Observed Climate-Biodiversity Relationships

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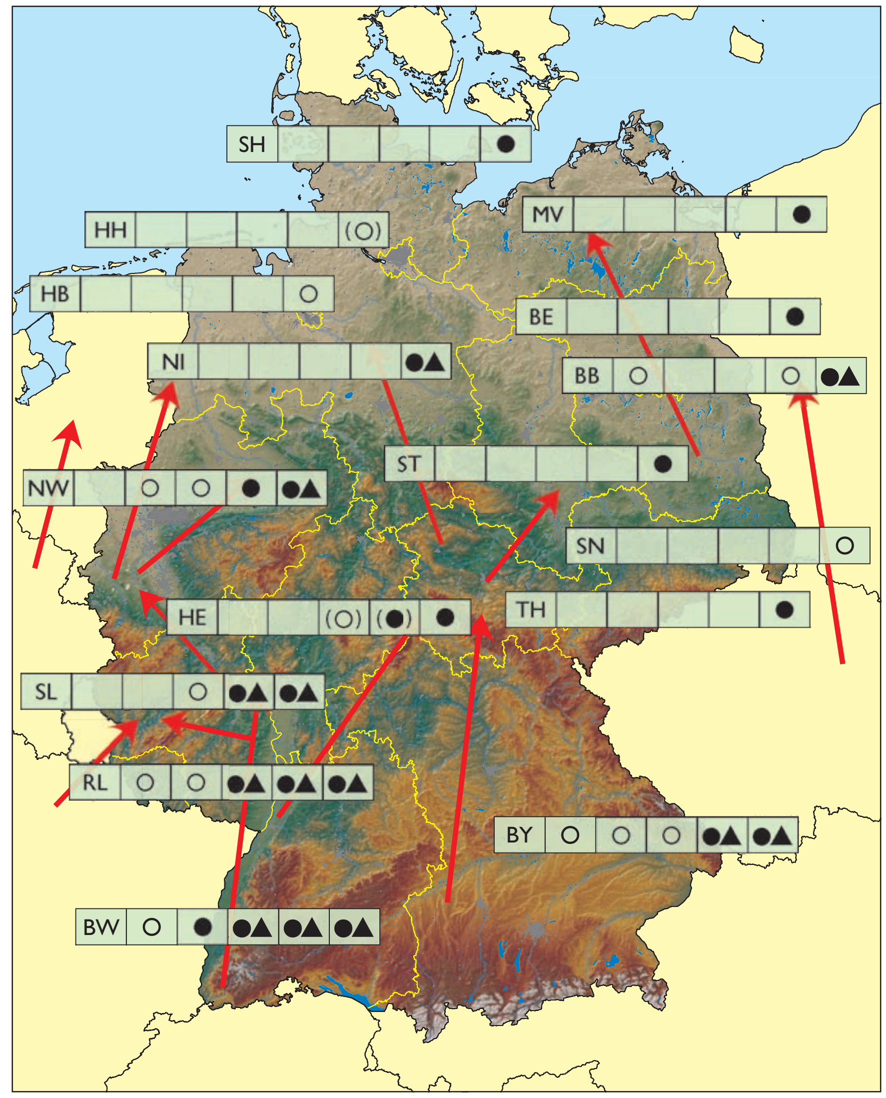
A number of species in a variety of ecosystems have been observed to respond to the climatic warming that has occurred in the last few decades (e.g., Parmesan 2006). A series of case studies elaborated within ALARM contribute to these findings as illustrated in the following with some examples of species' range shifts based on field data.

Northward range expansions

With climate warming, species in the northern hemisphere are expected to be able to extend their range northward and/or towards higher altitudes. There is increasing evidence with a widening range of taxonomic groups that such shifts are already in progress. Holly (*Ilex aquifolium*), an evergreen broad-leaved shrub or small tree species, is a classic example of a cold-limited species. In the last few decades, the species has expanded its range in northern Germany and southern Scandinavia in parallel with the expansion of its potential climatic range (Figure **1**) (Walther et al. 2005a). The same is true for insects, such as dragonflies. In southern Europe, some species of African origin have reached northern Italy (*Selysiothemis nigra, Trithemis annulata*) or have even crossed the Pyrenees in France (*Trithemis annulata*) (Ott submitted), while Mediterranean species, such as the Scarlet Darter (*Crocothemis erythraea*) (Figure **3**), have colonised Germany from south to north in only about two decades (Figure **2**). In the mid 1980s, the Scarlet Darter was found indigenous only in the south-west of Germany; however, it has since been recorded across the entire country including the northernmost states. Its northward expansion goes along with the trend of increasing temperatures (Ott 2007) and comparable range expansions of the species can be observed all over central Europe. Some birds and butterflies have also expanded their distributions recently at their northern range margins (e.g., Brommer 2004, Mitikka et al. 2008). A comparison of the occurrence of 48 butterfly species in the 10-km grid system used in the Finnish National Butterfly Recording Scheme (NAFI) between 1992-1996 and 2000-2004, showed that the ranges of 39 of the species have moved towards the north of Finland. Maximum shifts of over 300 km have been observed for three species, including the Poplar Admiral (*Limenitis populi*) (Figures **4** and **5**). However, not all species have migrated in the wake of a changing climate. Species whose range expanded most were mobile generalist species of non-threatened status, whereas the distributions of some red-listed butterfly species were rather stationary (Figure **6**).

