented in Table 6. Other variables have been included to explain participation decision; however, none of them was significant.

Table 6: Zero-inflated Poisson model for the demand attractiveness model based on outset locations

Variables	**ZIP coefficients**	***Std. Err.***
Trip demand		
Trip cost	-0.0188***	(0.00215)
Income	3.82e-05***	(8.22e-06)
Squared income	-5.57e-10***	(1.30e-10)
Log (% Urban substitutes availability)	-0.0702***	(0.0231)
Log (% Agricultural substitutes availability)	-0.0460**	(0.0185)
Log (% Wetland substitutes availability)	0.237***	(0.0778)
Log (% Water bodies substitutes availability)	-0.0683***	(0.0181)
Log (% Broadleaved substitutes availability)	-0.139***	(0.0221)
Log (% Mixed forest substitutes availability	0.0359**	(0.0172)
Constant	1.877***	(0.146)
Participation		

Trip cost	-38.23	(11,902)
Constant	3.988***	(0.583)
Log likelihood	-1063.1648	
LR chi^2 (9)	264.00	
Prob>chi^2	0.000	
AIC	2148.3295	
BIC	2187.3265	
Number of zero observations	162	
Number of non-zero observations	94	
Total observations	256	256

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Vuong test of ZIP vs. standard Poisson: z=2.46 Pr>z=0.0069
Alpha test on ZINB=1.082131 Pr>z=0.580
Coniferous forests are set as the base case coverage share

As expected, the trip cost negatively affects trip demand, and distance travelled as shown in Figure 4. The income variable displays as a U-shaped curve, having a low effect on demand attractiveness in the first classes of income and then showing an exponentially increasing demand for higher classes (see Figure 5). We captured this non-linear effect by adding the squared income as a variable in the model. This result is unusual in travel cost models, as income is commonly non-significant in explaining visitors' trips (Shresta et al., 2002; Parsons, 2003; Martínez-Espiñeira and Amoako-Tuffour, 2008; Garcia and Jacob, 2010, Roussel et al., 2016). The availability of substitutes around a potential outset location also influences visit numbers, which is common in recreation models (Sen et al., 2014; Schägner et al., 2016). The presence of urban areas, agricultural areas, water bodies and broadleaved forests negatively influences visits, and the presence of mixed forests and wetlands positively influences visits.

