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Optimising different types of biodiversity coverage of protected areas with a case study using Himalayan Galliformes☆

Jonathon C. Dunn [a], Graeme M. Buchanan [b], R. Will Stein [c], Mark J. Whittingham [a,1], Philip J.K. McGowan [a,*,1]

[a] School of Biology, Newcastle University, Newcastle-upon-Tyne, Tyne and Wear NE1 7RU, UK
[b] RSPB Centre for Conservation Science, RSPB, 2 Lochside View, Edinburgh park, Edinburgh EH12 9DH, UK
[c] Department of Biological Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada

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ABSTRACT

International targets have committed governments to expanding the global protected area (PA) network to 17% of the terrestrial surface by 2020. Optimising PA placement in the landscape is challenging due to a poor knowledge of biodiversity distribution and multiple definitions of conservation value. We explore these two issues using a case study of a highly threatened bird Order in a region of conservation concern where PA network effectiveness for biodiversity has not been formally explored previously. To determine if the existing PA network protects the most important areas for 24 species of Himalayan Galliformes, we use a novel method to compare the current network placement to results produced from Zonation prioritisation software and modelled species distributions. Specifically, we identify areas of high species richness and then weight maps by three different species specific conservation values. The current PA network captures ranges poorly. We found statistically significantly poorer fits between the optimal and the existing placement of the Himalayan PA network for Zonation results that were: (i) unweighted; (ii) weighted by Red List score; and (iii) weighted by endemism to the Himalaya. Across these and two other Zonation results, the placement of the optimal PA network covered 58% more of Galliformes distributions than the existing network. We advocate some refinements to the existing PA network to maximise Galliformes coverage and suggest that our method could be used to model the optimal PA network for a wide range of species and/or regions, something which will support the assessment and attainment of CBD targets.

1. Introduction

The uneven spatial distribution of both anthropogenic threats (Cincotta et al., 2000) and biodiversity (Gaston, 2000) makes site specific prioritisation of scarce conservation resources a necessity. This is manifested most commonly in the form of protected areas (PAs) that aim to either halt or manage such threats (Bruner et al., 2001). PAs are seen as an important contribution to biodiversity conservation, with site based conservation reported to be appropriate for 82% of birds, mammals and amphibians (Boyd et al., 2008), although the PA coverage of species' ranges can be described as only adequate and highly variable at best (Rodrigues et al., 2004). There has been a significant expansion in the number of PAs and the area that they cover in the last 20 years (Jenkins and Joppa, 2009) and the political recognition of the importance of these areas is demonstrated in the Convention on Biological Diversity's Strategic Plan for 2011, with the commitment to extend global coverage to 17% of the terrestrial surface (Secretariat of the CBD, 2010) as Aichi Target 11. Assessing how useful protected areas are for biodiversity conservation is challenging (Butchart et al., 2015) and Target 11 requires a range of measures to be taken for a meaningful appraisal to be made in addition to percentage targets in global coverage. These measures include ensuring PAs: are suitably representative, particularly of important areas for biodiversity and ecosystem services; provide effective conservation through equitable management; and are ecologically representative and well connected. It is not easy to measure these characteristics so that a useful assessment of the world's 150,000 or so PAs can be made (Woodley et al., 2012). The Biodiversity Indicators Partnership has suggested that three measures are used: a) management effectiveness of protected areas; b) coverage of protected areas; c) protected area overlays with biodiversity (www.bipindicators.net/globalindicators). Existing datasets have been identified to assess these three indicators and it is acknowledged that there are challenges in developing a robust and practical way of assessing progress towards Aichi Target 11.

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* Corresponding author.
E-mail address: philip.mcgowan@newcastle.ac.uk (P.J.K. McGowan).

[1] Joint last authors.

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A key facet of this target is the ability to place protected areas in a way that reflects the characteristics of biodiversity that we wish to conserve (clause three of Aichi Target 11 commits countries to establish protected areas in locations that are of 'particular importance for biodiversity and ecosystem services'). This presents two issues: i) defining the characteristics of biodiversity we are concerned with; and ii) how well we know where biodiversity occurs. The first issue is that different characteristics of biodiversity can be valued by conservationists in different ways (Nunes and van den Bergh, 2001) and these values are not always considered a scientific matter (Miller et al., 2006), reflecting the underlying values of humans, rather than nature (Vane-Wright, 2009). This can be problematic because conservation planners may have multiple objectives (Arponen, 2012). For example, biodiversity or conservation values that are the basis for area based prioritisation programmes that have been developed over the last 20 years include inter alia endemism (Endemic Bird Areas; Stattersfield et al., 1998), overall species richness (hotspots; Myers et al., 2000), representativeness (ecoregions; Olson et al., 2001), extinction avoidance (Alliance for Zero Extinction sites; www.zeroextinction.org) and phylogenetic distinctiveness (Jetz et al., 2014). The area covered by such programmes is so large that most of the terrestrial environment is covered by at least one programme (Brooks et al., 2006), but crucially, multiple studies have shown that different conservation values may be spatially incongruent (Ceballos and Ehrlich, 2006; Grenyer et al., 2006; Moritz et al., 2001; Orme et al., 2005; Prendergast et al., 1993; van Jaarsveld, 1998).

The second issue is that our knowledge of the spatial distribution of biodiversity is often incomplete (Lomolino, 2004; Whittaker et al., 2005) and uncertainties in this may not be acknowledged in systematic spatial conservation planning (Gaston and Rodrigues, 2003; Polasky et al., 2000; Rocchini et al., 2011). For example, the likelihood of species occurrence is often ignored, focusing on binary presence/absence data. Therefore, while every species may occur in a PA network, not all species may be represented equally in terms of optimal habitat quality and/or suitability (Rondinini et al., 2005, 2006) or represent coverage of sustainable populations, leaving important external populations vulnerable to threats (Pressey et al., 2004; Witting and Loeschcke, 1995). Further investigation of these two issues is needed because, so far, PA expansion has been found to have been inadequately targeted (Butchart et al., 2012, 2015) and a greater understanding of how to optimally place and expand PAs to capture different facets of biodiversity and conservation value while accounting for uncertainties in species' distributions could help rectify this, making it easier to understand how to achieve Aichi Target 11, thus enhancing the role of PAs in conserving biodiversity.

