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# Setting Favourable Habitat Reference Values for breeding birds: general principles and examples for passerine birds

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## Summary

Setting Favourable Reference Values (FRVs) can assist the definition of the conservation status of a species. FRVs may consider population, habitat, and range. FRVs can indicate a range of values for different parameters, which should allow the long-term persistence of a species/population. We propose a method for the definition of reference values for the habitat (FRV-H or HRV) of breeding bird species. HRV should cover habitat extent and quality, both required to ensure long-term persistence. Extent HRV should express a measure of suitable area, whereas quality HRV could be defined as the range of values for habitat variables known to affect habitat quality. To define an extent HRV, we built species distribution models (SDMs) and set extent HRV as the extent of potentially suitable habitat under a conservative approach. Quality HRV should refer to environmental determinants/correlates of occurrence and breeding success, and should be defined by the identification of the habitat factors affecting occurrence and reproduction. When habitat selection is adaptive, habitat suitability may approximate habitat quality, being correlated with breeding success. In that case, fine-scaled habitat/distribution models may be used to identify determinants/correlates of reproductive output, and such species-habitat relationships may help define quality HRV. We show examples using the Red-backed Shrike *Lanius collurio* as a model. The use of habitat selection models, which can be made spatially explicit generating distribution models, may assist the definition of both extension and quality HRVs. Species-habitat models can allow the individuation of factors and relative values affecting species occurrence/reproduction (quality HRV), and the definition of the spatial distribution and quantity of potentially suitable habitat (extent HRV). Our approach is one of the possible ones, aiming at finding a "suitable" trade-off between affordable data and scientific precision. HRVs should be used together with population and range FRVs to assess the status of a species/population.

## Introduction

Setting favourable reference values (FRVs) can assist the definition of the conservation status of a species (Brambilla *et al.* 2011), together with other criteria, such as demographic and range variation, within-species genetic variability and functional characteristics of ecosystems (Mehtala and Vuorisalo 2007). The guidelines for monitoring and reporting the conservation status of species and habitats of EU interest require member States to evaluate the conservation status of species, to assess their demographic trends and to provide an FRV for each species (European Commission 2005). FRVs can indicate thresholds (or a range of values) for different parameters, which should allow the long-term persistence of a species or a population. Species with all parameters lying above the FRVs are likely to be in "good" conservation status, whereas species with one or more parameters below the respective reference values are likely to be in a bad or inadequate conservation status (Gustin *et al.* 2009, 2010). The reference values may contribute to effective conservation planning because species or populations whose parameters strongly deviate from FRVs may be considered more 'at risk', and they can allow basic and transparent assessments of conservation status. FRVs should be used to evaluate conservation status, in particular to assess whether a species can be considered in favourable conservation status (FCS) or not. FRVs can be formulated for at least three different parameters. Until now, reference values have been proposed for bird populations, but not for other potentially important parameters, such as habitat or range, although these two other parameters are also advocated in the monitoring process proposed by the European Union within the framework defined by the EU Habitats Directive (92/43/CEE) and Wild Birds Directive (09/147/EC), which represent the main tools for EU member states to act against biodiversity decline.

According to EU guidelines, FCS for a species can be achieved only when all the following conditions are fulfilled: i) population data indicate that the species will survive in the long-term and will be a viable element within its habitat; ii) the species' range is not declining, nor at risk of decline; iii) the habitat of the species is of adequate size and will remain so to maintain its population on the long term.

FRVs (for range, habitat, population) should be established on a scientific basis, based on the best available conservation knowledge and in a transparent way. 'Best expert judgement' may be used to define it in absence of other data (European Commission 2005). Establishing FRVs must be distinguished from establishing concrete targets: setting targets is the translation of reference values into operational, practical and feasible short-, medium- and long-term targets/milestones. Member states are therefore encouraged to include FRVs in their monitoring reports, as the establishment of such values will strongly support discussions on status assessment and priority setting at the biogeographical or national level. Until now, except for a concise report on species conservation status in Denmark (Pihl *et al.* 2006) and population FRV in Italy (Brambilla *et al.* 2011), none of the member states of the EU has provided a comprehensive evaluation of FRVs for its breeding bird species included in Annex I of the Wild Birds Directive.

