Title: Considering the human response to climate change significantly changes the outcome of site-based and species vulnerability assessments

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Abstract

Aim: Despite the fact that human actions are largely responsible for the processes that threaten biodiversity, human are largely ignored in species and site-based conservation vulnerability assessments when it comes to climate change. Here we assess if (and by how much) the priorities identified by standard species and site based climate vulnerability assessments change when human vulnerability is considered.

Location: Southern Africa.

Methods: We used recently published predictive assessments of climate driven habitat range shifts in 164 range-restricted avian species, the predicted climate-driven species turnover in 331 Important Bird Areas (IBAs) and predicted changes in human vulnerability to climate change across Sub-Saharan Africa. Using these data, we assessed (i) the spatial relationship between human vulnerability and species and site-based vulnerability assessments and (ii) how individual species and site vulnerabilities changed when integrated with the human vulnerability data.

Results: We found a non-significant relationship between the areas identified as containing the most vulnerable species and sites when considering the direct impacts of climate change and the areas identified containing the most vulnerable human communities. Over one-fifth of species and one-tenth of sites moved from 'low risk' to having high risk when the human response to climate change was considered. These species and sites would be overlooked under standard vulnerability methodologies that only consider the direct impacts of climate.

Main conclusions: The lack of the spatial relationship between direct impacts of climate change on species and site and where humans are vulnerable is an important finding. Failure to consider the human response to climate change will result in systematically biased estimates of vulnerability that fail to recognize or focus conservation attention on species and sites that will be imperiled by climate-change induced changes. However, we show the integration of human vulnerability is not impossible and adds valuable information to vulnerability assessments.

Introduction

The extent to which climate change will impact global biodiversity is likely to be immense (Thomas et al., 2004; McClean et al., 2005; Maclean & Wilson, 2011; Garcia et al., 2012). Across Earth, human-forced climate change has already led to higher temperatures, altered rainfall regimes, and more frequent extreme weather and climatic events like droughts, floods and heat-waves (Seneviratne et al., 2012; IPCC, 2014). The consequences of such climatic changes for biodiversity, whether positive or negative, cannot be ignored. Shifting or shrinking species ranges across the globe (Parmesan & Yohe, 2003); changes in phenology leading to reduced fitness (Lane et al., 2012); mass coral bleaching events (Hughes et al., 2003); and complex changes in community composition and species interactions (Thomas, 2010); are just some of the impacts being reported.

As the dominant ecological conditions that drive species presence and abundance across landscapes are reshaped by anthropogenic climate change, human populations that occupy and use these areas are also being forced to adapt and cope with the changing climatic conditions (Berrang-Ford et al., 2011). There is now considerable evidence of humans responding to climate change, including through alteration of agricultural regimes (Howden et al., 2007; Liu et al., 2008), population migration and displacement (Warner et al., 2009), shifting fishing grounds (Pinsky & Fogarty, 2012), changing transport routes (Prowse et al., 2009), and through preparation for natural disaster relief (Jongman et al., 2014) (Others?). The impacts from both planned responses (e.g. armoring of beaches in response to sea-level rise and increased severe weather, Defeo et al., 2009), and unplanned coping responses (e.g. increasing use of water resources by pastoralists in national parks in response to droughts, Ogutu et al., 2009) are now thought to be seriously impacting many species and ecosystems (Table 1; Paterson, 2008; Turner et al. 2010; Chapman et al. 2014).

The scientific community has responded to the challenge climate change poses for conservation in a significant way, with a large volume of literature based on different methodological approaches now available that are primarily focused on understanding what current and future climate change is likely to mean for biodiversity and conservation in general (Chapman et al., 2014; Pacifici et al. 2014). For species vulnerability assessments, correlative approaches that relate the observed geographic range of a species to current climate; with the resulting models using spatially explicit climate projections to produce predictions of the potentially climate-suitable areas for a given species in the future are by far the most commonly used approach (e.g. (Thuiller et al., 2005; Willis et al., 2008; Carvalho et al., 2010; Forero-Medina et al., 2011). By projecting changes in size and position of a species' potentially suitable climate space, correlative models aim to provide an approximation of changes in suitable habitat under climate change. These models have the advantage of being spatially explicit and can be easily applied to a wide range of taxa and at various spatial scales. For site-based vulnerability assessments, the most common approach is use the correlative models described above to assess the expected changes in species composition due to climate change in each site (Araújo et al., 2004; Hannah et al., 2007; Hole et al., 2009, 2011). By assessing changes in species composition the assessments provide a measure of the extent to which climate change will reshape the existing character of the site.

