REPORT

Climate change and national crop wild relative conservation planning

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Abstract Climate change is likely to be one of the most important factors affecting our future food security. To mitigate negative impacts, we will require our crops to be more genetically diverse. Such diversity is available in crop wild relatives (CWRs), the wild taxa relatively closely related to crops and from which diverse traits can be transferred to the crop. Conservation of such genetic resources resides within the nation where they are found; therefore, national-level conservation recommendations are fundamental to global food security. We investigate the potential impact of climate change on CWR richness in Norway. The consequences of a 1.5 and 3.0 °C temperature rise were studied for the years 2030, 2050, 2070, 2080 and then compared to the present climate. The results indicate a pattern of shifting CWR richness from the south to the north, with increases in taxa turnover and in the numbers of threatened taxa. Recommendations for in situ and ex situ conservation actions over the short and long term for the priority CWRs in Norway are presented. The methods and recommendations developed here can be applied within other nations and at regional and global levels to improve the effectiveness of conservation actions and help ensure global food security.

Keywords Agriculture · Ex situ conservation · Food security · Genetic diversity · In situ conservation · Plant genetic resources

INTRODUCTION

Many regions throughout the world are projected to experience climate change-induced reductions in crop yields and additional associated challenges are mounting (e.g. pests, water supply and soil degradation) (Müller and Robertson 2014; Rosenzweig et al. 2014). The IPCC (2013) predicts that in the short term (2016–2035), the global mean surface temperature change is expected to be between 0.3 and 0.7 °C with the highest prediction set at 4.8 °C for the year 2100. At the Paris climate change conference (UNFCCC 2016), a global action plan to limit warming to below 2.0 °C increase was agreed. To help achieve this target Intended Nationally Determined Contributions (INDCs) were submitted by individual countries and if followed are predicted to limit global warming to approximately 3.0 °C temperature increase (UNFCCC 2015). While some locations may see crop yield increases (Olesen and Bindi 2002; Uleberg et al. 2014), the global average negative effects of climate change on many aspects of food security (McCarthy et al. 2001) and the interdependence of most countries on imports and exports of food (FAO 2009) mean it is becoming increasingly important to make our crops more climate resilient.

Crop wild relatives (CWRs) are a key resource in meeting this challenge as they are often found in a wide range of habitats, under variable environmental conditions. They are wild taxa closely related to our cultivated crops and, as such, tend to contain higher levels of genetic diversity (Tanksley and McCouch 1997; Buckler et al. 2001; Maxted and Kell 2009). The value of CWR in climate change adaptation is highlighted in a recent report by the FAO (2015) who recommend consolidating collections of wild species, including CWR, because of an increased adaptive capacity inherent in a greater genetic diversity,

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and the need to adapt agriculture to climate change. Some examples of the use of CWR in cultivar development include the transfer of cold tolerance from wild *Malus baccata* (L.) Borkh. to *M. domestica* Borkh. (Cummins and Aldwinckle 1979) and the improvement of drought tolerance in cultivated barley from wild barley (*Hordeum vulgare* L. subsp. *spontaneum* (K. Koch) Thell.) (Lakew et al. 2011) (see Maxted and Kell 2009 for more examples). Furthermore, the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (PGRFA) (2011) stresses the importance of expanding the programme on ex situ conservation to ensure maintenance of diversity of species including those that are adapted to extreme conditions and from those areas expected to be highly affected by climate change. The report also places emphasis on in situ conservation of genetically diverse populations to allow evolution and thus permit the continued generation of adaptive traits.