Following the rationale of the EU directives, we propose a practical method for the definition of reference values for the habitat of breeding bird species in Italy (FRV-H, or HRV, Habitat Reference Value). HRV should be used in a complementary way to population and range FRV for a thorough evaluation of the species/population conservation status.

## Methods

### *The Habitat Reference Value as a two-sided concept*

The HRV should span two dimensions: habitat extent, and quality. Habitat extent can be measured as the area potentially suitable for a given species, and extent HRV should be large enough to allow the population to be at its FRV or above in the long term. Habitat quality should theoretically be evaluated through fitness measures of a population (e.g. breeding success, survival, etc.). Habitat quality is "the ability of the environment to provide conditions appropriate for individual and population persistence" and varies according to resource available for survival, reproduction and population persistence (Hall *et al.* 1997). It is commonly measured through breeding success, as the latter is often the demographic feature most easily measured in the field.

On the basis of the above, HRV should refer to both habitat extent and habitat quality, as both are required to ensure long-term persistence of a species or population. According to the extent concept, HRV should express a measure of suitable area, whereas, in the case of quality, HRV could be theoretically defined as a base value or a range of values for some habitat variables or parameters which are known to affect habitat quality via an effect on reproduction or survival of a species. The commonest way to measure habitat quality is to evaluate the effect of habitat variables on breeding output (Förschler *et al.* 2005, Bionda and Brambilla 2012).

As an alternative, one may use the factors affecting probability occurrence as a proxy of the factors affecting habitat quality, on the basis of an adaptive habitat choice displayed by species: habitat selection is an adaptive process in many species, for which the most attractive habitats are also those which allow a higher breeding success (Sergio *et al.* 2003, 2004, Ortego 2007, Brambilla *et al.* 2010a, Brambilla and Ficetola 2012). Habitat suitability/attractiveness is likely to be a rough approximation of habitat quality in those species also, but it could be the only feasible one in several cases, as for many species it is hard to collect enough data to estimate breeding success and survival and to relate them to habitat parameters. However, one should be always aware of the risk tied to the potential occurrence of ecological traps and other mismatches between selected habitats and breeding performance: considering habitat suitability as a measure of habitat quality in those species will lead to a misinterpretation of the species-habitat relationships.

## *Extent HRV*

HRV should indicate a reference measure of the potentially suitable habitat, for a given species within a given geographical area (national, regional, etc.), and can be expressed in $km^2$ (e.g. national scale), or in ha (regional scale). The proposed extent should be enough to support the population at or above FRV.

To define an extent HRV, we built a distribution model using machine-learning, presence-only methods. Correlative species distribution models (SDMs) define relationships between occurrence points and environmental features and evaluate the environmental suitability of a given area for a given species. Models thus provide a measure of occurrence probability, which can be used for a variety of purposes (Araújo and Williams 2000, Ferrier *et al.* 2002, Raxworthy *et al.* 2003, Graham *et al.* 2004, Bourg *et al.* 2005, Thuiller *et al.* 2005, VanDerWal *et al.* 2009, Brambilla *et al.* 2009, 2010b, Fouquet *et al.* 2010, Elith *et al.* 2011). In the most recent years, such models have shown growing importance, and presence-only models are becoming prevalent (Jiménez-Valverde *et al.* 2008).

We used the software MaxEnt (Maximum Entropy Modelling, version 3.3.3k Phillips *et al.* 2006) to build SDMs relating species presence to environmental variables. MaxEnt assesses the probability of presence in a given cell on the basis of environmental features in that cell; it is considered one of the most efficient approaches to SDM using presence-only data (Elith *et al.* 2006, 2011).

Then we established values to set extent HRV as the extent of potentially suitable habitat under a conservative approach. The values most commonly used to define a cell as either suitable or unsuitable are the *maximum training sensitivity plus specificity threshold* and the *equal training sensitivity and specificity threshold*. Whenever the two values coincide, all areas above such thresholds should be considered suitable. When the two thresholds differ, we suggest considering as unsuitable - all areas below the lowest threshold; partly suitable - the areas with values between the two thresholds, and suitable - all areas above the highest threshold.

