A Systematic Approach to Incorporate the Human Response into Climate Change Conservation Planning

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Working with water terraces in Lower Nyando, Kenya.
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Introduction

The extent to which climate change will impact global biodiversity is likely to be immense (Thomas et al. 2004; McClean et al. 2005; Garcia et al. 2012). Over the course of the next century human-forced climate change will lead to higher temperatures, altered rainfall regimes, and more frequent extreme weather and climatic events like droughts, floods and heat-waves (IPCC 2012; Seneviratne et al. 2012). In the last two decades the scientific community has responded to this challenge with an increasing emphasis on understanding what current and future climate change is likely to mean for biodiversity and conservation in general. Innumerable studies have considered how the spatial range or competitive fitness of species will be impacted in the future by physical changes in climate (Hof et al. 2011; Parmesan and Yohe 2003; Walther et al. 2002).

As the dominant ecological conditions that drive species presence and abundance across landscapes are reshaped by anthropogenic changing climate, the human populations that occupy these landscapes will also be forced to adapt and cope with the changing climatic conditions. The impact that these changes in human behavior, such as responding to food insecurity or coping with extreme weather events, will have on species and ecosystems has been referred to as the 'indirect' impacts of climate change (Paterson et al. 2008; Turner, Bradley, and Estes 2010). The terms direct and indirect impacts are often poorly defined or applied in confusing and contradictory manners across the conservation and development literature. Confusion often arises because the same process can be classified as both direct and indirect impact depending on the circumstances that trigger the process (Salafsky et al. 2008). In this paper, we define the term "direct" to describe the proximate impacts that result from physical changes associated with climate change, and "indirect" to describe impacts that originate from human actions that are initiated or exacerbated by climate change (Turner, Bradley, and Estes 2010). For example, a change in the rainfall regime has a direct impact on a species if it alters the ecosystem in a manner that makes it less hospitable to that species. If the change in rainfall regime causes people to shift agricultural practices thereby clearing land that was previously habitat for that species, this impact on the species would be referred to as an indirect impact.

Using this definition, the direct impacts of climate change refer to changes that would be expected to affect species and ecosystems regardless of how human populations are respond. Examples of these impacts include rising temperatures that cause increased tree mortality (Allen et al. 2010), or rising ocean temperatures that lead to coral bleaching or changes in ocean chemistry that result in slower reef accretion (Hughes et al. 2003). Indirect impacts refer to changes in human behavior resulting from efforts to cope with, adapt to, or mitigate the risk of climate change related events. Examples of planned human responses that lead to indirect impacts to biodiversity include the armoring of beaches in response to sea-level rise and increased severe weather that causes erosion and beach narrowing (Defeo et al. 2009), or increased fire risk in the Amazon rainforest due to expansion of roads and human settlements in areas that were previously unsuitable for people (Malhi et al. 2009). Indirect impacts also include the unplanned responses of human communities as they attempt to cope with changing (and often extreme) environmental conditions. Examples of unplanned human responses that lead to indirect impacts include conflicts between wildlife and pastoralists for water resources in national parks (Ogutu et al. 2009) and increased poaching of iconic species such as lions (*Panthera leo*) (Hazzah et al. 2013) in response to droughts.

Many of the impacts of climate change will have both direct and indirect components which will have synergistic impacts on biodiversity. For example rising sea-levels will have a direct impact on coastal biodiversity as low-lying areas are inundated by higher seas (Galbraith et al. 2002) and an indirect impact as human populations relocate residences and activities to higher ground, converting native vegetation to agricultural and urban lands. A recent study that explored the magnitude of both indirect and direct impacts of climate change driven sea-level rise on habitat availability for selected mammal species globally found that the indirect impact of sea-level rise on biodiversity may be equal to or greater than the direct impact of sea-level rise (Wetzel et al. 2012).

While we refer to the human response to climate change as the indirect impacts of climate change, rather than indirect threat, because we recognize that not all responses will have an adverse impact on biodiversity, and prefer use the term indirect impact instead (Turner, Bradley, and Estes 2010). Some human responses to climate change may benefit biodiversity by reducing in impact of current stressors. Efforts to reduce atmospheric carbon through mechanism like REDD+ have the potential to prevent the destruction of intact forests and woodlands conferring significant benefits to biodiversity. Restoration of ecosystems such as mangroves or coral reefs to provide greater protection from storm surges associated with extreme climatic events is another example of how the human response to climate change may result in environmental benefits. The latter is an example of ecosystem based adaptation (EbA), an emerging approach in climate change adaptation that leverages ecosystem services to reduce human vulnerability to climate change (Jones, Hole, and Zavaleta 2012).

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 conservation interventions which are unlikely to succeed over the long-term.

Defining vulnerability to climate change

Vulnerability to climate change is commonly defined as the degree to which a species or system is susceptible to the adverse impacts of climate change (IPCC 2007; Dawson et al. 2011; Glick, Stein, and Edelson 2011). Vulnerability can be disaggregated into three underlying components, exposure (positively correlated with vulnerability, increased exposure leads to greater vulnerability), sensitivity (positively correlated with vulnerability, , increased sensitivity leads to greater vulnerability), and adaptive capacity (negatively correlated with vulnerability, higher adaptive capacity leads to lower vulnerability) (Dawson et al. 2011; Glick, Stein, and Edelson 2011). In this paper, exposure refers to the extent to which climatic conditions change in the species' range or system of change likely to be experienced based on the extent. Sensitivity is the degree to which the conservation target (e.g. species, ecosystem, ecological process) is affected by the change, and adaptive capacity is the ability to adjust to climatic changes to reduce vulnerability or capitalize on new opportunities.

Within the conservation arena, much of the literature on vulnerability has focused on quantifying exposure and sensitivity to the direct impacts of climate change on species (Thomas et al. 2004; Williams et al. 2008) or the identification of specific traits associated with vulnerability (Bagne, Friggens, and Finch 2011; Foden et al. 2013; U.S. EPA 2009; Young et al. 2011). The vulnerability assessment framework of the ICUN, for example, focuses on the biological traits of species to assess their susceptibility to climate change driven impacts (Foden et al. 2008; Foden et al. 2013) and does not consider the human responses. This shortcoming has been acknowledged and addressed in recent reviews (Watson and Segan 2013; Dawson et al. 2011; Bellard, Bertelsmeier, and Leadley 2012). Ultimately, the limited focus on the direct impacts of climate change creates a significant challenge because it ignores the other factors (and the complexity of interactions) that shape species and system responses to threatening process.

Conservation takes place in complex socio-ecological systems. In systems where the human 'footprint' is relatively low, the direct impacts of climate change maybe the primary driver of environmental impact. However, unmodified ecosystems are extremely rare, and most ecosystems are currently highly modified by human activity (Halpern et al. 2012; Sanderson et al. 2002). In these modified systems the ecological conditions of the future will continue to be shaped by the activities of human populations, and any forecast of the future state of the system (and associated vulnerability assessments) must account for the potential changes in those activities.

The incorporation of indirect impacts is an essential step in developing a more robust understanding of the how climate change is and will impact biodiversity (Paterson et al. 2008; Turner, Bradley, and Estes 2010). This understanding is essential for the conservation community to prioritize the landscapes, sites and species on which its efforts are to be focused, and the selection of effective conservation responses.

Aim of this report

The aim of this report is to illustrate the importance of incorporating the indirect impacts of climate change into climate change vulnerability assessments and conservation planning. This is done through the use of three southern African based case studies drawn from classic conservation targets. Africa is widely believed to be the most vulnerable continent to climate change from both a biodiversity and a social perspective (Brooks, Neil Adger, and Mick Kelly 2005; Samson et al. 2011). This impact that climate change is and will continue to have is massive. Climate change caused water stress caused by climate change is projected to impact between 75 and 250 million people (Boko et al., 2007). Mid-century declines in agricultural productivity could reach 50% in some areas. Biodiversity will undoubtedly experience the impact of human responses to these changes further underscoring the need for biodiversity conservation to account for human responses. Sub-Saharan Africa derives 80% of the locally consumed energy from woody biomass (World Bank 2009). The dependence on biomass to satisfy local energy demands makes the region's ecosystems especially vulnerable to climatic shifts in biomass as population's consumptions patterns change. The human response to climate change will also include addressing the human health impacts of climatic changes, including the impact of increased droughts and floods and changes in the prevalence and distribution of the vector borne diseases (WHO and WMO 2012).

The World Bank has estimated that $70–$100 billion USD will be required annually to 2050 to facilitate adaptation to climate change (World Bank 2010a). While this is the global cost of adaptation, the cost of adaptation in sub-Saharan Africa is estimated to be around $20 billion annually, with just under $4 billion more required to support North Africa and the middle east (World Bank 2010b). While these sums may seem like an impossibility for developing countries to reach, the burden of meeting the financial challenges of climate change adaptation is likely to be shared by developed countries, who in 2008 in Bali committed to providing both "adequate, predictable, and sustainable financial resources" and "positive incentives for developing country parties for the enhanced implementation of national mitigation strategies and adaptation action" (UNFCC 2008). As part of its Strategic Framework for Climate Change and Development (SFCCD), the World Bank identified making adaptation and mitigation a core part of its development strategy as one of its six key goals (World Bank 2009). Africa has received tens of millions of dollars in the past five years to be used in biodiversity conservation while taking climate change into account (Seimon et al. 2011).

World Bank lending to support climate adaptation projects globally doubled between 2011 and 2012, and spending in sub-Saharan Africa on adaptation projects experienced a six-fold increase (World Bank 2012). The increase in adaptation lending to over four billion in 2012 is further augmented by an additional seven billion allocated to mitigation projects. It is clearly of critical importance to understand how this money will be spent, and what the impact of these projects is likely to be on conservation interests.

In addition to shifts in the location of activities like agriculture, climate adaptation strategies are likely to include the development of 'hard' engineered solutions (e.g., dams for flood protection and water storage) to aide people adapt to climate change. For example, it is estimated that by 2020 $100 billion dollars will be spent on the development of hydropower plants only (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.

Here, we incorporate the indirect impact of climate change into three previously published vulnerability assessments that had only examined the direct impacts of climate change. We selected the studies from southern Africa to represent three classic conservation planning problems: (i) assessing the impacts of climate change on species; (ii) assessing the impacts of climate change on sites; and, (iii) assessing the impacts of climate change on regions. For each case study we first look at the vulnerability to the direct impact of climate change. We then use an 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. By doing this, we are able to identify those species, sites, and regions that may have been overlooked by vulnerability assessment 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 three case studies drawn from Southern Africa. Each case study uses previously published data on the vulnerability of the conservation target to the direct impacts of climate change. The case studies were selected to represent the broad suite of features commonly used as targets in conservation planning; 1) species 2) sites, and 3) regions.