We undertake such an investigation using a case study: we look at a bird Order (Galliformes) with 25% of its species listed as threatened with global extinction (IUCN, 2015) in a region that is of both increasing conservation concern (Hoffmann et al., 2010; Pandit et al., 2006) and is a target for protected area expansion (Venter et al., 2014). The Greater Himalaya provides important habitat for 24 species of the Order Galliformes (ENVIS, 2007), which are found throughout the entire Himalaya (ENVIS, 2007) and exhibit a range of extinction prospects. While the current Himalayan PA network has been shown to represent the ranges of all Himalayan Galliformes species in some way at least once (McGowan et al., 1999), we could be ignoring core parts of species' ranges and may not be capturing conservation value adequately (Terribile et al., 2009). The Galliformes lend themselves well to such a study as it has yet to be assessed whether: (i) the current PA network represents the most important areas for conservation within the Himalaya for Galliformes based on different types of conservation value; or (ii) the current protected network adequately represents these species of conservation concern. Further investigation into these issues could ultimately help to achieve Aichi Target 11 clause three in the region. To achieve these aims, the present study combines niche modelling with a reserve selection algorithm. First, we map Galliformes distributions in the Himalayas by creating environmental niche models. Second, we identify the areas of greatest conservation importance to these species based on a range of different criteria before assessing the coverage of these important areas within the current protected area (PA) network.

2. Materials and methods

2.1. Mapping Galliformes distributions within the Himalaya

Maxent uses a machine learning algorithm to produce niche models (version 3.3.3k; Phillips et al., 2006). Niche modelling predicts a species' geographic distribution as a function of occurrence records and environmental data layers (Guisan and Thuiller, 2005; Guisan and Zimmermann, 2000; Rushton et al., 2004) and can be particularly appropriate where sampling biases in occurrence records make it difficult to distinguish between a lack of survey effort and gaps in species occupancy (Funk and Richardson, 2002; Lombard et al., 2003; Polasky et al., 2000). Maxent has been found to perform well against other distribution modelling systems, performing well across a variety of metrics of model performance (Elith and Graham, 2009).

We created Maxent environmental niche models for 23 of the 24 species of Galliformes within the Greater Himalayas that had sufficient point locality data (i.e. we were not able to create a niche model for the Himalayan quail as there were not enough recent sighting records; Table 1; Dunn et al., 2015). These models were created using point locality data from the GALLIFORM: Eurasian Database V.10 (Boakes et al., 2010: http://dryad.org) for 23 species of Galliformes that occur in the Greater Himalaya, which was accurate to approximately 1 km and collected from a wide range of sources including museum specimens, ringing records, biological atlas data and trip reports. We omitted records without locality information or that had a locational uncertainty greater than 1 km. For further details on the number of locality records available for each species see Table 1. We only used post 1980 data to ensure temporal concordance between measures of land cover and sighting records (Boitani et al., 2011; Guisan and Zimmermann, 2000).

We used a range of candidate explanatory variables based on expert opinion (via members of the IUCN SSC Galliformes Specialist Group – for details see section Appendix A in the Appendices) as simple surrogates to cover the main potential determinants of bioclimatic variation. We used a subset of 4 bioclimatic variables (mean annual temperature, temperature seasonality, mean annual precipitation excluding snow and variation in precipitation) that were downloaded from www.worldclim.org/bioclim, 3 topographic variables (elevation, slope and aspect) that were downloaded from the 90 m Shuttle Radar Topography Mission (SRTM) at 30 arc sec (Jarvis et al., 2008). As a noncategorical summary of land cover we used Normalised Difference Vegetation Index (NDVI) variables from SPOT Vegetation sensor. Nine years of data (1999–2007) were downloaded from www.vito.be and were combined to create an average monthly NDVI raster. Model variables were standardised to the same spatial scale (1 km^2), projected to a South Asia Albers equal area projection and processed using ArcMap. Variables selected for inclusion in the final models were those that contributed >3% to the maximal model to avoid over fitting the models while maximising their predictive power. No attempts were made to omit collinear variables as machine learning methods have been shown to still perform well with such variables, especially when the study goal is predictive accuracy (Elith et al., 2011).

Our overall study site was delimited by the boundaries of specific WWF Ecoregions Olson et al. (2001); for full details see Table A.1 in the Appendices). We incorporated ecoregions as a categorical variable in the analysis to prevent extrapolation beyond the focal regions in which species occurred. Regularisation values were chosen based on AICc as recommended by Warren and Seifert (2011) (Table A.2). Our choice of feature function was determined by the smoothness of the response curves and also by the number of sample points after Phillips

Table 1
Further information on the number of locality records and the AICc of the maximal and minimal models. Asterisks (*) indicate the final model used.