Altitudinal range expansions

Advance of species' ranges and vegetation belts towards higher elevation have been observed in European mountains. On altitudinal gradients, shifts in forest belts are reported from north-eastern Spain. A comparison of present day and early twentieth century photographs (Figure **7**) shows that the European beech (*Fagus sylvatica*) forest in the Montseny Mountains (Catalonia, NE Spain) has not only become denser at its upper limit but the treeline has extended upwards with the establishment of new, vigorous outpost trees (Peñuelas et al.



first block: federal state (Germany)
second block: time before 1970, third block etc.: decades from 1970 onwards until present
o = species present, ● = autochthonous populations, ▲ = increasing populations, () = probably

Figure 2. Range expansion of *Crocothemis erythraea* in Germany in the course of the last decades of the twentieth century (Source: Ott 2007, updated).

2007). In the Alps, several mountain peaks have shown an increase in species richness as a consequence of climate warming (Walther et al. 2005b). In the course of the twentieth century, warmer temperatures have allowed species from lower areas to move upslope and reach the summits (Figure **9**).

Range contractions

Whereas the trend for range expansions has become increasingly visible, fewer examples exist for range contractions (caused by the deterioration of growth conditions in the former, pre-warming range of a species). Some stenoecious insects (species that have a narrow ecological range) that formerly had been much more widespread than today (e.g., *Coenagrion hastulatum, Aeshna juncea, Leucorrhinia dubia* (Figure **8**) have nearly become extinct in the Palatinate Forest Biosphere Reserve, Germany, a reference area to detect the effects of climate change on dragonflies within the ALARM-project. These species have also shown a strong decline on a regional (federal state) level as a consequence of the lack of precipitation in the last few years (Ott submitted). In north-eastern Spain, recruitment rates of beech at its lower range limit have been three times lower in the last few decades than those of the dominant species downslope, the Holm oak (*Quercus ilex*), a Mediterranean species (Peñuelas et al. 2007, see also Arrieta & Suarez (2006) for holly). In the

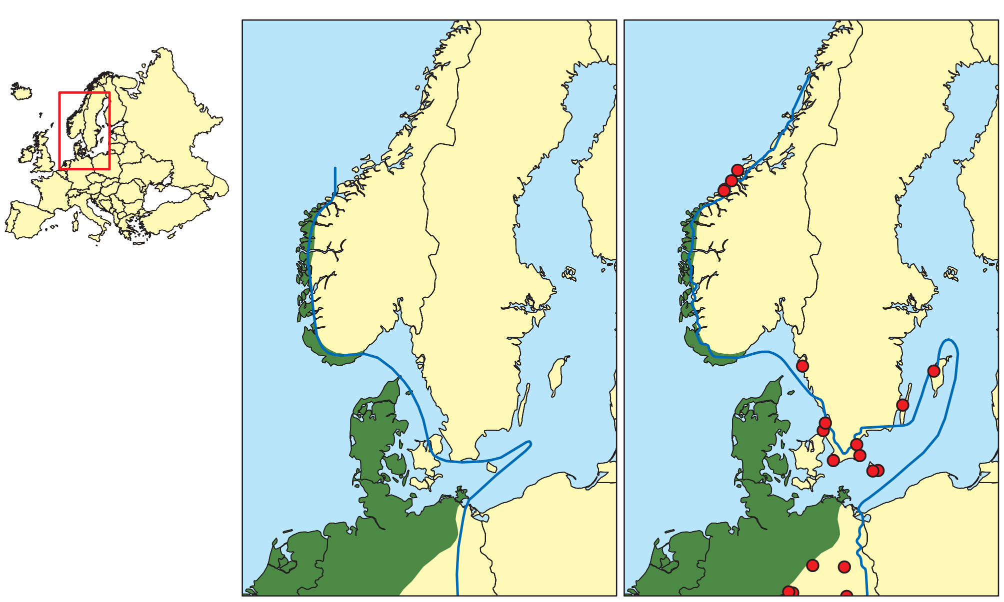


Figure 1. Historic (left) and updated (right) 0 °C-January-Isoline (blue line) and distribution of *Ilex aquifolium* (green area and red dots) in northern Central Europe and southern Scandinavia (Source: Walther et al. 2005a, updated).