IMPACT OF CLIMATE CHANGE ON HUMAN POPULATIONS

The spatial assessment of impact or 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, Davies, and Chesterman 2011). We selected the climate change impact assessment of people published by Midgley et al (2011) because it 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, Davies, and Chesterman 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. While there is no consensus yet on a single set of indicators that should be used to measure exposure, sensitivity or adaptive capacity of human populations, the indicators used in the study were selected and weighted to reflect their importance in southern Africa (Midgley, Davies, and Chesterman 2011).

We used impact (exposure and sensitivity) as a surrogate for the likely magnitude of the human response to climate change in each region (note that 'impact' is also referred to as 'problem areas' in Midgley et al. 2011, however we use the more familiar impact throughout this report). Impact captures both the magnitude of climatic change expected in an area (exposure) and the sensitivity of the human population to those changes, but does not account for the adaptive capacity of the affected human populations. The IPCC defines adaptive capacity as *"The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences"* (IPCC 2007). Adaptive capacity of human populations as quantified by Midgley et al. (2011) includes a broad suite of 19 indicators that capture relative differences in wealth, governance, health, infrastructure, and natural resources of the human population in the region. We chose to measure human response using impact rather than vulnerability because the primary purpose our measure had to fulfill was the identification of where people are most likely to be responding to climate change. In this preliminary assessment our focus was the identification of where the response is likely to be greatest, rather than focusing on the type of response the identified populations are likely to engage in.

We recognize that in doing this we group together both planned and unplanned responses of populations that can have dramatically different impacts on the environment, and that integrating and understanding local adaptive capacity is critical to identifying conservation responses (McClanahan and Cinner 2011). However, in areas where there is high adaptive capacity the response of human populations maybe more reliant on planned responses to climate change that leverage a mix of hard and soft solutions to reduce vulnerability (Berrang-Ford, Ford, and Paterson 2011). In areas where adaptive capacity is lower the responses are more likely to be reactive and more reliant on options that require less capital. Therefore, we use impact rather than vulnerability because many of the adaptation strategies that may be used by human populations with high adaptive capacity could also impact biodiversity (e.g. coastal armoring, dam construction). Areas in which these responses might be used are important to identify in our assessment, and use of human vulnerability which has lower values in higher adaptive capacity regions would have modified this signal. As such the vulnerability of conservation targets in countries with higher relative adaptation capacity (regionally Botswana, Namibia, South Africa) would be deemphasized through the use of vulnerability (Figure 1).

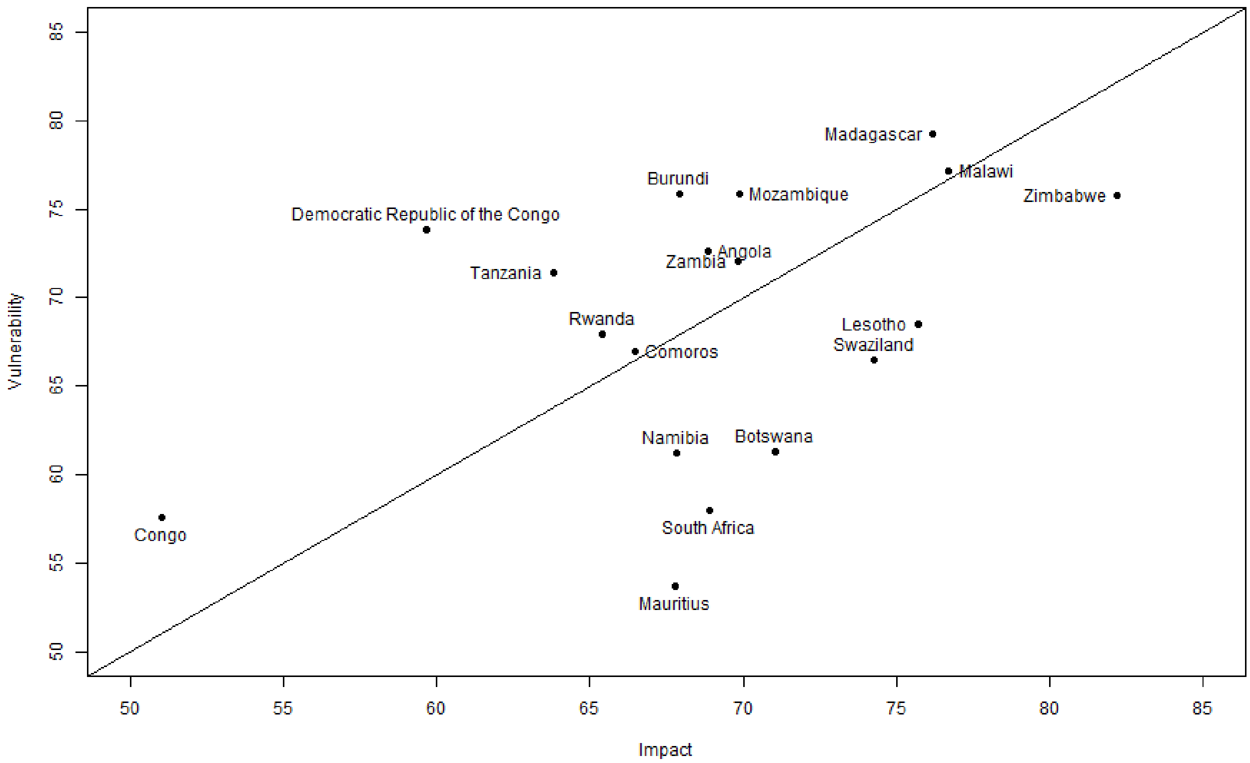

Figure 1. Average country level climate change impact (x-axis) and vulnerability (y-axis) of human populations. Countries that fall below the line have higher relative adaptive capacity that reduces overall country vulnerability relative to other countries in the region and forecasted impact.

The dataset used to measure likely Impact on human populations had a spatial resolution of 1 km^2 and pixel level impact ranged from 4 to 53, where higher numbers indicate greater degrees of forecasted impact in 2050 (Midgley, Davies, and Chesterman 2011). We rescaled the data to range between 0–100, by dividing all pixels by the highest value in the dataset (53) and then multiplying by 100. After rescaling mean impact within a grid cell was 65.3, and the distribution of impact scores exhibited a slight negative skew (Fig 2). The rescaled measure of human impact was used to calculate human impact in each of the conservation targets described below.

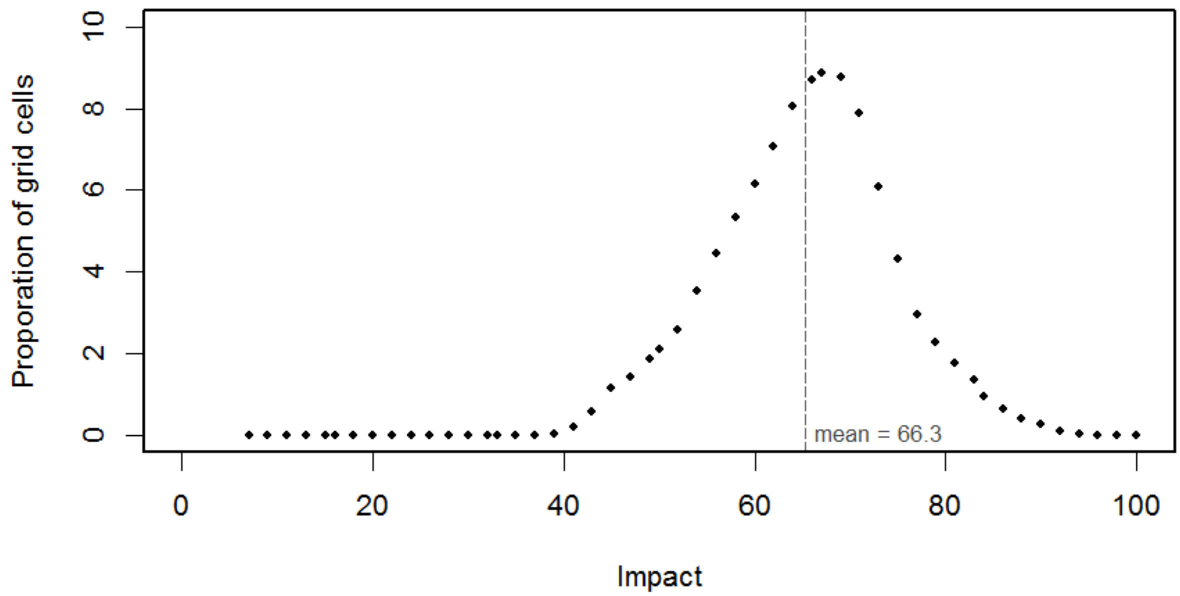

Figure 2. Density of the rescaled human impact scores at the grid cell level. After scaling values between 0–100, mean human impact measured at the grid cell level was 66.3, and the distribution exhibited a slight negative skew.

SPECIES VULNERABILITY ASSESSMENT: BIRDS

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 165 species with ranges that overlapped the study region. A single species, Aloatra Grebe (*Tachybaptus rufolavatus*) was excluded because it is thought to be extinct (BirdLife International 2013a), leaving us with 164 species. The scientific name for each species was used to joined each species range maps to the IUCN Redlist database to assess current threat status for each species (BirdLife International 2013a).

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 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. We calculated indirect impact from climate change as the average human impact within the species range of overlap. This is considered a conservative approach to estimating the impact of climate change on species range because it does not assume any dispersal of the species into areas outside the range the species currently occupies. Models that allow for species dispersal into areas that are not currently suitable, but are forecasted to become suitable in the future, result in lower estimates of range contraction. By not considering potential range expansion we may be overestimating the impact of climate change (Visconti et al. 2011).

SITE BASED VULNERABILITY ASSESSMENT: IMPORTANT BIRD AREAS

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 only to 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 distribution of 1401 bird species were overlain upon the spatial boundary of the IBA to identify predicted presence of each species both today and in 2055 based on the forecasted changes in climatic conditions (Hole et al. 2009). Species turner 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.

To calculate the indirect impact of climate change, we first applied a $50km^2$ buffer around the perimeter of the IBA to account for impacts from human activity that may originate from spatially proximate populations. Using the rescaled human impact index, we calculated the average climate change impact on human populations within each IBA inclusive of the $50km^2$ buffer around the IBA. We treated the average value of climate change in human populations in the IBA and the $50km^2$ buffer as the measure of the indirect impact of climate change on the IBA.

REGIONAL VULNERABILITY ASSESSMENT: ECOREGIONS

Ecoregions are defined as "relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities" (Olson et al. 2001). Iwamura et al. (2010) calculated the climatic stability of each terrestrial ecoregion using spatial data on five climatic variables; annual mean temperature, precipitation, cloud cover, vapor pressure, and diurnal temperature range. Iwamura et al. (2010) identified the climatic envelope occupied by each ecoregion today (1990–2002), and the predicted climatic conditions in the future (2047–2052) within the geography of the ecoregion (Iwamura et al. 2010). Climate stability was quantified as the proportion of the ecoregion's area that is forecasted in 2050 to have climatic conditions that fall inside the current climate envelope for the ecoregion. Climate stability ranges from 0 (highest instability) to 1 (completely stable). We treated climate stability as a measure of the direct impact of climate change on ecoregions. Using the rescaled human impact index, we calculated the average climate impact on human populations in each ecoregion for all ecoregions whose boundary intersected that of a SADC country (n=69). The average human impact within the ecoregion was treated as measure of the indirect impact of climate change.

