School of Geosciences

Confirmation Report

Quantifying vegetation shifts under climate change in extreme biomes

Kluane National Park & Reserve, Yukon, Canada © Sandra Angers-Blondin

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Table of contents

Introduction

This Confirmation Report provides an overview of the progress made as of 8th May 2018 on my PhD project 'Quantifying vegetation shifts under climate change in extreme biomes'. This document also outlines the next steps and explains in detail my research questions and future planning, as well as other relevant matters such as my teaching experience, training needed and project resources.

This Confirmation Report is submitted as one of the three requirements of the Confirmation process from the School of Geosciences at The University of Edinburgh, together with the Confirmation Presentation (taking place on 8th May 2018 at the PGR Conference) and the Confirmation Panel (on 22nd May 2018).

The Confirmation Panel will be composed of the following attendants:

- PhD Candidate: Mariana García Criado
- Principal Supervisor: Dr Isla Myers-Smith (School of Geosciences, University of Edinburgh)
- Advisor: Dr Janet Fisher (School of Geosciences, University of Edinburgh)
- External examiner: Dr Tiina Särkinen (Royal Botanical Gardens, Edinburgh)
- External examiner: Dr Aidan Keane (School of Geosciences, University of Edinburgh)

The internal co-supervisor (Dr Caroline Lehmann; School of Geosciences, University of Edinburgh) and the external co-supervisor (Dr Anne Bjorkman; Senckenberg Centre for Biodiversity and Climate Research) will not be present in the Confirmation Panel have provided feedback on the Confirmation Report in advance.

Background

Biome definitions and significance

A biome has been traditionally defined as an area of vegetation containing the same life-form (Woodward et al. 2004), and the most widely used climatic division of biomes was outlined by Whittaker (1975). His definition highlights deterministic links between biome and climate, and the fact that this relationship is mostly static. In fact, locations that are defined as a particular type of biome can be found outside of the marked limits to their distribution (Lehmann et al. 2014), see Figure 1. These structural definitions have changed in recent times, and current biome definitions consider the influence of soils and historical processes (Moncrieff et al. 2016a), or categorise biomes on the basis of their ecosystem function (Higgins et al. 2016). In addition, new approaches such as Biome Distribution Modelling have been proposed to delimit new biome boundaries (Särkinen et al. 2011).

In my PhD thesis, I will undertake a cross-biome comparison focusing on the tundra and savannah biomes, which I will define here as extreme biomes. Species distributions are often constrained by temperature extremes (O'Sullivan et al. 2017), and indeed the tundra is found at very cold temperatures and low precipitation conditions (Shantz 1954), while the savannah at very warm temperatures and is characterized by high rainfall seasonality (Staver et al. 2011).

The tundra biome has been traditionally defined geographically as the region above the treeline (Bryson 1966), usually found at high altitudes and latitudes, in the Antarctic and sub-Antarctic regions (Bliss et al. 1981). Other definitions of the tundra include the locations around the 6.5°C July isotherm (Macdonald et al. 2000) or the areas containing permafrost (Tedrow and Harries 1960). Regardless the definition, this biome is characterized by low temperatures, short growing season (Bliss 1962), and the presence of lichens, bryophytes, graminoids, forbs and shrubs (Janssen et al. 2016).

Arctic regions have been subdivided in diverse manners, with Middendorf (1864) originally dividing the biome into ‘high’ and ‘low’ tundra, or Alexandrova (1980) defining seven different types of tundra. However, the most widely used delimitation in recent times follows Walker (2000) and the Circumpolar Arctic Vegetation Map, which divides the tundra in four regions in a geobotanical approach based on dominant plant functional types.

On the other hand, there seems to be a slightly wider agreement on the definition of the savannah as a tropical grassy biome highly linked to fire dynamics and herbivory (Parr et al. 2014), composed mostly of trees, shrubs and C_4 grasses (Breymeyer 1996). Its boundaries have been delimited on the basis of its mean annual precipitation (Stott 1988) but also following a monthly mean temperature of above 10°C and strong seasonality (Scholes and Walker 1993). A more functional definition of the savannah based on their traits has been recently by Ratman et al. (2011). The potential distribution of the savannah biome following climatic gradients has been identified by Bond (2005), but the current and possible geographical range of this biome across continents have been well established by Lehmann et al. (2011).

Climatic conditions are bound to continue changing, and this could lead to significant consequences in the future establishment and definition of biomes (Neilson 1991). Global change processes could result on altered community structure and biodiversity composition, which could in turn alter ecotones and biomes, albeit biome shifts would probably lag after climatic changes (Hansen et al. 2001). As biomes, both tundra and savannah have unique species assemblages (Solbrig et al. 1996), and changes to biodiversity and ecosystem functions will likely occur in response to global change.

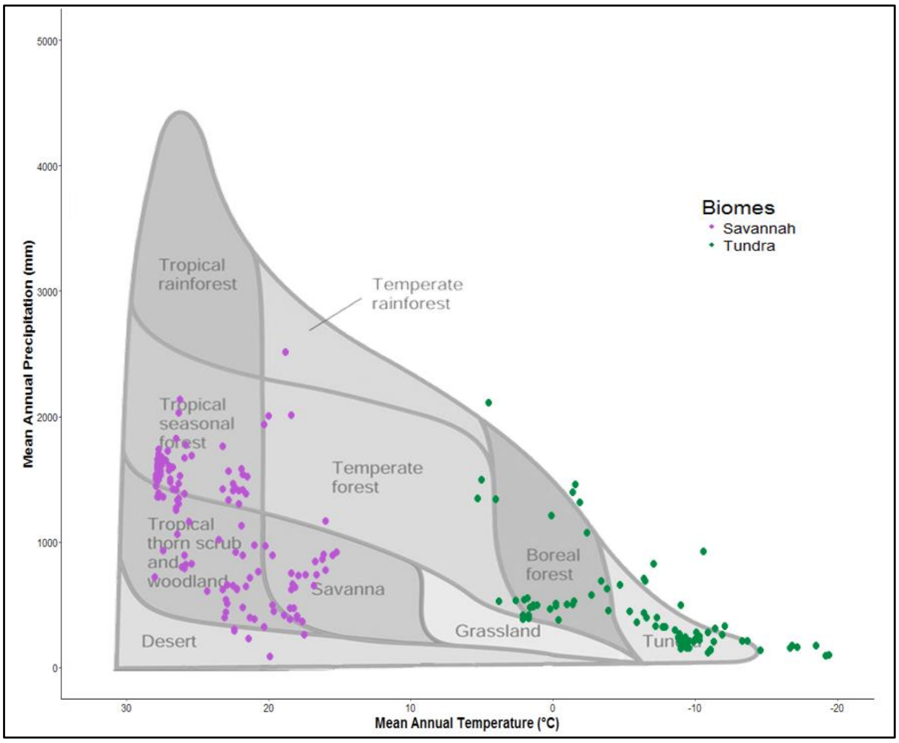


Figure 1. Current locations included in the preliminary analyses of my PhD thesis, showing that most locations classified as 'tundra' or 'savannah' extend beyond their delimited borders of a Whittaker plot. Each point represents a tundra or savannah study from the published literature. Around 400 records are included so far in this study.

Global change in extreme biomes

In the era of the Anthropocene (Steffen et al. 2011), accelerating human impacts on the planet have become amplified in recent years as a consequence of climate change (Bellard et al.

2012). The overharvesting of species from the wild, the overexploitation of natural resources, land use intensification and the pollution of terrestrial and aquatic ecosystems (Tilman et al. 2017) are only some of the current main threats to biodiversity. Consequences include habitat conversion, species extinctions (Thomas et al. 2004, Barnosky et al. 2011), and range shifts across taxonomic (Chen et al. 2011) and geographical scales worldwide (Thuiller et al. 2005).

Climate change effects are heterogeneous and spread. With temperatures over the twentieth century showed an unequivocal rising trend (Brohan et al. 2006), future global estimates project temperature increases ranging from 0.6 to 4.0 Celsius degrees in best and worst case scenarios, respectively (IPCC 2007). In addition, fluctuations in climatic conditions and increases of extreme weather events (Rosenzweig et al. 2001) have also been increasingly reported. Consequences for biodiversity and ecosystem services have been noticed across biomes, with some areas appearing particularly more vulnerable than others.

The Intergovernmental Panel on Climate Change identified the tundra at the most heavily affected biome under climate change (IPCC 2014) and the most rapidly changing terrestrial one (Post et al. 2009), with temperatures in the Arctic increasing at twice the rate than the rest of the planet (IPCC 2013). This warming has led to multiple responses at high latitudes, including the melting of sea ice and the thawing of permafrost (Hinzman et al. 2013, AMAP 2017). Likewise, tropical ecosystems are also forecasted to experience strong changes (Fearnside 2000) both for biodiversity and ecosystems (Midgley and Bond 2015), with savannahs being particularly responsive to climate change (IPCC 2014) and reportedly undergoing important alterations in vegetation structure in the last few decades (Moleele et al. 2002, Devine et al. 2017), mainly due to its open canopy structure (Parr et al. 2014).

Climate change impacts are especially important considering the significance of these two biomes as carbon sinks (Schaphoff et al. 2006, Williamson et al. 2016). In addition, the tundra is home to indigenous peoples and essential for albedo regulation (Juszak et al. 2014); while the savannah provides 30% of terrestrial Net Primary Production (Grace et al. 2006), is essential to local communities for farming, ranching and resource provision, and relevant for tourism (Lehmann and Parr 2016).

Biomes found at temperature and precipitation extremes such as the tundra and the savannah can be particularly vulnerable to large scale changing climatic conditions (Sala et al. 2000). Thus, it remains critical to quantify the biome specific-response of the tundra and savannah biomes in order to anticipate their responses to climate change. Since these two biomes are structurally similar, being dominated by lower woody vegetation and grasses, and are experiencing analogous yet contrasting environmental changes, it is fitting to compare their responses in order to obtain a more comprehensive overview of global change and its effects.

Climate change impacts on plant communities

Changes in climatic conditions have presumably led to a variety of shifts on plant species across the tundra and savannah biomes, including an advancing phenology (Parmesan and Yohe 2003), longer growing season length (Piao et al. 2007) and increased plant growth (Myneni et al. 1997). In tundra ecosystems, tree lines (Holtmeier and Broll 2005, Harsch et al. 2009) and shrub lines (Myers-Smith et al. 2011) are advancing towards higher latitudes and altitudes (Myers-Smith and Hik 2017), and satellite observations of vegetation indices indicate an overall greening trend (Bhatt et al. 2013). In the savannah, tree dieback has increased due to climate-induced causes, including warming and droughts (Allen et al. 2010) and vegetation phenology has been directly affected by herbivory and wildfire regimes (Chidumayo 2001), with woody encroachment leading to direct shifts in ecosystem function and biodiversity composition (Parr et al. 2012).