Specific studies on CWR have confirmed that they might be negatively affected by climatic change, with a high proportion of the species studied losing over 50% of their range size by 2055 (Jarvis et al. 2008). Broader-scale studies on terrestrial species have identified trends for distribution shifts to higher latitudes and elevations (Thomas et al. 2012) as well as increasing IUCN threat level due to climate change (Thuiller et al. 2005). However, few if any, studies have been done at a national level regarding the effects of climate change on the distribution of CWR. Norway is particularly interesting in respect of climate change effects upon species distribution as it is located on the periphery of Europe with the mainland stretching, from south to north, from 50°N to 71°N as well as having notable north–south and east–west climate gradients (Norwegian Ministry for Agriculture and Food 2008). At northern latitudes, surface temperature and precipitation are expected to increase (Solomon 2007), with the arctic warming at a faster rate than the global average (Arctic Climate Impact Assessment 2004). Initially, these changes may increase crop yields at high latitudes (Olesen and Bindi 2002), due to an extension of the growing season, possibly up to 1–3 months (Hanssen-Bauer et al. 2009). These effects of climate change will have important consequences for northern flora in particular, with areas potentially experiencing an increase in species diversity (Sætersdal, Birks and Peglar 1998) but some species populations may become restricted at their northern limit. Furthermore, currently well-adapted northern species may be increasingly challenged by rising incidences of new pests and diseases.

Recommendations were recently identified for the in situ and ex situ conservation of CWR at the national level within Norway (Phillips et al. 2016). That study pinpointed 204 priority CWR of which 44% were forage taxa, 43%

were food taxa and 13% were ‘other’ taxa such as medicinal or forestry species (Phillips et al. 2016). The Norwegian priority taxa are important from the global to the national level, due to their economic value, presence within the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA; www.planttreaty.org), importance to Norwegian research and/or within the Harlan and de Wet inventory of 173 globally important crops (Vincent et al. 2013). In order to determine actions required to mitigate the negative effects of climate change, species distribution models (SDM), which use environmental data to identify taxon-specific ecological niches (Phillips, Dudík and Schapire 2004) that may be suitable for populations to persist in, can be utilized. However, SDM assume that nature is static or on a linear path of change, often ignoring fecundity, dispersal, soil specificity and preference (Midgley et al. 2003), and it is therefore necessary to use the results with caution. Here, we aim to contribute towards the knowledge base on climate-smart conservation planning for CWR conservation by developing methods to identify priority taxa and genetic diversity that may be under threat. In light of climate change, it will be important to consider both incremental (adjustments made enabling the continuation of current practices) and transformational (fundamental changes in conservation practices) (Walker et al. 2004; Nelson et al. 2007; Stafford Smith et al. 2011) adaptation plans to ensure long-term flexibility and effectiveness of conservation strategies. The current protected area (PA) system throughout the globe (including national parks and nature reserves) is static (Peters and Myers 1991), often severely restricted in the future potential for expansion and may not have been established with the future effects of climate change in mind. In addition, it is highly likely that the rate of climate change will exceed the potential of populations to track climate by natural migration (Midgley et al. 2003; Jump and Penuelas 2005) and adaptation (Jump and Penuelas 2005), therefore increasing the need for ex situ conservation. Both in situ and ex situ conservation recommendations are made to ensure that this diversity is available for use by plant pre-breeders to help develop crops that are sufficiently robust enough to withstand predicted changes in climate not only within Norway but globally.

MATERIALS AND METHODS

Species data sources

The priority CWR inventory of Norway containing 204 taxa was used as the basis for the climate change analysis (Phillips et al. 2016). Taxa occurrence records were gathered from GBIF (GBIF 2013) and are the same as those

used by Phillips et al. (2016). During predictive distribution modelling, the same 14 taxa as in Phillips et al. (2016) were excluded from the final analysis due to lack of presence points. Hence, the following evaluation was done upon 187 of the priority CWR, with a total of 304 372 presence points utilized.