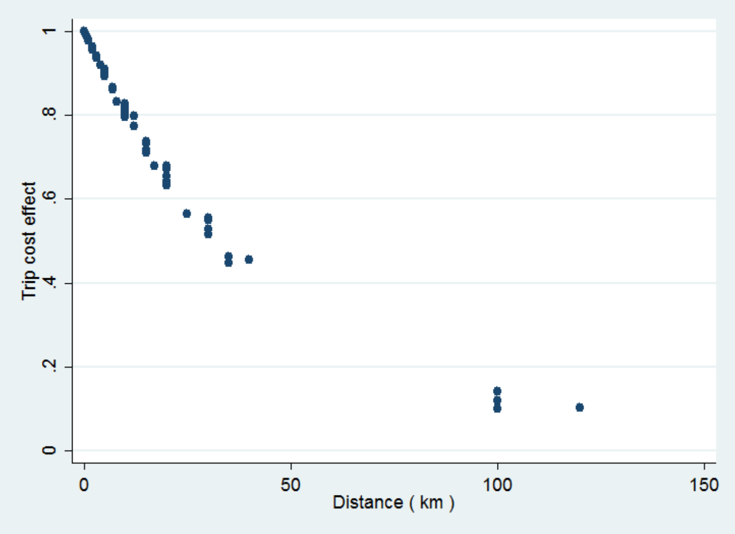

Figure 4: Effect of travel cost on travelled distance

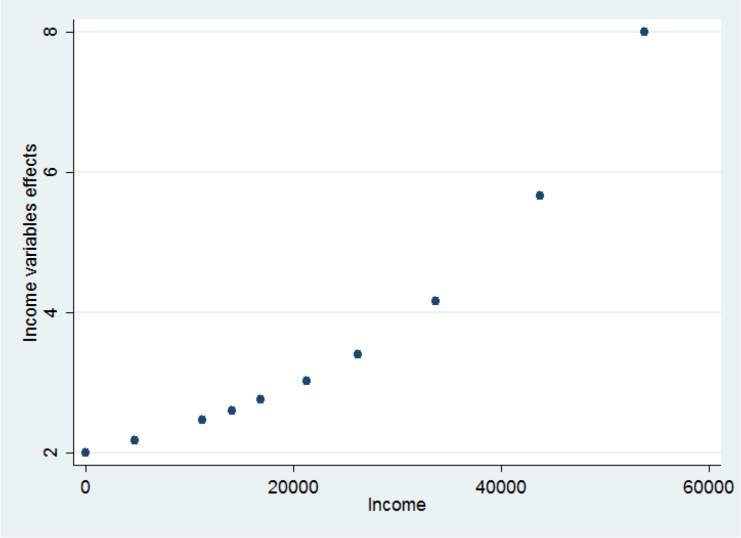

Figure 5: Effect of income on demand for forests (incomes are represented by medians in different income classes)

3.1.3. Combined attractiveness index (CAI)

The CAI is finally computed and mapped in the BVRP, as shown on the left side of Figure 6. Graphically, we can observe that attractiveness is principally concentrated in the centre of the BVRP, which is also the most elevated part of the area. A hotspot analysis statistically confirms this graphical insight (right side of Figure 6). Hotspot areas are characterised by high-density clusters of the CAI and surrounded by low-density clusters of CAI, referred to as coldspots. Hotspot analysis is performed by applying a combination of statistical analysis and spatial procedures using high/low clustering[13].

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[13] This is done with the command Getis-Ord General G from the ESRI ArcGIS© software package of spatial statistics.