INTEGRATING DIRECT AND INDIRECT IMPACT

Direct impact from climate change for each conservation target was measured with a ratio scale for all conservation targets, while the measure of indirect impact is an interval scaled measure of impact. For variables quantified on a ratio scale, like range loss for species, a species that loses 60% of range has lost twice as much as a species that loses only 30% of range. In contrast, indirect impact is measured on the interval scale, where the difference between a score of 30 and 60 reflects an increase in the level of indirect impact, but does not imply a doubling of indirect impact.

To avoid the introduction of additional subjectivity in our analysis through the aggregation of fundamentally different indices we chose to group targets based on the relative magnitude of each impact rather than combining direct and indirect impacts into a single aggregated index. By keeping the impact measures independent we are also able to distinguish between the different sources of impact confronting the conservation target and implications of that impact profile that may affect management strategies. To identify conservation target specific impact profiles we plotted indirect impact against direct impact for each conservation target. We then used mean value for each axis to divide the plotted space into four quadrants. To avoid over classification based on relative indices (labeling all targets as high risk because they were above mean), we specified a central polygon using the mean, one standard deviation above the mean, and a standard deviation below the mean on each axis to specify the end points. Linear interpolation between the four points was used to bound the central polygon. The central polygon was used to classify individual targets with impact profiles near the mean value of direct and indirect impact for all targets of its type. All targets were then placed into one of five categories based on the area of the plot they fell into (Fig 3). The five categories were: 1- Moderate, 2- low direct- low indirect, 3- High direct- low indirect , 4- High direct- high indirect, 5-Low direct- high indirect.

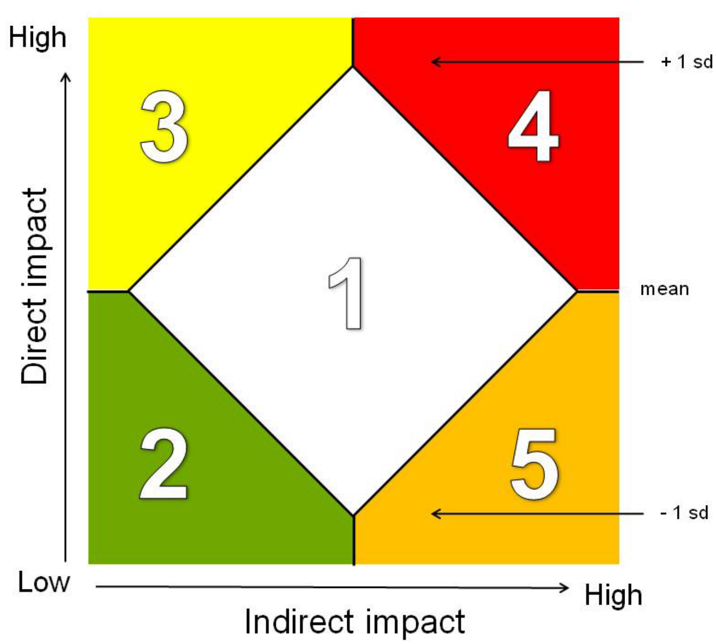

Figure 3. Shows a diagram of the biplot classification scheme matrix used to group conservation targets into one of five groups based on the relative presence of direct and indirect impacts. (1) White—Moderate direct and indirect impact, (2) Green—Low direct and indirect impact; (3) Yellow—High direct and low indirect impact; (4) Red—High direct and indirect impact, (5) Orange—Low direct and high indirect impact. The white area is defined using the mean value and a single standard deviation above and below to define the four corners of polygon, and linear interpolation between those points.

In addition to the broader groups we identified extreme examples within each of the groups to flag individual targets where management recommendations or conservation priorities would change most dramatically after consideration of the indirect impacts of climate change. To do this we considered a secondary classification scheme for each target that identified those targets that were identified most and least likely to be directly impacted by climate change. We defined low on both measures as features whose score was at least one standard deviation below the mean score. High impact was defined as those targets where the impact was greater than one standard deviation above the mean score.

Results

SPECIES ASSESSMENT: BIRDS

Mean direct impact (range contraction) for the 164 restricted-range terrestrial bird species was 39.6% (sd = 28.8) and mean indirect impact (human impact within the species overlap range) was 66.4 (sd =6.8). 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. There was a weak negative correlation between direct (range contraction) and indirect (human impact) impact of climate change (Pearson's r (162) =-0.42, $p<0.01$) (Fig 4).

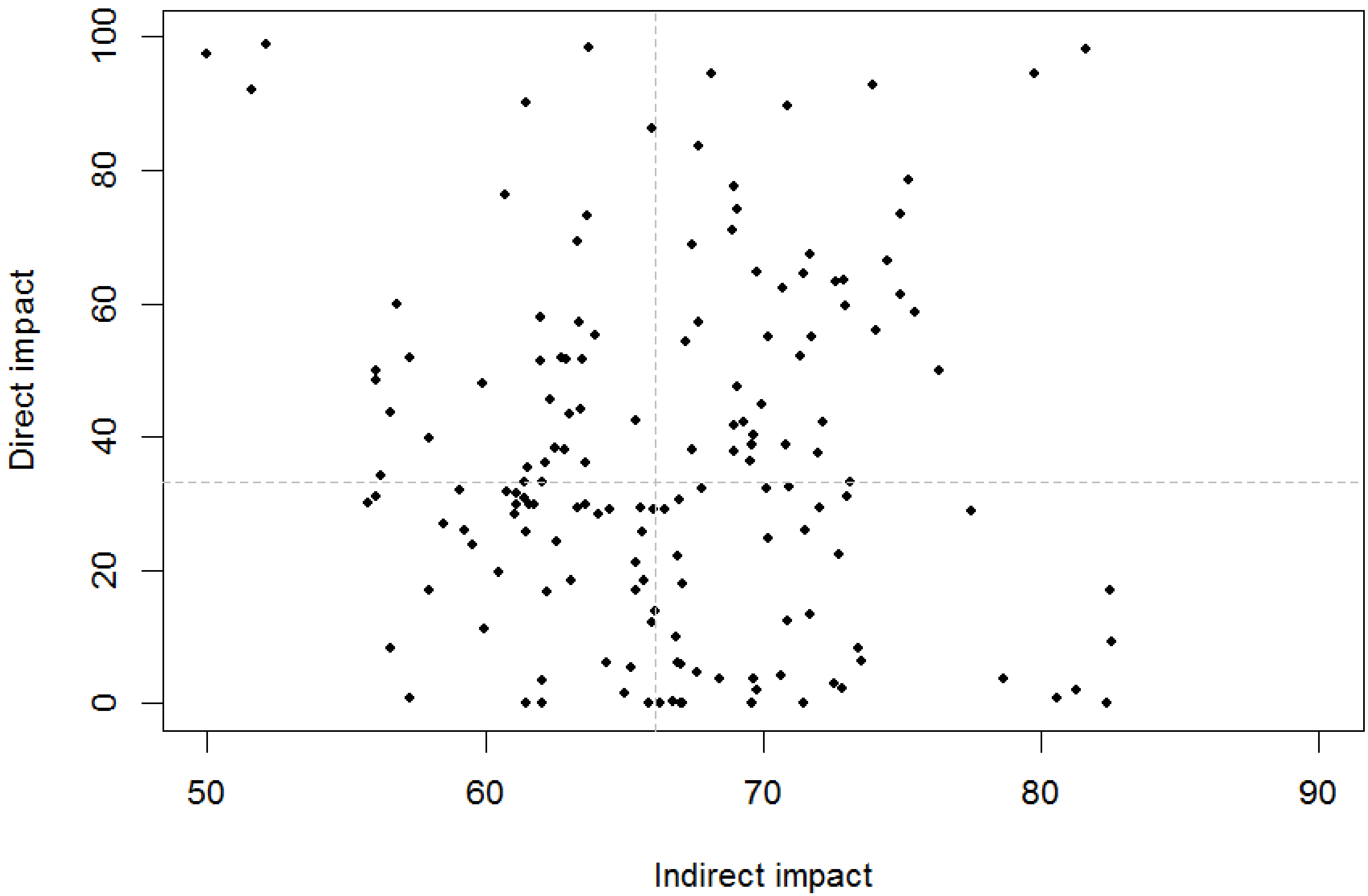

Figure 4. Forecasted range contraction due to the direct impact climate change by 2050 (y axis) for 164 avian species and the mean impact of climate change on human populations within the portion of the species that is forecasted to remain suitable in 2050 (x-axis). Dashed grey lines indicate the mean value for direct and indirect impact, and numbers correspond to species id in table s3 of the supplementary materials.

Applying the broad impact classification scheme we found that the moderate direct/indirect impact category included 81 (49.4%) of species and was the largest category, while the least populated category was low direct / low indirect which contained only seven (4.3%) of species (Table 1). Twenty-six species (15.9%)were placed in the high impact category for both direct and indirect impact. An additional 34 species (20.7% were identified as having high indirect impacts and low direct impacts, and thus are potentially overlooked in assessments focused only on direct impacts. For example the critically endangered Long-billed Tailorbird (*Artisornis moreaui*) is forecasted to lose less than 5% of current range, but had the third highest indirect impact score. The species is known from less than five locations in Tanzania and Mozambique and is currently experiencing range contraction due to clearing of native vegetation (BirdLife International 2013b).

Table 1. Relative Abundance of Conservation Targets Within the Five Impact Profile Categories

Classification	Birds	IBAs	Ecoregions
High Direct / High Indirect	26 (15.9 %)	42 (12.7 %)	15 (21.7 %)
High Direct / Low Indirect	16 (9.8 %)	68 (20.5 %)	6 (8.7 %)
Low Direct / High Indirect	34 (20.7 %)	81 (24.5 %)	10 (14.5 %)
Low Direct / Low Indirect	7 (4.3 %)	53 (16 %)	20 (29 %)
Moderate direct/indirect	81 (49.4 %)	87 (26.3 %)	18 (26.1 %)

Note: Classification was conducted independently for each conservation target based on the algorithm outlined in figure 3

Restricting the analysis only to those species at the edges of the direct and indirect impact spectrum we identified 32 (19.5%) species for which the direct impact of climate change would be smallest. Seven (21.9% of very low impact and 4.3% of all birds) of those species had very high indirect impact scores (Table 2), while only two were identified as likely to experience very low indirect impact. The Long-tailed Ground-roller (*Uratelornis chimaera)*, a Madagascan endemic, is an example of species with very low direct impact and very high indirect impact. It is not forecasted to lose any of its range due to the direct impact of climate change (suitable habitat is forecasted to almost double in size), however indirect impact within its range was the third highest of any species evaluated. A further 28 (17.1%) species were identified as being most impacted by the direct impact of climate change of which five were also at the highest levels of indirect impact.