Species distribution modelling

The potential distribution of taxa under both the present and future climate scenarios was mapped. The present bioclimatic variables used were obtained from freely available sources and were the same as those used by Phillips et al. (2016), which consisted of bioclimatic, geophysical and edaphic factors, each with the same extent and raster grid cell size (0.0416, approximately equal to $4 \times 8 \text{ km}^2$). Present-day climate refers to an interpolation of observed data which was representative of the years 1960–1990 (Hijmans et al. 2005). Environmental variables in the model were reduced in number from 105 to 13 variables in order to help minimize redundant or correlated variables which may affect the validity of the SDM. This was done by testing for collinearity (Dormann et al. 2013) between variables and running a principal components analysis (PCA) in SPSS 22 (IBM Corp 2013) to produce a list of uncorrelated variables. Experts within Norway were then consulted on which of these variables they considered most important for predicting plant distribution in Norway. The maximum entropy (MaxEnt) algorithm (Phillips et al. 2004; Phillips et al. 2006) was used to model the potential distributions for each priority taxon individually under both present and future bioclimatic variables (see Phillips et al. 2016 for settings used in MaxEnt). MaxEnt has been used robustly for predictions of climate modelling (Ramirez-Villegas et al. 2010; Warren et al. 2013) and has performed well in comparison tests with similar programs (Anderson et al. 2006; Elith et al. 2011).

The future bioclimatic variable data were obtained for the climatic variables only, as edaphic and geophysical variables were unlikely to change with climate change. The climatic variables used were isothermality, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation and precipitation seasonality (see Phillips et al. 2016 for more details). These data were gathered from CCAFS (www.ccafs-climate.org/data/) where climate data were available from numerous models and scenarios based upon the most recent IPCC report (Prather et al. 2013). The Norwegian Earth System Model, NorESM1-M (Bentsen et al. 2013), which was based upon the Community Climate System Model version 4 (CCSM4) (Gent et al. 2011), was used due to its specificity to climatic processes that are particularly important at northern latitudes (Bentsen et al. 2013). These models were

driven by the two relative concentration pathway scenarios (RCP 2.6, RCP 6.0), representative of the potential future variability and pathways of greenhouse gas emissions (Prather et al. 2013). RCP 2.6 was used in this study as it represents the agreed maximum temperature rise set out by the Paris agreement (1.5 °C) (Rogelj et al. 2012; UNFCCC 2016). RCP 6.0 represents the more likely development from the implementation of global INDC proposals of a 2.5–3.5 °C temperature increase by 2100 (Rogelj, Meinshausen and Knutti 2012; UNFCCC 2015). Analysis was undertaken for the years 2030, 2050, 2070, 2080 and compared to the present to allow visualization of the long-term pattern of distribution change of CWR.

Evaluation of the models' accuracy was done using two validation metrics suggested by Ramirez-Villegas et al. (2010), the Area under the ROC (Receiver Operating Characteristic) Curve of the test data (AUC_{Test}) and standard deviation of the AUC_{Test} data (STAUC) for each taxon. Models with an $AUC_{\text{Test}} > 0.7$ and STAUC < 0.15 are considered accurate and stable (Ramirez-Villegas et al. 2010).

Species richness, turnover and threat level

To determine the potential impacts of climate change upon the priority taxa, they were assessed under unlimited migration, with populations able to move to where the climate is suitable, and no migration scenarios, where populations cannot move from their present distribution, with the reality being that species will likely fall between these extremes (Higgins et al. 2003). Outcomes were analysed in ArcMap 10.2 (ESRI 2011) using Python scripting to automate and streamline the process.

Species richness was calculated under unlimited migration for the 187 taxa using DIVA-GIS (Hijmans et al. 2004) and Spatial Analyst tools in Arc Map 10.2, for present and future climate scenarios, respectively. The broad patterns of species richness throughout Norway were compared among the years studied. Change in taxon richness was studied under unlimited migration by comparing future with present potential taxon distributions, which allowed patterns in the direction of taxon distributional changes to be analysed.

Species loss and gain were assessed by the number of species found per grid cell and compared to the current species richness per grid cell for both unlimited and no migration scenarios. The turnover rate (T) was then calculated for the unlimited migration scenario following Thuiller et al. (2005):

$$T = 100 \times \frac{(L + G)}{(SR + G)},$$

where SR is the current species richness, L is loss of taxa per grid cell and G is gain of taxa per grid cell. Turnover

rate was calculated for both RCP scenarios per study year. Turnover was determined for mainland Norway (32 241 grid cells), which excluded Jan Mayen and Svalbard.