Vegetation shifts have been reported through a variety of methods, including repeat photography (Ward et al. 2014, Naito and Cairns 2015), satellite imagery (Wigley et al. 2010, Frost and Epstein 2014), experimental manipulations (Kraaij and Ward 2006, Hollister et al. 2015), long-term monitoring (Cannone et al. 2007, Roitman et al. 2008), dendrochronology (Lantz et al. 2010, Sahara et al. 2015) and remote sensing (Forbes et al. 2010, Mitchard et al. 2011). These different lines of evidence have produced different estimates of the magnitude of change, but an overall trend of increasing woody cover is unequivocal in these two biomes (Myers-Smith et al. 2011, Stevens et al. 2017).

The role of functional traits in determining plant responses to climate change has been increasingly studied (Lavorel and Garnier 2002). By grouping species with similar responses, the distinction becomes clearer between taxa that can adapt and those whose traits do not exhibit plasticity (Bellard et al. 2012), thus leading to the species being outcompeted or extinct. Growth and size-related traits are some of the most relevant when it comes to assessing primary productivity and decomposition rates (Chapin 2003). Biodiversity metrics at different levels can also be linked to each other. For example, tall species are thought to have large ranges (Murray et al. 2002), with height being an individual-level trait and ranges a species-level metric. On the other hand, large distribution ranges and commonness have frequently been associated with low extinction risk, and small population ranges correlated to higher extinction rates (Purvis et al. 2000).

Species distributions have been shown to shift in response to changing climate (Guisan and Thuiller 2005), and have become the main focus of macroecological studies due to their relevance for biodiversity conservation and ecosystem provision. This interest has led to an exponential increase in the use of Species Distribution Models (SDMs), which are based on the prediction of species distributions following their environmental preferences (Elith and Leathwick 2009). The most widely used predictors to create species-climate envelope models are bioclimatic variables such as temperature and precipitation (Araújo et al. 2005, Hijmans and Graham 2006), since they can be a determinant component to the establishment of species ranges. Thus, shifts in climatic variables as a consequence of global warming could translate into changes to species ranges, particularly at the most vulnerable biomes. These distribution shifts are one of the clearest biotic responses to global change, and can inform the way different taxa are expected to react to changing conditions.

Woody encroachment and drivers

Woody encroachment or expansion is defined as the increase of woody plant biomass, density and/or cover into otherwise open areas (Van Auken 2009). This is one of the most conspicuous processes of vegetation change across the globe and has been widely reported across ecosystems (Eldridge et al. 2011, Naito and Cairns 2011, IPCC 2014), particularly in the tundra (Myers-Smith et al. 2011), mesic grasslands (Knapp et al. 2008), arid grasslands (D'Odorico et al. 2012) and savannahs (Stevens et al. 2017). Woody expansion has become particularly evident in the tundra and savannah biomes and can sometimes be an early indicator of regime shifts (Xu et al. 2015).

Encroachment can lead to profound consequences in ecosystem function and structure, altering species distributions and richness (Price and Morgan 2008), ecosystem services (Wangai et al. 2016), ecohydrology (Huxman et al. 2005, Honda and Durigan 2016) and, ultimately, the persistence of these biomes at local scales (Scheiter and Higgins 2009, Moncrieff et al. 2014). Further, encroachment alters biodiversity composition and richness (Ratajczak et al. 2012). In the tundra, lower plants have declined (Wahren et al. 2013). In the savannah there is a shift from C4 to C3 plants (Bond and Midgley 2000), with reported plant and invertebrate biodiversity losses (Parr et al. 2012, Durigan and Ratter 2016, Abreu et al. 2017). However, although woody encroachment is resulting on concrete impacts on biodiversity and ecosystem services in these two biomes, their main drivers differ.

In the tundra, temperature has been reported as the main driver of shrub expansion (Matthew et al. 2001), with soil moisture as another limiting factor (Ackerman et al. 2017). Changing snow cover and depth could also have a strong role on encroachment (Hallinger et al. 2010). In the savannah, fire has been widely reported as a key factor (Staver et al. 2011, Archibald et al. 2013), together with herbivory (Archer et al. 2017). The role of rising CO_2 concentrations has also been attributed to vegetation change (Buitenwerf et al. 2012, Donohue et al. 2013). While it has been generally accepted that increasing CO_2 tend to lead to proliferation of C3 woody plants (Ehleringer et al. 1997), there are exceptions to this rule, with a reverse trend becoming evident recently (Reich et al. 2018). Similarly, precipitation has been considered an important factor (Roques et al. 2001), although in the meta-analysis performed by Stevens et al. (2017), higher precipitation was not correlated with encroachment rates.

While these drivers have been widely reported in the literature, major unknowns still remain. For instance, the effect of CO_2 fertilization in tundra plants has barely been examined (Oechel et al. 1994), and mostly studied in terms of the response of CO_2 fluxes to warming temperatures (Oberbauer et al. 2007). Likewise, wildfires have not been generally considered to be a threat to tundra ecosystems, but several fires have been reported in recent years there (Jones et al. 2009) in a likely response to warming temperatures and sea ice retreat (Hu et al. 2010). These fires could facilitate shrub recruitment and contribute to the overall pattern of woody expansion (Myers-Smith 2011), but they have been poorly studied so far. Furthermore, the interactions between these drivers could lead to unpredicted consequences in the phenology and distribution of plant species, setting up further gaps in the knowledge in terms of the effects and responses of these extreme biomes.

Research aims

The aim of my PhD project is to gain a quantitative understanding on biome behaviour by focusing on vegetation change across structurally similar biomes from a biogeographical perspective at macroecological scales. The outcomes of this project in terms of processes, traits and distributions could contribute to better model constructions and to anticipate future species responses in vulnerable biomes, particularly by identifying whether species' responses are generalizable or highly linked to the biomes they inhabit. A conceptual diagram of my thesis chapters can be found in Figure 2.

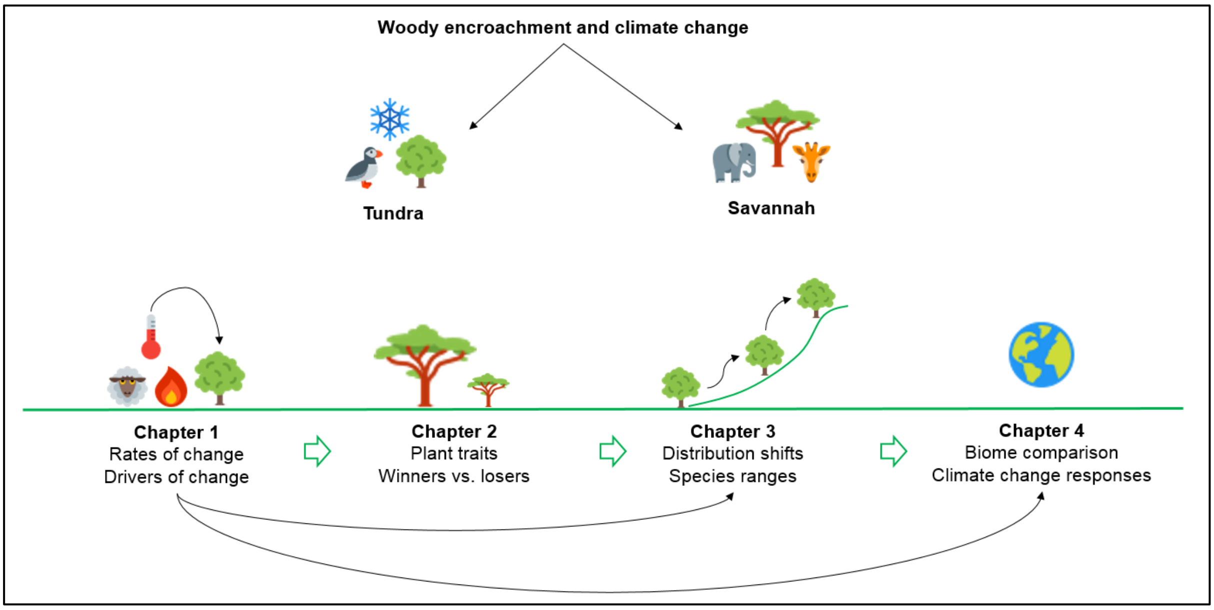


Figure 2. Conceptual diagram of my thesis chapters. Chapter 1 will set the basis of the rest of the chapters, contributing base information of rates and drivers of change to each chapter. Additionally, the data and results obtained from each chapter will feed directly into the analyses of the following chapters.

Project overview

My PhD thesis will contain four chapters, outlined below with their specific background, research objectives, methods and anticipated results sections.

Chapter 1 – How has vegetation cover changed in tundra and savannah biomes?

Background

Woody growth and encroachment has been reported at different scales, including biome-wide syntheses (Martin et al. 2017, Stevens et al. 2017), continent-wide studies across biomes (Pellizzari et al. 2017), and reviews of shrub expansion (Naito and Cairns 2011). While this process seems to be occurring in parallel in the tundra and the savannah, woody encroachment rates, patterns and timelines of change have not been compared between extreme biomes and remain inconsistent among studies. For example, Pearson et al. (2013) predicted a woody cover increase of up to 52% in the Arctic, but individual references indicate a range of shrub change observations. In addition, the relative contributions of different drivers to woody cover change in each biome remains unquantified (Sankaran et al. 2005).

A synthesis of the current status of woody encroachment together with an overview of the main drivers will therefore inform our understanding of global change across the world's nonforested ecosystems. This synthesis will enable improved forecasts of species' distribution change and contribute to a better understanding of biome-level responses to climate and anthropogenic change.

Objective and hypothesis

I will quantify and compare the rates of encroachment in tundra and savannah biomes and calculate the contribution of different identified drivers across studies and between extreme biomes.

H1: Rates of woody encroachment are similar across the savannah and tundra biomes.

H2: Tundra change is driven mostly by warming air temperatures, while fire and herbivory are the main drivers of change in the savannah.

Methodology

Data for this chapter is largely based on pre-existing published syntheses by Stevens et al. (2017), Myers-Smith et al. (2011) and Myers-Smith and Hik (2017), which have been supplemented via additional literature research. Information was extracted from the available literature on rates of change, drivers, and cover trends for trees (in the savannah) and shrubs (in both biomes) by searching in Web of Science and Google Scholar for the terms 'vegetation change', 'shrub encroachment', 'shrub expansion', 'tundra', 'arctic' 'woody encroachment', 'bush encroachment', 'plot', 'savannah'. Additional records were extracted from the International Tundra Experiment (ITEX) database. Only records that reported vegetation cover change in at least two points in time were retained, and scientific papers from all available years were included. Where a conversion to cover change could be made, studies reporting biomass change were retained.