Figure 3. The Scarlet Darter (*Crocothemis erythraea*). Photo: J. Ott.

Austrian Alps, permanent plots across the alpine-nival ecotone have shown that species that predominantly occur in the nival zone (upper part of the ecotone) have decreased in cover, whereas species that mainly grow in the alpine belt (lower part of the ecotone) have remained constant or even increased in cover (Figure **10**) between 1994 and 2004. Despite the changes in cover, which may be signals of ongoing range contractions and expansions, an actual shrinkage of the distribution range of individual species was not able (yet) to be detected in the observed area (Pauli et al. 2007).

Figure 4. The Poplar Admiral (*Limenitis populi*). Photo: J. Heliölä.

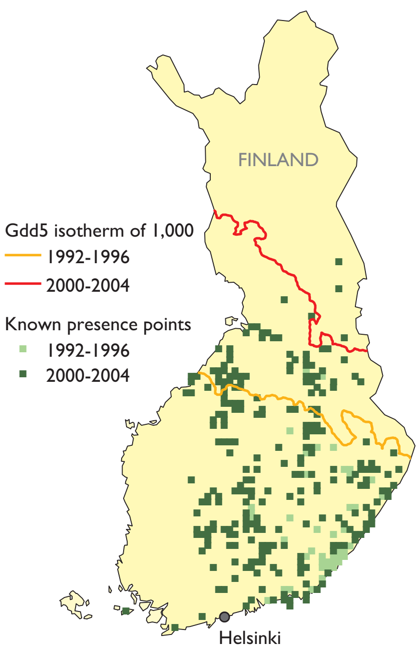


Figure 5. Distribution of the Poplar Admiral (*Limenitis populi*) in Finland in 1992-1996 and 2000-2004 (source: the Finnish National Butterfly Recording Scheme "NAFI"), and the isotherm of 1000 of the mean annual growing degree days (Gdd5) in 1992-1996 and 2000-2004.

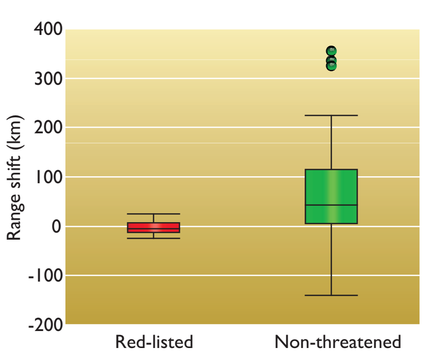


Figure 6. The relationship between the range shift (km) between 1992-1996 and 2000-2004 of 48 butterfly species in Finland and their Red list status. Boxplots show the median, quartiles, and outlier values within a category (Source: the Finnish National Butterfly Recording Scheme "NAFI").

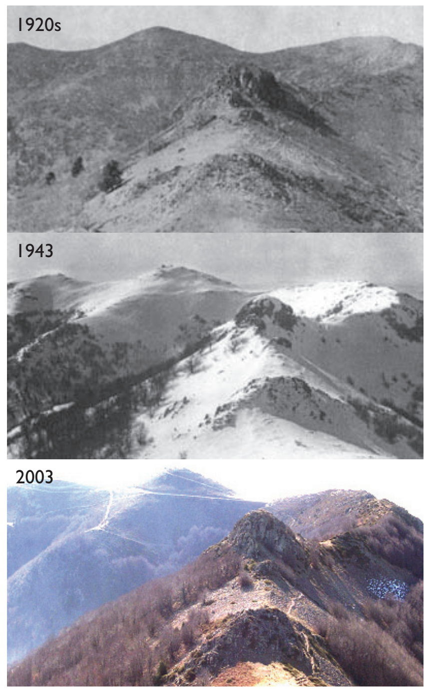


Figure 7. Altitudinal upward shift of European beech forest towards the top (ca. 1700 m) of the highest summits in the Turó de l'Home-Les Agudes ridge in the last century (for details see Peñuelas et. al. 2007). Photos: M. Boada and J. Peñuelas.

Figure 8. White-faced Darter (*Leucorrhinia dubia*). Photo: J. Ott.

Conclusions

Recent climate change has already affected a variety of species in various habitats and ecosystems in Europe and globally. Species respond to species-specific (combinations of) pressures and an in-depth mechanistic understanding is necessary to link observed range shifts to the relevant ecological drivers.