To determine the extent of taxon range, we compared the number of grid cells where a taxon was present under both no migration and unlimited migration, and present and future climatic scenarios. The level of threat for the priority taxa was then assessed using the IUCN Red List criterion A3(c) (IUCN 2001). This used the projected geographic range loss of a taxon as a proxy for population reduction to assign a threat category by the following parameters: Extinct (EX) is a taxon with a projected range loss of 100%, Critically endangered (CR) with a projected range loss of >80%, Endangered (EN) with a range loss of >50% and Vulnerable (V) with a range loss of >30% (IUCN 2001). The remaining taxa were considered least concern (LC) in terms of climate change impacts.

RESULTS

The potential effects of climate change showed a change in distribution for 187 priority CWR in Norway. Under the unlimited migration scenario, taxon richness increased across Norway from a predicted richness of 124 taxa under the current climate to a maximum of 150 taxa in the most taxon-rich areas for some of the scenarios (Figs. 1, 2, 3). Taxa tended to spread from the south-east of Norway towards the west and the north with the mountainous regions preventing further westward dispersal. Taxon richness also increased from the west coast and moved both eastwards and northwards, with the RCP 6.0 scenarios showing a larger area of Norway with increased taxon richness. This pattern of distribution change is reflected in Figs. S1 and S2, where gain in taxon richness tended to increase further northwards under both RCP scenarios, from the year 2030 to 2080. There was also a slight loss of taxon richness in the south-east, which was more apparent in the RCP 6.0 scenarios, although this region was still the area with highest taxon richness overall.

The pattern of taxon turnover also reflected this distribution change (Figs. 4, 5). From 2030 to 2080, under unlimited migration and RCP 2.6, the percentage turnover rate of taxa per pixel increased, from 29 to 68% (Table S1). Under RCP 6.0, turnover of taxa per pixel increased from 50 to 72% (Table S1). The area of Norway with a turnover of 100% tended to increase from 2030 to 2080, with the south-east and southern coast maintaining a low turnover rate and a large proportion of the mainland showing an increased turnover rate (Figs. 4, 5).

Climate change affected individual taxa under both unlimited migration and no migration scenarios from the year 2030 to 2080. Under no migration, the number of taxa

that lost area decreased under both RCP scenarios from the year 2030 to 2080 (Fig. S3). For unlimited migration, the number of taxa that lost area under RCP 2.6 reduced from 25% in 2030 to 12% in 2080, whereas under RCP 6.0 the number of taxa that lost area increased from 11 to 13% (Fig. S3). Under unlimited migration, there was an increase in the number of taxa gaining area under RCP 2.6 but a decrease in the number of taxa gaining area in RCP 6.0 from 2030 to 2080 (Fig. S4). Under no migration, none of the taxa gained area as they cannot expand their distribution, only lose area or maintain their current distribution.

The decrease in geographic range size for taxa was related to the level of threat using the IUCN Red List category A3(c) (IUCN 2001) (threat status of taxa under current climate is from Kålås et al. (2006)). As expected, under no migration, there was a higher number of taxa assessed as threatened with the most being 12% of taxa under RCP 6.0 (Fig. 6). For unlimited migration, the highest number of taxa threatened was 11% in the year 2080 for RCP 6.0 (Fig. 6). There tended to be higher numbers of taxa threatened under RCP 6.0 than RCP 2.6.

Nine taxa have been assessed as threatened under current climatic conditions, with data for further predictive modelling lacking for three taxa, and six taxa assessed as not threatened in the future, according to this study (Table S2). Under both migration scenarios, the severity of threat to the taxa tended to increase along with the number of threatened taxa. The number of critically endangered (CR) and Extinct (EX) taxa tended to increase (Fig. S5a, b) from 2030 to 2080 under both RCP scenarios. Furthermore, *Alopecurus pratensis* L. subsp. *alpestris* (Wahlenb.) Selander is predicted to go extinct in 2070 if there is no migration and in 2080 if there is unlimited migration (Table S2). Thirty-one taxa were assessed as threatened under the predicted climate change scenarios (Table S2).

