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EDITORIAL

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Climate change impacts on biodiversity: a short introduction with special emphasis on the ALARM approach for the assessment of multiple risks

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How to study multiple risks: setting the scene

Climate change and human modification of the landscape are synergistic (Travis 2003), and affect biodiversity and the stability of ecosystems. This is because certain species will be favoured by changes, while others will not. However, as stated by Fanslow (2006), the simplicity stops here, with Samways et al. (1999) illustrating the differential impact of climate change events on a range of closely related species. It is relatively easy to test how increased temperature will affect an organism. We can isolate almost any organism, put it in a box and observe how it responds to environmental changes we can simulate in a controlled setting, such as a laboratory. We might find, for example, that warming benefits this isolated organism. But what if warming also benefits a disease to this organism? What if temperatures become too warm for other organisms on which our hypothetical organism depends such as its prey when it is a predator or a pollinator of its host plant if it is a herbivore? What if warming benefits a competitor even more?

Once we step outside the small hypothetical box that defines just one organism, or some isolated parts of an ecosystem, and start to ask questions about how it will interact with other "boxes" in the environment, we are quickly inundated with uncertainty about how environmental change will reshape our world. Ecosystems are remarkably complex, which makes it exceedingly difficult to predict their behaviour (Walther 2010). In some cases, we may be able to understand how one species affects another species, but in a relatively simple hypothetical system of 50 species, for example, each species potentially interacts with 49 other species. This gives no less than 1,225 possible two-way interactions in a simple 50-species system. If then the frame of reference is expanded to larger areas with many more types of ecosystems, it is clear that even a large group of dedicated scientists could not study even a small percentage of the possible two-way interactions using traditional controlled experiments, much less the three- and four-way interactions that are often just as important.

Another challenging aspect to developing an understanding of interactions between components of a complex system is the matter of communication among scientists of different disciplines. The different scientific disciplines – which can be thought of as different boxes in which scientists work – have traditionally been viewed as distinct and have developed strikingly different languages. As a result, interdisciplinary collaboration tends to be rare because getting through language barriers with someone in a different discipline requires a lot of valuable time and energy for people who generally don't have a lot to spare.

When you want to understand processes in a very large scaled system, but cannot do experiments, modelling is a useful way to synthesize information gathered independently about components of a larger system.

One approach to understand environmental risks over large areas was followed by the EU funded research project ALARM, which had a scope matched only by the ambition of its acronym: "Assessing LArge-scale environmental Risks for biodiversity with tested Methods".

How to study multiple risks: the ALARM approach

The objective of the ALARM project (Settele et al. 2005, 2010; http://www.alarmproject.net) was to apply our best understanding of how terrestrial and freshwater organisms and ecosystems function and to use new ways to assess large scale environmental risks. The ultimate aim was to develop and test methods and protocols for such an assessment and provide information that can be used to reduce negative impacts on humans and, in turn, minimize negative human impacts – both direct and indirect.

Research was related to ecosystem services in the broadest sense including the relationships between society, economy and biodiversity. In particular, risks to biodiversity were assessed that arise from

– climate change,
– environmental chemicals,
– biological invasions and
– loss of pollinators

in the context of current and potential future European socio-economic development options and their respective land use patterns, for which scenarios were applied. Here, dragonflies are mainly and directly impacted by the first 3 factors, by the forth only indirectly.

Risk assessments in ALARM were hierarchical and examined a range of organisational (genes, species, ecosystems), temporal (seasonal, annual, decadal) and spatial scales (habitat, region, continent) determined by the appropriate resolution of current case studies and databases (compare Figure 1).

Socio-economics was a cross-cutting theme that contributed to the integration of driver-specific risk assessment methods, developed instruments to communicate risks to biodiversity end users, and indicated policy options to mitigate such risks.