Shifts at the rear, or retreating end of the distribution of species are considered to be of critical importance (Hampe & Petit 2005) for overall range shifts. There is less evidence of contemporaneous range contractions (compared to range expansions) and several reasons may explain such lags at the southern/lower range margins in response to climate change. Climate effects at the front edge may immediately be visible with the establishment of young populations beyond former range margins. At the rear end, climate first affects demography: regeneration becomes sparse, while a resilient old generation persists. The lack of regeneration and other factors may first cause a formerly contiguous distribution to fragment, but still occupy the same distribution periphery. These factors and processes may explain why the response of species is faster and more easily traceable at the upper/northern limit than at the opposite range margins.

We are at the very beginning of both the expected warming of climate but also the understanding of the ecological responses and their complexity (Walther 2007), linked to climate-induced dynamics of biodiversity change. Species are nested in ecological networks with complex temporal, spatial, and trophic interactions. As a consequence, if single species changes occur, the entire network is potentially influenced and expected subsequently to respond. With continued warming, one might expect not only an increase in the number of affected species but also in the variety of responses, which may unravel so far hidden consequences on higher trophic and complex levels of climate-biodiversity relationships.

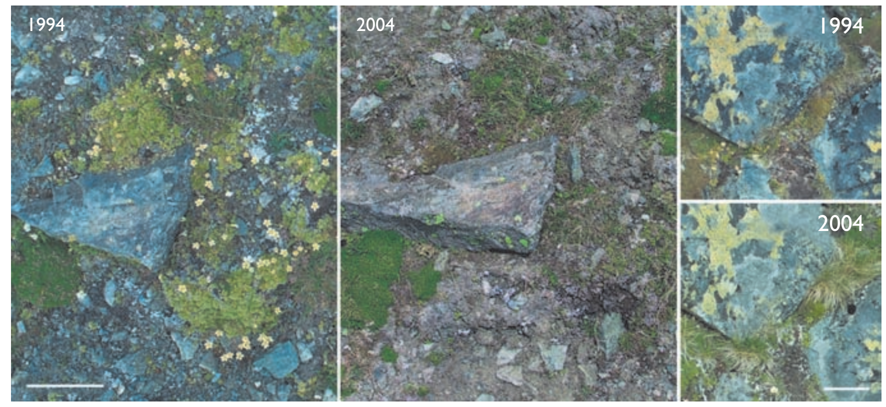


Figure 10. Photo pairs of permanent plots at the alpine-nival ecotone of Schrankogel (Tyrol, Austria; approx. 3000 m a.s.l.) in mid-growing season. Left and centre: the subnival to nival *Saxifraga bryoides* (light-green cushions, blooming on left side) showing a decrease in cover between 1994 and 2004. Right: the alpine pioneer grass *Oreochloa disticha* was among the species showing an increase in cover (Pauli et al. 2007). White bars indicate 10 cm.

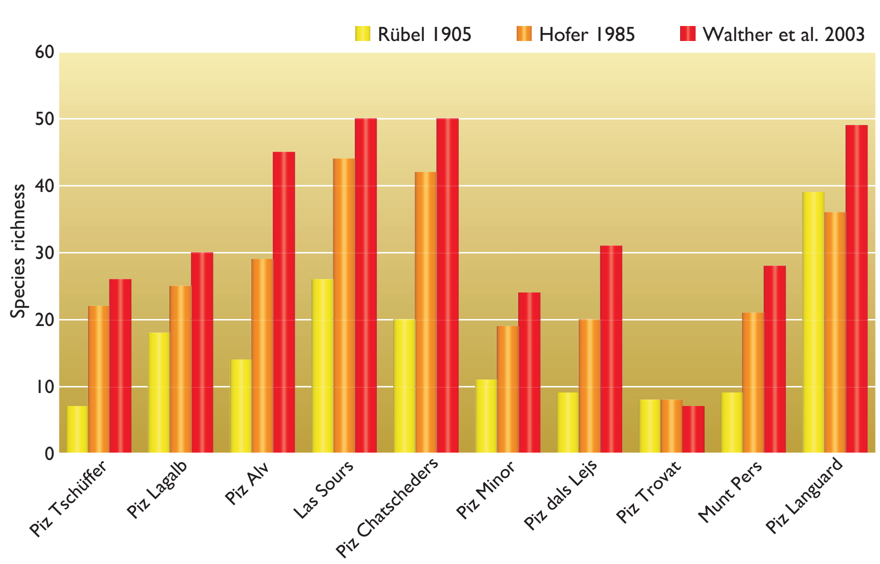


Figure 9. Three consecutive floristic surveys within a century of the same summits reveal a pronounced increase of the number of vascular plant species on mountain peaks of the Swiss Alps from early 20th century to early 21st century (Source: Walther et al. 2005b, modified).

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