## *Quality HRV*

The reference value for habitat quality should refer to environmental determinants (or at least correlates) of occurrence and breeding success of a species. Quality HRV should be defined by means of the identification of the habitat factors (e.g. landscape structure, vegetation traits, etc.) affecting species occurrence and reproductive output. However, this is not always possible and in several cases surrogates have to be used. When habitat selection is adaptive, i.e. most selected sites are also the ones which enable higher breeding outputs, habitat suitability may approximate habitat quality, being correlated with breeding success. When such an assumption is realised, fine-scaled habitat or distribution models may be used to identify environmental determinants or correlates of reproductive output, and species-habitat relationships defined by such models may help identify factors and respective values important for habitat quality and thus for the definition of quality HRV. The modelled relationships and the relative response curves may reveal thresholds, or range of values, potentially suitable to define a set of variables (and respective values), which concur to the definition of quality HRV.

We show an example with Red-backed Shrike *Lanius collurio*, based on SDMs realised by means of MaxEnt, and on the species-habitat relationships modelled by the program, which uses a flexible approach able to model also non-linear relationships. Model outputs may reveal the most important variables affecting species distribution (on the basis of estimates of variable importance such as jackknife test and percentage contribution) and the species response to such variables. The range of values corresponding to high probability occurrence can be selected as optimal values for the species, and thus used to define quality HRV. SDMs built using fine-scaled habitat traits related to landscape and vegetation structure, instead of rough bioclimatic data, may provide robust and detailed assessments, potentially able to estimate also breeding parameters (Brambilla and Ficetola 2012), thus qualifying as particularly suitable for the purposes of this work.

Apart from SDMs, other models quantitatively describing habitat preferences and factors affecting breeding success can similarly help define important habitat factors and relative "favourable" values (Brambilla *et al.* 2012a).

Given that HRVs should indicate habitat conditions "optimal" for a species, both for occurrence and reproduction, we argue that values suggested for HRV should describe optimal habitats, not just "suitable" ones.

HRV definition can hardly account for potential variation in habitat use during the course of the year, as many species breed within one habitat and then migrate or overwinter in others. Because of practical constraints, HRV for breeding bird species should primarily deal with habitat occupied during the breeding season. However, some species use different breeding habitats sequentially during a single season, and HRV definition may also concern species which can perform intra-seasonal dispersal between one brood and subsequent broods (Brambilla and Rubolini 2009, Gilroy *et al.* 2010, Brambilla and Pedrini 2011, Kragten 2011, Brambilla *et al.* 2012b). SDMs may help to evaluate both extent and quality HRVs in this problematic group of species, and species-habitat models should be produced and compared for all the main periods of the breeding season (e.g. for time of first and second brood).

### *Study model*

We developed examples to show a practical application of our approach, by defining extent and quality HRV on the bases of SDMs. We built an SDM (using MaxEnt) for the Red-backed Shrike in Lombardy (c. 24,000 km$^2$), northern Italy. The Red-backed Shrike is a passerine typically inhabiting low-intensity farming landscapes, with grasslands, shrubs and hedgerows. It needs both low vegetation plots (such as mown or grazed grassland) for feeding and shrubs and small trees for perching and nesting (Casale and Brambilla 2009). The SDM for the species was based on 863 independent territories mapped during the breeding season from 2007 and 2011 over the entire regional territory; methods and habitat variables were the same adopted by Brambilla and Ficetola (2012). The selected features for the model were linear, quadratic and hinge (Brambilla *et al.* 2013a). The model (Figure 1) shows excellent discriminatory ability (AUC of the ROC plot equal to 0.941).