Table 2. Bird Species at the Highest and Lowest Level of Expected Direct and Indirect Impact

		Indirect impact: High	Indirect impact: Low
Direct impact	**High**	5 (3 %) Slender-billed Flufftail (*Sarothrura watersi*) Subdesert Mesite (*Monias benschi*) Madagascar Pochard (*Aythya innotata)* Angola Cave-chat (*Xenocopsychus ansorgei*) Botha's Lark (*Spizocorys fringillaris*)	10 (6.1 %) Djibouti Francolin (*Francolinus ochropectus*) 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)*

Note: 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.

Family level analysis performed on families with three or more representatives in study region revealed that indirect impacts where highest for Brachypteraciidae (Ground Rollers), Mesitornithidae (Mesities), and Anatidae (Ducks, geese and swans) and lowest for Turdidae (Thrushes), Malaconotidae (Helmetshrikes, bushshrikes and puffbacks), and Ploceidae (Weavers and allies) (Fig. 5).

Analysis of IUCN Redlist status for range-restricted birds revealed that "threatened" species ("threatened" includes three ICUN Redlist status categories; 'critically endangered', 'endangered' and 'vulnerable') were forecasted to experience greater levels of indirect impact. Mean indirect impact for threatened species was 67.6 (sd= 6.5), while mean impact in the range of non-threatened species was 64.9 (sd=7.0) (two sample t(133) =2.4, p=0.02). However the between category variability in indirect impact for ICUN status was not significant (one-way ANOVA, F (5, 157) = 1.2, p =0.29) (Figure 6).

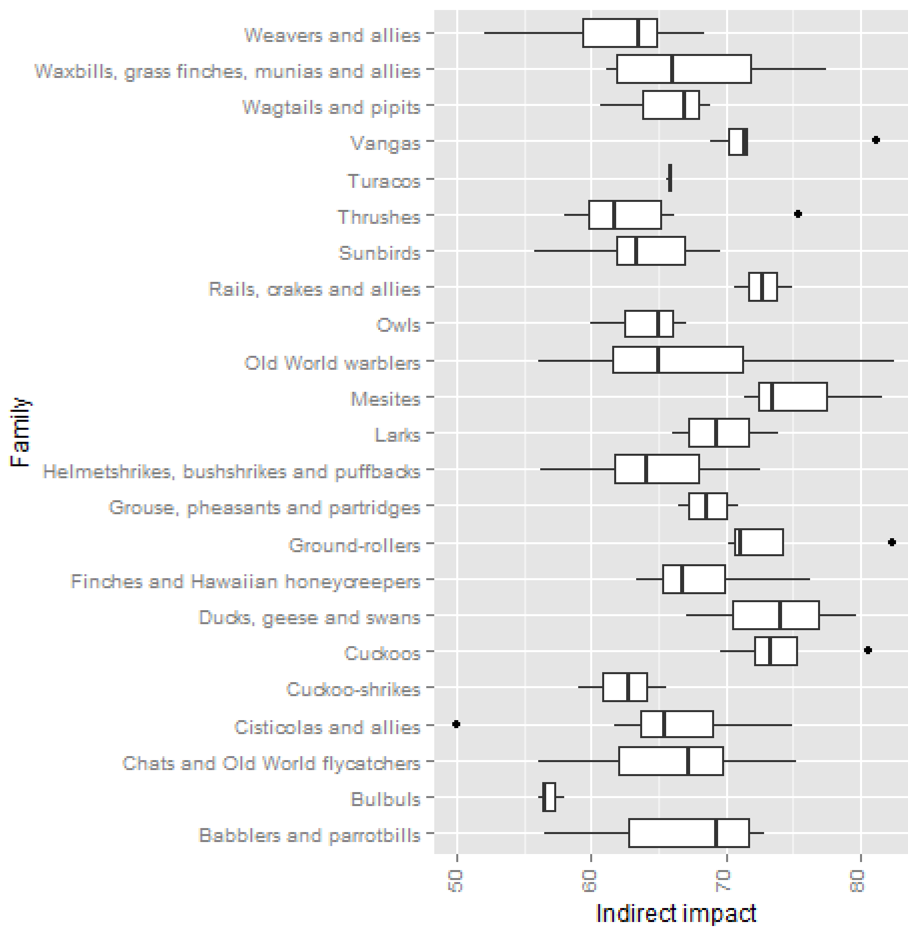

Figure 5. Indirect impact from climate change for restricted range terrestrial bird species, aggregated to the family level. Analysis excludes all species that are forecasted to lose all of their current range as a result o the direct impact of climate change. Only families with three or more representatives in the study region are included in the figure.

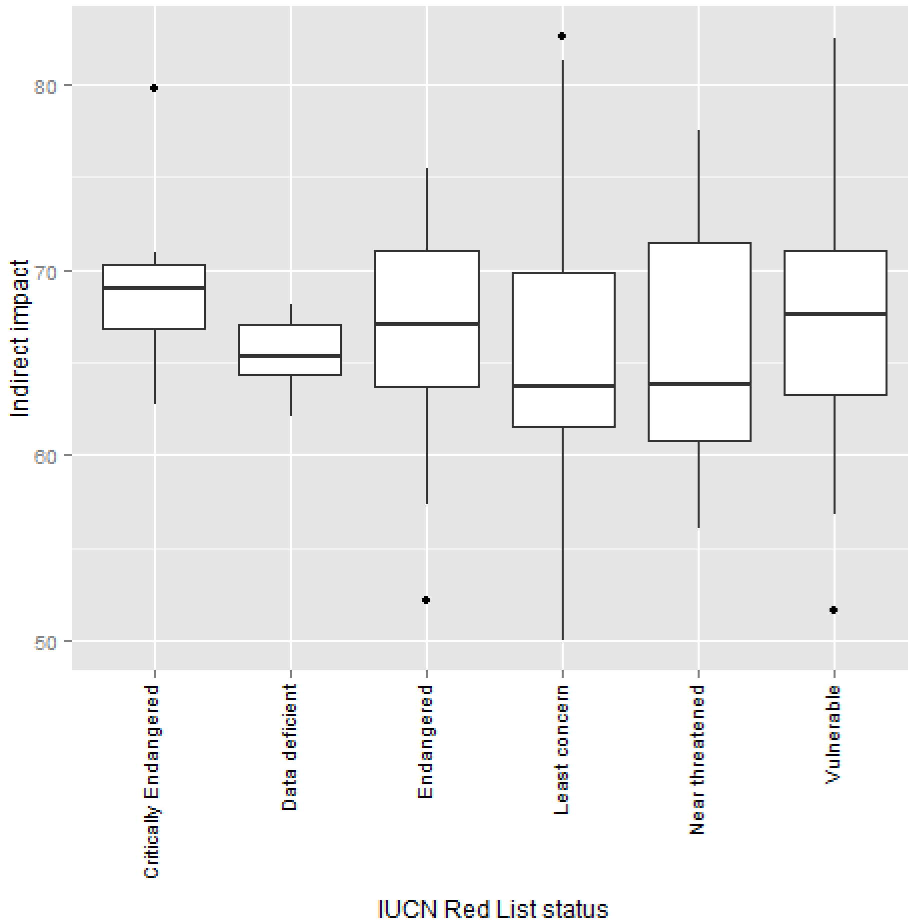

Figure 6. Indirect impact threat from climate change within the range of 157 range restricted terrestrial bird species, summarized by the IUCN Red List status. Analysis excludes all species that are forecasted to lose all of their current range as a result o the direct impact of climate change. IUCN Red List status reflects the conservation status and risk of extinction for each species and is widely recognized as the most systematic list of its kind.

SITE-BASED ASSESSMENT: IMPORTANT BIRD AREAS

Mean direct impact (species turnover) in IBAs was 22.6 (sd = 11.2) and mean indirect impact was 66.3 (sd =7.2). There was no correlation between direct and indirect impact in IBAs (Pearson's r (329) =-0.08, p=0.16) (Fig 7). Spatial overlay of the direct and indirect impact for IBAs, revealed the highest proportion of IBAs fell into the moderate and low direct / high indirect categories, 87 (26.3 %) and 81 (24.5 %) respectively (Fig 8). Two IBAs identified in the low direct / high indirect impact category were not predicted to experience any turnover due to the direct impact, these were Liqobong and Sehlabathebe National Park, both located in Lesotho. The smallest category by proportion of total IBAs was the high direct/high indirect category, which contained 42 IBAs or just 13% of the all IBAs, the lowest proportion of any of the three conservation targets identified as high impact to both (Table 1).

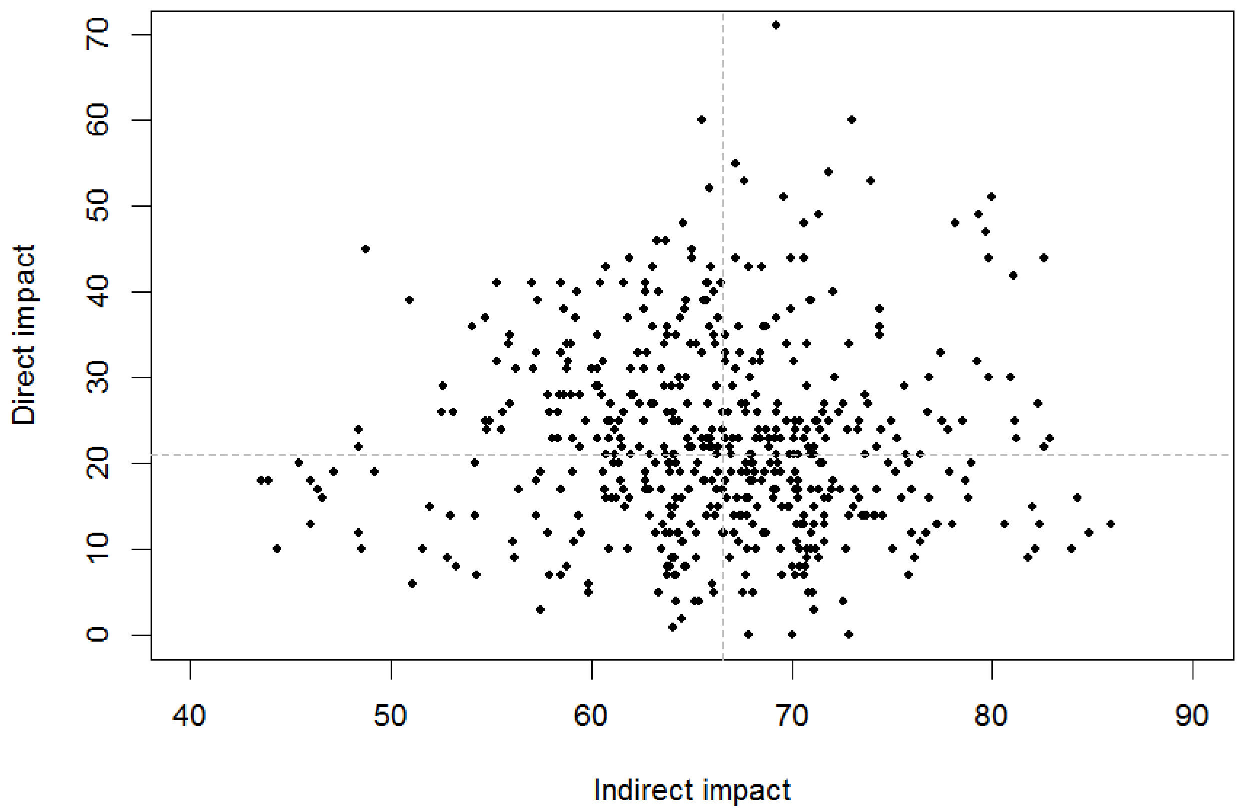

Figure 7. Forecasted turnover in species composition in the IBA, and mean human impact in the IBA and 50km^2 radius.