Common name	Latin name	Number locality records	Model	Number model parameters	AICc
Blood pheasant	*Ithaginis cruentus*	56	Maximal	17	1381
			Minimal*	7	1356
Blyth's tragopan	*Tragopan blythii*	36	Maximal	10	903
			Minimal*	4	901
Buff-throated partridge	*Tetraophasis szechenyii*	15	Maximal	7	370
			Minimal*	4	359
Cheer pheasant	*Catreus wallichi*	463	Maximal*	76	10,946
			Minimal	28	11,097
Chestnut-breasted hill partridge	*Arborophila mandelli*	27	Maximal	10	677
			Minimal*	4	656
Chukar	*Alectoris chukar*	77	Maximal*	18	2070
			Minimal	6	2080
Common peafowl	*Pavo cristatus*	65	Maximal	16	1673
			Minimal*	9	1667
Common quail	*Coturnix coturnix*	12	Maximal	2	342
			Minimal*	2	342
Common hill partridge	*Arborophila torqueola*	68	Maximal	17	1714
			Minimal*	5	1710
Himalayan monal	*Lophophorus impejanus*	303	Maximal	79	7867
			Minimal*	36	7789
Himalayan snowcock	*Tetraogallus himalayensis*	62	Maximal	20	1588
			Minimal*	6	1574
Kalij pheasant	*Lophura leucomenalos*	202	Maximal	81	5368
			Minimal*	28	5186
Koklass pheasant	*Pucrasia macrolopha*	275	Maximal	72	7150
			Minimal*	29	7132
Red junglefowl	*Gallus gallus*	116	Maximal	41	2999
			Minimal*	22	2968
Rufous-throated hill partridge	*Arborophila rufogularis*	53	Maximal	19	1187
			Minimal*	14	1183
Satyr tragopan	*Tragopan satyra*	132	Maximal*	23	3142
			Minimal	13	3147
Sclater's monal	*Lophophorus sclateri*	37	Maximal	10	944
			Minimal*	6	933
Snow partridge	*Lerwa lerwa*	19	Maximal	16	759
			Minimal*	9	499
Tibetan eared pheasant	*Crossoptilon harmani*	52	Maximal	12	1329
			Minimal*	6	1314
Tibetan partridge	*Perdix hodgsoniae*	33	Maximal	7	896
			Minimal*	4	894
Tibetan snowcock	*Tetraogallus tibetanus*	98	Maximal*	20	2669
			Minimal	8	2677
Temminck's tragopan	*Tragopan temminckii*	16	Maximal	7	425
			Minimal*	5	413
Western tragopan	*Tragopan melanocephalus*	350	Maximal	91	8393
			Minimal*	22	8384

and Dudík (2008) (see Table A.3). We used locations from which there were other Galliformes (N = 2567 records with unique locations) to generate a targeted set of pseudo absences (we used the Maxent default setting of 10,000 pseudo absences). Thus our pseudo absences were chosen from sites with the same sampling bias as the presences for a suite of species that were observed with similar sampling techniques. This 'target group' approach (Phillips and Dudík, 2008) reduces the potential for species distribution model results to be affected by sampling biases in focal species records in both time and space (see Boakes et al. (2010) for a description of the sampling biases in the dataset that we use). For example, in our case study Nepal and North West India have received more survey attention vs. the North East of India and the number of systematic surveys has fluctuated since the 1980s.

The ability of each model to discriminate between occupied and unoccupied areas was estimated from the area under the curve (AUC) of the receiver operating characteristics (Phillips et al., 2006). Ten cross validations were undertaken to generate folds of randomly selected presence data, allowing us to run the model ten times, exclude each fold in turn and using the partition to validate the data (Phillips and Dudík, 2008). These model results were then clipped to the overall study region for use in Zonation. To see these model results as well as further details of the Maxent models including representation curves see Fig. A.1 and Table A.4 both in the Appendices.

2.2. Identifying important conservation areas as measured by different conservation values using Zonation and accounting for uncertainty

Zonation produces a hierarchical prioritisation of the landscape based on complementarity and the biological value of sites (Moilanen, 2007; Moilanen et al., 2005). This complementarity based algorithm estimates the optimal set of areas with the highest cumulative value and with the potential to account for connectivity between different sites. The Zonation hierarchy is generated by the iterative removal of cells, whose loss causes the smallest decrease in conservation value in the remaining network. This algorithm can be tailored through priorities and connectivity responses defined by the user and assigned to biodiversity features in the analysis (Arponen et al., 2005). In addition to a nested graduation of conservation value throughout the landscape, an associated set of curves that describes how well each species does at any given level of cell removal is produced. The graduated zones within a landscape correspond to different degrees of conservation value and may be used as a guide to determine the level of protection needed. This differs from previous target based planning or maximum coverage approaches as it is a hierarchy of nested results, rather than a single optimisation (Moilanen, 2007). Zonation has been used before in the identification of important areas for Italian butterflies (Girardello et al., 2009) and for fish in New Zealand (Moilanen et al., 2008) and has been found to give comparable results to other systematic conservation planning software such as Marxan, while retaining a focus on the connectivity of sites (Delavenne et al., 2012).

Uncertainty in data were accounted for by weighting species by the confidence we had in the Maxent results based on expert opinion and smoothness of AUCs (area under the curve) of the receiver operating characteristics (see Appendix B in the Appendices; Phillips et al., 2006). As we were unable to generate a full niche model for the Himalayan quail (see Dunn et al. (2015)), we used the Species of Special Interest (SSI) feature to include point locality data in the place of a species distribution map (Moilanen, 2012). We also used the standard deviation results from the Maxent model cross validations as a measure of uncertainty in a distribution discounting analysis. Thus for each species, we subtracted the model standard deviation from its respective niche model. This had the effect of retaining only the Maxent results with the highest certainty in the final Zonation results (for details see Moilanen et al. (2006)). In ecological terms, the distribution discounting ensured that we obtained a robust reflection of each species' habitat preferences in our spatial prioritisation analysis.