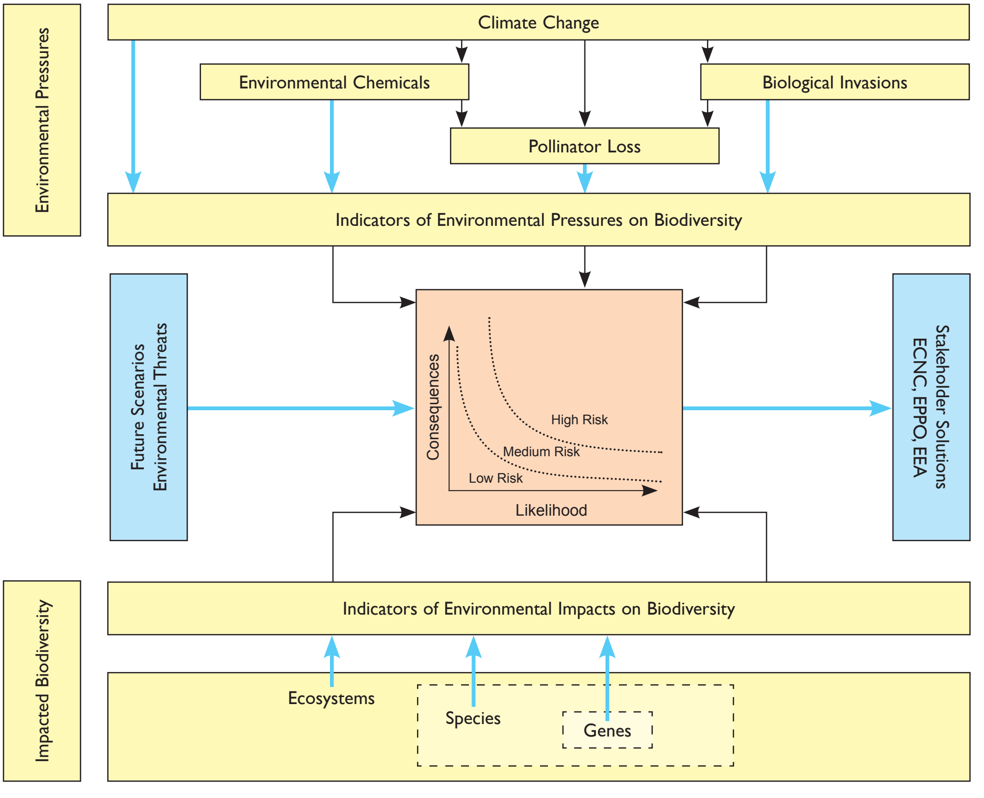

Figure 1. The ALARM research approach (from Settele et al. 2010)

So as to have a platform for practical interdisciplinary research, a field site network (FSN) was established within ALARM, where the different ALARM modules conducted joint research. All sites included freshwater as well as terrestrial habitats, including both lotic and lentic environments. The FSN covered most of European climates and biogeographic regions, from Mediterranean environments through central European and boreal zones to the subarctic (see Hammen et al. 2010a, 2010b, for further details).

The feature of ALARM that has set it apart from overly complex model exercises is that it made use of scientific narratives (or storylines) based on scientists' best understanding of the environmental systems they study (Spangenberg 2007a, Spangenberg et al. 2010, in press). ALARM puts these narratives together to paint a larger picture of how something as large and complex as the environment of a continent will react to different environmental and – interacting with them – socio-economic driving forces.

Just as challenging as reaching an understanding of how environmental change will play out, is translating that understanding into language that policymakers and the general public can understand.

To illustrate what we were trying to do through the ALARM project, we may contrast different forms of environmental storytelling: scientists tend to be reluctant to let a good story to distract attention from the facts, while journalists or activists can often be accused of ignoring facts for the sake of a good story. The goal of ALARM is to find a compromise between these ways of telling environmental stories and treat stories as the envelopes to carry facts, bearing in mind that facts are often the basis for a good story. For dragonflies the example of the expansion of the Scarlet Darter (*Crocothemis erythraea*, see Ott 2001, 2007b, 2010a, 2010b) is meanwhile well known and besides scientific papers also many popular articles or presentations start with this "success story".

After expanding its geographic reach in early 2007 by adding scientists and institutions particularly from outside the European Union, ALARM encompassed a total of more than 250 scientists from 68 institutions from 35 countries, with a total budget of more than 20 Mio. Euro (slightly more than 50% funded by the EU). The consortium was co-ordinated by the German Helmholtz-Centre for Environmental Research – UFZ. ALARM started in February 2004, and the EU funding lasted for 5 years until early 2009. It was an Integrated Project (IP) within the 6^{th} Framework Programme of the European Commission (EC) within the sub-priority 6.3 - Sustainable Development, Global Change and Ecosystems.