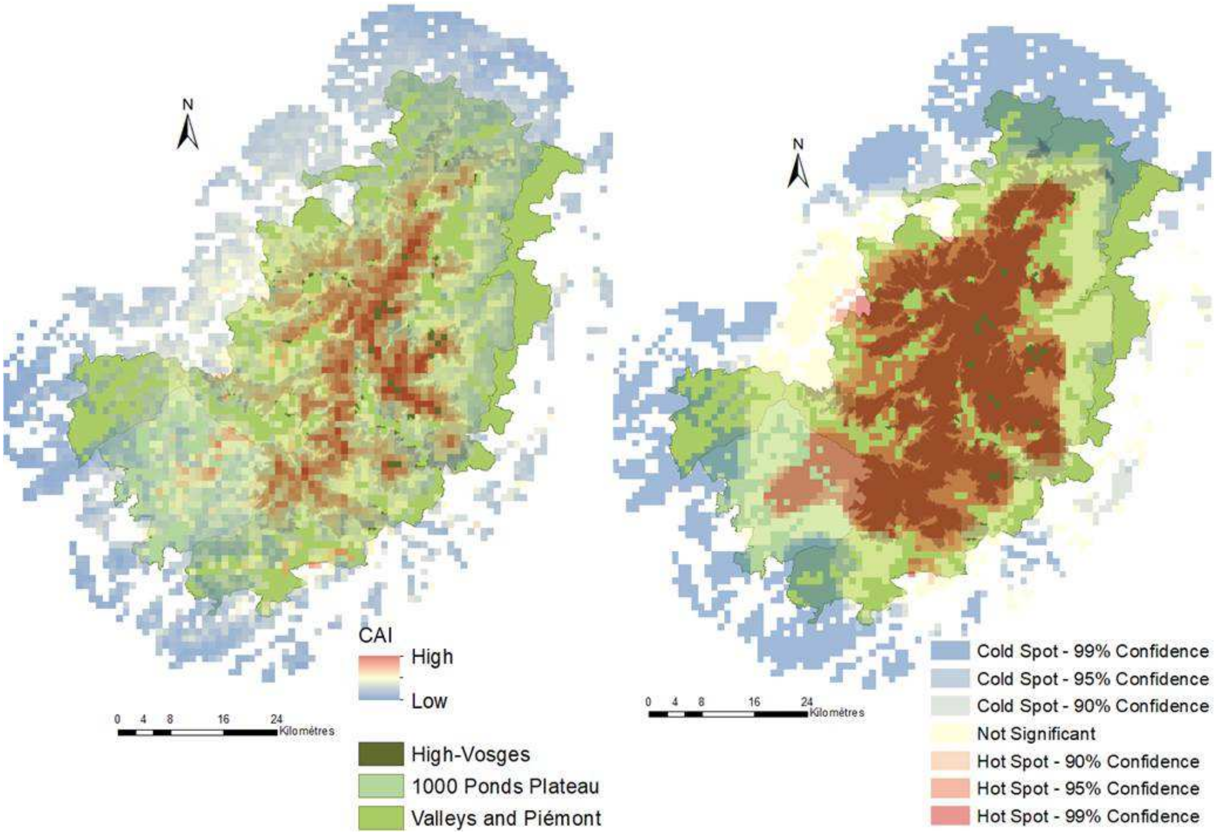

Figure 6: Spatial distribution of the combined attractiveness index (left) and hotspot analysis (right)

Thus, the results allow us to presume a high influence of elevation, which is confirmed by the Pearson correlations presented in Table 7. The correlations show that the CAI is primarily determined by the supply index SAI, which, in turn, is highly influenced by elevation and, to a lesser extent, by the DAI even though the correlation is also strong. This means that biophysical attributes are particularly critical to take into account in outdoor recreation models.

Table 7: Pearson correlation of the CAI, SAI and DAI

	Supply Index – SAI	Demand Index – DAI	Combined Index – CAI
Supply Index – SAI	1.0000		
Demand Index – DAI	0.3926***	1.0000	
Combined Index – CAI	0.9538***	0.6224***	1.0000

Moreover, we can observe that demand and supply are significantly correlated but not very strongly. This result confirms the fact that models driven by individuals may have a truncated view of recreation, as the analysis of both sides of this ES flow reveals different and potentially complementary information.

3.2. Habitat quality

The InVEST output on the habitat quality index is presented in Figure 7 and is based on two indexes produced: degradation and suitability. Degradation can be interpreted as a relative level of habitat degradation to the current landscape. A high score in grid cells means that the habitat degradation in the cell is high relative to other cells. The same reasoning can be applied to habitat suitability, where a high level can be interpreted as a better habitat quality with regard to the distribution of habitat suitability across the rest of the BVRP (Tallis et al., 2013).

Figure 7 shows spatial heterogeneity in terms of quality across the study area. The BVRP seems separated into two negatively correlated parts. The western part shows the highest quality index of habitats; inversely, the lowest index appears in the eastern part of the site.