Our basic Zonation settings (prioritising areas with the highest species richness after distribution discounting) were then weighted by four measures of species specific conservation value (for a similar approach see Girardello et al. (2009); Table A.5): i) IUCN Red List category; ii) regional range change scores; iii) endemism to Himalaya; and iv) phylogenetic distinctiveness. Red List categories represent a composite measure of global extinction risk, range changes scores represents a simple measure of regional range declines, endemism scores represent the proportion of each species' geographic range that overlaps the Himalaya and phylogenetic scores (Stein et al., 2015) represent a measure of evolutionary distinctiveness (full details of each weight and how they were calculated are given in Appendix B of the Appendices). In the absence of weighting data (e.g. regional range change scores), we left scores with a weighting of 1. Ten grid cells were removed in each iteration step (warp factor). This warp factor was chosen after comparing results for other warp factor values and finding that model result was relatively insensitive to changes in warp factor between 1 and 10.

We compared the spatial distribution of five different Zonation scenarios (one unweighted and four weighted) and examined representation curves for each measure of conservation value. The top 18.1% of the study area for each Zonation analysis was extracted and compared using the Kappa statistic, a measure agreement between categorical results using Map Comparison Kit 3.2.3 (Visser and De Nijs, 2006) and a Spearman rank correlation of the continuous results using ENMTools (Warren et al., 2008, 2010). The 18.1% figure was chosen to represent the most important areas of the study area based on the current proportion of the Himalayas taken up by protected areas, which is also close to the Aichi Target 11 figure of 17%.

2.3. Assessing the representation of important conservation areas for Galliformes conservation within the protected area network

Protected Area shapefiles (a total of 119 from IUCN PA categories I–IV) were downloaded from www.protectedplanet.net (downloaded 01/02/2014; see Fig. 1 and Table A.6 for further details) and used in the same Zonation analyses as before. In doing this, the most important conservation areas within the landscape were ‘forced’ through the existing PA network (for examples see Cabeza and Moilanen (2006); Kremen et al. (2008); Leathwick et al. (2008)). Thus, if important conservation areas are spatially congruent with the existing PA network, the most important conservation areas within the landscape should be in the same place. We compared representation curves at the level of cell removal (proportion of landscape lost) that corresponded to the geographic area of our existing protected area network. This was 118,543 km^2 out of a possible 654,772 km^2, corresponding to 18.1% of all land in our study site. This comparison was made across all species and shown both as an average value for both all species and species with the smallest proportion of their range within the top fraction of the Zonation result (denoted as ‘worst off species’).

Finally, we compared the top 18.1% of Zonation results from differently weighted Zonation results to see how much they overlapped spatially with the existing PA network. If important areas of Galliformes biodiversity are represented significantly less well in the current protected area network vs. the optimal Zonation results, it might suggest that protected areas are situated in the wrong place.

3. Results

3.1. Mapping Galliformes distributions within the Himalaya

The modelled distributions indicated that Galliformes were distributed across the entire study area (Fig. 1). AUC values ranged from 0.95 ± 0.01 (SE) for western tragopan to 0.47 ± 0.13 (SD) for common quail (indicating a poor model – for further details see Appendix B). AUC values were high across the majority of our distribution models