## Results

### *Extent HRV at the regional scale*

Starting with the SDM obtained for Red-backed Shrike in Lombardy, each of the 1-ha (average territory size of the species in Lombardy) cells of the regional area was reclassified as unsuitable, potentially suitable and suitable, according to the thresholds selected (*maximum training sensitivity plus specificity threshold*, equal to 0.185, and *equal training sensitivity and specificity threshold*,

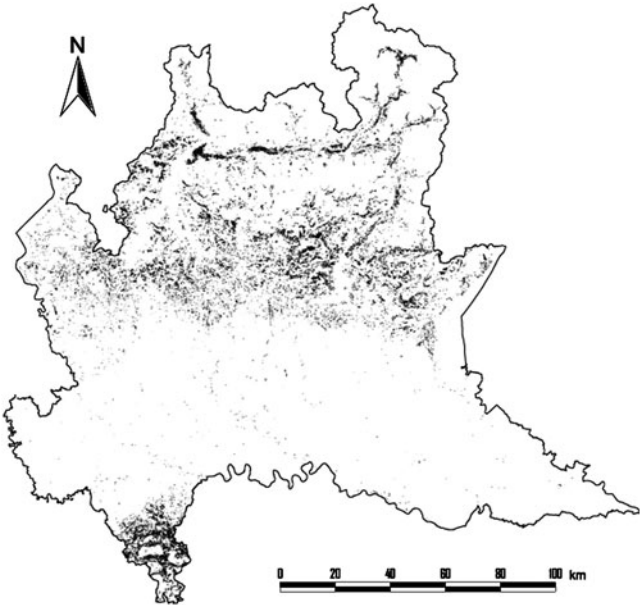


Figure 1. Species distribution model for *Lanius collurio* in Lombardy used for the definition of extent HRV. White - unsuitable area; pale grey - partly suitable area; dark grey - suitable area.

equal to 0.271). Cells with occurrence probability lower than 0.185 were classified as unsuitable, cells with occurrence probability between the two thresholds (0.185–0.271) as potentially suitable, and cells with occurrence probability above 0.271 were considered as suitable.

On the basis of the model output, 52,416 ha can be considered as potentially suitable and 111,501 ha as suitable. Overall, the study region includes 163,917 ha (corresponding to c.7% of the regional area) potentially suitable for the species, on the basis of vegetation and landscape traits (land-cover, linear elements, elevation, slope, aspect, etc.). Such a value can be taken as extent HRV for the species in Lombardy.

### *Quality HRV based on species distribution model*

We used the above SDM, built with fine-scaled habitat traits, to define quality HRV for the same species in the same region, Red-backed Shrike in Lombardy. For that species, a previous SDM (worked out for the same region with a slightly lower amount of occurrence data) could also estimate reproductive parameters (Brambilla and Ficetola 2012). According to a jackknife test of variable importance (and coherently with percentage contribution of variables), the most important factors for the species in Lombardy were permanent grassland, elevation, slope, broadleaved woodland and continuous hedgerows. Considering the species-habitat relationship curves, it is possible to propose as "favourable values", corresponding to high suitability (occurrence probability > 0.5), the following: permanent grassland (percentage cover > 40%), elevation (< 1,700 m asl), slope (< 30°), broadleaved woodland (absent or very scarce), shrubs (percentage cover 5–50%) and continuous hedgerows (length > 25 m). Those figures together (i.e. all conditions fulfilled) can be taken as a quality HRV for Red-backed Shrike in the study region, and the habitat they define closely resembles the habitat mosaic depicted as ideal for the species by a previous assessment of its ecological preferences, based on variables measured in the field (Brambilla *et al.* 2009, Casale and Brambilla 2009).

## Discussion

The use of reference values can contribute to the definition of the conservation status of a species or a population (Gustin *et al.* 2009, 2010). If the condition of a species (population) clearly deviates from the favourable reference terms proposed for it, that species cannot be considered to have a healthy status. Reference values have been recently proposed (and developed for some species/parameters) as a tool for species conservation and they represent the minimum thresholds to be fulfilled for a bird species to be considered in favourable conservation status.

FRVs basically apply to three different levels: population (FRV-P), range (RRV) and habitat (HRV), and all the deriving conditions have to be fulfilled for a species/population to be in favourable status. Defining a method for setting HRV is a challenging task. The HRV concept is necessarily two-sided, as the status of the habitat of a species depends on both its spatial availability (extension) and characteristics, which can affect local occurrence, density, and reproduction (quality).