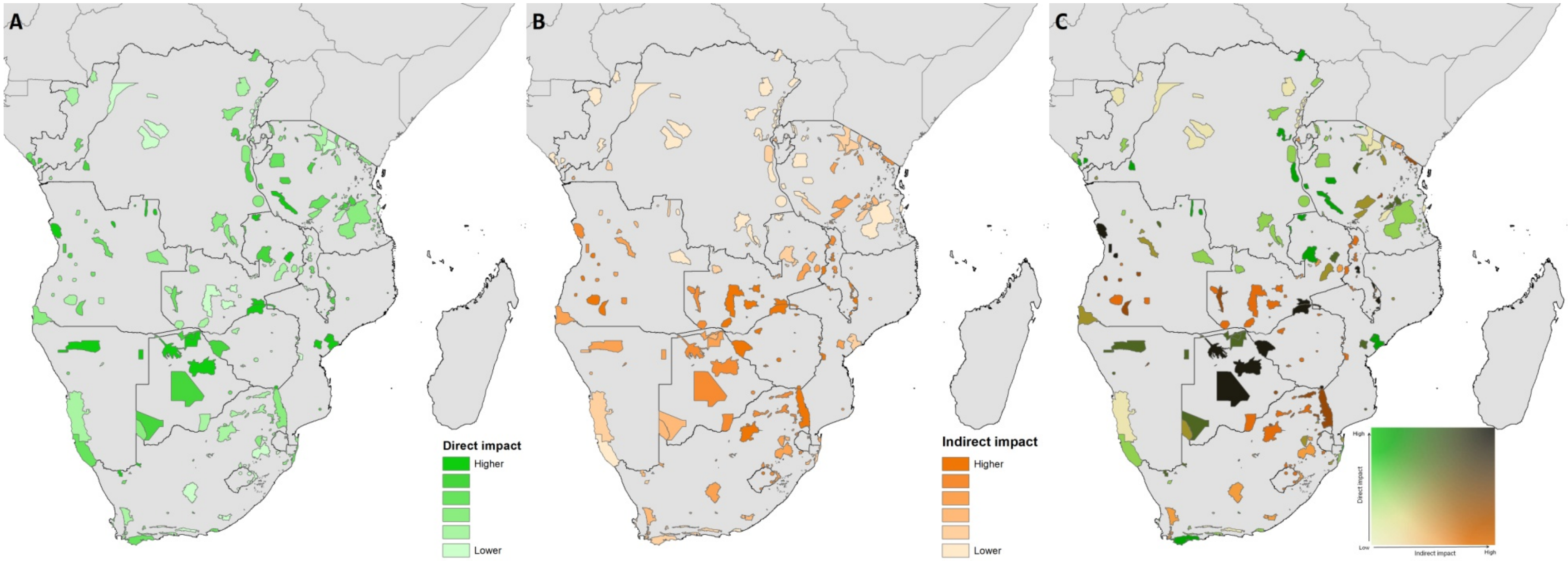

Figure 8. A) Forecasted turnover in IBA species composition by 2050 due to climate change (direct impact). Darker colors indicate higher levels of turnover. B) Impact of climate change on human populations inside and within a 50km radius of each IBA. Darker colors indicate greater degrees of human impact (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.

Spatially assessing the distribution of the impact categories we find that the moderate impact class was distributed uniformly throughout the study region, while low impact categories were concentrated in the north of the region. IBAs with high level of impact on both axis were concentrated in Botswana, southern Malawi, northern Namibia, and western Angola. The low direct / high indirect impact category IBAs were spatially concentrated in northeast South Africa including Lesotho and Swaziland, northern Malawi, Zambia and Zimbabwe (Fig 9).

Restricting the analysis only to those IBAs at the edges of the direct and indirect impact spectrum we identified 48 (14.5%) very low direct impact IBAs (impact less than one standard deviation below the mean), of which six (12.5% of low impact and 1.8% of all IBAs) had very high direct impact scores (Table 3). These six include Mafika-Lisiu in Lesotho, Dzalanyama Forest Reserve in Malawi, Chimanimani mountains in Mozambique and Zimbabwe, Chisamba and Kafue flats in Zamiba, and the Mavuradonha mountains in Zimbabwe. These sites are most likely to be overlooked by vulnerability assessments focused only on the direct impact of climate change. We further identified 55 (16.6%) IBAs where the direct impact of climate change was likely to be greatest, of which seven (12.7% of high impact, 2.1% of all IBAs) were also identified as sites where the indirect impact of climate change was likely to be very high (Table 3). These are sites where conservation efforts to deal with climate change may be further complicated by the human response.

Country level analysis of the IBAs revealed differences in between country profiles. Botswana, Malawi and Zimbabwe have the greatest proportion of IBAs identified as at high risk to both impacts (56%, 47% and 50% respectively) (Fig 9). South Africa has the most IBAs in the low direct, high indirect impact profile (n=28), however this accounted for less than a third of South Africa's IBAs. All of Lesotho's IBAs (n=6), 53% of Malawi's (n= 10), and 50% of Zimbabwe's IBAs (n=9) fell into the low direct/high indirect category the highest proportions by country.

Table 3. IBAs at the Highest and Lowest Level of Expected Direct and Indirect Impact

		Indirect impact	
		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

Note: 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.

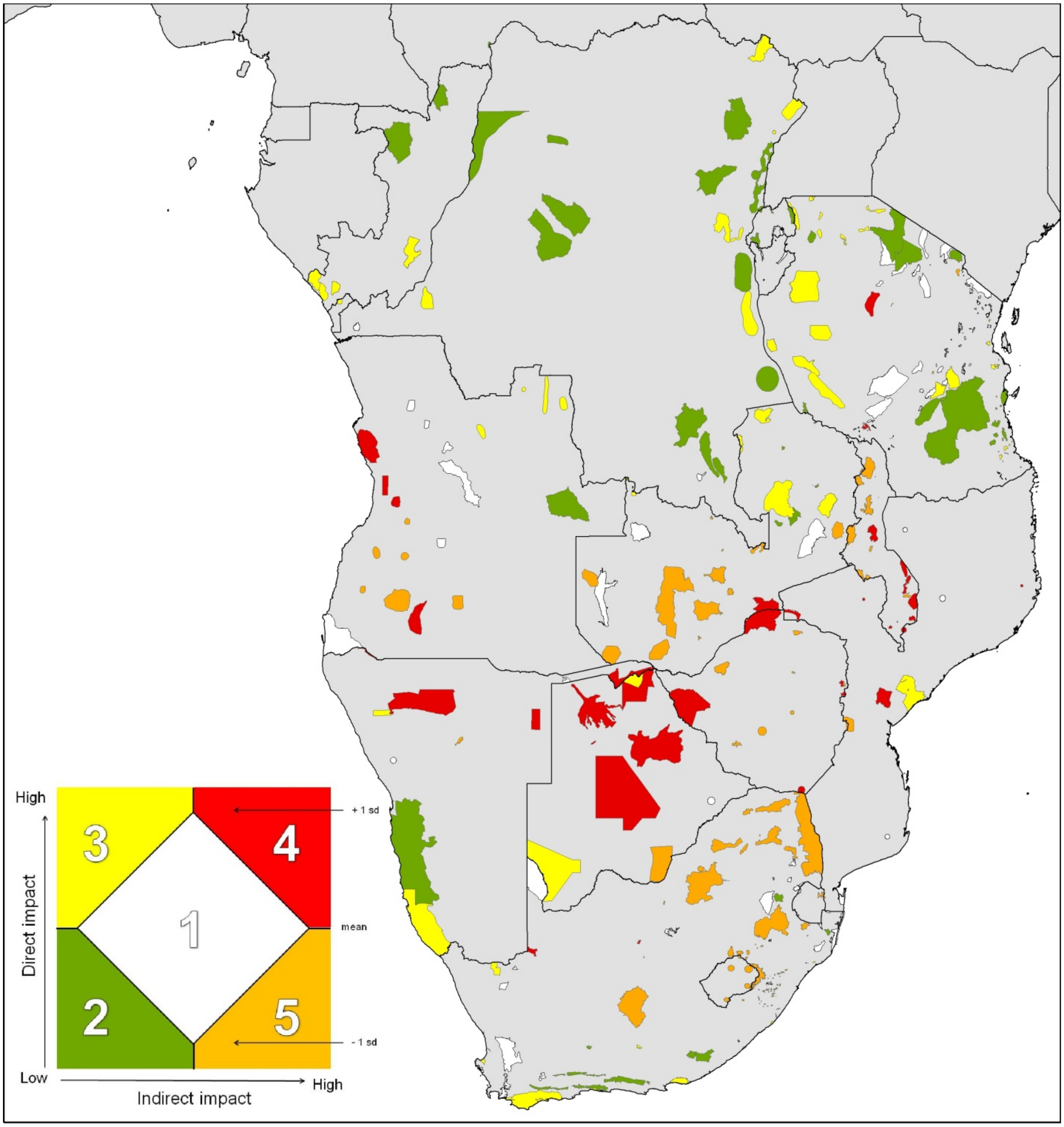

Figure 9. IBAs categorized based on the species turnover (direct impact) and human response (indirect impact).