In the following chapters we will detail some of the more climate related aspects of biodiversity conservation in general and of the ALARM approaches which are also relevant to dragon- and damselflies in particular.

Integrated long-term scenarios as a starting point for assessing biodiversity risks

Scenarios, narratives, models, and strategy development

Biodiversity is influenced by a combination of natural processes (e.g. evolution, succession, catastrophes) and anthropogenic pressures (e.g. land use, nitrogen deposition, climate change, alien species invasions). From a policy point of view, this situation constitutes an urgent need to identify the human drivers causing pressures on biodiversity, and to develop strategies and policies to mitigate the resulting impacts in order to minimise biodiversity losses (Spangenberg et al. in press).

Given that just like the environment, society and the economy are complex, developing (i.e. neither deterministic nor stochastic) systems, their future interaction and thus the development of biodiversity pressures cannot be predicted or expressed as quantified risks. However, since the system development is path dependant, such pathways can be evaluated by scenario techniques, with each pathway represented by a scenario narrative or story line, and some aspects of each illustrated by computer modelling. In turn, the modelling results have to be interpreted in the context of the narrative to integrate the qualitative elements into the scenarios and the strategy proposals derived from them. Such scenarios are means for the evaluation of potential risks, and policy strategies are the search for or the creation of bifurcation points in the trajectories.

Developing effective strategies for biodiversity conservation and management requires the transdisciplinary combination of capabilities, concepts, insights and tools of several disciplines (e.g. ecology, chemistry, economics, and political science) with non-scientific knowledge, and so does scenario development. A major challenge is to ensure that the assumptions used in the various modelling exercises are consistent (or at least their interpretation is), that the issues addressed are relevant and the assumptions made are plausible. The latter is the contribution of non-scientific knowledge and experience, realised in the case of ALARM by establishing a multi-stakeholder Consultative Forum, which had significant influence on the scenario formulation.

Regarding the contribution of quantified modelling, so far no comprehensive model has been developed integrating the diverse relevant ecological, economic, individual and societal processes (and even if it existed, it would not be too helpful). Instead, socio-economic, climate and biodiversity models exhibit a wide range of assumptions concerning population development, economic growth and the resulting pressures on biodiversity, and they deal with significantly different time scales and spatial framings.[1]

Therefore it is necessary to derive consistent assumptions and scenario interpretations from a comparative analysis of models and scenarios from several disciplines,

[1] Within ALARM, socio-economic, land use and nitrogen deposition models are run, one using the output of the other as input parameter, but land use and biodiversity models must be reconciled by interpretation on the basis of the storyline.

assessing their overlaps and the possible contradictions between the results of one and the assumptions of other scenarios. Within the ALARM scenario development process, this is done by interpreting the modelling results against the backdrop of a joint narrative. A complementary, cross-disciplinary knowledge base needs to be developed in order to support effective policy decisions and provide a basis for future modelling exercises on all levels. This requires the close cooperation within an interdisciplinary team of economists, climatologists, land use experts, biologists, modellers and policy experts. The three internally coherent but amongst them contrasting scenarios developed are one of liberal policies (GRAS), one of a continuation of rather mixed EU policies (BAMBU) and one of consequential sustainability policies (SEDG) (see chapter "Three basic scenarios.." below, for further details).

Usually, scenarios are based on rather linear extrapolations of past trends, which is a rather unrealistic assumption given the uncertainty inherent to the dynamics of evolving systems. Consequently, the effects of non-linear developments need to be taken into account (Walther 2010). Thus, complementing the rather linear scenarios underpinned by simulation runs, *shock scenarios* have been developed. They serve as sensitivity analysis for the basic scenarios, and although their probability of occurrence cannot be quantified, they illustrate how different future developments can and most probably will be from an extrapolation of past trends.

