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Modeling the response of tropical highland herbaceous grassland species to climate change: The case of the Arsi Mountains of Ethiopia ☆

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ABSTRACT

Global warming is forcing plant and animal species to respond either through pole-ward or upslope migration to adjust to temperature increases, and grassland communities are not an exception to this phenomenon. In this study, we modeled the response of herbaceous species of grasslands within the Arsi Mountains in Ethiopia under no-migration and with migration scenarios to the projected 4.2 °C increase of temperature by 2090 (under the A2 emission scenario). For 67 species of grasses and legumes, we determined the current and predicted altitudinal limits and calculated current and projected area coverage using a Digital Elevation Model. The results indicated that the projected warming significantly reduced altitudinal ranges and habitat areas of all the species studied. All the studied species faced range contraction and habitat loss with range shift gaps among forty two species under the no-migration scenario. With the migration scenario, however, the forty two species with range shift gaps are predicted to benefit from at least some habitat area retention. Between growth forms, legumes are predicted to lose significantly more habitat area than grasses under the no-migration scenario while no significant difference in habitat area loss is predicted under the migration scenario. It can be concluded that management options are required to facilitate upslope species migration to survive under the warming climate. This could involve leaving suitable dispersal corridors and assisted colonization depending on species behavior and level of extinction risk predicted under the projected warming.

1. Introduction

Grasslands constitute a significant portion of the tropical environment, and the area under grasslands is contracting over time due to crop land expansion, increased intensity of grazing, and an overall environmental degradation. Grasslands are highly responsive to temperature, precipitation and grazing pressures (Adler and Levine, 2007; Anderson, 2006; Vicca et al., 2007; White et al., 2012). The distribution of grasslands is determined by many environmental factors among which climate, mainly through temperature, determines floristic distributions along altitudinal gradients (Pausas and Austin, 2001; Colwell and Rangel, 2010). Among the dominant and important floristic constituents of grasslands, grass species have a wider range of adaptation to the different climatic gradients than any other family of flowering plants, while legumes have a relatively narrow range of adaptation (Gebru, 2009).

However, the current global warming in conjunction with increased grazing pressure and land use for other purposes places pressure on the distribution and floristic composition of grasslands (Klein et al., 2007). Under warming scenarios, climate change will induce upward species movements as long as the elevation of the landscape will allow this to happen (Colwell et al., 2008; Kreyling et al., 2010; Laurance et al., 2011; McCain and Colwell, 2011; Sheldon et al., 2011). However, the net movement of species upslope could lead to disappearance and decline of species in the lowlands, and at lower elevations, and also lack of a source pool of species adapting to higher temperatures to fill gaps causing 'lowland biotic attrition' (Colwell et al., 2008; Feeley and Silman, 2010). On the other hand, there could be extinction of mountain top species where there are no more escape routes available to move into (Colwell et al., 2008; Jansson, 2009; Kreyling et al., 2010).

The response to the observed and predicted climate change, however, is species and mountain range specific (Pauli et al., 1996; Klanderud, 2008). Some species are unable to shift into a

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newly suitable geographic range due to dispersal barriers and/ or insufficient dispersal capabilities related to species differences, altered species interactions, phenology, resource availability, loss of dispersal vectors and other factors causing extinction risks without species range shift (Feeley and Silman, 2010; Larsen et al., 2011; Friggens et al., 2012; Urban et al., 2012). Many mountain plant species are slow growers with narrow habitat bounds. They tend to be intolerant to competition from the incoming fast-growing lowland species which are therefore more likely to expand into new regions because of their wider range of adaptation (Cochrane, 2011; Angert et al., 2011; Hoiss et al., 2013). As a result, range differences between present and future ranges- 'range shift-gaps' develop earlier for narrow-ranged species (Colwell et al., 2008). Furthermore, human-induced disturbances through land fragmentation and heavy grazing pressure in many tropical mountain areas, including in Ethiopia, have left very narrow strips of road side, farm boundaries, river banks, very steep slopes and very isolated patchy area closures or refugia as dispersal corridors available for species redistribution. The opportunities for a species to move freely elsewhere are limited. Thus because of climate-driven habitat loss, increased physiological stress, extreme climatic events, changes in fecundity and other factors (Pauli et al., 1996; Feeley and Silman, 2010; Larsen et al., 2011), the chance for extinction or population decline at a given site is high (Colwell et al., 2008).

Thus a priori knowledge of which species are likely to exhibit range shift-gaps, range contractions, habitat area loss, habitat area gain or extinction risk under global warming would be of great benefit to resource managers and others (Angert et al., 2011). An effective response to these threats requires reliable information on which species are likely to be threatened (Akcakaya et al., 2006) under two scenarios. The first scenario is where the species will not have the chance to shift its current upper range limit due to lack of dispersal corridors or suitable habitat to move into while there will be climate forced shift in its lower altitudinal range limit. The second scenario is where each species is not subjected to anthropogenic barriers and has suitable dispersal corridors to shift both its upper and lower altitudinal limits. Hence, this paper presents predicted responses of economically and environmentally important herbaceous grassland species of the Ethiopian highlands to the two scenarios, taking the case of the Arsi Mountains. We use the model developed by Colwell et al. (2008) which has also been used for similar studies by Kreyling et al. (2010) and Feeley and Silman (2010).