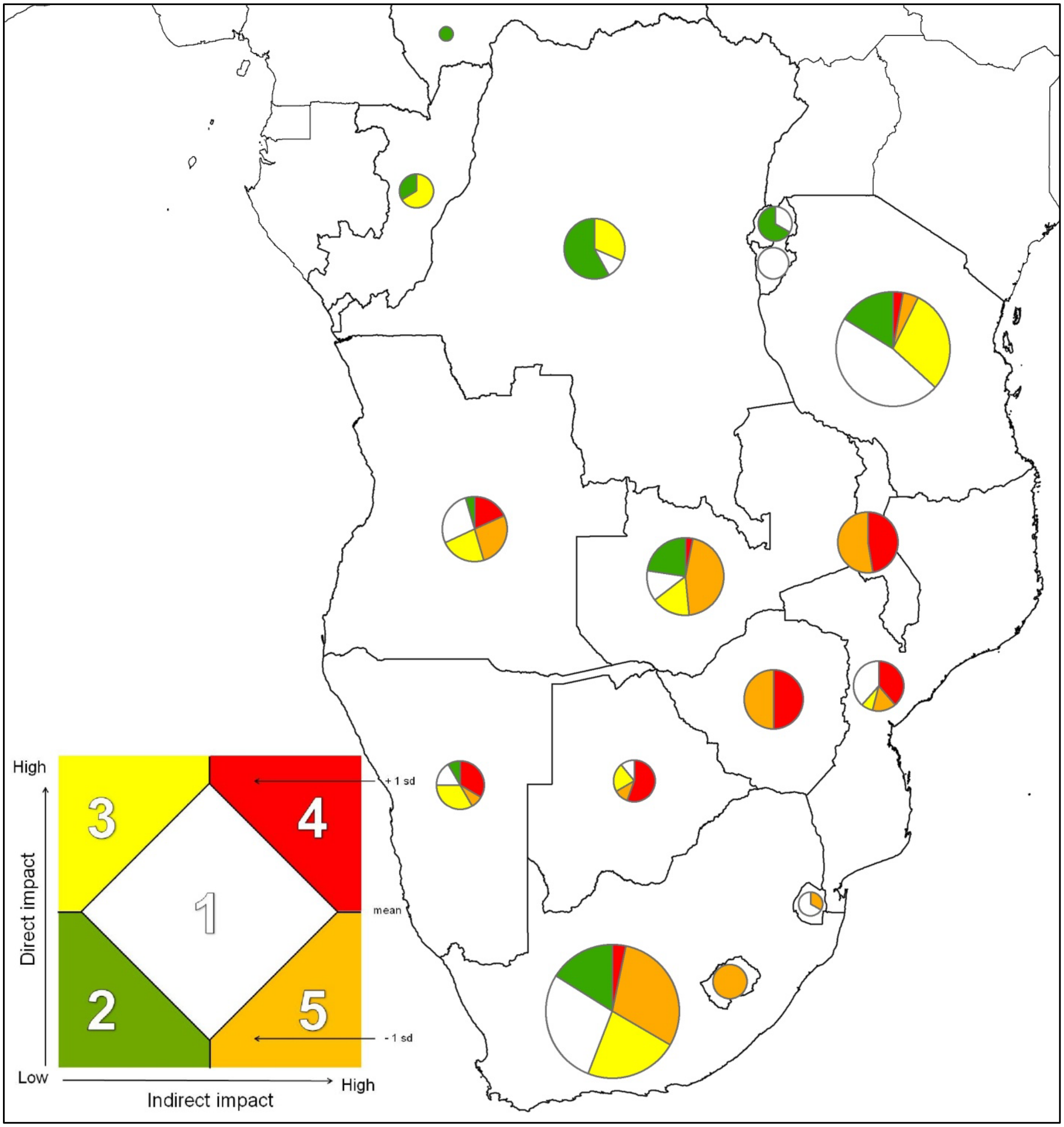

Figure 10. Country level of summary of 331 IBAs in the SADC region categorized based the forecasted prevalence direct and indirect climate change impacts in 2050. Direct impact to climate change is expressed as the forecasted species turnover due to climate change by 2050 (higher values indicate greater species turnover). Indirect impact of climate change is expressed as forecasted impact of climate change on human population within a 50km^2 radius of the IBA (high level indicate human populations will be more impacted by climate change). Pie charts indicate the proportion of each country's IBAs that fall into each impact profile.

REGIONAL ASSESSMENT: ECOREGIONS

Mean direct impact (climate stability) of ecoregions was 54.8 (sd = 15.3) and mean indirect impact (human impact) was 64.7 (sd =7.0). There was no correlation between direct and indirect impacts of climate change at the ecoregion level (Pearson's r (67) =-0.22, p=0.06) (Fig 11). Overlaying indirect and direct impact we are able to identify 15 ecoregions where the direct impact of climate change is likely to be exacerbated by the response of human populations (indirect impact). These ecoregions are spatially aggregated along coastal Madagascar, and on the mainland in eastern South Africa stretching north to southern Zambia and west to Namibia and southern Angola (Fig 12 & 13). We identified an additional 10 ecoregions where direct impact is relatively low, but where indirect impact is high. These ecoregions include the sub-humid and tropical forests of central and western Madagascar and the woodland forest mosaic ecosystems on the border between Malawi, Mozambique, Zambia and Zimbabwe, and are most likely to be overlooked by vulnerability assessments focused on direct impacts (Fig 12 & 13).

Restricting the analysis only to those ecoregions at the edges of the direct and indirect impact spectrum we identified eight (11.6%) very low direct impact ecoregions, none of which fell into either the very high or low indirect group (Table 4). Of the eight ecoregions identified as most likely to be most impacted by the direct impacts of climate change, of which three fell into tails of distribution for indirect impact. Both ecoregions identified as at the highest level for both direct and indirect impact were located in Madagascar.

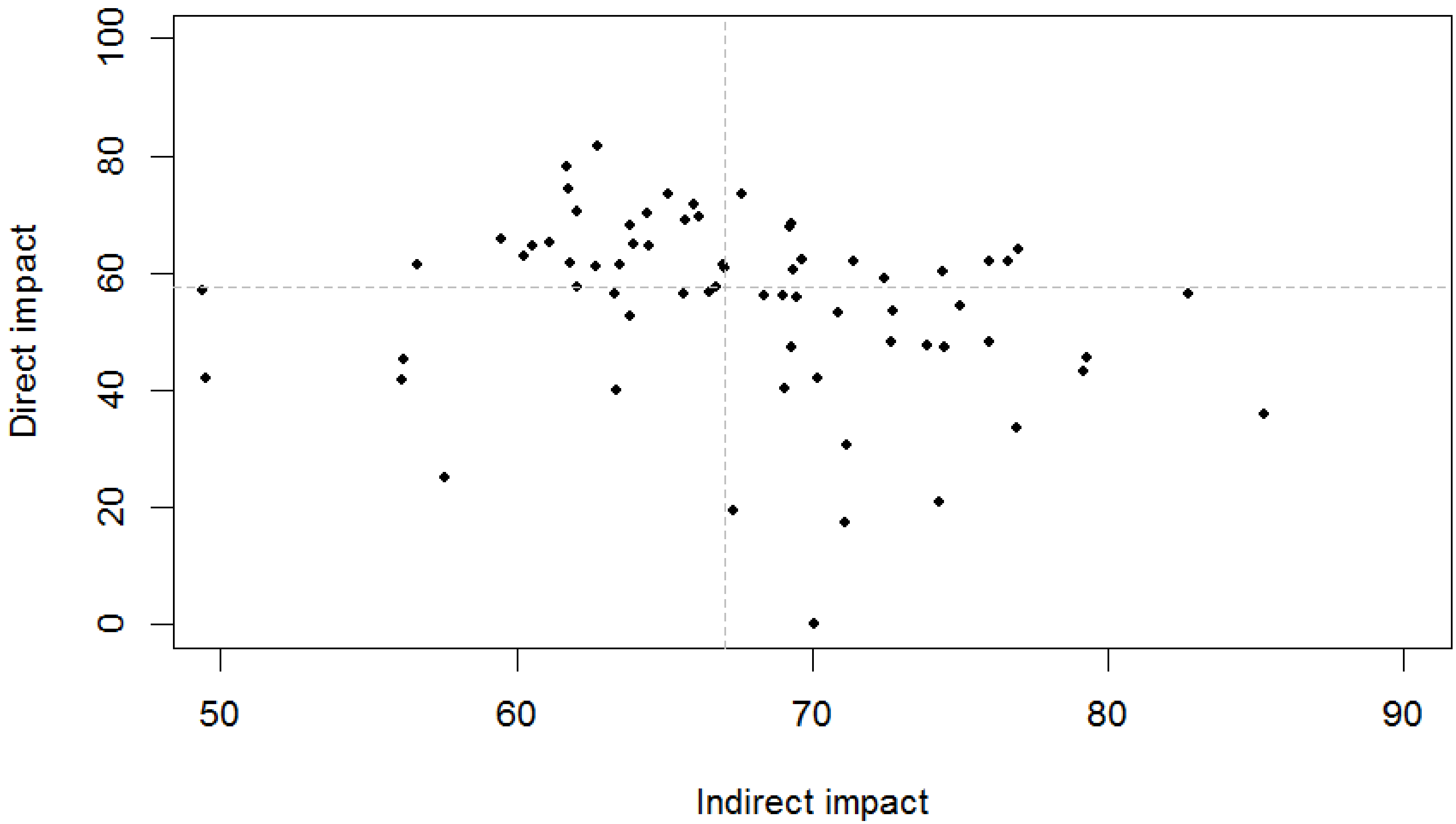

Figure 11. Forecasted direct and indirect impact of climate change in the ecoregions in SADC countries. Direct impact is expressed as the climate stability of each ecoregion per (Watson, Iwamura, and Butt 2013). Indirect impact is expressed as the mean impact of climate change on human populations within the ecoregion (Midgley, Davies, and Chesterman 2011). The horizontal dashed line represents the median vulnerability of human populations in ecoregions and vertical dashed line indicates median stability of ecoregions in the SADC region.