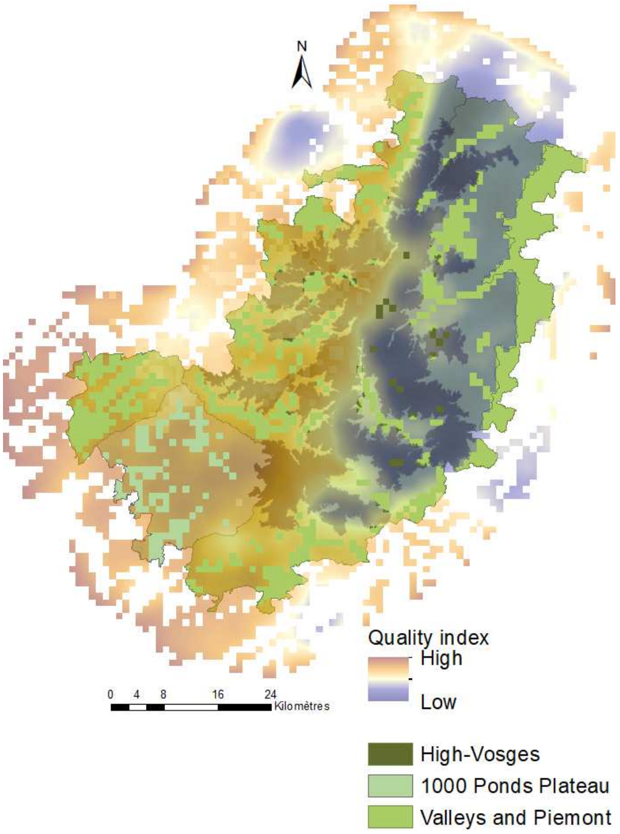

Figure 7: Habitat quality in the BVRP

4. PUBLIC POLICY IMPLICATIONS

The relationships between habitat quality and the recreation attractiveness indexes can be analysed with Spearman correlations as well as their coherence or incoherence with the strategies formulated for three territories presented in section 2.1. The statistical results are presented in Table 8.

First, as expected, a negative but low correlation appears between the attractiveness index and habitat quality. This predictable result statistically shows that strong recreational attractiveness is opposed to a good quality of the habitats. Regarding BVRP management strategy, the Spearman statistics tend to validate the choices made in terms of recreation; however, the results are more ambivalent with regard to habitat quality.

In the *High Vosges*, the objective is to conciliate biodiversity conservation with recreational attractiveness. Our results on recreational attractiveness show that, if it is not the sole area, this territory is effectively the most attractive territory in the area, with the other two territories showing a negative correlation with our attractiveness index. Overall, however, habitat quality is negatively correlated with the territory, even though habitat quality seems high in the western part of the *High Vosges* (see Figure 7). The conciliation between the two objectives is thus not achieved, and recreation seems to be privileged to the detriment of habitat quality (a Spearman test between quality and attractiveness confirms the correlation of the two variables in the territory).

Regarding the *1000 Ponds Plateau*, the charter objective is to preserve habitat quality and to limit the decline from agricultural/industrial activities. We can observe that in terms of habitat quality, the territory effectively benefits from high habitat quality. This area is the sole territory showing a positive correlation with the index. The goal seems relevant here, even though it does not give the impression of being ambitious, as it aims to preserve the strength of the area and not to ameliorate a weakness. Limiting the decline of the territory could be achieved by developing a real recreation policy around agricultural/industrial products and by developing a better communication plan around the habitat richness of the area. The CAI map (Figure 6) shows that the hotspot of attractive forests covers a good part of this territory. Individuals' preferences for good habitat quality can also be tested in our model to further simulate the expected effect of such policy on expected visits in the area.

Finally, the aim of BVRP managers in the *Valleys and Piedmont* area is to control urbanisation and habitat fragmentation. The habitat degradation index, which is also an indicator of habitat fragmentation, shows that the objective does not tends to be reached in this territory; the correlation with fragmentation is positive, even though the coefficient is low. This result confirms that the objective is relevant in this territory.

Table 8: Spearman correlations between recreation, habitat quality indexes and territories

	Recreation	Habitat quality	
	CAI	Suitability	Degradation
CAI	1.0000		
Suitability	-0.0607***	1.0000	
Degradation	*n.s.*	-0.9747***	1.0000
High Vosges	0.6373***	-0.2393***	0.2114***
1000 Ponds Plateau	-0.1606***	0.5203***	-0.5147***
Valleys and Piedmont	-0.5534***	-0.1106***	0.1358***

***p<0.01

n.s: non-significant

Overall, we can conclude that the strategy to tackle the different issues raised in the three territories under study is consistent, even though the objectives are not necessarily reached. However, two points could be highlighted: (1) based on the results of the habitat quality model, the efforts required to conserve and protect habitats in the *High Vosges* are insufficient. The proximity to anthropogenic threats is strong despite the importance of habitat conservation value in the area. (2) Based on previous public policy results, we can observe that the strategy of the park is to maintain the strengths present in the area (in terms of recreational attractiveness or habitat quality) rather than developing or improving the weak points. They follow a cost-efficient strategy. In both cases, additional incentives need to be put in place to support local policies to act in a spirit of territorial dynamism that is respectful of their environment (Polasky et al., 2011). The developed method allows testing the effect of different forest policy schemes on the attractiveness and habitat quality of the BVRP. This testing can be performed simply by simulating changes in variables of interest in pixels to produce new maps (*e.g.,* the development of a new trail or a change in the forest cover share). This action will be done by the BVRP, notably to orient decisions in the development of the territorial forestry charter[14], in which the results produced here are already planned to be used.

