Biological Conservation 221 (2018) 103–113

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

More than range exposure: Global otter vulnerability to climate change

C. Cianfrani[a,*], O. Broennimann[b], A. Loy[c,1], A. Guisan[a,b,1]

[a] University of Lausanne, Institute of Earth Surface Dynamics (IDYST), Geopolis, 1015 Lausanne, Switzerland
[b] University of Lausanne, Department of Ecology and Evolution (DEE), Biophore, 1015 Lausanne, Switzerland
[c] Università del Molise, Environmetrics Lab, Department of Biosciences and Territory, Contrada Fonte Lappone, I-86090 Pesche, Italy

ARTICLE INFO

Keywords:
Freshwater ecosystems
Climate change
Vulnerability
Fragmentation
Human footprint
Intrinsic sensitivity
Extrinsic exposure

ABSTRACT

Climate change impact on species is commonly assessed by predicting species' range change, a measure of a species' extrinsic exposure. However, this is only one dimension of species' vulnerability to climate change. Spatial arrangement of suitable habitats (e.g., fragmentation), their degree of protection or human disturbance, as well as species' intrinsic sensitivity, such as climatic tolerances, are often neglected. Here, we consider components of species' intrinsic sensitivity to climate change (climatic niche specialization and marginality) together with components of extrinsic exposure (changes in range extent, fragmentation, coverage of protected areas, and human footprint) to develop an integrated vulnerability index to climate change for world's freshwater otters. As top freshwater predators, otters are among the most vulnerable mammals, with most species being threatened by habitat loss and degradation. All dimensions of climate change exposure were based on present and future predictions of species distributions. Annual mean temperature, mean diurnal temperature range, mean temperature of the wettest quarter, precipitation during the wettest quarter, and precipitation seasonality prove the most important variables for otters. All species are vulnerable to climate change, with global vulnerability index ranging from −0.19 for *Lontra longicaudis* to −36,9 for *Aonyx congicus*. However, we found that, for a given species, climate change can have both positive and negative effects on different components of extrinsic exposure, and that measures of species' sensitivity are not necessarily congruent with measures of exposure. For instance, the range of all African species would be negatively affected by climate change, but their different sensitivity offers a more (*Hydrictis maculicollis*, *Aonyx capensis*) or less (*Aonyx congicus*) pessimistic perspective on their ability to cope with climate change. Also, highly sensitive species like the South-American *Pteronura brasiliensis*, *Lontra provocax*, and *Lutra perspicillata* might face no exposure to climate change. For the Asian *Lutra sumatrana*, climate change would instead lead to an increased, less fragmented, and more protected range extent, but the range extent would also be shifted into areas with higher human disturbances. Our study represents a balanced example of how to develop an index aimed at comparatively evaluating vulnerability to climate change of different species by combining different aspects of sensitivity and exposure, providing additional information on which to base more efficient conservation strategies.

1. Introduction

Environmental degradation caused by human activities is reducing and fragmenting natural habitats (Butchart et al., 2010), and climate change is predicted to further impact ecosystems by causing changes in species' phenology, ranges, and community composition (Chen et al., 2011). Thus, the identification of currently vulnerable biotas and predictions of future impacts are key to developing effective conservation priorities (Brook et al., 2008; Butchart et al., 2010; Chen et al., 2011). In particular, identifying which species to prioritize for conservation in vulnerable ecosystems is of crucial importance.

1.1. Assessing species' extrinsic exposure to climate change

A common practice for evaluating current and future threats to species is to use models to predict suitable habitat distributions and how these may change over time and space (Guisan et al., 2013; Pacifici et al., 2015). With climate change in particular, understanding the changes in the extent of a species' suitable habitat provides valuable information on the species' exposure to the intensity of the threat (i.e., on their extrinsic *range exposure*) (Dickinson et al., 2014; Pacifici et al., 2015). However, considering only the changes in the extent of suitable habitat ignores other potentially important consequences of climate

* Corresponding author.
E-mail address: carmen.cianfrani@unil.ch (C. Cianfrani).
1 Shared last authorship.

https://doi.org/10.1016/j.biocon.2018.02.031
Received 18 April 2017; Received in revised form 11 February 2018; Accepted 23 February 2018

change on the distribution of species. Depending on its intensity, climate change may cause dramatic changes not only in the extent but also in the spatial patterns of species' future suitable habitats (Crooks et al., 2017). For instance, changing the level of fragmentation of suitable habitats may be sufficient to jeopardize species' persistence (Ewers and Didham, 2007). Climate change can also shift suitable habitats to areas that are less efficiently protected and/or under greater human pressure (Araujo et al., 2011). However, whereas the role of reserves has been repeatedly assessed, human footprint, as a proxy for human pressure, has been more rarely studied in combination with range change predictions under climate change, despite representing a crucial element in comprehensive evaluations of extinction risks (Pressey et al., 2007; Wilson et al., 2011). All these factors—changes in extent of suitable habitat, fragmentation, protected area efficiency and human footprint in suitable areas—constitute different facets of species' extrinsic exposure to climate change and are primarily determined by geographic location.