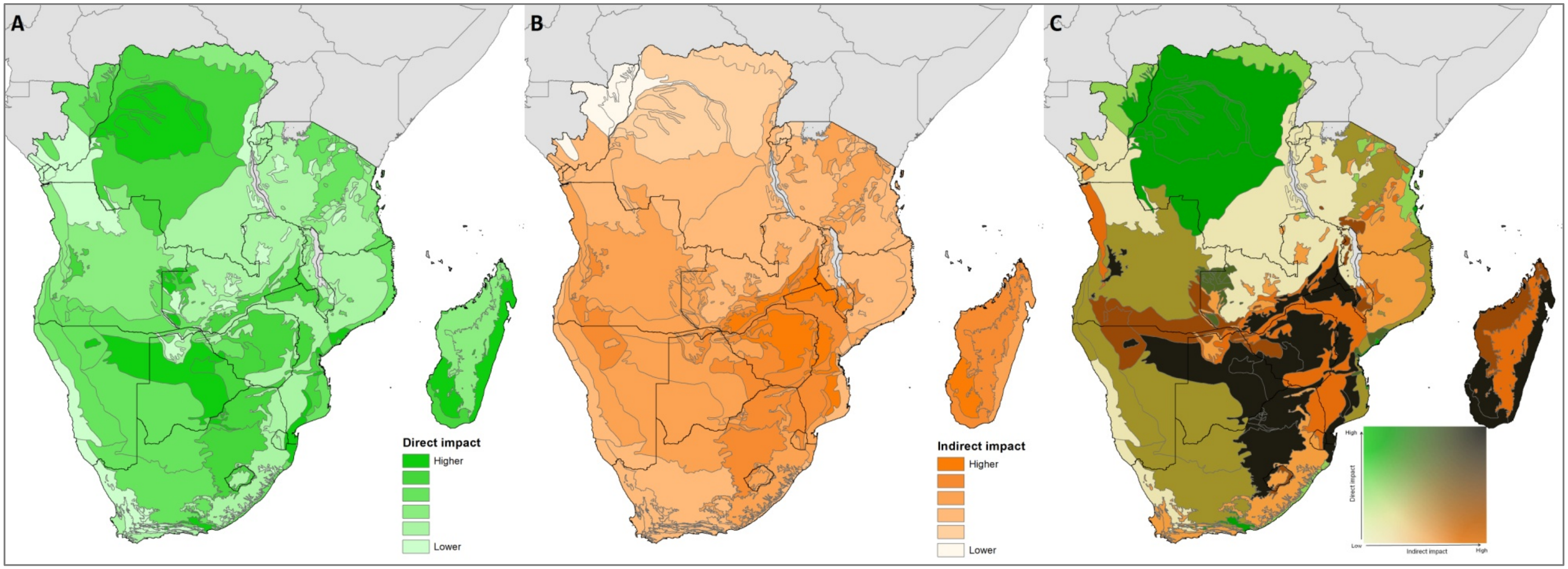

Figure 12. A) Ecoregion stability, darker colors indicate increasing degrees of instability (higher direct impact) B) Impact of climate change on human populations within the ecoregion, darker colors indicate increasing degrees of human impact (indirect impact on biodiversity). C) Overlay of ecoregion stability and impact on human populations. 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.

Table 4. Ecoregions at the Highest and Lowest level of Expected Direct and Indirect Impact

		Indirect impact	
		High	**Low**
Direct impact	**High**	2 (1.2 %) Madagascar ericoid thickets Madagascar succulent woodlands	1 (0.6 %) Central Congolian lowland forests
	Low	0 (0 %)	0 (0 %)

Note: No ecoregion identified as likely to experience low direct impact was identified as either high or low for indirect impact.

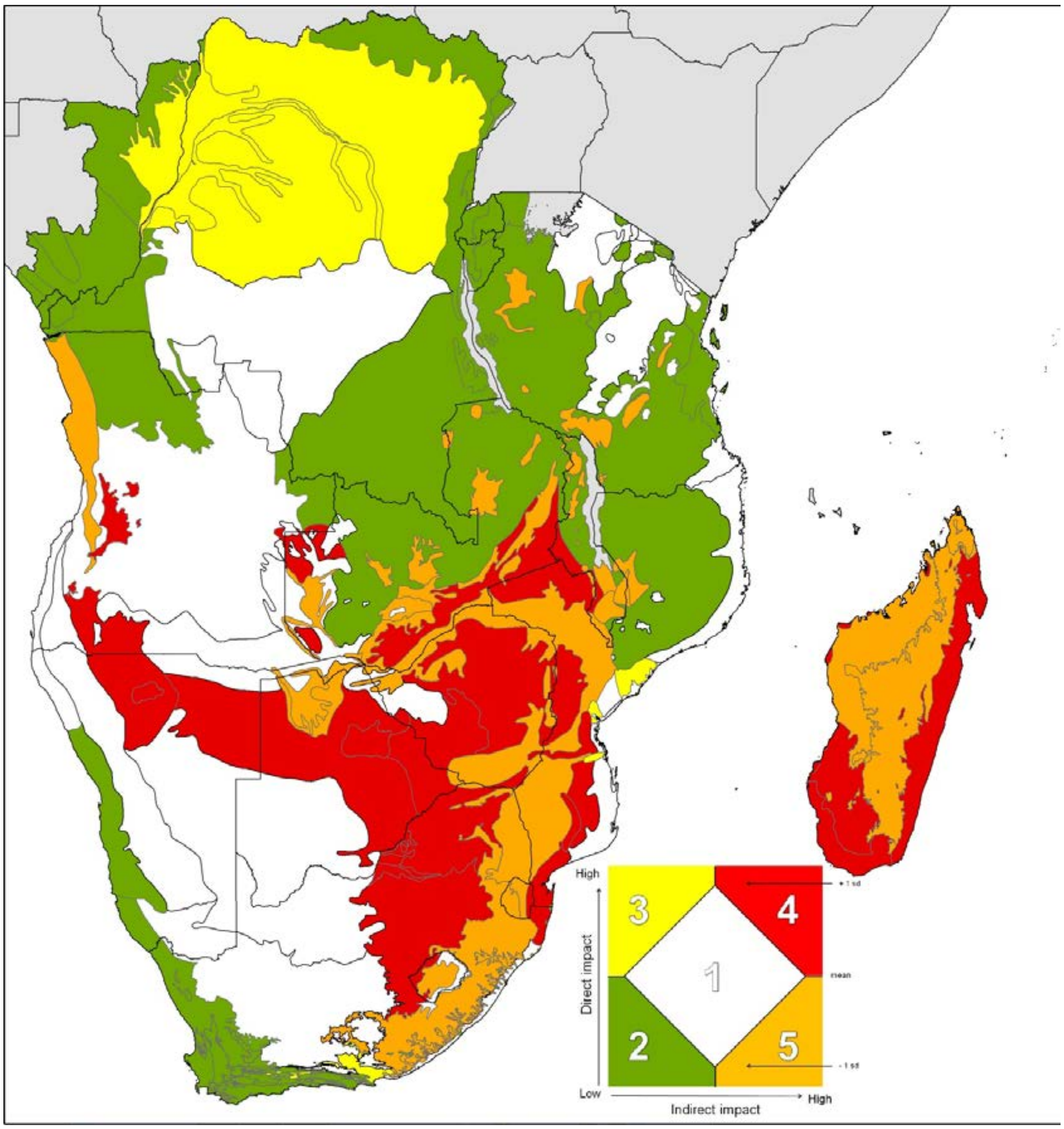

Figure 13. Overlay of direct and indirect impact from climate change to ecoregions in the SADC region. Ecoregions are grouped and colored in accordance with the relative magnitude of direct and indirect impact forecasted to be present. Yellow and red ecoregions are those where most likely to be identified by assessments that focus on direct impacts only. Orange ecoregions are most likely to be overlooked by conservation vulnerability assessments that focus only on the direct impact of climate change. Methods for assigning ecoregions into one of the five categories are detailed in Figure 2.

Discussion

The essential contribution of our work is the development of a framework that improves our understanding of the risk climate change poses for different conservation targets through the formal incorporation of human responses to climate change; referred to in this paper as indirect impacts. By applying this framework to three commonly used conservation targets (species, sites, regions), we have demonstrated how our understanding of vulnerability is altered, and how this impacts both conservation priorities and choice of conservation strategies Through the incorporation of information about the likely human response to climate change (indirect impacts) we have identified regions, sites, and species that are likely to be impacted by climate change, but would have been overlooked by vulnerability assessments focused solely on the direct impact of climate change (Tables 1–4). The work has broad implications for the development of effective management strategies and the allocation of conservation resources, of which specific sites and species qualify as priorities for climate change funding.

Human populations, as they seek to reduce their vulnerability to the negative impacts and take advantages of new opportunities that climate change provides, are modifying their activities. It is imperative that we use information about the potential shape of this response to inform our conservation planning. By ignoring the indirect impacts of climate change in conservation planning we fail to account for the reality and complexity of socio-ecological systems we work in. This failure is likely to result in sub-optimal management and allocation of scare conservation resources that could jeopardize our ability to ensure achievement of our long term conservation objectives. It also means our conservation priorities may overlook the very suite of species, sites and ecosystems that are most threatened by climate change. Moreover, the failure to consider the full scope of the interaction in the socio-ecological system may also cost us the opportunity to identify areas and adaptation solutions that benefit both biodiversity and people. 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 identified that benefited both people and biodiversity.

The lack of correlation between the direct and indirect impact indicators for IBAs and ecoregions and weak correlation for species suggests that the incorporation of the human response to climate change will provide novel information to the assessment of conservation vulnerability (Fig 2). Human populations are critical actors in socio-ecological systems, and this work shows the shortfall of not considering the human response to climate change or in assuming the response of human communities is driven by the same climatic cues. Numerous assessments of climate change have highlighted that for both species and human populations, exposure to climate change is not directly correlated to impact or vulnerability (Bellard et al. 2012; Midgley, Davies, and Chesterman 2011). If the lack of the 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 direct impacts must be re-examined.

The incorporation of the likely human response for the three conservation targets has unique planning implications. For species, 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. When we incorporated the indirect impact of climate change into 164 species vulnerability assessments, we found a set of species whose vulnerability to climate change is systematically underestimated by vulnerability assessments focused only the direct impact of climate change. Two stand-out examples that emerged from our assessment were Pollen's vanga (*Xenopirostris polleni*) and Black-cheeked Lovebird (*Agapornis nigrigenis*). Pollen's vanga occupies rainforests in Madagascar and is currently listed as near threatened, but is expected to lose habitat to forest clearing and degradation in the next decade (BirdLife International 2013b). 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 increased habitat loss of the species. The Black-cheeked Lovebird is a vulnerable species known primarily from records in south west Zamiba. The species has experienced recent declines in population that are thought to be linked to reduced surface water within its range (BirdLife International 2013a). Declines in surface water are through to be linked to climate change and exacerbated by wells drilled for human consumption (BirdLife International 2013a). Both warmer temperatures and a projected decline in rainfall in January and February (Jain 2007) could increase human demand for water to offset agricultural declines. For both of these species, they were considered not vulnerable when considering only the direct impacts of climate change but were identifies as highly vulnerable when the indirect analysis was integrated into the assessment.

When targeting action at species identified as vulnerable to climate change a common recommendation is to identify and protect corridors or stepping stones 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 (Nuñez et al. 2013; Willis et al. 2008), 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 common sense "no-regrets" conservation strategy, because action in these areas will benefit the species today, and will continue to yield benefits even if the species range shift does not follow the anticipated path (Glick, Stein, and Edelson 2011). However, these seemingly low risk approaches may look entirely 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 targeted effort in a part 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.