Despite significant recent advances, a potential shortcoming to these approaches (and in fact, to almost all conservation climate vulnerability assessments to date, e.g. Williams et al., 2008; Foden et al., 2013, etc.) is that they focus only on the direct impacts of climate change on species and ecosystems (Dawson et al., 2011; Bellard et al., 2012; Watson & Segan, 2013). By doing this, they simply ignore the human response to climate change, arguably a significant oversight considering that almost all imperiled species are vulnerable due to the direct actions of humans (Hoffmann et al., 2010).

Here, we assess if vulnerability assessments change when human vulnerability to climate change is taken into account. We use two previously published vulnerability assessments that examined the direct impacts of climate change. These case studies, based in southern Africa, represent two classic examples of vulnerability assessment common in the conservation literature: (i) those that consider the direct impacts of climate change on a set of species (Carvalho et al., 2010; Visconti et al., 2011); and, (ii) those that consider the impacts of climate change on set of sites of conservation concern (Hannah et al., 2007; Hole et al., 2011; Monzón et al., 2011). For each case study we first examine vulnerability to the direct impact of climate change. We then use a published ex-ante assessment of the impact of climate change on human populations as a measure of the magnitude of the likely human response the conservation ‘target’ will be exposed to (Midgley et al., 2011). By doing this, we are able to identify those species and sites that may have been overlooked by vulnerability assessments focused only on direct impacts. We use this more complete understanding of the potential impact of climate change to revaluate vulnerability and discuss the implications for conservation management.

Methods

Case study assessment

We illustrate how the incorporation of the human response to climate change may alter our perception of climate change vulnerability using two case studies drawn from Southern Africa, a region widely recognized for its outstanding biodiversity (Biggs et al., 2008). Each case study uses previously published data on the vulnerability of the conservation target to the direct impacts of climate change.

Africa is widely believed to be the most vulnerable continent to climate change from both a biodiversity and a social perspective (Brooks et al., 2005; Samson et al., 2011). Forecasted impact on human populations is dire; water stress will impact 75 to and 250 million people (Boko et al., 2007), and mid century declines in agricultural productivity could reach 50% in some areas. Efforts to aid human populations in adaptation to these changes are likely to be immense , with one estimate suggesting the costs of adaptation could be between $3-37 billion annually (Stern, 2007), which may have far-reaching consequences on biodiversity. Given the likely size of the human response, there is an urgent need to assess what the impact of those responses will be on Africa’s socio-ecological systems.

Impact of climate change on human populations

The spatial assessment of impact and vulnerability to climate change has become an increasing popular focus in the past decade (Sherbinin, 2013). Spatially explicit information on likely impact of climate change on human populations in southern Africa was sourced from an analysis of regional vulnerability within the fifteen countries that are members of the Southern

African Development Community (SADC) (Midgley et al., 2011). Midgley et al (2011) considered a suite of risk factors (including exposure to extreme events, food/water security, demographic change, potential conflict and health) and the assessment was conducted at a sub-country scale which is more instructive for regional planning that country based metrics (Midgley et al., 2011). The study quantified the vulnerability of human populations to climate change based on the exposure of human populations, their sensitivity to those changes, and their adaptive capacity to respond to the changes.

We used impact (exposure and sensitivity) as a surrogate for the likely magnitude of the human response to climate change in each region (Glick et al., 2011). Impact captures both the magnitude of expected climatic change (exposure) and the sensitivity of the human population to those changes, but does not account for the adaptive capacity of the affected human populations. We chose to measure human response using impact rather than vulnerability because our primary objective was the identification of where people are most likely to respond to climate change, not what type of response they are likely to engage in. In doing this we aggregate a wide range of human responses (both planned and unplanned) that can have dramatically different impacts on the environment (Turner et al., 2010).