In these studies, woody encroachment has been quantified using satellite imagery, aerial photography, repeat photography, ecological monitoring and experimental manipulations. For data to be comparable, an annual rate of vegetation change was calculated for each location. Associated climatic data was extracted from the Climatologies at High Resolution for the Earth's Surface Area (CHELSA) database (Karger et al. 2017), and land use data from the Land Use Harmonization database (Hurtt et al. 2011).

Mann-Whitney tests and Kruskal-Wallis tests will be carried out to compare differences between biomes, climatic variables and trend responses. Linear models will be fixed for each site in order to calculate the rate of change in precipitation and temperature variables (mean annual temperature, mean annual precipitation, maximum annual temperature, minimum annual temperature, temperature and precipitation of the warmest and coldest months, and precipitation seasonality) for the period 1978 – 2013. A linear mixed model with continent as fixed effect will be performed in order to account for the effects of woody encroachment per continent. Finally, a power analysis will be undertaken in order to define the significant effect sizes for each trend (increase, stable and decrease). All analyses were carried out in the software and programming language R version 3.4.3 (R Core Team 2018) and RStudio (RStudio Team 2016).

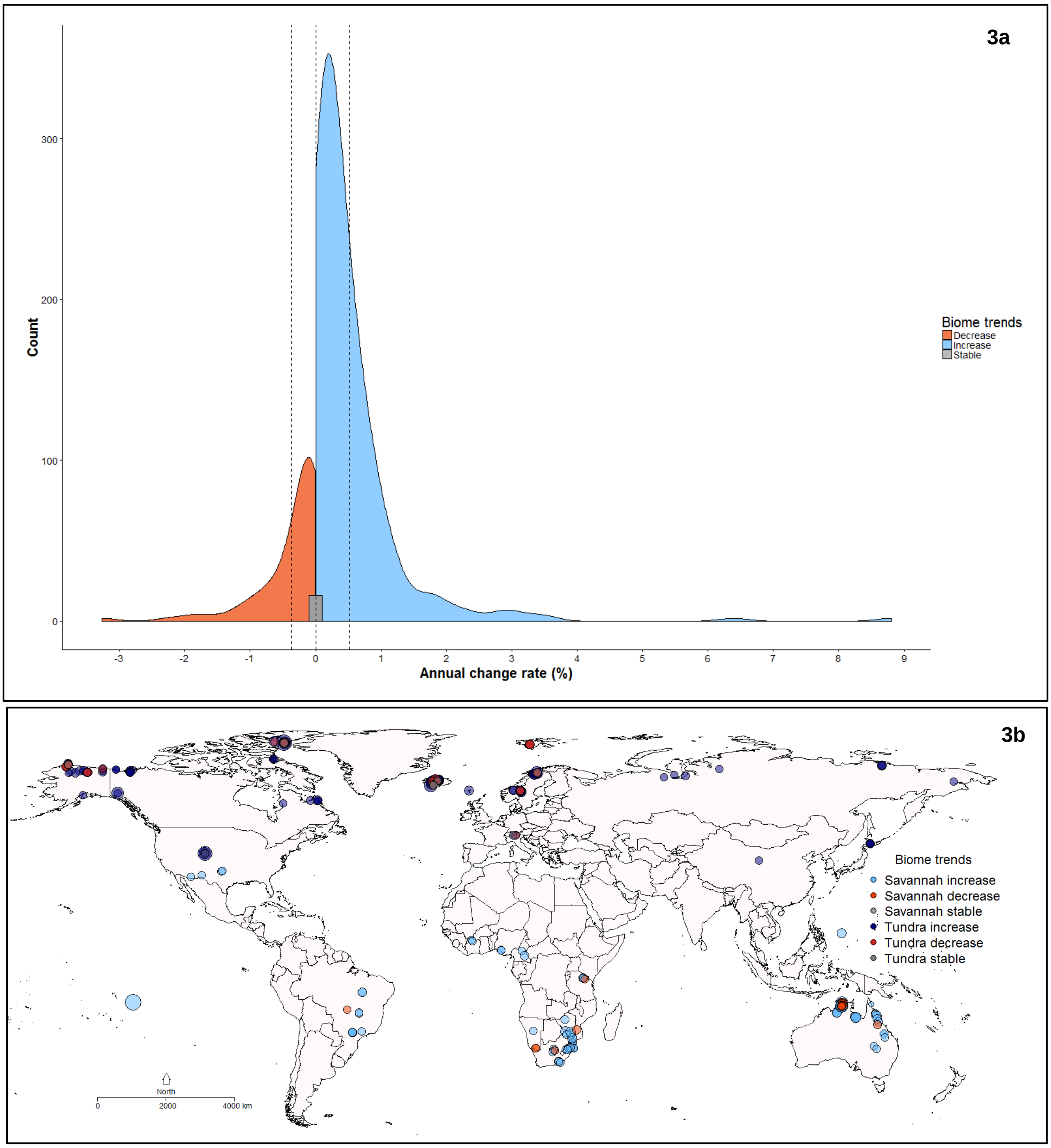
Preliminary results

Currently, I am writing this chapter as a manuscript for publication that I am to submit for review by December 2018 in Global Ecology and Biogeography or Global Change Biology. This chapter will form the basis of the rest of chapters of my PhD thesis.

Preliminary results show a predominant increasing trend in woody cover in the two biomes (Figure 3a) that was examined at three different scales. Across geographical locations, increasing woody cover is widespread in all continents for both biomes (Figure 3b), although it is noteworthy that publication bias has possibly taken place at more accessible locations or sites with reported encroachment rates.

Across time, most studies included in this chapter started around the 1990s in the tundra and around the 1960s in the savannah, with savannah monitoring schemes being longer in average than in the tundra (Figure 3c). Finally, most increasing trends in the climatic space are reported at high-rainfall savannahs at their maximum temperature limit, while more increasing trends are reported for average to warm and wet conditions within the tundra biome (Figure 3d).

These results indicate that, while there is no clear geographical pattern to woody expansion, some trends are visible when it comes to climate, and thus encroachment could follow changing climatic conditions, especially for warmer and wetter sites. However, not all patterns are straight-forward and consideration should be given to all the factors that interact with these species, such as biotic interactions. I will examine the reported drivers of change in each biome and plot the number of times they have been mentioned for each biome. This will hopefully shed more light into the driving forces behind woody encroachment in each of the biomes. I anticipate that warming temperatures will be the main cause of change in the tundra, while fire and herbivory will be the key factors driving change in the savannah.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Decrease
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Stable
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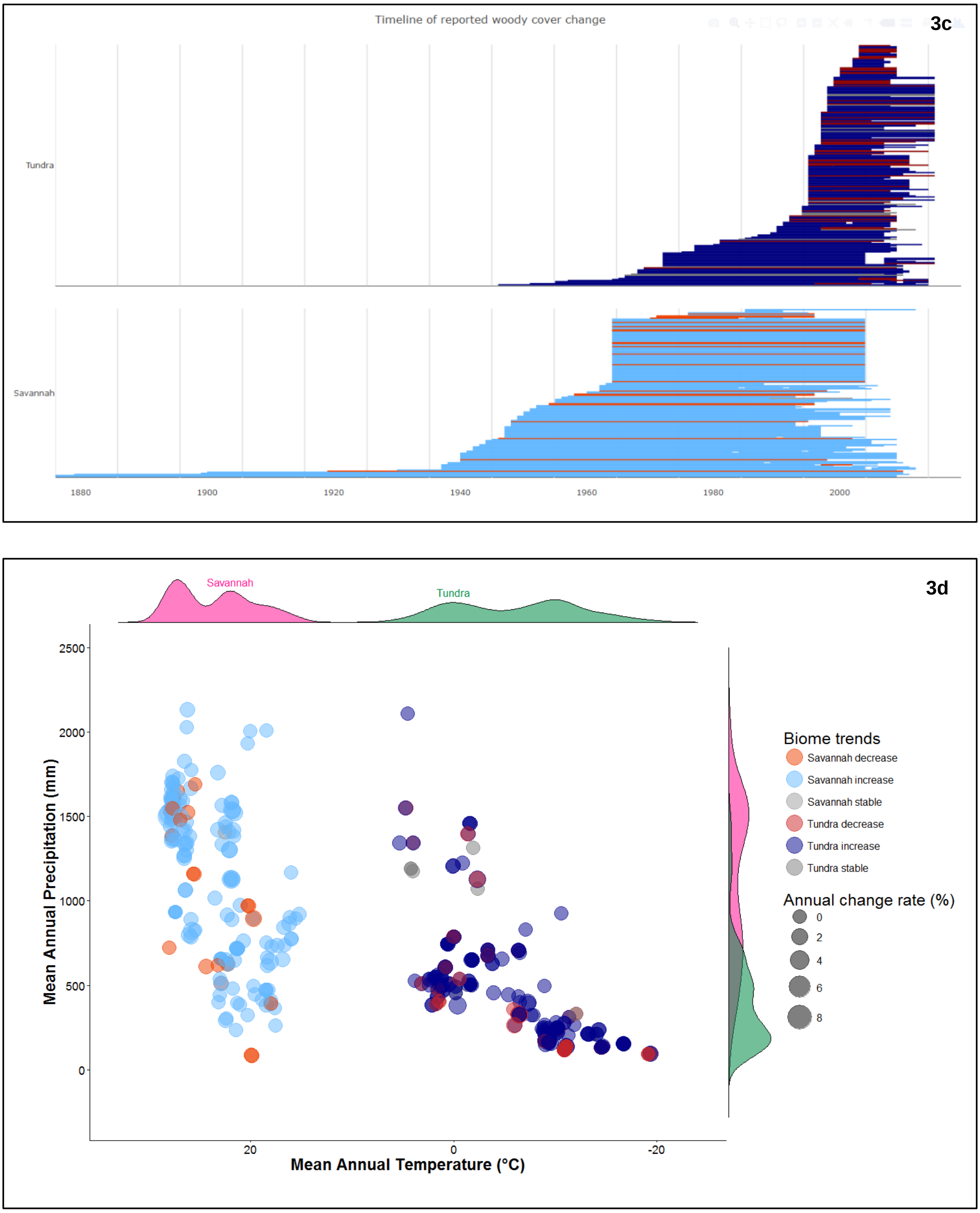

Figure 3a) Density plots displaying the count of records as a function of their woody cover change trend, **Figure 3b**) Rates of encroachment in the two biomes, **Figure 3c**) Timelines of the different published studies on woody encroachment, and **Figure 3d**) Rates of change in the two biomes within the climatic space.

Chapter 2 – Which traits make species more susceptible to different population trends under climate change?