1.2. Assessing intrinsic sensitivity of species to climate change

However, vulnerability to climate change also depends on intrinsic factors (Garcia et al., 2014; Guisan, 2014; Pearson et al., 2014; Butt et al., 2016; Santini et al., 2016), i.e., species' *sensitivity* (Williams et al., 2008b), which defines their ability to withstand specific threats. Intrinsic sensitivity is believed to be controlled mainly by ecological traits, such as dispersal ability, phenotypic plasticity, physiological tolerance to thermal stress and desiccation and genetic diversity of the species, i.e., features that will determine its adaptive capacity (Williams et al., 2008a). In locations where two species have the same exposure to climate change, overall vulnerability is expected to be greater for the species with the higher sensitivity to that specific threat (Purvis et al., 2005). Consequently, both the intrinsic sensitivity and extrinsic exposure should be considered in climate change impact assessments (Purvis et al., 2000; Polaina et al., 2016).

1.3. Assessing overall vulnerability through joint assessments of exposure and sensitivity

Assessing both intrinsic sensitivity and extrinsic exposure has been shown to provide a more comprehensive perspective because different combinations of these factors may reveal distinct types of vulnerabilities, each with specific implications for prioritizing conservation and performing strategic planning (Williams et al., 2008b; Foden et al., 2013; Dickinson et al., 2014; Garcia et al., 2014). Although extrinsic exposure and intrinsic sensitivity are intuitively clear concepts, their conversion into measurable indicators that enable a quantitative definition of vulnerability is a trickier task (Maggini et al., 2014).

1.4. Otters as threatened top predators of freshwater ecosystems

Freshwater ecosystems have been—and still are—heavily impacted by past and current human activities (Millenium Ecosystem Assessment, 2005) and are also potentially the most vulnerable to climate change (Milly et al., 2005; Dudgeon et al., 2006; Vorosmarty et al., 2010). Current pressures on freshwater ecosystems result from crop irrigation, contamination (e.g., industrial pollution and inadequately treated wastewater), land-use practices (e.g., increased erosion and sedimentation), and infrastructure (e.g., dams, diversions, and levees) (Vorosmarty et al., 2010). As top freshwater predators, otters are among the most vulnerable mammals in the world, and most species are still threatened by habitat loss and degradation. This is aroused because otters require large swathes of suitable freshwater and riverine habitat and are known to be particularly sensitive to anthropogenic impacts that affect their pristine habitats (Kruuk, 2006). Over the last century, the 11 extant freshwater otter species worldwide have undergone severe declines due to habitat loss, direct persecution, and bioaccumulation of pollutants (Sergio et al., 2006) (Kruuk, 2006). In 1974, concern for the fate of these highly vulnerable top predators led the International Union for the Conservation of Nature (IUCN) Species Survival Commission to establish the Otter Specialist Group. Legal protections and water pollution regulations in the 1990s enabled otter recoveries across Europe and North America (Kruuk, 2006). Nevertheless, most species remain endangered, especially in Asia and Africa, and new threats, such as climate change, might even put recovering populations at medium- to long-term risk of extinction (Kruuk, 2006).

1.5. Aim of the study

Here, we quantitatively assess the vulnerability to climate change of all otters (Lutrinae sub-family) that inhabit freshwater ecosystems by considering multiple dimensions of both sensitivity and exposure to climate change. These multiple dimensions are combined in a global vulnerability index at the species level, under the assumption of a behavioural plasticity that allows otter species to shift their distribution with unlimited dispersal capacity (adaptive capacity) inside the same continent. Multiple dimensions of sensitivity and exposure to climate change were obtained by developing model-based distribution maps under current and future climatic conditions. Moreover, we examined coverage in protected areas and human footprint values in the current and future suitable areas. We then developed comparable measures for these six aspects, evaluated their trends for each species, and used these to calculate a global vulnerability index (Fig. 1). This framework, which integrates the distinct components of sensitivity and exposure, provides more comprehensive information on which to base conservation strategies.

2. Materials and methods

We developed a vulnerability index to climate change that considers multiple dimensions of both sensitivity and exposure to climate change (Fig. 1). We developed two measures of species sensitivity to climate change based on climatic niche analyses, and four measures of species range exposure to climate change by combining species distribution models (SDMs; Guisan et al., 2017), networks of protected areas (WDPA, www.wdps.org) and human footprint data (Sanderson et al., 2002). These six measures were combined to provide a final integrated species vulnerability index to climate change (Fig. 1).

2.1. Measures of species intrinsic sensitivity to climate change

Sensitivity to climate change defines the ability of species to withstand climate change threats (Williams et al., 2008a, 2008b); for this reason we chose i) climatic niche *specialization* (i.e. niche breadth), a measure of the climatic tolerance of a species, and ii) climatic niche *marginality*, a measure of the specificity of the species' climatic requirement relative to the available climates (Hirzel et al., 2002).

For each species, we calculated both their specialization and marginality (Hirzel et al., 2002) along each bioclimatic variable used for developing the SDMs. We extracted the values of the bioclimatic variables from each pixel of the suitable area for all species and from the entire world (background). We defined the specialization for each variable as one minus the ratio of the standard deviation of the distribution of the variable inside the suitable climate to that of the background across the world. In this way, small specialization values (near 0) indicate generalist species, and high values (near 1) indicate specialized species. For each variable, the marginality was defined as the absolute difference between the mean values within the biome and the mean values within the species' suitable climates; this absolute difference was divided by 1.96 times the standard deviation of the variable within the world (Hirzel et al., 2002). All specialization and marginality values were then averaged respectively across all variables to yield overall specialization S and marginality M indices per species