Given the interaction of the economic, social and natural systems, one illustrative shock to each of the systems is taken into account. The climate shock (collapse of the thermo-haline circulation, vulgo: the Gulf Stream) is conceptualised as a modification of the liberal GRAS scenario (as it provides the highest probability for such a shock occurring). The economic shock (Peak Oil: oil price quadrupling) and the societal shock (a pandemic) are applied to BAMBU, the current politics scenario, as they are not dependant on the policy changes assumed under both variants. Economic and social aspects, environmental impacts of the shocks and of the most plausible reaction of the political system to them are developed in the scenario narratives.

The scenarios and their interpretations have been presented to decision makers to support reflexive policy development efforts. They identify the most important drivers, show how they need to be modified, changed or abandoned in order to achieve a significant reduction of biodiversity loss, contributing to the new EU policy goals for 2020 and beyond. In this context, ALARM provides an up-to-date information base for decision makers which intend to ex ante evaluate policy strategies before implementing them. Thus, feedback circles, rebound effects and other system characteristics can be taken into account, supporting policies for effective protection of biodiversity

Three basic scenarios and three deviations (shocks)

<u>GRAS (GRowth Applied Strategy)</u>: Deregulation, free trade, growth and globalisation are policy objectives actively pursued by governments. Environmental policies focus on

damage repair and limited prevention based on cost-benefit-calculations. No emphasis is put on biodiversity.

BAMBU (Business-As-Might-Be-Usual): Policy decisions already made in the EU are implemented and enforced. At the national level, deregulation and privatisation continue except in "strategic areas". Internationally, there is free trade. Environmental policy is perceived as another technological challenge.

SEDG (Sustainable European Development Goal): The sustainability of societal development is enhanced by integrated social, environmental and economic policy. Policy aims for a competitive economy in a healthy environment, gender equity and international cooperation. SEDG is a normative scenario with stabilisation of GHG emissions.

GRAS-CUT (Cooling Under Thermohaline collapse): Deregulation, free trade, growth and globalisation are policy objectives (as for GRAS) before a climate shock

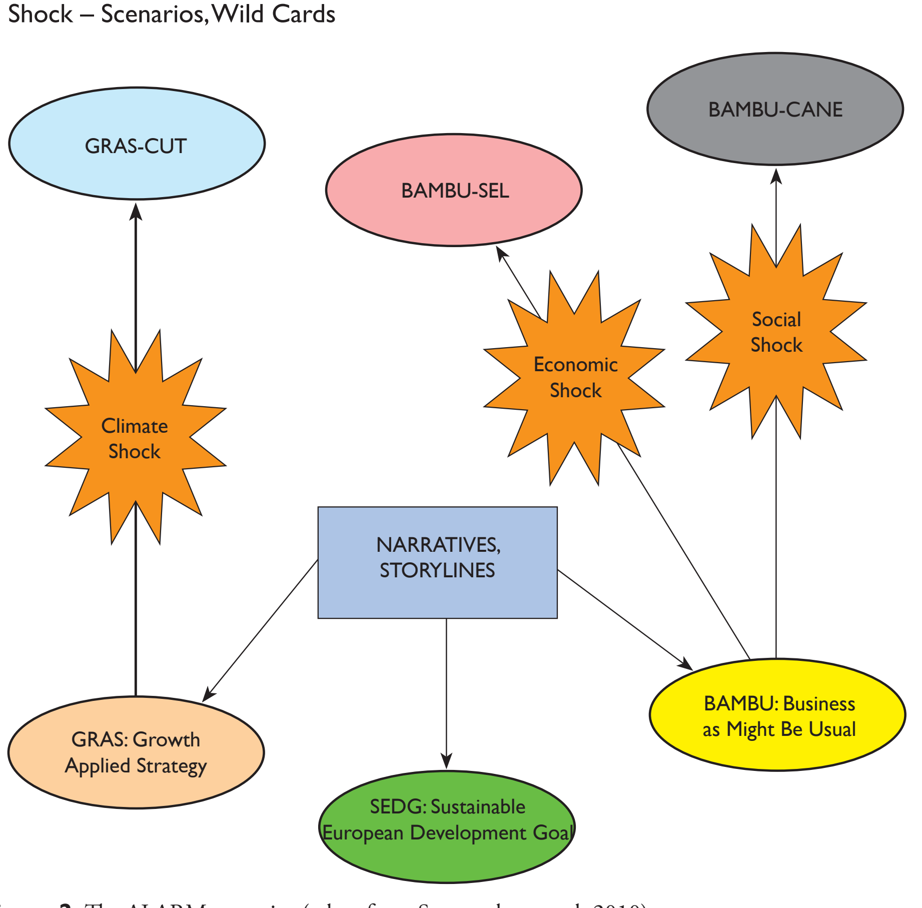

Figure 2. The ALARM scenarios (taken from Spangenberg et al. 2010).