DISCUSSION

The climate change analysis of the priority CWR for Norway shows a trend of increasing CWR richness under both RCP scenarios, from the present to the year 2080. Taxon richness appears to spread from present areas of richness in the south-east, to the inland regions of Norway and northwards. This suggests that current limiting factors to plant growth in the north, such as all-year-round low temperatures (Olesen and Bindi 2002) and others, are expected to become less pronounced as the climate changes, leading to an increase in taxon richness. This is supported by Sætersdal et al. (1998) and Parmesan and Yohe (2003), who find that in the northern hemisphere temperate regions during cold periods, the geographic ranges of most species are restricted to one or a few refugia in the south

Fig. 1 The predicted distribution of 187 priority CWR in Norway under the current climatic conditions. *Red areas* indicate taxon-rich areas with up to 124 taxa found there, and *green areas* indicate low taxon richness. Raster grid cell size 0.0416, approximately equal to $4 \times 8 \text{ km}^2$

and with subsequent warming each species expands its range with increasing species richness, mainly northward. This may also be associated with a gradual lengthening of the growing season in the north due to increasing temperatures, as well as increasing shrub abundance in the arctic (Tømmervik et al. 2004). This could be positive for farmers, who may be able to extend and increase the production of food and forage within Norway, thereby improving food security at national level. Furthermore, the CWR populations that successfully migrate or adapt with climate change may be key in aiding farmers to adapt their crops to future climatic changes. Leading-edge populations (in this case, those populations spreading northwards) are expected to be stable or increasing (Nekola 1999) and show

positive demographic rates (Foden et al. 2009). This is compared to trailing-edge populations, which often have reduced genetic variation (Lesica and Allendorf 1995). Furthermore, the diversity found at the leading and trailing edges may be unique (Hampe and Petit 2005) and could help underpin efforts of plant breeders to develop varieties adapted to new conditions (Jarvis et al. 2008).

When this pattern of shifting distributions is compared with the turnover of taxa per grid cell, it can be seen that locations in the south tend to maintain low levels of taxon turnover. This suggests that species composition in the south may remain stable in comparison with the majority of the mainland, where the turnover rate increases. However, it is important to note the study does not model species that

Fig. 2 The average predicted taxon richness of 187 priority CWR in Norway under RCP 2.6 for the years **a** 2030, **b** 2050, **c** 2070, **d** 2080. Raster grid cell size 0.0416, approximately equal to $4 \times 8 \text{ km}^2$

Fig. 3 The average predicted taxon richness of 187 priority CWR in Norway under RCP 6.0 for the years **a** 2030, **b** 2050, **c** 2070, **d** 2080. Raster grid cell size 0.0416, approximately equal to $4 \times 8 \text{ km}^2$

Fig. 4 The average turnover of taxa per grid cell under RCP 2.6 for year **a** 2030, **b** 2050, **c** 2070, **d** 2080. Value is in percent, with 100 representing a complete turnover of all taxa within that cell. Zero means the taxa within the cell stay the same. Raster grid cell size 0.0416, approximately equal to $4 \times 8 \text{ km}^2$

Fig. 5 The average turnover of taxa per grid cell under RCP 6.0 for year **a** 2030, **b** 2050, **c** 2070, **d** 2080. Value is in percent, with 100 representing a complete turnover of all taxa within that cell. Zero means the taxa within the cell stay the same. Raster grid cell size, approximately equal to $4 \times 8 \text{ km}^2$