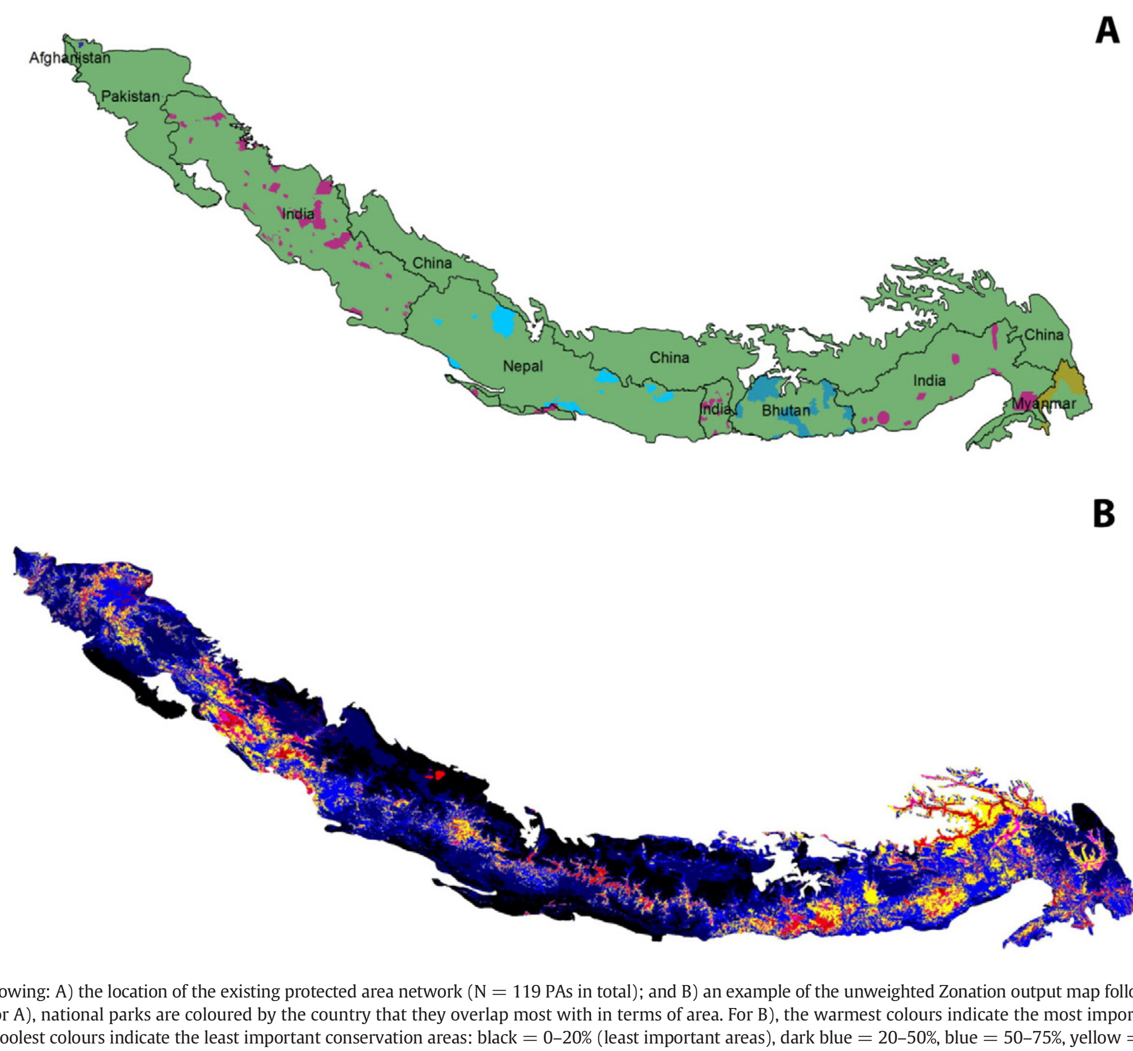

Fig. 1. Maps showing: A) the location of the existing protected area network (N = 119 PAs in total); and B) an example of the unweighted Zonation output map following distribution discounting. For A), national parks are coloured by the country that they overlap most with in terms of area. For B), the warmest colours indicate the most important conservation areas and the coolest colours indicate the least important conservation areas: black = 0–20% (least important areas), dark blue = 20–50%, blue = 50–75%, yellow = 75–90%, pink = 90–95%, dark red = 95–98% and red = 98–100% (most important areas). The top fraction (18.1%) of each Zonation output corresponds to an area of approximately 118,513 km^2 out of a total of 654,772 km^2, which is equal to the current area taken up by PAs.

(Table A.3) and across 23 species the mean AUC was 0.84 ± 0.08 (SD). Individual Maxent maps for each species are shown in the Appendices (Fig. A.1).

3.2. Identifying important conservation areas as measured by different conservation values using Zonation and accounting for uncertainty

The results from the Zonation analysis broadly indicate the areas of high Galliformes species richness were: North West India, Central Bhutan and North East India and along the southern border of China (as shown by the unweighted Zonation result map in Fig. 1). These areas were proven to be consistently important for Galliformes of conservation concern, regardless of which of the four types of conservation value were examined (Fig. 2). Zonation representation curves and maps for each type of conservation value are shown in Appendix B (Figs. A.3 and A.4).

Examination of details did highlight some statistically significant differences (both categorical and continuous) between types of conservation value (see Table 2 and Fig. A.5 in the Appendices). On its own, weighting by Red List places greater importance towards areas in Eastern India/Myanmar whereas weighting by endemism places greater importance on areas in Bhutan/Eastern India. Areas weighted by phylogenetic distinctiveness do not overlap with areas weighted by range changes in the North West of the Himalaya (Fig. 2). Similarly, areas weighted by endemism do not overlap with areas weighted by Red List in the South East of the Himalaya (Fig. 2). The area of overlap between every different Zonation scenario is 29,688 km^2, which is 4.5% of the total study site area and 25.2% of the area taken up by the top fraction (i.e. top 18.1%) of any one Zonation result.

Table 2
Spatial comparison of different Zonation solutions (optimal) based on both continuous output (Spearman rank coefficient, intercept and slope) and categorical output of top 18.1% of the solution (Kappa, $K_{location}$, $K_{histogram}$ and fraction agreement). Zonation output codes: BA = basic, DD = distribution discounting, EN = endemism, RL = Red List, PD = phylogenetic distinctiveness and RRC = relative range change. Values of Kappa (after Landis and Koch (1977)): <0 = no agreement, 0–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–1 = almost perfect agreement.

	Categorical				Continuous		
Comparison	Kappa	$K_{location}$	$K_{histogram}$	Fraction agreement	r^2	Intercept	Slope
BA X DD	0.79	0.79	1.00	0.94	1.00	0.00	1.00
DD X EN	0.53	0.53	1.00	0.86	0.84	−0.34	0.67
DD X RL	0.49	0.49	1.00	0.85	0.99	−0.01	0.99
DD X PD	0.55	0.55	1.00	0.87	0.99	−0.01	0.99
DD X RRC	0.56	0.56	1.00	0.87	0.99	−0.01	0.99
EN X RL	0.61	0.61	1.00	0.88	0.99	0.26	1.26
EN X PD	0.33	0.33	1.00	0.80	0.97	0.04	1.04
EN X RRC	0.44	0.44	1.00	0.80	1.00	0.12	1.12
RL X PD	0.24	0.24	1.00	0.77	0.98	−0.01	0.98
RL X RRC	0.34	0.34	1.00	0.80	0.99	−0.01	0.99
PD X RRC	0.39	0.39	1.00	0.82	0.98	−0.01	0.98

Overlap between the basic Zonation result and the distribution discounted Zonation result (based upon uncertainty in predicted range) is very high (Table 2). This suggests that accounting for uncertainty in Maxent results does not change the spatial location of the Zonation result greatly.