(the collapse of the thermohaline circulation) in 2050. Alternative economic and environmental policies are then introduced in reaction to this shock.

BAMBU-SEL (Shock in Energy price Level): High prices for energy and high price volatility is to be expected, and absolute scarcities may occur in the near future - 2015. Alternative economic and environmental policies are then introduced in reaction to this shock.

BAMBU-CANE (ContAgious Natural Epidemic): A global pandemic in the near future - 2015, causes changes in population numbers, distribution and behaviour, with subsequent social and political implications. Alternative economic and environmental policies are introduced in reaction to this shock.

For all scenarios the impacts on biodiversity (species groups and ecosystems in different biomes) have been explored by deliberation methods, with the ALARM scientists serving as the expert base (Marion et al. 2010)

Observed and projected climate change in Europe

The Intergovernmental Panel on Climate Change (IPCC) estimates a 0.07±0.02°C per decade increase in global surface temperatures over the last 100 years (IPCC 2007). Temperature reconstructions present strong evidence that this magnitude has been the largest over the last 1000 years (Folland et al. 2001). Furthermore, the 1990s are likely to have been the warmest decade of the last millennium (Folland et al. 2001) with a continuation of the trend until 2009 (Jones and Moberg 2003 and updates[2]). 20th century annual mean temperature rise in Europe was 0.08±0.03°C, thus slightly larger than the global mean with the warming being more pronounced during winter than summer (Luterbacher et al. 2004).

Precipitation patterns are spatially and temporally more heterogeneous than temperature with some regions experiencing dryer conditions while others have become wetter. Due to the large variation, significant trends are generally more difficult to detect. Increases in temperature lead to increased water-holding capacity of the atmosphere, altering the hydrological cycle and thus also precipitation events (Treydte et al. 2006). Globally, observed annual precipitation records indicate a twentieth-century increase of about 9 mm over land areas (excluding Antarctica), although this trend is relatively small compared to the century-long variability (New et al. 2001). European trends in annual precipitation reveal a wettening in northern Europe while large parts of southern Europe show little change or drying (IPCC 2007).

Climate extremes are rare events that fall in the tails of the distribution of e.g. daily temperature or precipitation. In order to statistically detect any trends in the frequency and magnitude of extreme weather situations, longer observation time-series are required compared to changes in the mean climate. A global analysis with a large set of

[2] Source of updated values until 2009: http://www.cru.uea.ac.uk/cru/data/temperature (assessed: 21 September 2010).

indices of daily climate extremes such as a warm spell duration index, the number of frost days or the occurrence of very wet days was conducted by Alexander et al. (2006) for the period 1951–2003. They found significant increases in daily minimum and maximum temperatures throughout the globe and increases in precipitation extremes over many areas, although much less spatially coherent. Table 1 gives an overview of observed and projected changes in extremes and the level of confidence. Observed

Table 1. Change in extremes for meteorological phenomena over the specified region and period, with the level of confidence (Source: IPCC, 2007). In the IPCC terminology, "very likely" expresses a 90–99% chance and "likely" a 66–90% chance.