The use of models of habitat selection, which can be made spatially explicit, generating distribution models, may assist the definition of both extension and quality HRVs. Species-habitat models are based on the definition of the relationships between a species and the environmental traits of the occupied habitat; they can allow the individuation of factors and relative values affecting species occurrence and reproduction (quality HRV), and the definition of the spatial distribution and quantity of potentially suitable habitat (extent HRV).

Our approach to extent HRVs is transferable to several other contexts, as it is based on 'standard' production of SDMs, but model accuracy depends on resolution and accuracy of the layer data available for modelling distribution. Most importantly, the use of SDMs or other species-habitat models based on occurrence and/or habitat selection for the definition of quality HRV, should be subjected to an evaluation of the coherence between habitat suitability and quality. In our study example, previous knowledge suggests that habitat suitability and quality are correlated (Brambilla and Ficetola 2012).

Extent HRV defined on the basis of SDMs should be large enough to support a population at its respective FRV or above (when defined as the number of pairs or individuals). Extent HRV can also be used to convert density-based population FRVs into population size. By applying favourable density values (proposed as FRV for abundant species; Brambilla *et al.* 2011) to the area defined as extent HRV, it should be possible to extrapolate a 'favourable' potential population at the same spatial scale used for distribution modelling, which could be taken as population FRV (based on population size, instead of density). Notably, habitat suitability estimated by SDMs may help calculate the upper limit of abundance (VanDerWal *et al.* 2009).

Our extent HRV is based on present availability of potentially suitable habitat. Although back-casting the past species' distribution and forecasting the future one (and hence past and future habitat availability) is sometimes feasible (see e.g. Acevedo *et al.* 2012), detailed habitat data for past and future scenarios are hardly ever available. Whenever possible, changes from past and future prospections of habitat availability can be taken into account. A recent (last 20–30 years) reduction in habitat availability should result in an extent HRV larger than the current extent of suitable habitat: ideally, HRV should be more ambitious, to compensate for recent habitat losses. Future scenarios or visions can be used to calibrate values according to supposed changes in the next decades. Extent HRV larger than the current extent of suitable habitat can be proposed for species for which the ongoing or predicted environmental changes are leading to an increase in suitable habitat.

The definition of quality HRV is somewhat complicated by availability of data encompassing both habitat selection and effect of habitat features on breeding performances (and potentially other reproductive and/or population parameters).

We believe it is important that environmental factors used for quality HRV definition are measured at a relevant spatial scale, which for several bird species should coincide with the scale of breeding territories. Such fine-scaled factors are also more likely to affect breeding success (Brambilla and Ficetola 2012) than large-scaled, coarse factors (e.g. bioclimatic data). The increasing availability of high-resolution habitat data will allow better assessment of ecologically relevant traits at fine spatial scales (Mendenhall *et al.* 2011, Brambilla and Ficetola 2012).

In addition to the spatial scale, the geographical scale at which HRVs are proposed should also be carefully considered. In many species, regional differences in habitat preferences and factors affecting habitat quality can occur (see e.g. Whittingham *et al.* 2007), and thus it may be worth investigating the species' ecology and formulating the consequent reference values at regional or sub-national levels, to avoid encompassing too large a difference in species' responses to habitat factors.

Species performing within-season shifts in habitat/distribution pose a challenge for HRV definition (Brambilla *et al.* 2012a,b). For those species, a single value of quality HRV or two different quality HRVs have to be defined according to the degree of change in species-habitat relationships between the two broods, and the optimal solution for the same species may vary across areas and regions and according to area-specific potential patterns of temporal occurrence.

Obviously, ours is one possible approach, aiming at finding a "suitable" trade-off between affordable data and scientific precision, but several other solutions might be found, including e.g. fine-scaled studies of habitat selection (Brambilla *et al.* 2012a, Ceresa *et al.* 2012, Brambilla *et al.* 2013b). Territory size, importance of micro-habitat, data availability on breeding success, etc. might orient the choice between SDMs and habitat preference models for the definition of quality HRV (Brambilla *et al.* 2012a).

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