Background

Traits are defined as measurable features at the individual level (Violle et al. 2007) and have been widely used to disentangle the relationships of taxa with their environment. In recent years, the study of functional traits has increased as a tool to study community ecology, with these defined as those variables measured from single individuals and linked to function or performance (McGill et al. 2006). Examples of functional traits include height, specific leaf area (SLA) or leaf dry matter content (LDMC) (Moles et al. 2009, Messier et al. 2010). Functional traits can be usually well predicted by environmental gradients (Shipley et al. 2016), and thus they could provide an appropriate indicator of how plant species will react to different climatic conditions (Díaz et al. 2015).

However, there are other metrics that can contribute to the study of species responses at different levels (Messier et al. 2010). For example, phylogenies can help understand evolutionary and adaptation potential, together with patterns of diversity, abundance and distribution (Webb et al. 2002) at the species and community levels. Likewise, structural properties such as biomass or cover can provide information at the community and ecosystem level (Grime 2001).

When studying traits, the relationships between them must be kept in mind. While there are a few key ecologically important traits in plant communities, certain traits correlate with each other (Diaz et al. 2004). For example, in the tundra, summer warming is the primary factor linked to taller plant canopy height, SLA and LDMC (Elmendorf et al. 2012, Bjorkman *et al*., in revision). In the savannah, functional traits like leaf area and bark thickness are determinant in reaching fire-resistance and fire-suppression thresholds, which in turn control the distribution and extent of the savannah biome (Hoffmann et al. 2012). This also means that higher-level metrics can be directly affected by lower-level traits. For instance, specific leaf area (measured at the individual level) is directly related to the production of biomass and cover (measured at the community or ecosystem level) (Chapin 2003). Therefore, the organisation of traits is highly hierarchical (Marks 2007) and this needs to be accounted for in the analyses.

Here, I propose the use of appropriate metrics at different scales, from the individual to the biome level. By identifying the traits that are highly correlated with population change, I will identify those taxa groups more prone to population increases and decreases.

Objective and hypothesis

The objective of this chapter is to identify the specific traits that make tundra and savannah species more susceptible to population increases and decreases as a result of shifting climatic conditions and their associated effects like competition and lack of suitable habitats. Using these traits, I will identify particular winner species (i.e. those with enhanced growth under climate change) and losers (i.e. those that will find population decreases or smaller ranges).

H1: The most determinant traits for population change across organisational scales will be plant height at the individual level, taxonomic group at species and community level, biomass at the ecosystem level and range size at the biome level, in both the tundra and the savannah.

H2: The importance of particular traits will differ widely between the tundra and the savannah biomes.

H3: There will be a larger number of 'loser' species in the tundra than in the savannah.

Methodology

Building from the database compiled as part of Chapter 1, I will extract trait data from available databases such as ITEX, TRY (Kattge et al. 2011) and the Tundra Trait Team (TTT), which contain information on plant species' phenology, cover, abundance and distributions. I will use different metrics (or traits, for the purposes of this chapter) for each biodiversity level of organization, with a preliminary selection of traits outlined in Figure 4. It is likely that I will use different metrics in each of the biomes – for example, SLA is an important trait in the tundra, but might be less useful in the savannah. When specific trait measurements are not available for each record, I will extrapolate trait data of species found at near locations and provide an estimate range of values through hierarchical Bayesian techniques. I will then identify the relative importance of each trait in population changes at the different organisation levels through a Principal Component Analysis (PCA). These traits will afterwards be analysed together with changing climatic conditions, which will help identify the species with the largest variations in these traits following climate change (i.e., those with highest climate sensitivity), and ultimately, the taxonomic list of winners (i.e., those with the winning traits) and losers (i.e., those with the losing traits).

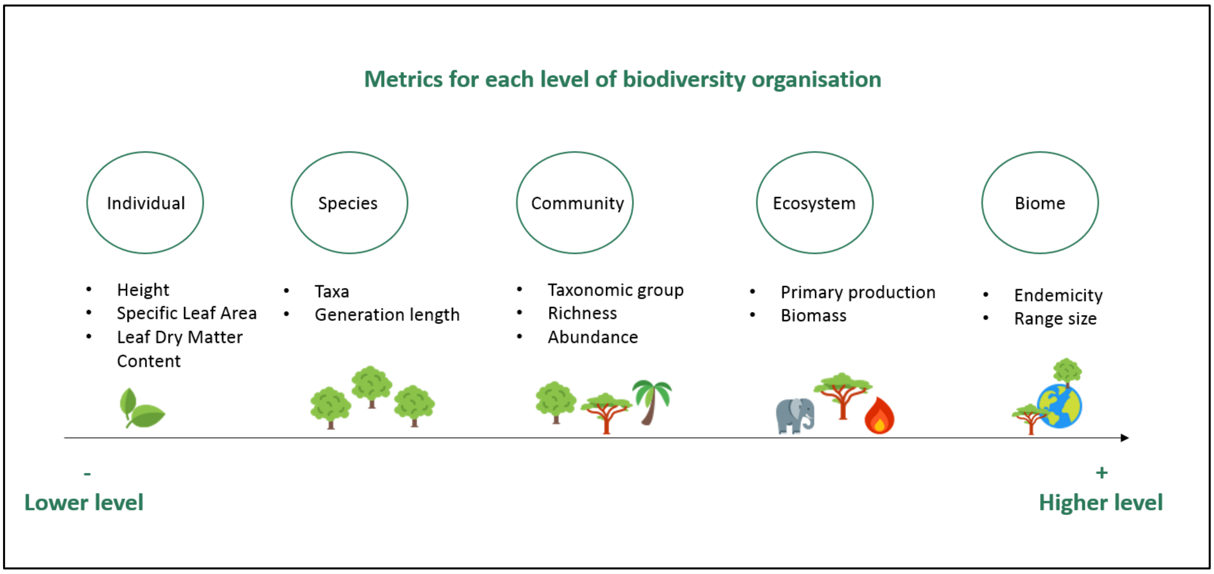

Figure 4. Preliminary selection of functional traits per organisational biodiversity level.

Anticipated results

Certain traits will be better predictors of population changes than other. It is likely that some of these traits will be linked to climate sensitivity, and thus those species with higher within-species variability could show a greater climate sensitivity. Since savannah species are thought to be affected by climate less than tundra species, it is expected that there will be more 'loser' tundra species and more 'winner' savannah species.

Chapter 3 – How are the ranges of different species in tundra and savannah biomes expected to shift as a consequence of climate change?

Background

Shifts in species distributions are one of the most conspicuous evidences of climate change effects (Pecl et al. 2017). While plants are not able to shift their ranges at the same speed as animal species (Davis and Shaw 2001), clear movement patterns have been observed, both towards higher latitudes (Chen et al. 2011) and elevations (Steinbauer et al. 2018).

This is particularly concerning for species found at cold Arctic environments like the tundra, whose spatial ranges are particularly influenced by warming temperatures. Distribution shifts might be limited here by the lack of available habitats for species to further extend their ranges northwards (Norberg et al. 2012), leading to biodiversity loss and associated local extinctions. Likewise, the limits to species distributions in the savannah can be influenced by increasing

CO_2 concentrations, changing water availability and wildfire regimes (Cramer et al. 2001). Projections with dynamic vegetation models show a decrease in the extent of savannahs at their boundaries with forests and/or grasslands (Moncrieff et al. 2016b). However, projections of range shifts are rarely tested with real-world data across the world's biomes.

Therefore, it is particularly important to identify a) the limiting factors controlling species distribution changes, and b) the predicted range expansions of dominant species. By explicitly incorporating the dynamic nature of tundra and savannah species under global change using real-world data, I will delimitate new species' range limits, quantify potential future rates of change and limits to range expansions, and estimate the impacts that range shifts could have on changing biodiversity in tundra and savannah ecosystems.

Objective and hypothesis

The aim of this chapter is to estimate extents and rates of range shifts and resulting impacts on biodiversity of plant species under different climate change scenarios for dominant tundra and savannah species.

H1: Shrub tundra species will shift towards colder climates, while woody savannah species will follow increased precipitation conditions.

H2: Range shifts will progress more rapidly in tundra versus savannah ecosystems.

H3: Biodiversity change will be more ample in the tundra than in the savannah biome.

Methodology

Species distribution models (SDMs) are one of the most useful tools to forecast species ranges under climate change, although results differ depending on the model being used and the ecological factors being incorporated (Araújo and New 2007). SDMs have been critiqued because of their failure to incorporate evolutionary history, dispersal ability and biotic interactions (Pearson and Dawson 2003), which can diminish the usefulness of the models since these would forecast fundamental as opposed to realised niches. Indeed, it has been suggested that species interactions are actually important at macroecological scales (Araújo and Luoto 2007). Depending on the application, consideration should be given not only to the type of SDM needed, but also to the variety of input data (Guillera-Arroita et al. 2015).

In order to overcome this, Anderson (2017) suggests modelling predictor species twice – one where the interactor exists and another when it does not, in order to quantify its effect on the target species' range. Other SDMs are based on empirical relationships, correlating climate with observed distributions and assuming that current distributions reflect climate sensitivity and account for biotic interactions (Pearson et al. 2002). In addition, certain models allow for additional data to be embedded, and this has been done for example with traits (Wittmann et al. 2016). I aim at inputting as much data as possible on species' interactions and traits prior to modelling the future distribution of dominant species in order to overcome this issue.

I will use temporal vegetation change data (including biotic interactions when available), trait data (from Chapter 2) and climatic data (CHELSA, (Karger et al. 2017) to estimate how plant distributions could shift over time with climate change (Elith and Leathwick 2009). My aim is to project the estimated distribution of species in the near future under the four climate change scenarios defined by the (IPCC 2014). SDMs will be undertaken in the R packages 'sdm' or 'biomod2'.

Current tundra species ranges have been outlined by the ARCFUNC project funded by the Danish National Research Foundation. Models on savannah species will build on the Dynamic Global Vegetation Model ADGVM2 developed by Scheiter et al. (2013). Several statistical models will be built in the 'sdm' package in R (Naimi and Araújo 2016) in order to better understand the distribution that best fits different dominant species, e.g. Generalized Linear Models, Generalize Additive Models, regression trees, random forests or maximum entropy, among others. I will also aim to incorporate the trait information obtained as part of Chapter 2.

Anticipated results

Dominant species are expected to shift towards higher latitudes and altitudes in the tundra with warming temperatures (Elmendorf et al. 2015), and savannah species are expected to expand with increased precipitation. SDMs will quantify the extent of these range shifts (which I anticipate will be larger in the tundra) and identify the areas that are more prone to regime shifts and ecosystem changes. I expect these regions to be closer to ecotones and transition boundaries.

Woody plant species will encroach less woody-dominant ecosystems in both biomes, thus effectively transforming the landscape where niches are available. I anticipate that deciduous shrubs will expand their ranges in the tundra, as opposed to evergreen shrubs which will likely experience range contractions. In the savannah, trees and deciduous shrubs are likely to expand their ranges.