Midgley et al. (2011) quantified human impact at one km^2 resolution, on a scale that ranged from 4 to 53, where higher numbers indicate greater forecasted impact in 2050 (Midgley et al., 2011). We rescaled all impact scores between 0-100, by subtracting the minimum score from each, dividing by the range and then multiplying by 100:

$$(1) \qquad S_p = (P_S - \min P)/(\max P - \min P) \times 100$$

After rescaling mean impact within a grid cell was 65.3, and the distribution of impact scores exhibited a slight negative skew. The rescaled measure of human impact was used to calculate exposure of conservation targets to the human response.

Species vulnerability assessment

Species with specialized habitat requirements and species that occupy smaller geographic ranges have frequently been identified as more vulnerable to stressors including climate change (Sekercioglu et al., 2008; Foden et al., 2013). Restricted-range terrestrial bird species are defined as avian species that occupy a range smaller than 50,000 km^2 (Hannah et al., 2013). Using five GCM forecasts and seven species distribution models Hannah et al. (2013) assessed the vulnerability of 1,263 restricted-range terrestrial bird species (Hannah et al., 2013). The dataset developed for the analysis included range maps for each species based on current conditions and the forecasted range for each species in 2050 and 2080 based on forecasted climatic conditions. We limited our assessment to the 164 extant species with ranges that overlapped the human vulnerability assessment.

Following standard practice for the assessment of species vulnerability to the direct impact of climate change, we calculated the intersection between the current range of each species and the forecasted range in 2050 (Carvalho et al., 2010; Visconti et al., 2011). Areas that were forecasted to be suitable for the species in both the current and future period are referred to as areas of overlap. We calculated the proportion of each species range that was expected to remain climatically suitable by dividing the area of overlap for the species by its current range size. We then calculated range contraction for each species as the difference between one and the proportion of species range forecasted to remain climatically stable. Range contraction was used as a measure for the direct impact of climate change on the species. Species exposure to the human response to climate change was calculated as the mean human impact score within the area of overlap.

Site based vulnerability assessment

Important Bird Areas (IBAs) are areas identified by Birdlife International and partners as critical for the conservation of avian species (Hole et al., 2009). The IBA network in southern Africa includes 863 sites in 42 countries. We restricted our analysis to only those IBAs that overlap with the SADC region (n=331). The vulnerability of IBAs to the direct impacts of climate change was evaluated with respect to expected changes in species composition due to climate change in each IBA. The current and predicted future range maps of 1401 bird species were overlain upon the spatial boundary of the IBA to identify predicted presence of each species today and in 2055 (Hole et al., 2009). Species turnover was defined as the sum of all species expected migrate into or emigrate out of the IBA, divided by the total number of species predicted to be present in the IBA either today or in 2055 (Hole et al., 2009). Species turnover within each IBA was treated as the measure of the direct impact of climate change on the IBA. We calculated IBA exposure to the human response to climate change as the mean human impact score within the IBA inclusive of the 50km^2 buffer around the IBA. A 50km^2 buffer around the IBA was used to account for impacts from human activity that may originate from spatially proximate populations (McDonald et al., 2009).

(B) Integrating direct impact and human response

To identify where conservation priorities and management recommendations change most dramatically after consideration of exposure to the human response to climate change we integrated direct and indirect scores and classified each conservation target with respect to relative level of direct impact and human response. We classified scores as 'high' if they were greater than one standard deviation above the mean for the feature class (IBAs or species), and 'low' if the score was at least a standard deviation below the mean.

Results

Species assessment

Mean direct impact (range contraction) for the 164 restricted-range terrestrial bird species was 39.6% (sd = 28.7) and mean exposure to the human response was 66.6 (sd = 6.4). There was a weak negative correlation between range contraction and exposure to the human response (Pearson's r (162) =-0.42, p<0.01). Seven species are forecasted to lose their entire range to the direct impact of climate change, while nine species were not forecasted to experience any range contraction. We identified 28 species with mean range loss of 88.5% (sd = 11.4) as high direct impact species, and 32 species with a mean range loss of 3.2% (sd = 3.1) as low direct impact species. We further identified 21 species as highly exposed to the human response (mean = 77.1, sd =3.5), and 28 species with low exposure to the human response (mean= 56.7, sd = 2.7) (Fig 1). Group differences between species identified as high and low direct impact (Welch's t-test, t (30.5) =-38.2, p < 0.01) and high and low exposure to the human response (Welch's t-test, t (28.4) =7.1, p < 0.01) were significant.