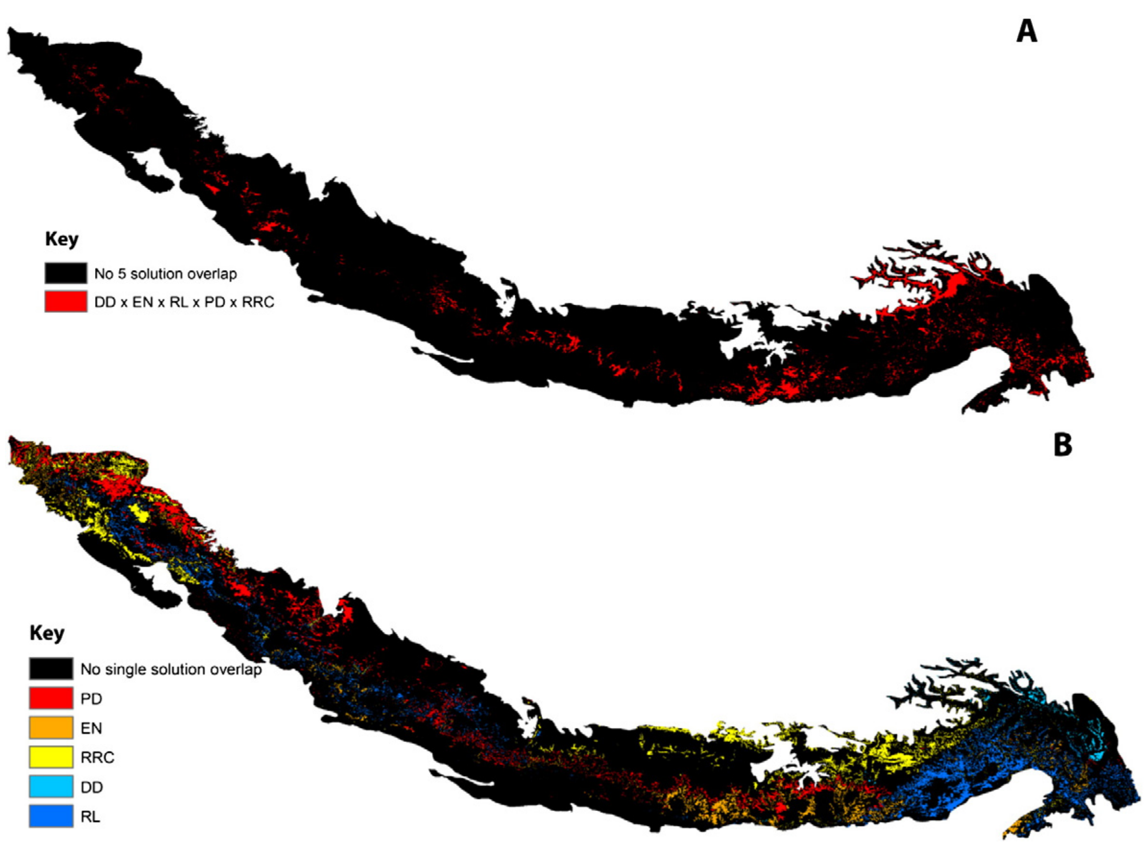

Fig. 2. Maps showing the level of overlaps for: A) all Zonation results; and B) single Zonation results only. For a more detailed breakdown of the areas involved see Table A.7 in the Appendices. Most of the areas are coloured black, which indicates a lack of overlap between Zonation results for each respective scenario, while the different colours for each scenario show the extent of overlap. The area of overlap between all Zonation results corresponds to an area of approximately 29,688 km^2 and 23.5% of this area overlaps with the current PA network. The Zonation output codes: DD = distribution discounting, EN = endemism, RL = Red List, PD = phylogenetic diversity and RRC = relative range change.

Table 3
A comparison of the proportion of species' distributions remaining between the optimal and constrained Zonation results at the level corresponding to the protected area network (18.1%). A 1 tailed equality of proportions test revealed that the optimal Zonation results averaged across all species contained a significantly greater proportion of all species distributions than the constrained Zonation results for DD ('distribution discounting'), EN ('endemic species') and RL ('Red List') species (proportions are given to 2 d.p., hence small differences between X^2 values between average Zonation results 'EN' and 'RL'). The mean increase in distributions covered from the optimal vs. constrained analyses across the five conservation prioritisation scenarios was 58% (e.g. (0.3–0.19)/0.19 = 0.58, thus a 58% increase for the optimal Zonation result vs. the constrained one). However, for the worst off species only, there were no significant differences between constrained and optimal Zonation results across all results. Note: the overall size of the Zonation result areas between the optimal and constrained Zonation results remains constant and only the proportion of species distributions represented by each Zonation result changes.

Zonation result	Average proportion distributions remaining				Minimum proportion distributions remaining			
	Optimal	Constrained	X^2	p value	Optimal	Constrained	X^2	p value
DD	0.30	0.19	2.74	0.05	0.10	0.09	0.00	0.50
EN	0.30	0.18	3.06	0.04	0.09	0.08	0.00	0.50
RL	0.30	0.18	2.92	0.04	0.09	0.08	0.00	0.50
PD	0.26	0.18	1.50	0.11	0.15	0.10	0.70	0.20
RRC	0.28	0.19	2.07	0.08	0.10	0.09	0.00	0.50

3.3. Assessing the representation of important areas for Galliformes conservation within the protected area network

If we were able to place the current PA network in an optimal manner, the maximum proportion of each species' Himalayan range that we could safeguard would be c.29% (on average across the five different conservation prioritisation scenarios; see Table 3). However, our results indicate that the existing PA network provides a poorer fit than the optimal Zonation result as derived via three out of five different conservation prioritisation methods. Specifically, the optimal Zonation results retain almost twice the proportion of species' ranges in comparison to the constrained Zonation result for: (i) total species richness (unweighted results); (ii) for species at the greatest risk of global extinction (result weighted by Red List score); and (iii) for species with the narrowest endemism to the Himalaya (result weighted by endemism).

While the top fraction of each optimal Zonation result corresponded to an area of 118,543 km^2 of land, on average, only 21,095 km^2 (17.8%) of that area was found to be inside the existing PA network (see Table 4). This means that 82.2% of land that is important for Galliformes of conservation concern (as measured across our different conservation values) does not have any legal protection. When the top fractions for each Zonation scenario were combined, just 23.6% of this area (6,993 km^2) fell within the current PA network, which corresponds to 1.1% of the total study site area (see Fig. A.6 to see the combined top Zonation fractions that are outside the current PA network). Taken together, these two results indicate that the existing PA network does not capture the most important areas for Galliformes of conservation concern.