2. Materials and methods

2.1. Description of the study area

The study area is located in the Arsi Zone of the Oromiya National Regional State, Ethiopia and extends from 7°27′46.048″N to 8°24′54.605″N latitude and 38°59′32.009″E to 39°37′55.082″E longitude within the central highlands of Ethiopia. The landscape is generally sloped with increasing altitude from the lowest point in the Central Rift Valley (less than 1500 m) to the highest point at Chilalo Mountain (4036 m) (Fig. 1).

Modified by altitude, the climate of the study area varies from warm tropical conditions in the Rift Valley to cool Afro-alpine highland conditions in the mountains. The area has three annual seasons: the dry season – October to January, the small rainy season – February to May and the main rainy season – June to September. The mean annual rainfall varies from 663 mm (1967–2008) at Koka (1595 masl) in the Rift Valley to 817 mm (1967–2008) at Kulumsa (2200 masl) and 1149 mm (1967–2008) at Asela (2350 masl). The mean daily maximum to minimum temperature range also varies from 29.8 to 14.9 °C (1967–2008) at Koka to 23.1–10.0 °C (1967–2008) at Kulumsa and 21.5–9.0 °C (1967–2008) at Asela.

The vegetation of the study area varies from the Acacia-wooded grassland in the Central Rift Valley to the degraded Afro-alpine montane forests and associated grassland in the highlands (White, 1983; Friis, 1992). The lowlands in the Rift Valley were once dominated by Acacia woodland but much of the land is now under cultivation with beans, maize, sorghum, teff and wheat. The mid altitudes to highland areas are dominated by plantations of exotic *Eucalyptus* species. The native montane tree species such as *Cordia africana, Juniperus procera, Hagena abyssinica, Olea africana* and *Podocarpus fulcatus* have steadily disappeared with small remnants scattered in agricultural fields and small uncultivated areas. A large area of land is under extensive cultivation of barley, faba bean, field pea, flax, rapeseed and wheat. The upper Afro-alpine region, above 3000 masl is home for the endemic Mountain Nyala (*Tragelaphus buxtoni*) and is dominated by Hagenia–Juniperus vegetation types. The upper most extremes are covered by species of *Artemisia, Erica and Hypericum* (Friis, 1992; Evangelista et al., 2007). At present much of the Afro-montane forest has been cleared and replaced by cultivation of cereal crops. It is common to see barley cultivated at above 3400 masl extended beyond the 3200 m limit reported in 1989 (Evangelista et al., 2007). Such progressive encroachment of cultivation although primarily due to increasing human demographic pressure, might also be a sign of rising temperatures opening up higher areas for cultivation.

2.2. Sampling

A total of 60 observational plots, each 50 m by 50 m, were surveyed at the end of the main rainy season when the majority of grasses and legumes come into flower. Sampling thus took place between August in the Rift Valley and October 2010 in the mountains. Sampling was done along an altitudinal gradient from Rift Valley starting at 1342 m southward up to 3410 m altitude on the Chilalo Mountain. Beyond this limit we were not able to sample on moorlands because of heavy grazing pressure by domestic animals during the main rainy season and intensive Giant mole rat foraging and damage leading to an absence of vegetation cover to sample.

The major part of the land in the study area is kept under extensive cultivation and hence sampling was conducted on random plots scattered along an altitudinal gradient on lands not cultivated for a minimum of five years. Sampling sites included un-grazed sanctuaries, farm land boundaries, hill sides, road sides, river and stream sides, enclosures, school yards, church yards and other institutional compounds and grazing lands. For each sampling plot a quadrat of 1 m^2 was thrown and the central point was used as a reference point. Specimens of grasses and legumes located within 25 m radii to the north, south, east and west of the reference point were collected and identified at the International Livestock Research Institute (ILRI) Addis Ababa Herbarium facility and the National Herbarium of Addis Ababa University. Identification and nomenclature of voucher specimens followed Hedberg and Edwards (1989) and Phillips (1995). For each plant species we recorded geo-references and altitudes with GPS.

2.3. Estimation of current and future altitudinal range of plant species

The altitudinal range was assigned to be zero for species recorded only at one sampling plot and these were excluded from the analysis. All the noted ranges were interpolated by assuming continuous ranges from lowest to the highest occurrence in the data set. The current range of occurrence for each species was determined as 2.5% and 97.5% quintiles of the actual observed lower and upper altitudinal limit, respectively for each species as indicated by Feeley and Silman (2010) rather than range estimate downslope or upslope half-way to the nearest plot and