Threatened species ("threatened" includes three ICUN Redlist status categories; 'critically endangered', 'endangered' and 'vulnerable') are expected to be more exposed to the human response. Mean human response for threatened species was 67.6 (sd = 6.5), while the human response in the range of non-threatened species was 64.9 (sd = 7.0) (two sample t (133) = 2.4, p = 0.02). However between status individual differences (eg. 'critically endangered' and 'endangered') in exposure to the human response for ICUN status were not significant (one-way ANOVA, F (5, 157) = 1.2, p = 0.29).

Overlaying direct impact and exposure to the human response we identified seven low direct impact species (25.0% of low direct impact species and 4.2% of all birds) and five high direct impact species (17.9% of high direct impact species and 3.1% of all birds) that are likely to be highly exposed to the human response (Table 2).

(B) Site-based assessment: Important Bird Areas

Mean direct impact (species turnover) in IBAs was 22.6 (sd = 11.2) and mean exposure to the human response was 66.3 (sd = 7.2). There was no correlation between direct impact and exposure to the human response in IBAs (Pearson's r (329) = -0.08, p = 0.16). We identified 48 (14.5%) IBAs as low direct impact sites with a mean species turnover of 7.6% (sd = 3.0), and 55 (16.6%) high direct impact sites with a median turnover of 44.3% (sd = 6.8). A further 50 (15.1%) sites were identified as highly exposed to the human response (mean score = 79.2, sd = 2.8), and 49 (14.1%) IBAs where exposure to the human response was likely to be low (mean score = 56.7, sd = 3.5). Group differences were significant between sites, both for high and low direct impact (Welch's t-test, t (76.1) = -36.1, p < 0.01), and high and low exposure to the human response (Welch's t-test, t (92.4) = -35.4, p < 0.01).

Overlaying direct impact and exposure to the human response we find that six low direct impact IBAs (1.8% of all IBAs) are likely to be highly impacted by the human response to climate change (Fig2, Table 3). This included two sites, Liqobong and Sehlabathebe National Park, that are not expected to experience any species turnover as a result of direct climate change impacts. These sites are most likely to be overlooked by vulnerability assessments focused only on the direct impact of climate change. We identified an additional seven high direct impact IBAs where the human response is also likely to be high, further complicating management (Table 2).

Discussion

While there are a number of published papers that have identified the need to incorporate the human response (Turner et al., 2010; Watson & Segan, 2013; Watson, 2014), this is the first work to our knowledge that formally assesses if and how human vulnerability to climate change impacts conservation vulnerability assessments. We found no positive correlation for either site-based or species vulnerability and human vulnerability to climate change. This is an important finding because it means the assumption that the direct impacts of climate change are the only thing factor we need to consider when assessing vulnerability to climate change is not valid. If the lack of correlation observed in our results holds true for conservation targets in other regions (and we assume that it will), then climate change conservation priorities identified without respect to human response must be re-examined.

When individual targets were considered, only five (3.0%) species and seven (2.1%) sites identified as highly vulnerable to the direct impacts of climate change, had human populations that were also identified as highly sensitive to climate change. Conversely, we found that seven (4.3%) species and six (1.8%) sites identified as least likely to be affected by the direct impacts of climate change, contained highly sensitive local human populations. Human populations are critical actors in socio-ecological systems and are the primary force driving processes that currently threaten species (Hoffmann et al., 2010). The incorporation of their heterogeneous response to climate change provides essential information to the assessment of conservation vulnerability.

Assessments of species vulnerability are used by governments, conservation organizations, and industry to inform planning and allocate resources (Hoffmann et al., 2008; Joseph et al., 2009; Bernazzani et al., 2012; Brown et al., 2013) (Others/Alternatives?). It is critical that such processes be informed by the best available science about what impacts are likely to occur. We show that the incorporation of the human response has the potential to alter the list of species prioritized for immediate conservation attention and the areas where actions are targeted. For example, we found that the Long-tailed Ground-roller (*Uratelornis chimaera)*, a member of Madagascan endemic family that is highly vulnerable to habitat loss (BirdLife International, 2014), is not forecasted to lose any of its range due to the direct impact of climate change. When human vulnerability was assessed, it was the third highest of any species evaluated – the species lives in an area which contains some of the most vulnerable human communities on the planet (Midgley et al., 2011). The impact of climate change is likely going to be devastating for the local human population which is one of the most vulnerable in the region, and the forecasted reduction in agricultural productivity in surrounding areas (Hannah et al., 2013) could intensify the pressure to clear additional land to maintain current yields, resulting in direct habitat loss for the species. It is clearly going to more vulnerable to climate change in the near future and efforts need to be put in place to ensure the species persistence.