Fig. 6 The predicted number of threatened taxa as determined by the IUCN category A3(c). For full list of threatened taxa, see Table S2

may move into Norway from the south and east, but it should be expected that such taxa will, provided they can reach the region (Henningsson and Alerstam 2005; Huntley et al. 2008; Hof et al. 2012), and monitoring of such changes should be undertaken. This high turnover rate is also seen in Thuiller et al. (2005), who show that the Boreal region (which covers south-east Norway) and southern Fennoscandia (which incorporates southern Norway) could in principal gain many species from further south. There appears to be a larger change in the turnover of taxa per grid cell under the lower temperature increase of RCP 2.6 (29–68%), than RCP 6.0 (50–72%), perhaps suggesting that the 1.5 °C rise in temperature is more favourable to the priority CWR taxa than a 3.0 °C increase.

This high turnover rate and change in taxon richness are important for how CWR populations may be conserved in Norway. With such a dynamic change in taxa distribution predicted and the expectation that the effects of climate change will be felt sooner (Stafford Smith et al. 2011), it will be necessary to create flexible conservation strategies for CWR. This will mean using both in situ and ex situ conservation actions for specific taxa as well as at larger multi-taxa conservation scales. In terms of in situ conservation, the current PA network in Norway encompasses large areas with unique landscape conservation value, such as mountain plateaus which are often dominated by climax communities that do not tend to support CWR diversity (Jarvis et al. 2015). These reserves may require incremental changes in management strategies, such as increased levels of species monitoring to account for new CWR taxa that are predicted to spread into the reserves. However, multiple authors suggest that new reserves may be needed to purposely account for climate change impacts (Sætersdal et al. 1998; Araújo et al. 2004). This would require transformative management actions such as clustering reserves in

areas of temporal overlap (Araújo et al. 2004), creating reserves in hotspots of future diversity (Heller and Zavaleta 2009), conserving the ‘core’ of populations (Araújo et al. 2004) and improving connectivity between reserves by creating corridors so species can migrate (Halpin 1997). Corridors and areas outside of formal PAs are important for CWRs (Jarvis et al. 2015) as many are common taxa with wide distributions (for example, *Trifolium* sp., *Phleum* sp., *Rubus* sp.). For widespread taxa with well-connected populations, a reduction of genetic diversity within populations is likely to contribute to population extinctions but is less likely to threaten the existence of the species (Jump and Penuelas 2005). Corridors could be considered a short-term, incremental change, as connecting reserves could be flexible in their design and management for the protection for CWR outside of formal PAs, an approach suggested as critical in the face of climate change (Franklin et al. 1992; Lovejoy 2005; Thomas et al. 2012). Close cooperation with landowners and relevant stakeholders would be essential if these situations were to arise. All CWR populations will benefit from an in situ conservation approach as it allows continued evolution of traits that may be required in the future. For all priority taxa but particularly for those predicted to lose many populations, ex situ conservation will be a complementary tool to aid conservation actions.

Ex situ conservation will be a vital tool for the conservation of CWRs in Norway. If CWR populations are monitored and changes in genetic diversity and/or population size are identified [i.e. a reduction below 10 000 individuals per population as the minimum number recommended by Iriondo et al. (2012)], then collecting of seeds from these populations could be undertaken. Taxa could be prioritized for ex situ conservation based upon their predicted level of threat using the IUCN criteria. For example, *A. pratensis* subsp. *alpestris* (Table S2), which is

predicted to become extinct, could benefit from immediate collecting of seeds with regeneration and translocation of populations also a possibility, meaning a more transformational management plan will be required. The taxa that are predicted to lose area but not become threatened will require monitoring and collecting of seeds incrementally, perhaps on a less frequent timescale, when negative impacts are identified. It will also be necessary to ensure that a range of genetic diversity is collected, perhaps targeting ecogeographically diverse populations using an Ecogeographic Land Characterization map (ELC) as done by Phillips et al. (2016). As well as protecting threatened populations, ex situ conservation will ensure that the genetic material is available for use by plant pre-breeders to adapt our crops to climate change.