Chapter 4 – Are extreme biomes responding similarly to climate change?

Background

Temperature and precipitation have been traditionally used to explain biome classification (Woodward et al. 2004). Primary production changes between biomes with climatic variation

(Knapp and Smith 2001), and species are expected to respond to climate differently among biomes, according to their own biology and ecological preferences (Hansen et al. 2001). Likewise, biodiversity redistribution can have profound consequences in the provision of ecosystem services but also in human health and well-being (Pecl et al. 2017). Ultimately, this can also lead to shifts in biome delimitation, and to the creation of “hybrid” (Hobbs et al. 2014) or “novel” ecosystems (Morse et al. 2014).

Following an overview of woody encroachment trends and drivers (Chapter 1), traits and winners vs. losers (Chapter 2), and species distribution shifts (Chapter 3), Chapter 4 could have different focuses. The first option would entail an analysis of overall biome responses under climate change, and the second, a conservation-driven comparison with management recommendations and implications for biome forecasting and protection under climate change. A third option would involve a combination of the two.

Objective and hypothesis

The objective of this chapter is to test whether species responses to global change drivers are generalizable across biomes or, alternatively, highly linked to the biomes that they inhabit. Findings will improve projections of future plant responses to global change through species modelling in order to inform biodiversity conservation.

H1: Both biomes are expected to decrease in area in the near future.

H2: The tundra will have a smaller extent due to a treeline and shrubline advance, and the savannah due to forests and agricultural lands gaining ground.

H3: The tundra will contain greater areas of vulnerable regions than the savannah.

Methodology

By combining the analyses and datasets from previous chapters into one new synthetic analysis, I will test whether the responses of plant species to climate change in terms of vegetation trends and drivers (Chapter 1), traits (Chapter 2) and range shifts (Chapter 3) are biome-specific. Attribution analyses could be performed in order to understand which factors (i.e. temperature, precipitation, CO_2 concentration, wildfires and herbivory) play a significant role on the responses to climate change in each biome, and in order to quantify an overall climate change effect in each of the biomes.

I will map the most vulnerable regions of the tundra and savannah biomes, by outlining the drivers that are identified to have the greatest influence in each biome now and under future projections using available gridded datasets. The specific analytical framework for this chapter has yet to be decided, but structural equation models might provide an appropriate approach.

Anticipated results

While the net effect of climate change in each of the biomes could be similar, different drivers are expected to influence each biome in different ways. An estimation of the contribution of each of the factors in each biome could be provided, together with an overall calculation of the effect of climate change in each biome. In addition, regional variation is expected within each biome across continents and environmental gradients. The geographical areas that are most at risk due to climate change will likely correlate to those where climatic conditions are shifting more rapidly.

Time plan

My PhD project is envisaged to last for three years, from September 2017 to September 2020 (Figure 5). The aim is to publish three scientific articles by the end of the project. In the first year the focus will be on Chapter 1 and a paper is expected to be finalised by the end of 2018. During the second year I will work on Chapters 2 and 3. In the third year I will complete Chapters 3 and 4 and finish writing my PhD thesis. The PhD finishing date could be extended until September 2021 if needed, but sources of funding will have to be sought in that case to cover for the extra year, given that my current funding only grants three years of funding.

I will undertake two fieldwork campaigns as part of my PhD project – one in the Arctic tundra and another in the savannah (see Appendix I). This PhD project does not entail fieldwork itself, but my supervisory team and I agree that developing my field skills should be a key component of this project in order to better understand the biomes that I am working with. I believe that by carrying out small projects in these ecosystems, I will be able to improve my knowledge on global vegetation change and this will certainly contribute to my further development and training as a scientist.

I will attend relevant conferences throughout the duration of my PhD and seek to present posters and give oral presentations (see Training section). The confirmation panel will take place in May 2018 and the viva is envisaged to occur in September 2018.

Table 1. Gantt chart outlining the timetable of the project. Each quarter represents three months of the year.

Activity	2017		2018				2019				2020			
	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Chapter 1														
Literature review														
Data analysis														
Paper/chapter writing														
Chapter 2														
Literature review														
Data analysis														
Paper/chapter writing														
Chapter 3														
Literature review														
Spatial modelling														
Paper/chapter writing														
Chapter 4														
Literature review														
Data analysis														
Paper/chapter writing														
Fieldwork														
Thesis writing														
Conferences														
Confirmation Panel														
Viva														

Project resources

Resources needed

The main resource required for this project is a computer with enough capacity to carry out spatial and statistical analyses of large biodiversity datasets. The provided University computer is not suitable for the purposes of handling large biodiversity datasets, therefore an appropriate computer will have to be purchased. Access to server or cluster computing might be required, which can be granted by the University of Edinburgh. The equipment needed to undertake fieldwork will be supplied through the supervisory team and borrowed from the School of Geosciences.

Budget

A total of £3,000 (£1,000 per year) is provided by the School of Geosciences as part of the Research Training Support Grant (RSTG). A breakdown of the envisaged expenses is provided in Table 1 below.

Table 2 Summary of expenses.

Activity	Cost (£)	Description
Fieldwork	900	Most Arctic fieldwork-related costs will be covered by Dr Myers-Smith as part of the Walters Kundert Fellowship and the UK-Canada Arctic Bursary Fund. An additional amount is included to account for matching funds for fieldwork equipment.
Laptop	1,200	MacBook Pro or similar computer with enough capacity to carry out statistical and spatial analyses with large datasets.
Conferences	2,100	Estimated conference cost of £400 to attend around five international scientific conferences.
Training	800	Budget to attend two training courses in European locations.
Total needed	**5,000**	**Total amount needed to cover all PhD-related expenses.**
Total provided by RTSG	**3,000**	**Total amount covered by the RTSG.**
Extra funding needed	**2,000**	**Total amount to seek for funding.**

Funding applied for

As mentioned in Table 1, around £2,000 additional funding will be needed to cover PhD-related costs. So far, I have applied to the following funding bodies:

1. British Ecological Society (BES) Travel Grant (January 2018). I was awarded £500 to cover the costs related to my attendance to the IBS conference in Portugal (see Training section).
2. Weir Fund (March 2018). I have applied for £1,500 to provide matching funds for the fieldwork season in the Arctic (see Appendix). The outcome of this award is not known yet.
3. James Rennie Bequest (March 2018). I have been granted £338.84 to cover my travel-related costs to attend the Eurogard conference in Portugal (see Training section).
4. Go Abroad Fund (March 2018). I have been awarded £350 to provide matching funds for the fieldwork season in the Arctic (see Appendix).
5. Innovation Initiative Grant (March 2018). I have applied for £1,733.8 to develop a board game named Conservation Quest in order to enhance the learning experience of the Conservation Science course students. The outcome of this award is not known yet.

Data management plan

I will work mainly with digital data, through databases, maps and photos, part of which are available through my supervisory team. Additional data will also be gathered through fieldwork both in the Arctic and in the savannah. Information for Chapter 2 on traits will be obtained through requesting access to TRY databases, and tundra data for Chapter 3 on species distributions will come from Signe Normand's research group at Aarhus University.

The data is stored in different servers depending on their size. I use the TeamShrub digital storage space managed by Dr Myers-Smith and a GitHub account to allow for version control and a safe record of my files, also allowing for collaborative work. I also store my files in the M drive (2 GB; providing regular back-ups) and the DataStore drive (550 GB) provided by the University of Edinburgh. Moreover, I use several cloud storage spaces (e.g. Dropbox, Google Drive) to allow for additional data back-ups.

New figures and analyses will be produced mainly through the statistical software and programming language R and the mapping software QGIS. Regarding the documentation of the data, R scripts will always contain a detailed explanation of the code used, and the spatial data (shapefiles) will contain attribute tables with metadata.

After submission of my thesis, I will seek consent from the data holders (e.g. the sTUNDRA project members) in order to make the original raw data publically available. If they agree, this data can be stored in a digital repository such as the DataShare of the University of Edinburgh, NERC data centres, or other international data repositories such as Dryad or TRY. Since some databases have been compiled collectively or contain data from different holders, some restrictions might apply.

For the different papers that may arise from my PhD, my code will be version controlled in GitHub and made publically available insofar as possible at the time of publication in an effort to make my contribution towards open science best practice.

Supervisory arrangements

As the PhD candidate, I count on a supervisory team composed of one principal supervisor, an internal co-supervisor, an external co-supervisor and an advisor.

Principal supervisor (60%): Dr Isla Myers-Smith, School of Geosciences, University of Edinburgh.

Co-supervisor (35%): Dr Caroline Lehmann, School of Geosciences, University of Edinburgh.

External co-supervisor (5%): Dr Anne Bjorkman, Senckenberg Biodiversity and Climate Research Centre, Germany.

Advisor: Dr Janet Fisher, School of Geosciences, University of Edinburgh.

As the PhD candidate, I am responsible for organising the meetings with the supervisory team. Regular face-to-face weekly meetings are scheduled with both Dr Myers-Smith and Dr Lehmann when possible. These meetings usually entail a revision of progress and the setting of future tasks. Skype meetings are scheduled with Dr Bjorkman when needed and I meet with her in person during conferences and her visits to Edinburgh.

The principal supervisor is in charge of supervising the administration aspects of the project and to provide general guidance and feedback throughout the project, together with expertise on tundra ecosystems and biodiversity analyses. The co-supervisor will provide feedback on general matters and expertise on savannah-related issues. The external co-supervisor will provide input on Bayesian hierarchical modelling, trait analyses and the ITEX database when needed. Finally, the advisor is in charge of organising the confirmation panel and the viva, and providing pastoral support if needed.

Training

Training courses

By May 2018, I will have undertaken the following training courses:

1. Induction course for Tutors and Demonstrators and Tutoring and Demonstrating workshop (September 2017)
2. Numeracy, Modelling and Data Management DTP training courses: Reproducible research, Version control with Git, Introduction to R 1, Introduction to R 2, Introduction to QGIS (September – November 2017)
3. Research Planning and Management in the GeoSciences (September – December 2017)
4. Coding Club: programming and statistics in R, multiple sessions (September – May 2017)
5. Diversity in the Workplace Training (October 2017)
6. Unconscious bias training course (October 2017)

7. EndNote online webinar (October 2017)
8. Prepare for Doctoral Success course (October – November 2017)
9. Fieldwork First Aid course (November 2017)
10. British Ecological Society (BSE) – Understanding science policy in Scotland (November 2017)
11. EdinbR talks on spatial data in R (January 2018)
12. Confirmation PhD workshop (February 2018)
13. Producing a thesis using word (February 2018)
14. Writing and Designing Your Academic Posters workshop (Edinburgh, March 2018)
15. Species Distribution Models using the sdm package (Portugal, March 2018)

I will also attend the Expedition First Aid Course at the University of Edinburgh in May 2018.