This work also has broad implications for species based management strategies in the face of climate change, including the expansion of protected areas and identification of corridors to accommodate species as they move to more suitable areas (Lawler, 2009; Watson et al., 2011). Numerous methods have been suggested for the identification of climate change corridors, including the use of forecasted change in species range (Willis et al., 2008; Nuñez et al., 2013), shifts in ecosystems (Ponce-Reyes et al., 2012), and maximizing abiotic diversity (Game et al., 2011). Targeting actions within forecasted range of overlap for a species is commonly thought to be a "no-regrets" conservation strategy, because action in these areas will benefit the species even if the expected range shift does occur (Glick et al., 2011). However, these seemingly low risk approaches may look different when we consider the potential response of people within the range of overlap. For species like the vulnerable Dusky Tetraka (*Bernieria tenebrosa*) or the critically endangered Madagascar Pochard (*Aythya innotata*) allocating resources to the areas where current and future habitat overlap would result in targeting portions of the species range where the impacts of climate change on people is likely to be far higher than the impact across the species overall range. If these areas are more likely to be impacted by human populations as they seek to respond to climate change, then they may no longer look like 'no regrets' conservation opportunities.

Priority sites and site based management priorities based on the movement of species in response to the direct impact of climate change (Araújo et al., 2004; Hannah et al., 2007; Hole et al., 2011) or assessing the relative difference in climatic conditions (Iwamura et al., 2013) may also need to be revisited to reflect the human response. Understanding how the direct impacts of climate change will shape species composition is necessary but not sufficient to prioritize resources between sites or identify appropriate management actions. In and around these areas the human response to climate change is already underway.

In the Kafue flats IBA in Zambia, the direct impact of climate change is expected to be relatively low (turnover less than 10%), but the human population is likely to be highly impacted (table 3). The site is a seasonally flooded wetland that stretches almost 70km across at the widest point the area of inundation. Hydropower dams regulate flow through the area, and although in principle the flow regimes mimic natural inundation regimes, fears around water shortages have meant that those agreements have not always been honored (BirdLife International, 2013). The expected increase in both the frequency and intensity of extreme climatic events such as droughts (Seneviratne et al., 2012; IPCC, 2014) may increase pressure on managers to deviate away from natural flow regimes and towards one that primarily serves to satisfy the water demands of local agriculture. Such a deviation could be devastating to species dependent on natural flow regimes. Climate change clearly poses a risk to site, but that risk is only realized when the human response to climate change is incorporated into the vulnerability assessment. The situation is not unique. Birdlife International estimates that 50% of African IBAs are threatened by habitat loss to agriculture (BirdLife International, 2004), and climate change is likely to significantly alter agricultural suitability (Adeloye, 2010) reshaping the nature of the threat.

Identifying a site as likely to be impacted by the human response to climate change modifies our understanding of vulnerability and can create opportunities for site based management that benefit species by targeting human populations. For example, Hazzah et al. (2012) found that when pastoralists were given access to land inside protected areas during droughts to allow livestock to graze, thus reducing drought induced loss of livestock, they were less likely to kill lions and had more positive attitudes towards the protected area (Hazzah et al., 2013). Identifying and promoting human responses to extreme events (eg. droughts, floods) that avoid adverse impacts on biodiversity is critical as the frequency and intensity will both be exacerbated by climate change (Seneviratne et al., 2012; IPCC, 2014).

The essential contribution of our work is the development of a framework that improves our understanding of the risk climate change poses for species and sites through the formal incorporation of human responses to climate change. The framework allows us to identify conservation targets previously thought to be at relatively low levels of risk to climate change induced impacts, that are potentially imperiled by the response of human populations to climatic change. Understanding where people are most likely to respond to climate change is only the first step in the process of incorporating that response into conservation planning frameworks. The formulation of appropriate conservation interventions at the local level requires an understanding of what the responses will be, and what impact they will have on biodiversity. It is only through efforts to better understand the full impacts of climate change that we will be able to identify and prioritize realistic interventions that aid species and systems in adapting to these climatic shifts. Moreover, the failure to consider the full scope of the interaction in the socio-ecological system may result in a lost opportunity to identify areas and adaptation solutions that benefit both biodiversity and people.