4. Discussion

PAs have a vital role to play in achieving global biodiversity targets (Rodrigues et al., 2004; Secretariat of the CBD, 2010), with such areas ideally placed where levels of biodiversity and the impact of threatening processes are high (Ricketts et al., 2005). Understanding the role of PAs in conserving biodiversity is very difficult, especially given the multiple demands placed on them as shown by Aichi Target 11. Assessing whether the placement of the PA network in the Greater Himalaya for Galliformes is optimal is a particularly important case study, as the region has been identified as a priority for conservation efforts and Galliformes contain a high proportion of species of conservation concern. We found that there were some differences in the location of important conservation areas identified based on different ways of valuing biodiversity, and that for three of the five different ways of prioritising biodiversity conservation, the configuration of the existing PA network was significantly worse than the optimal Zonation result. We can have a high degree of confidence in our results, because the methods that we used allowed us to account for uncertainties in our knowledge of the spatial distribution of biodiversity.

Table 4
A comparison of the spatial overlap between the top fraction of the optimal Zonation results and the existing protected area network. The top fraction is constant and corresponds to 18.1% or 118,513 km^2 of the study region. On average, only 17.8% of any top fraction is contained inside the existing PA network (as measured across the five conservation prioritisation scenarios). Zonation result codes: BA = basic, DD = distribution discounting, EN = endemism, RL = Red List, PD = phylogenetic distinctiveness and RRC = relative range change.

Optimal result	Area of top fraction inside PA network, km^2	Percentage of top fraction inside PA network
DD	21,336	15.6
RL	20,868	17.9
RRC	19,862	17.0
PD	23,321	20.1
EN	21,443	18.4

4.1. Implications for the conservation of Galliformes

Protection of at least 17% of terrestrial land is required by CBD targets (Secretariat of the CBD, 2010), but over 18% of the Greater Himalayan area is already protected, passing this target. However, we found evidence that the current PA network fails to adequately represent the distributions of Galliformes in the Greater Himalaya at the level of the CBD target for both: i) unweighted Zonation results (all Galliformes); and ii) Zonation results weighted by IUCN Red List (Galliformes threatened with global extinction) and endemism to the Himalayas (Galliformes with the majority of their global range in the Himalaya). In contrast, we find that the current PA network reasonably represents the distributions of Galliformes weighted by phylogenetic diversity and range changes. The overlap between different priority areas is small in terms of the overall proportion of the Greater Himalaya and only a fifth of the overlapping area is already captured by the current Himalayan protected area network. This implies that although different values of conservation are represented somewhere within the current PA network, they are often not in the same locations or in sufficient amounts to achieve the CBD target.

We found species at the greatest risk of global extinction and those with the narrowest endemism to the Himalaya to be less well covered by the current PA network than the optimum Zonation result, which suggests that redesigning the PA network would result in greater capture of the ranges of these species and so higher safeguarding of Himalayan Galliformes. This need not be based exclusively on the modelled data given here, but could incorporate locations identified as Important Bird and Biodiversity Areas (IBAs; BirdLife International, 2008), which prioritises bird species with high global extinction risk and endemism above other criteria. At the very least, the most important areas of combined conservation value that are currently outside the PA network could be used as a guide to expand or better orientate the PA network.

To aid conservation management, we have provided three resources in the Appendix: (i) a map of the most important conservation areas outside the existing PA network (Fig. A.6); (ii) a .kml file of these areas that can be used with Google Earth; and (iii) a table of seven localities with geographic coordinates (Table A.8). Nevertheless, it is worrying that we are underrepresenting distributions for Galliformes species threatened with global extinction in the current Himalayan PA network by 58% (average distribution of species covered – see Table 3).

4.2. Implications for Aichi Target 11

While our results have direct conservation implications for the Himalaya (caveats notwithstanding), in a broader sense they demonstrate that meeting the Aichi percentage coverage target may be difficult to achieve if we wish to simultaneously capture different conservation values in areas that are of 'particular importance for biodiversity and ecosystem services'. In this way our study can be said to act as a microcosm of the challenges other countries and areas face in meeting their commitments to Aichi Target 11 and specifically clause three.

Percentage based targets have been criticised, as different levels of PA coverage may be needed depending on the specific biodiversity outcomes that we wish to achieve (Rodrigues et al., 2004). For example, it may be that more than 17% of the land in our study region requires formal protection to minimise Galliformes extinctions in the Himalaya and our study does not consider the efficacy of PAs in preventing extirpations. To prevent extinctions within PAs, effective enforcement is essential, but Clark et al. (2013) show that South East Asian PAs are not effective in preventing habitat conversion and Hilaluddin and Ghose (2005) and Kaul et al. (2004) show that hunting of Galliformes is prevalent across the Himalayas. These studies emphasise that both management effectiveness and biodiversity outcomes are important in determining efficacy. This is because, even if the location of the PA network did adequately represent important Galliformes of conservation concern, it might not offer much in the way of actual protection. Better enforcement would require greater resources, and it is established that protected areas are underfunded (McCarthy et al., 2012). Therefore, the governments responsible might need to allocate greater funding to these protected areas for them to be most effective.