Conferences and seminars

By May 2018, I will have attended the following conferences and seminars:

1. Royal Society of Edinburgh (RSE) – Spotlight on Scotland's Biodiversity (October 2017)
2. EEB Changing Landscapes conference (November 2017)
3. Several Global Change Seminars on relevant topics (September 2017 – May 2018)
4. Several Biodiversity Journal Club meetings (September 2017 – May 2018)
5. Global Change Symposium (November 2017). I gave a two-minute presentation on my research.
6. British Ecological Society (BES) – Ecology Across Borders (Belgium, December 2017)
7. Several talks on plant ecology at the Royal Botanical Gardens (Edinburgh, February 2018)
8. Scottish Tropical Ecology and Biology Student Meeting (STEB; Edinburgh, March 2017). In this conference I gave a five-minute presentation on my research (Figure 6b).
9. International Biogeographical Society (IBS) – Climate Change Biogeography (Portugal, March 2018). In this conference I presented for the first time a poster on my research.
10. International Tundra Experiment meeting (Stirling, April 2018). I presented a poster on my research (Figure 6a).

In the near future, I will attend the following conferences: Annual PGR conference (Edinburgh, May 2018; I will give a 10-minute oral presentation) and the Eight European Botanic Gardens Congress (Portugal, May 2018; I will give a 15-minute oral presentation on my previous IUCN work). I will study the possibility of attending the next BES conference in December 2018

(Birmingham, UK) and will apply for a presentation slot at the next IBS conference in January 2019 in Spain in order to present the findings from my first paper and thesis chapter.

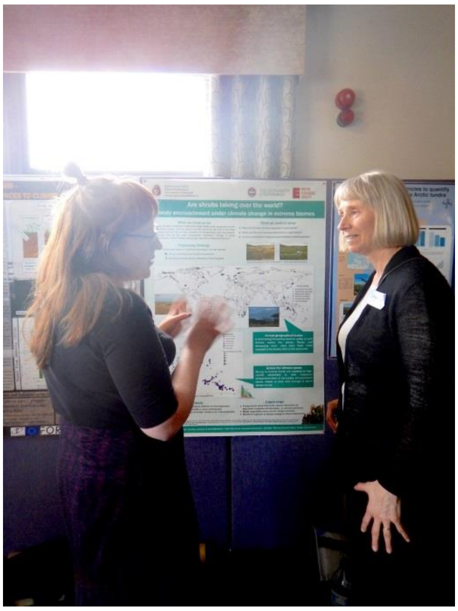
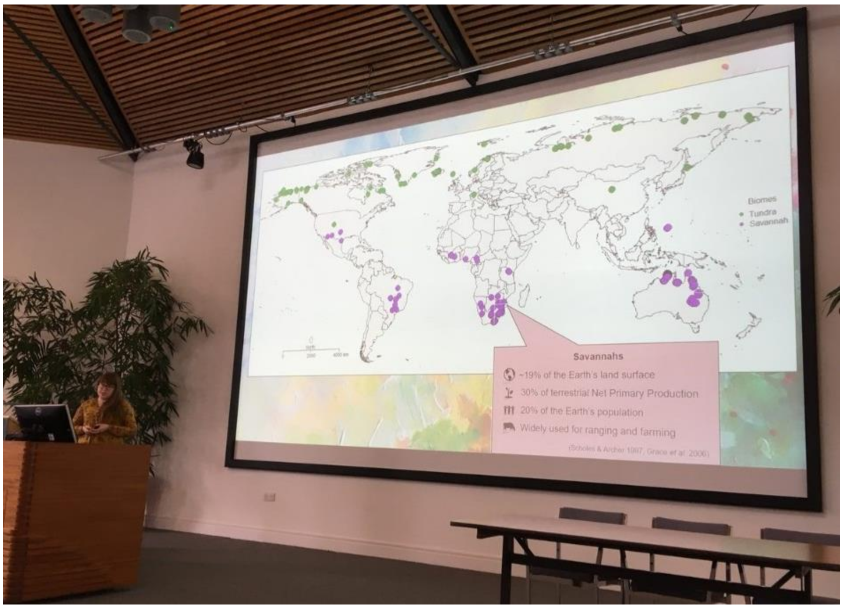

Figure 6a) Poster presentation at the ITEX conference, and **Figure 6b**) Oral presentation at the STEB meeting.

Future training needed

Identified future needs of training include:

1. Spatial modelling and raster handling in R
2. Statistical modelling in R
3. Bayesian hierarchical models in Stan
4. Species distribution modelling
5. Botanical identification skills

Support on the above can be provided by the supervisory team and the research group Team Shrub at the University of Edinburgh. Further training opportunities will be identified together with them.

Additional activities

As of April 2018, I am the co-coordinator of the Edinburgh University Biosphere and Atmospheric Programme (EUBAP) seminar series. EUBAP is run by PhD students and postdocs and is attended by PhD students and members of academic staff. Seminars aim at bringing internal and external researchers and cover a range of topics relating to the biosphere and to the atmosphere (and interactions between). These are a great opportunity for students to practice pre-viva talks, to network and discover other research areas.

In addition, I have been collaborating with Dr Anne Bjorkman on the production of a review article about plot-based vegetation change in tundra ecosystems for the Circumpolar Biodiversity Monitoring Program, to be published in a special issue of AMBIO during 2018. I also regularly collaborate with outreach activities as part of the Team Shrub research group, such as the art-science exhibition to be launched in May 2018.

Finally, I am still involved with certain aspects of my previous work at the International Union for Conservation of Nature (IUCN), and have recently published the European Red List of Lycopods and Ferns (García Criado et al. 2017), which I will present in the Eurogard congress in Lisbon, Portugal, in May 2018. I have also been a contributing author in the recent Europe and Central Asia regional assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which will be made available during 2018.

Teaching experience

I am currently funded by the Principal Career Development Scholarship (PCDS) granted by the School of Geosciences. This scholarship entails a teaching requirement of 60 hours per academic year. Thus, my overall teaching requirement is of 180 hours of my PhD.

I have been teaching during the first semester as a Tutor in the Conservation Science course (Year 4 Undergraduate), which is directly related to my professional experience. This amounted to 90 hours of teaching, which include tutoring (through discussion groups and activities) and demonstrating (through marking and fieldtrips). During the second semester, I taught in the Research Design in Geography course as a Demonstrator. In addition, I have attended the Fieldwork First Aid course, the Tutoring and Demonstrating induction and an extra tutoring session, which also count towards my teaching requirement.

Overall and as of May 2018, I have completed a total of 117.5 hours. The exceeding completed hours above 60 roll over to count for my teaching requirement during the second year, as agreed with the Tutoring and Demonstrating Administrator. In the future, I will continue working as a tutor and/or demonstrator. My intention is to teach on different courses in order to learn different teaching styles and expand my teaching experience. I believe that I will be able to complete my overall teaching requirement by the end of the second year.

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Appendix I - Fieldwork

A description and background of the fieldwork to be undertaken in the summer of 2018 (the tundra component) is outlined below. Plans for a second fieldwork season in the savannah will be defined during 2018 and will possibly entail travel to an African country.

Quantifying tundra shrub change over time from repeat photography

Summary

Shrub expansion is occurring at accelerated rates due to warming temperatures, however change rates are inconsistent across the Arctic. By developing a new procedure to translate repeat photography data into quantitative cover change on Qikiqtaruk-Herschel Island, I will calculate past rates and forecast future shrub encroachment in this tundra ecosystem.

Scientific background and justification

Climate change is leading to large-scale changes in ecosystem services and biodiversity composition across the planet. Range shifts have been noted across a wide range of geographical and taxonomical scales (Elmhagen et al. 2015), but the tundra remains the most vulnerable biome due to its presence at temperature and precipitation extremes (IPCC 2014). One of the most conspicuous changes is shrub encroachment, which is taking place at accelerated rates across the Arctic (Elmendorf et al. 2012, Martin et al. 2017). Continued monitoring has taken place at Qikiqtaruk-Herschel Island, Canada, for a few decades (Myers-Smith *et al*., in prep), through plot surveys, unmanned aerial vehicles (UAV; drones) and repeat photography. The aim of my project is to integrate these three different methodologies in order to quantify the rate of shrub encroachment that has taken place in the island during recent years and to be able to forecast predictions of plant change across the tundra.

Study site details

My proposed study site is Qikiqtaruk – Herschel Island, which is part of the Yukon Territory, Canada (69.6°N, 138.9°W) and is inside the Arctic Circle (Figure A1). The island (115.5 km^2) is designated as a Territorial Park. It is located in the traditional land of the Inuvialuit people and contains a characteristic set of Arctic fauna and flora. The climate in this Arctic region has warmed and the ecological impacts have been documented through an extensive ecological monitoring programme that was established in 1999, making Qikiqtaruk an Arctic research focal site. As a result, a large network of researchers and practitioners is in place, including the International Tundra Experiment (ITEX), the Yukon Parks rangers and local people. Dr

Isla Myers-Smith, my PhD supervisor and leader of the Team Shrub research group, has been conducting research in Qikiqtaruk for over 10 years and thus the working relations and logistics (including accommodation and facilities) are clearly established in a safe environment. We will be in daily contact with the Yukon Parks rangers, in particular with Park Biologist Cameron Eckert who oversees the monitoring programme. We will also coordinate with researchers from the Alfred Wegener Institute (AWI), Germany, who will be undertaking their research at the same time. We have applied for research permits as of April 2018. The second study site is Kluane National Park (60.59°N, 139.58°W), where we will only spend a total of 10-12 days working on a common garden experiment that is currently set up there.

Figure A1. Location of the study sites in northern Canada.

Methodology and outcomes

The Team Shrub research group has been collecting plant monitoring data for several years across Qikiqtaruk. For one particular site along a watershed, Ice Creek (69.57N°, 138.91W°), a series of repeated photographs are available where the rates of change are visible and conspicuous (Figure A2). Repeat photography is sometimes the only available resource to document vegetation change, including increasing shrub cover (Lantz et al. 2013, Naito and Cairns 2015); yet understanding quantitative change from oblique photographs alone is a substantial challenge. I hypothesise that shrub cover has accelerated at this site and that it will continue to increase at a similar or slightly higher rate in the future. However, I require quantitative data to test exact rates of previous shrub expansion to make informed future predictions.