5. CONCLUSION

In this paper, we study the habitat quality and recreation attractiveness potentials in a French regional park. To do so, we used the InVEST module to assess habitat quality and developed an inventive method to evaluate the recreation attractiveness potential. The method is based on two count data models. The first is a hedonic function of biophysical aspects that are conducive to deriving a function of the supply attractiveness of recreational sites. The second is a travel cost model that helps in deriving the demand attractiveness based on agents' socio-demographic characteristics. The models are based on a previous survey (comprising a part of the studied area) and are fed by GIS data. The functions are further transferred in the whole area covered by the park under study, enabling us to predict the "combined" attractiveness of recreational sites in a spatially explicit way, accordingly to the sites and visitor characteristics. Two indexes are thus developed, (1) a habitat quality index and (2) a recreational attractiveness index, which are finally statistically compared with the spatial planning strategy pursued by park managers. This comparison helps to highlight and locate the strengths and weaknesses of the established planning strategy.

The method developed in this paper for recreational service mapping is reproducible for any extrapolation of a single-site or multiple-site travel cost model, allowing for a better apprehension of the spatial repartition of the service. Our work illustrates the need to work on ecosystems with a spatial approach for local public policy orientation. Indeed, at present, land planners principally rely on GIS technology for the definition of planning strategy. Producing spatial information thus appears particularly critical for ESs to be accounted for in day-to-day decision-making. Moreover, from a methodological perspective, this paper demonstrates that travel cost models should include the biophysical context of visited ecosystems, as they play a large part in the recreational trip choice. However, travel cost models are predominantly a-spatial and specified only with the socio-demographic characteristics of individuals. This aspect does not enable specifying preferences for the biophysical characteristics of different destination sites, which are really useful for land managers; more importantly, it tends to ignore a significant part of the trip decision choice.

Two principal refinements of the study are possible to provide better policy orientations. First, the recreational attractiveness index developed is valid only for the local population, that is, the population living in and around the park. Although a large part of the area is visited by local people, with 86% of the French people visiting the park come from the Grand Est and

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[14] The territorial forestry charter brings together all the actors of a territory to define a programme of actions to enhance their forest areas. It takes into account all the forests uses in a territory: economic, environmental and social.

Bourgogne Franche-Comté regions (ORTA, 2011), a significant part of recreationists, approximately 35%, are tourists coming from other countries (principally Germany and Belgium). Their preferences should also be studied to complete the recreational attractiveness index. Second, we consider only motorised trips, which is typical in travel cost studies. Although 84% of visitors visit forests by using their car (ORTA, 2011), the remaining part of visitors who use others means of transport should be accounted for to improve our model.

We will conclude on directions that can be taken in future research. Here, we evaluate a state of the art of recreational service and habitat quality in a positive analysis. An interesting extension would be to adopt a normative analysis and thus to optimally allocate different services with spatial optimisation modelling (*e.g.*, by using production possibility frontiers). Doing so would allow emphasising areas that benefit from comparative advantages in the provision of different ESs. The spatial assessment of wood production can enrich the analysis because it will allow the analysis of trade-offs between services (and the opportunity costs of producing one supplementary unit of non-production ESs). The functions developed in this paper will serve as inputs in the optimisation model. Furthermore, the inclusion of biophysical attributes is critical, as we have observed in this paper; however, what visitors actually perceive in regard to those attributes remains an open question. Indeed, here, we make the implicit assumption that individuals perfectly perceive the biophysical attributes of visited sites using GIS data. Further research should investigate the accuracy of this assumption, for instance by estimating the model with perceived variables on characteristics of the forest or perceived distance travelled, to compare results with the GIS based model.

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