Better managed PAs may result in greater conservation effectiveness/outcomes than the present configuration. A better approach could be to identify which areas and habitats that harbour significant populations of Galliformes are needed to minimise extinctions and to redesign and/or expand the PA area network accordingly (Fuller et al. (2010) use this approach). We only looked at PAs in IUCN categories I–IV (PAs established primarily for biodiversity conservation) and other effective area based conservation measures are also being considered (e.g. "multiple use" PAs in categories V–VI). For example, community forests in Nepal have been shown to have high conservation value even if they lack formal protection, as they generate livelihood opportunities that decrease pressures placed on PAs (Dahal et al., 2014). We did not include categories V–VI because we sought to include PAs established primarily for biodiversity conservation vs. 'multiple use' PAs in our analysis. This amounted to omitting 21 extra PAs from our study, mainly from China. These 21 PAs provided a 117% increase in the total area of the study region taken up by PAs. Despite this, only 16% of the areas we identified as priorities for expansion fell within the existing V–VI category PAs, making it unlikely that including these 'multiple use' PAs in our analysis will affect our results significantly.

4.3. Caveats

Our results come with some caveats: the first relates to our use of a species' environmental niche as a proxy for species occurrence. Thus, the realised niche of a species may depend on biogeographical, historical or biotic factors in addition to the abiotic factors used in our model, potentially decreasing the reliability of some of these models (Guisan and Thuiller, 2005; Rondinini et al., 2006). However, these areas should be more accurate than extent of occurrences, as used in previous analyses (e.g. Venter et al., 2014). We investigated potential variations in model reliability by using a combination of distribution discounting and model weighting. Our results showed that accounting for variation in the niche modelling process did not change the location of the results given by Zonation greatly. This is likely to be due to the use of the core area algorithm rather than an artefact of the distribution discounting method itself. Nevertheless, by accounting for uncertainties in this way, we are able to ensure that our results are robust.

The second caveat is related to the first, as by using niche modelling in conservation planning we run the risk of adding commission errors (false positives) to our analysis (Rondinini et al., 2006). If these commission errors are large, we might overestimate the true proportion of important conservation areas represented within the PA network (Rodrigues and Gaston, 2001). Given that some of our species are threatened by hunting, it is possible that there are some instances where they are locally extinct in areas of good habitat. One way to account for this is to test our distribution models using field based studies, though this may be impractical across such a large area. However, it is important to point out that by using the core area algorithm in Zonation, we do retain areas of distributions with the highest probabilities of occurrence for each species (Moilanen, 2007; Moilanen et al., 2005), which reduces the likelihood of commission errors and that such errors may be small in comparison to other methods of representing species distributions such as extent of occurrence (Beresford et al., 2011; Rodrigues, 2011).

The third caveat is that PA placement is often biased towards economically low value areas (Joppa and Pfaff, 2010, 2011a), so the fact that we found the existing PA network to be less than optimally placed for Galliformes could be an artefact of this pattern. However, it is unlikely that this is true, as many Himalayan Galliformes are typically found in forests, which can be in both economically high and low value areas. An extension to our analysis would be to conduct a counter factual study to compare our results with those obtained where the placement of the existing PA network is randomised, potentially using a 'matching' approach to control for the fact that PAs are not randomly distributed across the landscape (e.g. Joppa and Pfaff, 2011b). One other explanation for our results is that the PA network was not designed explicitly for Galliformes alone. Thus, it would be informative to conduct our analysis with other taxonomic groups before any changes to the existing PA network in the Himalaya were definitively made. This is important, as there are a disproportionately large number of other threatened terrestrial species in the Himalaya (Hoffmann et al., 2010), with current levels of deforestation predicted to wipe out almost a quarter of endemic species, including 366 endemic vascular plant taxa and 35 endemic vertebrate taxa by 2100 in the Indian Himalaya alone (Pandit et al., 2006).

Finally, it is important to note, that while the current network does not adequately represent Galliformes species of conservation concern at present, species distributions may move with climate change (Root et al., 2003), so the placement of the PA network may be even more sub-optimal in the future (Hannah et al., 2007). This may have important ramifications, especially for alpine specialist species such as blood pheasant (*Ithaginis cruentus*), which may be trapped on effective 'sky islands' (Heald, 1967) making them particularly susceptible to climate change (Kupfer et al., 2005). We have also grouped together different categories of PA, with different levels of protection afforded (Dudley, 2009) and some of the PAs cross-international boundaries (9% of the 119 Himalayan PAs are transnational) with different management regimes between countries and different countries controlling different proportions of the PA network. Therefore, in the future it may be necessary to investigate how climate changes may affect Galliformes distributions, to assess the representation of Galliformes within different types of PA categories and for greater cross border cooperation between Himalayan countries to occur if we are to ensure the continued survival of this bird Order. Similarly, we have not incorporated projected land use changes in our analysis. Incorporating projected land use models (e.g. Pouzols et al., 2014) and agricultural costs (e.g. Dobrovolski et al., 2014) into our priority setting would be a useful extension that would increase the relevance of our results for practitioners and policy makers.

5. Conclusion

Overall, in this paper we illustrate some of the difficulties in achieving Aichi Target 11 by using Himalayan Galliformes as a case study. We found that the current protected area network failed to capture these important localities for some types of conservation value. This suggests that expanding PA networks to achieve the 17% coverage of 'areas of particular importance for biodiversity' required by Aichi Target 11 may be difficult to achieve, both globally and nationally. We tested four different measures of species specific conservation value relating to preserving biodiversity patterns and species with the highest need of protection, but other qualitatively different measures, such as cost effectiveness could be investigated further. In line with other studies, we suggest that conservation planners and legislators also need to devote more efforts to the problem of enforcement within Himalayan PAs if we are to effectively prevent extirpations. Finally, although an important group from a conservation point of view, Galliformes represent a small fraction of the total biodiversity within the Himalayan region and it is important for future research to assess whether the results we observe are congruent with results based on other taxa. This paper provides an example of the need to consider different types of conservation value when assessing the spatial configuration of PAs. The methods that we use could be applied to other species and regions, something that will help attain CBD targets.

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Map. KMZ file containing the Google map of the most important areas described in this article.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi: http://dx.doi.org/10.1016/j.biocon.2016.01.015. These data include the Google map of the most important areas described in this article.

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