It is also important to recognize that some human responses, such as efforts to reduce atmospheric carbon through mechanism like REDD+, can provide significant benefits to biodiversity (Turner et al., 2010). Leveraging the services provided by natural ecosystems to reduce human vulnerability to climate change, referred to as ecosystem based adaptation (EbA), is an emerging approach in climate change adaptation that offers the promise of improving outcomes for both people and biodiversity (Jones et al., 2012). For example, Hannah et al. (2013) identified areas where climate change is likely to impact both agricultural yield and biodiversity, as a possible suite of areas where adaptation interventions to could be targeted to benefit people and biodiversity. These proverbial "win-wins" will be critical to efficiently allocating resources to meet the needs of biodiversity and people.

In the inter-dependent and complex socio-ecological systems that we work in, the identification of adequate and sustainable management responses to climate change requires considering all the ways in which those systems may be impacted (both direct and indirect) by climate change (McClanahan et al., 2008). Failure to account for all impacts will lead to near sighted, sub-optimal conservation interventions which are unlikely to succeed over the long-term. It also means our conservation priorities may overlook the very suite of species, sites and ecosystems that are most threatened by climate change.

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Tables

Table 1. Examples of the how human responses to climatic change result in impacts on species and ecosystems.

Climate event	Issue	Description	Reference
Drought	Resource conflict	Increased competition for water resources and forage areas between wildlife and pastoralists. Droughts encourage pastoralists to increase herd size to facilitate herd recovery after drought years, augmenting competition with wildlife.	(Oguto 2007,2008)
Drought	Direct resource conflict	Pastoralist access to protected areas for grazing during drought periods reduced retaliatory killing of lions.	(Hazzah 2013)
Drought	Unintended impact	Increased human water extraction may exacerbate impact of droughts on endemic cave dwelling species.	(Shu 2013)
Drought	Resource conflict	Increased resource conflict and poaching during drought event	(Greste 2009)
Sea level rise	Coastal armoring	Coastal armoring can enhance erosion on unarmored beaches, narrower beaches result in reduced habitat, and chances in trophic structure, and reduced species diversity.	(Defeo 2009)
		*****NEED MORE EXAMPLES*****	

Table 2. Bird species identified as most (and least) vulnerable to the direct impacts of climate change, and at the highest and lowest levels of exposure to the human response to climate change. Low impact is defined here as an impact score at least one standard deviation below the mean, and high impact is defined as an impact score greater than one standard deviation above the mean.

		Human response	
		High	Low
Direct impact	High	5 (3.0 %) Slender-billed Flufftail (*Sarothrura watersi*) Subdesert Mesite (*Monias benschi*) Madagascar Pochard (*Aythya innotata)* Angola Cave-chat (*Xenocopsychus ansorgei*) Botha's Lark (*Spizocorys fringillaris*)	9 (5.5 %) Bannerman's Turaco (*Tauraco bannermani*) Ethiopian Bush-crow (*Zavattariornis stresemanni*) Banded Wattle-eye (*Platysteira laticincta*) Grey-necked Picathartes (*Picathartes oreas)* White-tailed Swallow (*Hirundo megaensis*) Appert's Tetraka *(Bernieria apperti)* Green Longtail (*Urolais epichlorus)* Bamenda Apalis (*Apalis bamendae)* Bates's Weaver *(Ploceus batesi)*
	Low	7 (4.3 %) Long-tailed Ground-roller (*Uratelornis chimaera*) Running Coua (*Coua cursor*) Verreaux's Coua (*Coua verreauxi*) Black-cheeked Lovebird *(Agapornis nigrigenis)* White-breasted Mesite (*Mesitornis variegatus)* Lafresnaye's Vanga (*Xenopirostris xenopirostris)* Thamnornis Warbler (*Thamnornis chloropetoides)*	2 (1.2 %) Grey-headed Greenbul (*Phyllastrephus poliocephalus)* Golden-naped Weaver (*Ploceus aureonucha)*

Table 3. IBAs at the highest and lowest level of expected exposure to the direct impacts of climate change and human response. Low impact is defined as impact scores at least one standard deviation below the mean, and high impact was defined as scores greater than one standard deviation above the mean.