The IUCN methodology used in this study only takes into account one red list criterion (A3(c)), which assesses the population size reduction, for which we have used the percentage of area lost as a proxy, following Thuiller et al. (2005). The use of the change in distribution extent as a proxy for population changes is an allowable assumption according to the IUCN. However, considerations such as whether the size of habitat patches can support viable populations must also be taken into account (Foden and Young 2016). An alternative to this method may be to use the framework suggested by Foden et al. (2013) and Foden and Young (2016) for assessing three different dimensions of climate change vulnerability of populations. This will aid in a more taxon-specific management strategy allowing effective conservation of threatened populations.

Adaptation of populations as well as migration will be crucial for survival of CWRs in situ in the long term. There is little evidence that adaptation alone will be able to keep pace with climatic changes (Jump and Penuelas 2005; Thuiller et al. 2008). Furthermore, climate change is also expected to exceed the potential of populations to track climate by migration (Midgley et al. 2003). Uncertainty surrounding the capacity of populations to adapt or migrate in response to climate change strengthens the need to apply both in situ and ex situ, as well as incremental and transformational conservation strategies to CWRs in Norway. As well as uncertainties in how the taxa will respond, there are uncertainties associated with the methods used to create the predictions. The models used in this study do not account for the soil or other habitat conditions that may remain unfavourable for the CWR taxa. It is also likely that the presence points used do not reflect the entire geographic range of the CWRs and may be subject to sampling bias (Araujo and Guisan 2006; Loiselle et al. 2008). Maldonado et al. (2015) found that often diversity patterns overestimate species richness when data from large public databases is utilized. We tried to limit these effects by basing future predictions on a predicted distribution,

created in MaxEnt, of taxon richness under the current climate, not only on the observed distribution data. Furthermore, over 96% of the GBIF records used had coordinates accurate to three or more decimal places. However, in further studies, the use of ignorance maps (Rocchini et al. 2011; Ruete 2015) as well as the use of tools such as GeoQual in the CAFITOGEN package (Parra-Quijano et al. 2016) may allow the filtering out of unreliable occurrence data.

CONCLUSION

For management strategies to be effective for CWR within Norway, the continued monitoring of populations will be required (Stafford Smith et al. 2011). A monitoring programme for CWR within Norway should include thresholds that if met will mean taking the next course of action. These thresholds could include monitoring of population sizes with a focus upon those trailing-edge populations, for example, if they fall below 10 000 individuals (Iriondo et al. 2012), then conservation action will be required; use of the IUCN categories as thresholds to prioritize the collecting of threatened taxa (i.e. those that are predicted to become extinct or critically endangered would be the first priorities to collect) and identifying leading-edge populations to allow the planning of conservation areas that allow populations to migrate to the nearest suitable location or PA. The strength of PAs is that they are already working now to protect biodiversity and to passively conserve CWR that happen to occur within them. Therefore, the use of PAs in terms of climate change equates to a ‘no-regrets’ conservation decision (Stafford Smith et al. 2011), especially if new PAs are created. Informal PAs for CWR such as those acting as corridors (increasing connectivity from the south-east to northwest in Norway) in the landscape should be flexible in their location, design and management to allow for the uncertainties associated with the climate change predictions and species responses. Ex situ conservation is likely to be essential as a back-up to in situ resources by making the genetic diversity available to plant pre-breeders. Ex situ conservation can be used to incrementally collect populations that are showing negative responses to climate change by meeting the thresholds (including population size and IUCN threat level) set out in the monitoring programme.

Pitcock and Jones (2000) state that climate change will not be a new stable equilibrium, but an ongoing transient process that requires an ongoing adaptation process. This is clear from the results and recommendations presented above, which can enhance the previous work on a national CWR conservation strategy for Norway (Phillips et al. 2016). Although this study was conducted at a national level, the methodologies and recommendations have

applicability at regional and global levels. Furthermore, it is at the national level that such recommendations will need to be implemented. Unless we increase our knowledge on the impact of climate change upon CWR, we will not be able to effectively conserve and utilize taxa to improve food security in the face of climate change.

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