The implications of incorporating the human response into climate change vulnerability assessments and conservation planning is fundamentally different at the site scale than it is for species, because sites are generally a conservation response rather than a target of conservation in itself. When considering the impact of climate change on sites important for conservation (e.g. protected areas, IBAs), the questions generally posed are framed around the movement of species in response to the direct impact of climate change. To what extent will species move into or out of the site in response to climate change (Araújo et al. 2004; Hannah et al. 2007)? Or how should management respond to shifts in species composition within a sites (Hole et al. 2011)? Understanding the answer to these questions is fundamental to understanding what the value of that site will be in the future and how the site may contribute to wider conservation objectives.

However, understanding the future composition based on the direct impacts of climate change is not sufficient to prioritize resources between sites or identify management actions at a site. Many IBAs are already impacted by human activities- Birdlife International in the past found that over 50% of Africa IBAs are threatened by habitat loss to agriculture (BirdLife International 2004). In and around these sites designated for conservation, people are already responding to climatic changes in ways that are having adverse impacts on the species inhabiting those sites. A good example is the Kafue flats IBA in Zambia, which is at low risk to the direct impact of climate change (turnover less than 10%) but also identified as an area where the human population is likely to be highly impacted (table 3). The site is a seasonally flooded wetland that at the widest point the area of inundation stretches almost 70km across. Hydropower dams have been constructed that regulate the flow through the area, and although in principle the simulated flow regimes were aimed to mimic natural inundation regimes, fears around water shortages have meant that those agreements have not always been honored (BirdLife International 2013c). The expected increase in both the frequency and intensity of extreme climatic events such as droughts (Seneviratne et al. 2012) may increase the potential for human wildlife conflict in areas like Kafue flats in the future. Increased drought frequency is likely to be accompanied by additional pressure on managers to deviate away from natural flow regimes and towards one that primarily serves human to satisfy water demands of local agriculture. Such a deviation could be devastating to species dependent on the annual flooding patterns. Proactive planning that identifies areas where conservation managers will face additional challenges in response to changing human demands are an essential part of planning for the future in sites where the impact of climate change on people is likely to be high.

The implication of incorporating the human response to climate change at the ecoregional scale depends on the conservation objectives for the ecoregion. Objectives for ecoregional conservation could be maintenance of the diversity within the ecoregion or preservation of the undistributed qualities of the place (*ref*). Ecoregions are ecologically distinct units (Olson et al. 2001) that are commonly used as coarse surrogates for biodiversity by international funding institutions and conservation organizations seeking to identify global conservation priorities (Funk and Fa 2010; Watson, Iwamura, and Butt 2013). However the composition of species and functions that contribute to the unique qualities of the ecoregion today are likely to be reshaped by climate change. If the goal is place-based conservation, or ensuring that human disturbance of an area is minimized, then an understanding of where human activity may increase or change as a response to climate change will allow for the identification of areas where conservation success may be difficult to achieve.

One approach to dealing with this is to prioritize resources to those ecoregions that are least likely to be impacted by these direct impacts of climate change (Iwamura et al. 2010). Watson et al. incorporated the extent to which the ecoregion was currently modified by human activities to identify management objectives and suites of activities likely to be employed to achieve those objectives (Watson, Iwamura, and Butt 2013). A second approach developed by Gillson et al. (2013) utilizes a framework that incorporated rate of climate change and both the level of intactness and the current amount of protection within an area to identify conservation strategies for dealing with climate change. Both approaches advance earlier efforts that consider only the direct impact of climate change, but neither explicitly considers what people will do in the future within an ecoregion. We identified two ecoregions where these frameworks fail. One was the Eastern Zimbabwe montane forest-grassland mosaic ecoregion where the direct impact of climate change is likely to be low, but where the impact of climate change on human populations is likely to be high. Areas suitable for agriculture have already been extensively cleared within the ecoregion, but intactness overall remains high and although further areas are at risk of clearing, a number of national parks are present and the ecoregion is thought to be well protected (WWF 2012). The direct impact of climate change would seem to suggest that the ecoregion may not be a priority for climate change funding, but the impact of climatic changes on the human populations within the ecoregion suggests that efforts to mitigate the indirect impacts of climate change is likely to be required.

Understanding the human response to climate change provides us insight into the cost, likelihood of success and potential complications of achieving conservation, factors which can be explicitly incorporated into decision making frameworks (Joseph, Maloney, and Possingham 2009). The discipline of conservation planning has collectively acknowledged that conservation actions do not occur in a vacuum and that their achievement requires consideration of other users (both current and potential) of the land/seascapes and sometimes requires difficult trade-offs between conservation objectives and the objectives of other stakeholders (eg. agriculture, forestry, mining sectors). In order to identify where these trade-offs may occur spatially explicit information on the cost of likelihood of achieving conservation objectives in an area has been incorporated into the planning effort to inform the identification of conservation priorities (Fuller et al. 2010; Klein et al. 2008; Polasky 2008). An understanding of how climate change may alter the suitability of the land and seascape for other uses is a logical next step to understanding and prioritizing conservation action. The incorporation of information on future human use of the area is also essential to estimating the probability that our conservation actions will succeed, and allowing us to avoid one of the common mistake in conservation planning: not acknowledging risk of failure (Game, Kareiva, and Possingham 2013). In the arctic for example, we already know that melting sea ice is creating new opportunities for shipping and for exploration of petroleum and minerals in areas that were previously not accessible (Prowse 2009). Ignoring these changes in how humans will use the landscape will place the conservation future of those landscapes in unnecessary risk.

CAVEATS

It is important to note a number of potential caveats to the current analysis. In calling specific attention to these caveats we hope to aid in the interpretation and application of the results, and to highlight areas that could be advanced through future research. First, we note that the use of aggregate measure of human impact (e.g. a weighted index that includes multiple underlying drivers) means that we are unable to identify the exact source (or sources) of the expected impact in any individual locality. Potential sources of the impact include reduced agricultural yield, sea-level rise, droughts, declining human health and the potential synergy between these changes and increased natural resource demand from population growth (Midgley, Davies, and Chesterman 2011). The human response to each is likely to be different, and understanding the individual responses are critical to formulating appropriate conservation responses.

The response of human communities to the similar climatic shifts or impacts will also vary with respect to the adaptive capacity of that society, or the society's ability to organize action and marshal resources to support adaptive responses that reduce vulnerability and take advantage of new opportunities. For example projected exposure to climate change is relatively low in the Democratic Republic of Congo, but low relative adaptive capacity and forecasts for high population growth lead to its identification as an area of high vulnerability (Midgley, Davies, and Chesterman 2011). The spatial signature apparent in vulnerability (which includes adaptive capacity) is noticeably different from the impact measure we use in our assessment. Midgley et al. suggest that there are five major clusters of vulnerability to climate change in the SADC region; 1- North Central Tanzania, 2- East-Central Madagascar, 3- Angola, 4- Democratic Republic of Congo (DRC), 5- southern and central Mozambique, Malawi, Zimbabwe and southern Zambia (Midgley, Davies, and Chesterman 2011). These are areas where the dominate response to climate change may be reactive, and conservation managers should be prepared for potential abrupt changes in human behavior (Berrang-Ford, Ford, and Paterson 2011). Analyzing the human response with a measure that included adaptive capacity may yield different results, but the incorporation of societal adaptive capacity is critical to understanding how human communities will respond to climate change.

The relationship between higher societal adaptive capacity and likely impact of that society's response to climate change on biodiversity is not straightforward. Adaptive capacity is positively correlated with indicators like governance and strong rule of law. Strong rule of law and an organized and well coordinated societal response to climate change may be able to mediate some of the potential averse human responses to climate change. In countries with higher governance and ability to enforce existing laws it may be less likely that human coping responses will result in negative impacts inside the boundaries of areas already designated for protection. Following this logic we may conclude that using impact as a measure of indirect impact areas with high adaptive capacity will overestimate the impact of the human response on sites already designated for protection. However the response of societies with higher adaptive capacity and more economic resources may also be more likely to include hard infrastructure solutions like the construction of dams that negatively impact species and ecosystems. Thus the implication for individual conservation targets of increased adaptive capacity may be entirely different.

These differences in the human response to climate change are already observable today, where higher levels of government are more likely to be involved in the forward looking or planned adaptation, while at the local level the impetus to adapt is more likely to be in response to and observed impact (Berrang-Ford, Ford, and Paterson 2011). In addition to understanding the sources and types of risk it is also critically important to understand the local context. Understanding the interplay between land tenure, gender, infrastructure, economic and technical capacity will all be essential parts of understanding how populations will respond (Ngigi, Denning, and MDG Centre 2009) and are critical to the identification of appropriate conservation responses (McClanahan et al. 2009).

In addition to the different types of responses, the human impact layer we use to quantify the likely impact of populations is a measure of local level impact. The use of this as a measure of human response assumes that all human response's will be undertaken in an area that is spatially proximate to the to the impact populations. Differences in the exposure, impact and vulnerability of human populations may also lead to migration of human populations from areas of higher impact to areas of lower impact (Midgley, Davies, and Chesterman 2011). The prospect that whole nations may be forced to relocate in response to climate change has attracted the attention of the popular press and might be at the forefront of public awareness. However, the possible displacement of communities on a smaller scale and the potential for "climate refugees" or movement of populations both between and within countries is also real and needs to be accounted for. Efforts are already underway to map areas from which people will be seasonally or permanently displaced (Warner et al. 2009), and these efforts must be augmented by efforts to understand where these populations are likely to migrate into, so that the impact of the these demographic shifts can be accounted for in conservation planning.

The use of mean impact within the geographic range of the conservation target could mask underlying heterogeneity in the impact across the range of human populations living within the area of interest. The heterogeneity in human response within conservation target could provide conservation practitioners with the option of directing management action toward areas with greater or lower expected human impact. Where the likely impact on human populations is more homogenous, options for targeting conservation management toward higher or lower risk human populations will be more restricted.

Conclusion

Our work has broad implications for research at the nexus of socio-ecological systems and how these complex systems will respond to climate change. Understanding where people are most likely to respond to the impacts of climate change is only the first step in the process of incorporating that response into conservation planning frameworks. To understand and formulate appropriate conservation responses at the local level we need to begin to build in an understanding of what the responses will be, and what impact they will have on biodiversity. Targeting conservation projects in areas where the human response is likely to be greater may reduce the probability of success for delivery of conservation benefits, but offer greater potential benefit to at-risk human populations if the intervention is designed to benefit both biodiversity and people.

Here, for the first time, we have provided a methodological framework for the inclusion of the indirect impacts of climate change into conservation vulnerability assessments and planning. The framework allows us to identify conservation targets not previously thought to be at risk to climate change, that are potentially imperiled by the indirect impacts of climatic shifts. While the inclusion of human response to climate change within our framework may result in a longer list of species or areas we need to work in to mitigate the impacts of climate change or a broader suite of species, we do not view this as a negative outcome. 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. The acknowledgement within conservation planning that people are also impacted by climate change also provides the opportunity to identify interventions that benefit both biodiversity and human populations. These proverbial "win-wins" will be critical to efficiently allocating resources to meet the needs of biodiversity and people.

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