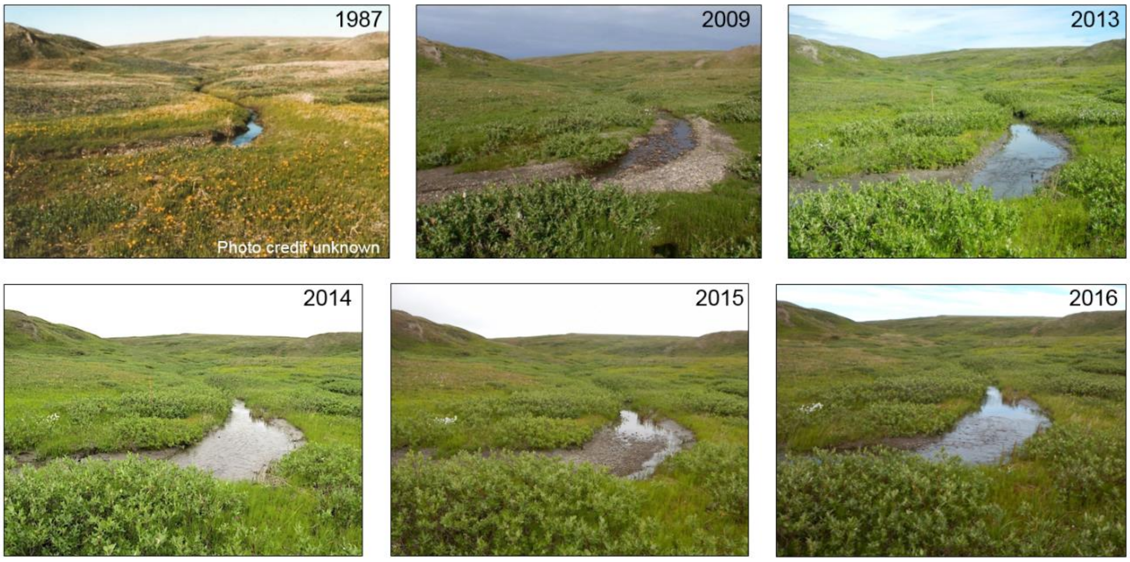

Figure A2. Sample of the repeated photographs taken at Ice Creek over the years.

The aim of my project is to quantify past and future rates of shrub encroachment at this location in the footprint of the photograph time series. I can then use these data to back cast shrub cover in earlier parts of the time series and estimate change rates over time. I will 1) measure cover and canopy height of all the shrubs present in this watershed through vegetation surveys following standardized protocols (e.g., collection of geographic locations and shrub plant sizes), and 2) take additional photographs of the site in order to complete the timeline series and quantify this region from multiple angles. Finally, I will 3) analyse nadir UAV images (with the camera angle pointing towards the ground) collected over the last three years in combination with the repeated oblique photographs through photo analysis software (e.g., ImageJ). This combined data collection will enable me to infer past shrub growth rates (1987 to 2008) and to quantify future rates of shrub encroachment.

In addition to this photography project, I will collaborate with my colleagues in the field on general plant monitoring by surveying active layer depth, plant cover and phenology around the island. We will also look into the relationship between species pool and local species turnover around Qikiqtaruk. Finally, a drone pilot will fly the device over the monitoring plots, and I expect to help them so I can get some basic knowledge of UAV manipulation and techniques. In Kluane, we will continue monitoring the common garden experiment that is currently set up to extract further phenology information.

I will liaise with the Yukon Parks rangers and Inuvialuit people to ask about their perspectives on vegetation change and the implications for park management and traditional livelihoods and practices. I will involve the Park rangers in the data collection and interpretation of results, and I will present my findings to local people and Yukon Territorial Park management. In order to disseminate the results, I will post updates on my work in the Team Shrub blog (www.teamshrub.com) and I will publish my work in an international scientific journal.

Schedule

My fieldwork season will take place between July and August 2018. Further preparation will take place between May and June 2018 when all the logistics will be arranged and shipments sent to Canada. I will fly from Edinburgh to Vancouver or Whitehorse on the week of July 1st, depending on logistics and flight availability. From there, we will drive to Kluane National Park, where we will spend 5-6 days at the Kluane Research Station. Afterwards, we will fly from Whitehorse to Inuvik, from where we will take a charter flight to Herschel Island around July 15th. This trip is largely dependent on weather conditions, so the exact date is yet to be confirmed, but it will be arranged in consultation with the Yukon Parks rangers and in collaboration with the AWI research group. Departure from the island is envisaged to take place on August 11th, and a flight from Inuvik to Whitehorse will be arranged in the following days. Afterwards, we will drive to Kluane again, where we will spend another 5-6 days maintaining the common garden. Finaly, we will fly back to Edinburgh at the end of August. During the fieldwork period and the autumn of 2018, I will analyse the photographs and the UAV images. I will prepare the scientific article during the autumn of 2018 and the winter of 2019.

Risk assessment

During my time in the field, I will always carry out fieldwork together with other colleagues and will be in direct touch with the Yukon Parks rangers via radios. I will also have access to a satellite phone to communicate via e-mail outside of the island, and in the case of emergency, helicopter transport to Inuvik will be available. In addition, I have completed a Fieldwork First Aid course (November 2017) and will undertake the Expedition First Aid course in May 2018. My fellow colleagues have also undertaken one or both of these courses, and are experienced on undertaking fieldwork at remote locations. Environmental impact will be minimal since the vegetation surveys that I will perform will be non-destructive, and I will ensure that no waste is left behind in the island. Please see the attached risk assessment form for a more detailed explanation on the dangers that may arise and the actions taken to avoid them.

Participant contributions

I will be collaborating with a number of researchers in the island, including the AWI and ITEX research groups, although I will mainly work with Gergana Daskalova and Sandra Angers-

Blondin (PhD in Earth and Atmospheric Sciences) from my research group Team Shrub at The University of Edinburgh. While each of us is responsible for a small project, we will always work together in the field in order to ensure that we are accompanied at all times. Our research group's Principal Investigator, Dr Isla Myers-Smith, will provide logistics and organisation support prior to our departure.

Financial statement

Most costs will be covered by grants held by Dr Myers-Smith. Additional funds to cover field equipment and gear will be taken from my Research Support Training Grant (RTSG), granted from the Principal Career Development (PCD) scholarship from the School of Geosciences and my personal finances. I have also applied to different grants to cover additional costs related to the field season (see Project resources section).

Personal statement

While I have previously undertaken fieldwork during my BSc and MSc studies, I have never had the chance to carry out my own independent project in the field, and my PhD thesis does not involve fieldwork. Thus, this project poses a unique opportunity to improve my technical skills, including vegetation sampling and monitoring, repeat photography analysis and UAV image interpretation. By managing my own fieldwork, I will also improve my project management, organisational and logistics skills, and will deal with problem solving with limited resources, which will contribute skill sets to my future career path. The cooperative nature of research in the island will be extremely useful to me too, since I will expand my contact network with whom I could collaborate in the future. Finally, by working on the Yukon Territory, I will be able to get to know and learn from the Inuvialuit people, which will be exceptionally enriching both personally and professionally. In conclusion, this experience will not only enable me to contribute to an international long-term ecological monitoring programme, but also to advance my own scientific career and development as an individual.

Appendix II – Ethics form

THE UNIVERSITY *of* EDINBURGH
School of GeoSciences

Research Ethics and Integrity Assessment Form

PART 1 - First Pass Assessment

1. Are you an undergraduate, MSc or PhD student?

[x] YES Complete Part 2 of the Research Ethics and Integrity Assessment Form (as 'Self' or 'Fu

[ ] NO **Go to Question 2**

2. Has your research been reviewed by an external body (e.g. NHS, BAS)?

[ ] YES Complete a Confirmation of External Review Form .

[ ] NO **Go to Question 3**

3. Does your research involve human subjects (e.g. interviewing, participant observation, PAR, survey, audio/film recording)?

[ ] YES Complete Part 2 of Research Ethics and Integrity Assessment Form (as 'Self' or 'Full').

[ ] NO **Go to Question 4**

4. Does your research involve environmental fieldwork (e.g. sampling, directly monitoring a site, environmental disturbance, trans-boundary movement of specimens /samples)?

[ ] YES Complete Part 2 of the Research Ethics and Integrity Assessment Form (as 'Self' or 'Fu

[ ]

NO **Go to Question 5**

5. Does your research involve the use of data/material provided by an external source (e.g. other researcher, agency, data repository) or archival work?

☐ YES Complete Part 2 Research Ethics and Integrity Assessment Form (as 'Self' or 'Full').

☐ NO **Go to Question 6**

6. Are you confident that you understand the requirements of the Data Protection Act (1998) and that you have appropriate documented agreements and procedures in place to cover your collaborative working relationships with academic or non-academic partners (including local field assistants), extending to how intellectual property, publication and authorship will be shared?

☐ YES **Go to Question 7**

☐ NO Complete Part 2 Research Ethics and Integrity Assessment Form (as 'Self' or 'Full').

7. Are you confident that your work meets the standards of integrity required by the UoE and that you have a sound and justifiable plan regarding dissemination of the results of the research (e.g. to potential beneficiaries such as funders, study participants, land occupiers or owners, local communities, etc.)?

☐ YES **Please email the Research Ethics and Integrity Secretary (ethics@geos.ed.ac.uk) with your project title and a copy of this First Pass Assessment. The Research Ethics and Integrity Committee reserve the right to obtain a written record of your reasoning.**

☐ NO Complete Part 2 of the Research Ethics and Integrity Assessment Form (as 'Self' or 'Full').

PART 2 - Research Ethics and Integrity Assessment Form

Tick either Self or Full Assessment		
SELF ASSESSMENT	X	Read Research Ethics and Integrity Self-Assessment Guidance Notes
FULL ASSESSMENT		Read Self-Assessment Guidance Notes in conjunction with Full Research Ethics and Integrity Assessment Guidance Notes
Has a member of the Committee been consulted prior submission?		If ticked please provide the name of Committee Member **Name**

Title of Research Project: Quantifying vegetation shifts under climate change in extreme biomes

Duration of Research Project: 3 years

Name of Principal Investigator: Mariana García Criado

Signature of Principal Investigator: Date: 07/05/2018

(Electronic signatures / typed names are accepted)

Research Institute (staff and PhD only): Global Change

Email of Principal Investigator: mariana.garcia.criado@ed.ac.uk

Co-Investigator(s) email(s) (if applicable): n/a

Student supervisor information **(if applicable)**
Name of Supervisor: Isla Myers-Smith Signature of Supervisor*: Isla Myers-Smith Date: 07/05/2018 (Electronic signatures accepted or typed name and date if supplied with the email from your supervisor which verifies approval)

Type of student **(if applicable)**	Tick	Student Number	Name of your programme secretary
Undergraduate Honours			

	Undergraduate students should attach the completed form to their dissertation research/project proposal. The ONLY time an Undergraduate student should submit a form to the School Research Ethics and Integrity Committee is if their research requires a Full Assessment.		
Taught MSc			
MSc by Research			
	MSc students should attach the completed form (signed by their supervisor) to their dissertation research/project proposal or forward the form to their Programme Director for review as instructed in their programme handbook. The ONLY time a Masters student should submit a form to the School Research Ethics and Integrity Committee is if their research requires a Full Assessment.		
PhD	**X**	**s1771678**	pgrsupport@geos.ed.ac.uk
	PhD students should submit their form (signed by their supervisor) to the School Ethics and Research Integrity Committee at least 3 weeks in advance of their Confirmation Meeting.		