		Human response	
		High	Low
Direct impact	High	7 (2.1 %) Lengwe National Park Liwonde National Park Headwaters of the Cahora Bassa Dam Lower Zambezi National Park Limpopo-Mwenezi flood-plain and pans Middle Zambezi valley Save-Runde junction	8 (2.4 %) Luia Mount Hoyo Reserve Orange River Mouth Wetlands Swartkops Estuary & Chatty Salt Pans Katavi National Park Lake Victoria-Bumbire Islands Ugalla River Game Reserve Mweru Wantipa National Park
	Low	6 (1.8 %) Mafika-Lisiu Dzalanyama Forest Reserve Chimanimani mountains` Chisamba Kafue flats Mavuradonha mountains	7 (2.1 %) Bangui Forests west of Lake Edward Lomako-Yekokora Ngiri Salonga National Park Virunga National Park Rufiji Delta

Figures

Figure 1. Exposure of restricted-range terrestrial bird species to the direct impacts and human response to climate change A) Proportion of species in an area identified as at the highest exposure to the direct impact of climate change. B) Proportion of species identified as at the highest level of exposure to the human response to climate change.

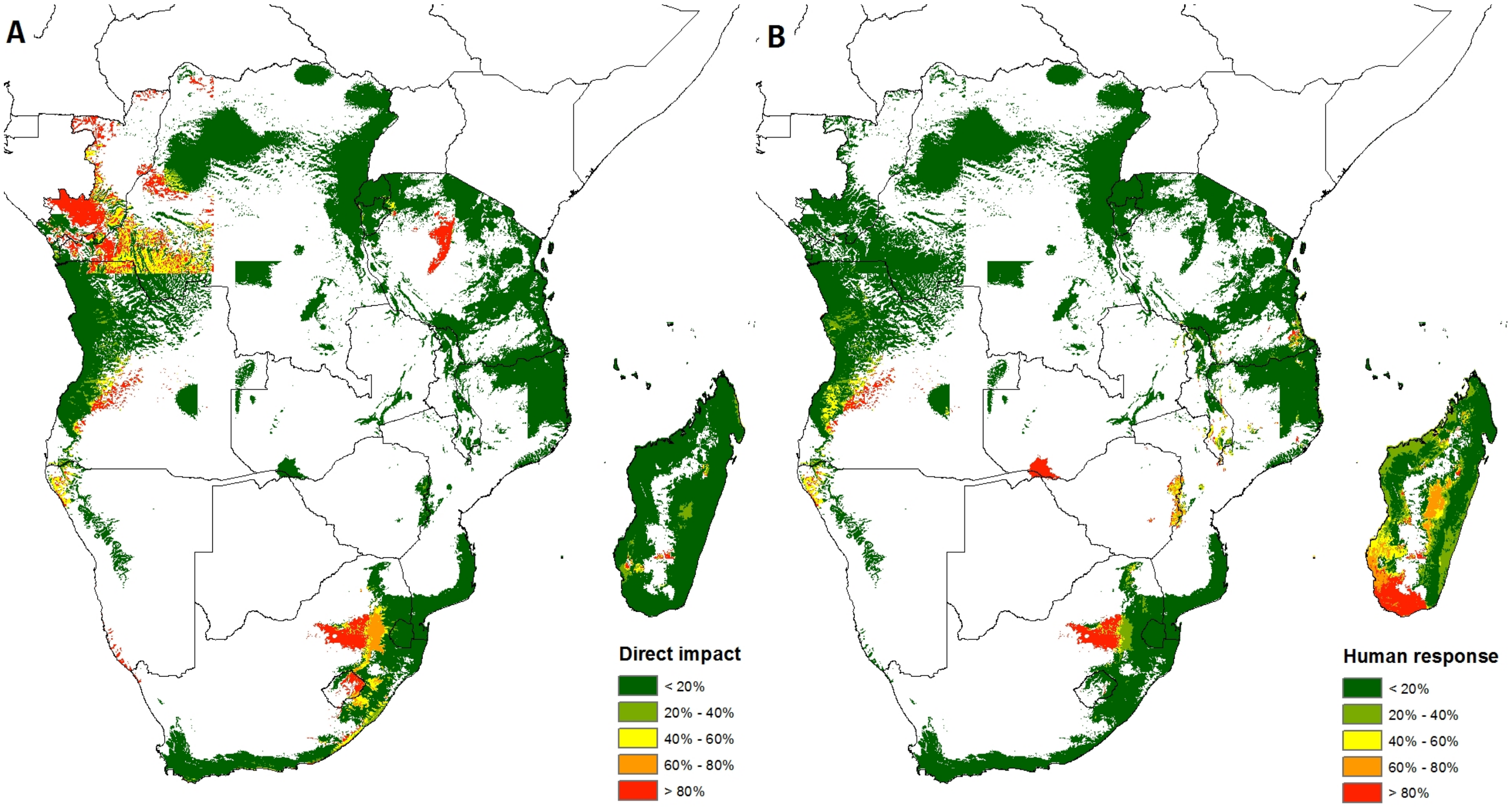
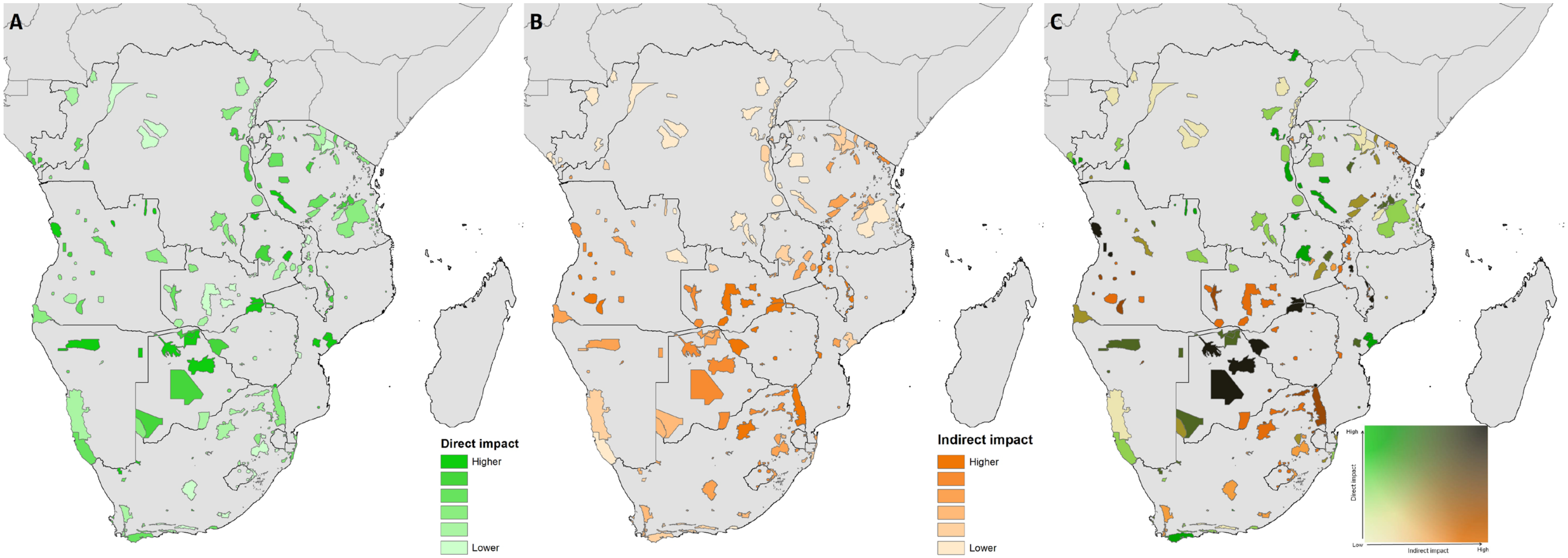


Figure 2. Direct impact and exposure to human response to climate change on IBAs in southern Africa A) Forecasted turnover in IBA species composition by 2050 due to climate change (direct impact). Darker colors indicate higher levels of turnover. B) Impact of climate change on human populations inside and within a 50km radius of each IBA. Darker colors indicate greater degrees of human impact (indirect impact on biodiversity). C) Overlay of direct and indirect impact of climate change. Dark brown areas indicate high indirect and direct impact of climate change. Dark orange areas indicate high indirect impact and low direct impact. Light areas have low relative indirect and direct impact.



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