**Fast climate change velocity drive species to reduced levels of genetic diversity**

**Summary paragraph**

**1st paragraph text body**

**General introduction**

Species that track suitable areas can stay in population stasis (Darwin).

Ongoing climate change caused by anthropogenic activities may challenge the survival of thousands of species on our planet in the coming century (Citation needed).

Given the expected rapid pace of climate change, tracking suitable conditions has been suggested to be a more likely response than adapting in situ (Parmesan, 2006)

Regions with higher species endemism and genetic diversity have been found to be associated with climatic stability (Carnaval et al., 2009; Sandel et al., 2011; Yannic et al., 2014). Thus, climate change velocity has a large impact on species’ distributions, abundances and on their genetic diversity.

Determining the effect of climate change on the level of genetic diversity maintained can eventually also determine the fate of the whole population (Hewitt, 1996; Arenas et al., 2012).

Evidence of climate-induced range contractions and associated erosion of genetic diversity are beginning to be recognised (Rubidge et al., 2012).

There is a large gap in what is known about the connection between rapid climate change and range shifts, and contractions and the following effect on genetic diversity (Cooper et al., 2015)

**2nd paragraph text body**

**Specific introduction**

Species late quaternary dynamics

Include something about the vulnerability of Holarctic species. The Holarctic region has the highest estimated values of climate change velocity

Species have repeatedly been exposed to fluctuations in climate through their evolutionary history, with the glacial-interglacial cycles of the Pleistocene as a prominent example.

According to the Intergovernmental Panel on Climate Change the climatic oscillations since the Last Glacial Maximum are thought to have occurred at a rate 10 times slower than the present climatic warming (Citation needed).

However, studies from high- resolution Greenlandic ice cores show that large and abrupt changes in climate have happened more often than previously assumed (Citation needed).

As a means of trying to understand future responses, the climatic fluctuations during the Late Quaternary and subsequent species’ responses are a frequently used analogue. Evidence exists in the fossil record to suggest that climate change altered the past distribution and abundance, impacted biotic interactions and led to population extirpation and the extinction of entire species (Hewitt, 2004; Campos et al., 2010b; Moritz & Agudo, 2013).

3rd **paragraph text body**

**Question + Hypothesis + short methods (Data)**

To date, no studies have tested the influence of the pace of climate change on levels of genetic diversity. In this thesis I address this outstanding issue among extant and extinct Holarctic mammals during the Late Quaternary

I used a database containing both spatio-temporal radiocarbon-dated fossil data and spatial radiocarbon-dated heterochronous DNA sequences to assess the demographic histories of 11 mammal species distributed across the Northern Hemisphere. This approach in congruence with the large spatial and temporal extent of the study allowed the quantification of the influence of climate change velocities on levels of genetic diversity … and ultimately the extinction of some mammal species. I evaluate whether a link exists between the pace of climate change and the subsequent levels of genetic diversity maintained within species.

**Results**

3 main results:

1. Climate change velocity across the Holarctic region (No species specific)
2. Species-specific climate change velocity (using the fossil record)
3. Effects of fast an slow climate change velocity on species genetic diversity
   1. Nucleotide diversity
   2. Haplotype diversity

4th **paragraph text body**

**Results 1+2**

Climate change velocity for the Holarctic region was not included as a section in Ditte’s manuscript. We have to write the results for the region. This result is boarder in extent and purely climatic.

The velocities for each species show great variation across the Late Quaternary both among and within species (fig. 5). Most species had median velocities of maximum 0.2 km yr-1. For all analyzed species there is an increase in velocity around either Bølling/Allerød interstadial or Younger Dryas.

In general, the period after LGM and until the Holocene-Pleistocene transition was that of the fastest change for most species.

The periods ranked the most stable (rank 1) has the largest spread with the greatest proportion of the stable climates recovered in the period from 50-26kya. On the other hand, the highest-ranking time periods (those with the fastest changes) are clustered around 19-10kya for 7 out of 11 species, which coincides with the climatic transitions of Bølling/Allerød and Younger Dryas.

5th **paragraph text body**

Results 3a + 3b

Species are in general more negatively affected following the fast change compared to the stable climate (we have to do a proper test for this).

7 out of 11 species showed a decrease in nucleotide diversity after a fast change (fig. 8 and table 10). Similarly, a decrease was observed in 3 out of 5 species after a period of climatic stability (fig. 8). However, there is a large variation in how the different species are affected.

The changes in nucleotide diversity were not always accompanied by change in haplotype diversity (table 10). In general, the change in haplotype diversity following the stable climate was less prominent compared to the fast change (fig. 9). As for nucleotide diversity, the majority of species lose haplotype diversity following the fast change in climate. There is also an overall tendency for larger reduction in haplotype diversity after a fast change in climate compared to the stable (fig. 10D).

**6th paragraph text body**

**Discussion focus on the results 1+2**

Velocities obtained here are highly species-specific due to the use of coordinates. A period classified as fast for one species can be stable for another species and vice versa. For example, the fastest velocity for *Equus* was 0.112 km yr-1 in comparison to the fastest for *Mammuthus* being 0.523 km yr-1. Thus, it implies that *Mammuthus* may have had to migrate faster than *Equus* in order to track changes*,* potentially leading to the loss of individuals with more limited dispersal abilities, reducing the genetic variation arriving to new habitat patches (Hewitt, 1996). As exemplified by these two species, dispersal ability and whether suitable climate is available or accessible nearby, the velocity of climate change could impact species differently.

The effect of climate change velocity also depends on the landscape. Topographically heterogeneous areas offer a buffering effect for species, decreasing the distance with which they have to move (Lyons et al., 2010; Sandel et al., 2011). Many of the species present in this study inhabited the steppe-tundra that was widespread during Pleistocene (Koch & Barnosky, 2006). Living in a steppe environment meant that species must have moved large distances to track changes, making it easier for the species with the ability to migrate fast to track their preferred climatic conditions (Loarie et al., 2009).

**7th paragraph text body**

**Discussion focus on the results 3a+3b**

Ditte’s discussion about genetic diversity patterns is very species specific. We should write something more general related to the “big picture” of fast vs stable climate change.

It is, to our knowledge, the first time species’ genetic response to climate change has been related to the pace of these using heterochronous DNA sequence data from multiple species from different trophic levels.

**8th paragraph text body**

**Discussion general (anthropocene effects)**

I think we should include a paragraph to discuss about the possible effects of humans and gentic structure (Ditte wrote about the latter, but we need something more general, in the manuscript is mainly about the lion and hyena)

**9th paragraph text body**

**Discussion applicability (forecasting genetic responses and informing about species responses to climate change)**

I think we should include a paragraph discussing/proposing how our results can be used to inform about future responses and species conservation

**10th paragraph text body**

**Conclusion**

I found that the climate change velocity was highly variable across the study period showing a slightly different pattern than the Greenlandic ice core.

There is an overall tendency for a fast change in climate to induce a larger decrease in genetic diversity than a slow. The species that experience an increase in genetic diversity seem to have in common large dispersal ability, ecological flexibility and a broad climatic tolerance. These species are, on the other hand, also those that experience a velocity in the lower end.

Species that decrease in genetic diversity have in common a more tight relationship with a specific type of vegetation. These species by far also suffer from the highest velocities.