Check List before submission	
I have read the appropriate Guidance Notes	X
I have completed all relevant check boxes	X
I have included a Research Summary	X
I have completed the Additional Statement box (where appropriate)	N/A
I have appended all other relevant documents (where appropriate) (NB: If you are an undergraduate, MSc or PhD student submitting a Full Research Ethics and Integrity Assessment please attach your Plain Language Statement(s), Consent Form(s), and copies of formal agreements, email correspondence, etc. as appropriate)	

After this form is completed

Email the completed form (along with any additional supporting documents) to the Committee Secretary by emailing ethics.geos@ed.ac.uk. The form will be logged and reviewed by the Committee and a Determination returned to you within 3 weeks.

Research Project Assessment

Research Summary

Woody encroachment has been increasingly reported at locations across the planet, including in the tundra and the savannah, two biomes thought to be particularly vulnerable to climate change. While woody expansion has taken place at similar temporal scales, the drivers and magnitude of change across biomes differ. In my PhD thesis, I will provide an overall synthesis of woody encroachment to quantify the rates of vegetation change and calculate the contribution of different drivers to shrub expansion in each biome. In addition, I will identify the plant traits that play a key role in determining tundra and savannah shrub species' vulnerability to climate change. Using these analyses, we will identify taxa that are more prone to population increases, declines and extinction, i.e. the winners and losers, under climate change. Finally, we will examine how the distribution ranges of dominant species in the tundra and the savannah could shift as a consequence of climate change. We will use four different climatic scenarios issued by the Intergovernmental Panel on Climate Change and spatial modelling to test possibilities of future shrub encroachment. This work will enable cross-biome comparisons of climate change responses by identifying whether species' responses are generalizable or highly linked to the biomes they inhabit. Fieldwork will take place in the Canadian Arctic during the summer of 2018, together with three other team members. This will entail vegetation monitoring through surveys and repeat photography. A second fieldwork season will possibly take place during 2019 in the African savannah with one other team member.

1	**Legal, moral responsibilities, codes of conduct** This box must be completed for all research projects	*yes*	*no*	*N/A*
A	Are there any conflicts of interest between the researchers, funding bodies, the institution, and/or research subjects/environments?		X	
B	Is the research compliant with the Data Protection Act (1998) and University of Edinburgh Data Protection procedures?	X		
C	Separate from any legal obligations, is there a moral responsibility to provide feedback or results to research participants/landowners?		X	
D	Will you take all necessary measures to maintain the integrity of the research?	X		
E	Are you aware of codes of conduct from professional associations that should guide your research?	X		
F	If the research is to take place outside the UK, will the research be, or has the research been, reviewed in the host country?	X		
G	Does your research concern groups which may be construed as terrorist or extremist?		X	
Guidance relating to legal and moral responsibilities and a sample list of Codes of Conduct can be found in the Self-Assessment Guidance Notes. If applicable, include a statement on how conflicts of interest will be addressed in the Additional Statement box at the end of the form. If applicable, include a statement on why the research will not be ethically reviewed in the host country in the Additional Statement box at the end of the form. If you answer YES to 1G please complete and submit a Prevent Duty Form (available via the ethics webpages) alongside your completed Ethics				

Assessment Form.

2	**Rights of human subjects** Complete this box *only if* the project involves living human subjects, or if your work requires extensive interaction with land users or other people in the course of your research.	*yes*	*no*	*N/A*
A	Is confidentiality adequately handled by normal tenets of ethical academic research?			
B	Are the research subjects capable of understanding their rights and of providing informed consent?			
C	Are the research subjects 18 years of age or over?			
D	Will research subjects be informed of your responsibilities to report any evidence of abuse or criminal activity?			
E	Will research participants be informed about your obligations under the Data Protection Act (1998)?			
	If NO to any of these, Full Ethics Assessment required			
	Guidance relating to subjects' rights, confidentiality, and the Data Protection Act (1998) can be found in the Self-Assessment Guidance Notes (those completing a 'Full' assessment should also read the Full Ethics Assessment Guidance Notes). If applicable, procedures for maintaining confidentiality and data protection issues must be addressed in the Additional Statement box at the end of the form. If applicable, please also append forms/statements that will be used to obtain informed consent and a Plain Language Statement to the end of the form.			

3	**Potential harm, discomfort or stress for living human subjects or non-humans** This box must be completed for all research projects.	*yes*	*no*	*N/A*
A	Is there significant foreseeable potential for psychological harm or stress for those involved in your research (including the research team)?		X	
B	Is there significant foreseeable potential for physical harm or discomfort for those involved in your research (including the research team)?		X	
C	Is there significant foreseeable potential for violation of cultural or social norms/practices?		X	

D	Is there significant foreseeable potential for conflict or discomfort for any humans or non-humans your research will impact upon?		X	
	If YES to any of these, Full Assessment is required			
	Guidance relating to the minimisation of harm, discomfort, or stress can be found in the Self-Assessment Guidance Notes. If applicable, include a statement on procedures to minimise harm, discomfort and/or your stance in relation to the violation of cultural norms and practices in the Additional Statement box at the end of the form.			

4	**Effect on environment** Complete this box *only if* your project includes environmental fieldwork that involves sampling or directly monitoring a site, or if your research will involve movement in or through sensitive environments.	*yes*	*no*	*N/A*
A	Will the fieldwork be conducted in an environmentally sensitive area or area of Special Scientific Interest, OR require *crossing* a sensitive area?		X	
B	Have appropriate steps been taken to gain permission to access the field site(s) (including privately held land)?	X		
C	Will the landowner/responsible agency be informed of your responsibilities to report any evidence of abuse or criminal activity?	X		
D	Will samples be collected and removed in sufficient quantities to have a negative physical/environmental impact on the site and/or its eco-system?		X	
E	Will the conduct of the fieldwork significantly disrupt the site and/or its environment?		X	
F	Does the fieldwork involve sampling rare/endangered or harmful taxa/species?		X	
G	Will the research involve transporting samples/specimens between countries or across other significant boundaries?		X	
	If YES to A, D, E, F or G, Full Ethics Assessment required			
	Guidance relating to environmental fieldwork can be found in the Self-Assessment Guidance Notes (those completing a 'Full' assessment should also read the Full Ethics Assessment Guidance Notes). If applicable, include a statement on how you will attempt to gain permission in the Additional Statement box at the end of the form. If applicable, append any written agreement with the land owner to the end of the form.			

5	**Institutional/agency consent** This box must be completed for all research projects	*yes*	*no*	*N/A*

A	Have permissions for access to archives and data repositories been arranged?	X		
B	Where data has or will be obtained from another researcher, agency, archive, or other source, is it clear that the intended usage adheres to the terms of supply?	X		
C	Will issues of data handling and consent be dealt with adequately and following procedures agreed with agencies, archives, and/or land managers?	X		
Guidance relating to data protection and consent can be found in the Self-Assessment Guidance Notes				

6	**Collaborative working** Complete this box *only if* the research will involve working collaboratively with other academic/non-academic partners and/or employing local field assistants (including guides/translators).	*yes*	*no*	*N/A*
A	Is there a formal agreement in place regarding the collaborative relationship with the academic partner(s) (if applicable)?			
B	Is there a formal agreement in place regarding the collaborative relationship with the non-academic partner(s) (if applicable)?			
C	Is there a formal agreement in place regarding the employment of local field assistants (including guides and translators)?			
D	Will care be taken to ensure that all individuals involved in implementing the research adhere to the ethical and research integrity standards set by the UoE?			
E	Have you reached agreements relating to intellectual property, publication and authorship?			
Guidance relating to collaborative working, the employment of local field assistants, and intellectual property rights can be found in the Self-Assessment Guidance Notes. If you answer YES to A, B or C please outline the format of this (e.g. written contract, email correspondence, witnessed verbal agreement) in the Additional Statement box at the end of the form. If you answer NO to any of the above please include a statement on your plans for agreeing the nature of any collaborative/working relationship(s) in the Additional Statement box at the end of the form. If applicable, append any written agreements to the end of the form.				

7	**Dissemination and benefit sharing** This box must be completed for all research projects	*yes*	*no*	*N/A*
A	Will the research reports, associated publications and other outputs accurately	X		

	reflect the data collected?			
B	If the research will be undertaken outside the UK, will the research findings, associated publications and, where feasible, data be made available in the country where the research took place?	X		
C	Will you disseminate the findings to the study participants or land owners?	X		
D	Is the research expected to benefit the academic partners (directly or indirectly)?	X		
E	Is the research expected to benefit the non-academic partners, research participants and/or local communities (directly or indirectly)?	X		
Guidance relating to dissemination and benefit sharing can be found in the Self-Assessment Guidance Notes. If you answer NO to A, B or C please include a statement justifying your decision in the Additional Statement box at the end of the form.				

8	**Other Approval**	*yes*	*no*	*N/A*
A	Does the sponsor require formal prior ethical review?		X	
	If Yes, by what date is a response required?			
B	Does the project require the approval of any other institution and/or ethics committee?		X	
	If Yes, by what date is a response required?			

Additional Statement

If relevant, please explain how you will address the ethical and integrity issues raised by the questions above ('Self' assessments max. 500 words; 'Full' assessments max. 1,000 words).

END OF FORM TO SUBMIT

Approval confirmation from my supervisor, Isla Myers-Smith.

Re: [IMPORTANT] Ethics form for conf report

MYERS-SMITH Isla

Mon 07/05/2018 23:55

To:GARCÍA CRIADO Mariana <Mariana.Garcia.Criado@ed.ac.uk>;

Hello Mariana,

Thank you for sharing your ethics form with me. I approve and

verify the contents. Isla

```
--
Dr. Isla H. Myers-Smith
School of GeoSciences, University of Edinburgh
113 Crew Building,
The King's Buildings
West Mains Road,
Edinburgh EH9 3FF
phone: +44 (0) 131
650 7251 e-mail:
isla.myers-
smith@ed.ac.uk
http://teamshrub.com
/
```

On 07/05/2018 17:12, GARCÍA CRIADO Mariana wrote:

Hi Isla,

Here is the ethics form that I need to supply with my confirmation report, which I intend to send tomorrow. It seems like I need your signature, but if you answer directly this email I can also use this as proof that you verified and the ethics form. Could you just answer this email with your approval so I can attach it to the form please?

Thanks a lot!
Mariana

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