Phenomenon	*Change*	*Region*	*Period*	*Confidence*
Low-temperature days/nights and frost days	Decrease, more so for nights than days	Over 70% of global land area	1951–2003 (last 150 years for Europe and China)	Very likely
High-temperature days/nights	Increase, more so for nights than days	Over 70% of global land area	1951–2003	Very likely
Cold spells/snaps (episodes of several days)	Insufficient studies, but daily temperature changes imply a decrease			
Warm spells (heat waves) (episodes of several days)	Increase: implicit evidence from changes of daily temperatures	Global	1951–2003	Likely
Cool seasons/ warm seasons (seasonal averages)	Some new evidence for changes in inter-seasonal variability	Central Europe	1961–2004	Likely
Heavy precipitation events (that occur every year)	Increase, generally beyond that expected from changes in the mean	Many mid-latitude regions (even where reduction in total precipitation)	1951–2003	Likely
Rare precipitation events (with return periods > ~10 yr)	Increase	Only a few regions have sufficient data for reliable trends (e.g., UK and USA)	Various since 1893	Likely (consistent with changes inferred for more robust statistics)
Drought (season/year)	Increase in total area affected	Many land regions of the world	Since 1970s	Likely
Tropical cyclones	Trends towards longer lifetimes and greater storm intensity, but no trend in frequency	Tropics	Since 1970s	Likely; more confidence in frequency and intensity
Extreme extratropical storms	Net increase in frequency/intensity and poleward shift in track	Northern Hemisphere (on land)	Since about 1950	Likely
Small-scale severe weather phenomena	Insufficient studies for assessment			

changes in the frequency of temperature-related extremes show generally increases in heat events and decreases in cold events.

The projected warming until the end of the 21st century is 1.1 – 6.4°C in global mean annual temperature (IPCC 2007)[3]. Global annual precipitation is projected to increase by 1.3 – 6.8% until the period 2071–2100 according to simulations under the SRES A2 scenario (IPCC 2001). Projections for Europe show wetter conditions in northern Europe mainly during winter and drier conditions in southern Europe for the summer (Ruosteenoja et al. 2003). Still, observed increase in atmospheric CO_2 over the past decades was mostly above the mean (but within the 95% confidence intervals) of the extreme A1FI scenario (Le Quere et al. 2009).

One of the main objectives of the ALARM project was to study the risks of climate change to biodiversity in Europe. Both historic information about climate as well as climate scenarios projecting changes into the future are needed for this. Historic climate datasets on a regular grid system developed by the Climatic Research Unit (CRU) at the University of East Anglia, UK, provide high-resolution information for key climate variables in monthly time steps throughout the 20th century (New et al. 2002, Mitchell et al. 2003). The datasets consist of six variables: mean surface temperature, diurnal temperature range, precipitation, vapour pressure and cloudiness.

Coupled atmosphere-ocean global circulation models (AOGCMs) are the most sophisticated tools currently available for simulating responses of the climate system to increases in greenhouse gas concentrations. Projected changes in climate variables from AOGCMs were used to construct the core set of ALARM climate scenarios for Europe that continues the historic dataset into the 21st century (Fronzek et al. 2010). For the scenarios, labelled GRAS, BAMBU and SEDG, narrative storylines have been developed (see previous chapter) and also other drivers of biodiversity change were quantified to allow a multi-pressure assessment.

For the BAMBU basic scenario, simulations from three different AOGCMs were selected covering a wide range of climate model uncertainties to represent the scenario. Simulations from one AOGCM, the HadCM3, have been used to represent climate changes in all three ALARM scenarios. The range of temperature and precipitation changes is summarized in Table 2.

The spatial pattern of simulated changes in temperature and precipitation are shown below for the GRAS scenario with the HadCM3 AOGCM. For the five ALARM climate scenarios described here, this scenario gives the strongest warming by the end of the 21st century. In this scenario, winter warming until the period 2071–2100 (relative to 1961–1990) shows a gradient from south-western to north-eastern Europe with the smallest increases of *c*. 3°C over the Iberian peninsula and the largest increases of more than 10°C in northern Finland (Figure 3, left). Summer warming is strongest in the Mediterranean countries (Figure 3, right).

[3] Estimated change by 2090–2099 relative to 1980–1999 with a 90% likelihood for six alternative scenarios of greenhouse gas emissions.

Table 2. Simulated changes in annual mean temperature (°C) and annual precipitation by 2071–2100 relative to 1961–1990 averaged over Europe for the ALARM scenarios.

Scenario (SRES)	Climate model	Temperature change (°C)	Precipitation change (%)
BAMBU (A2)	NCAR-PCM	3.0	3.8
BAMBU (A2)	CSIRO2	4.6	5.8
BAMBU (A2)	HadCM3	5.0	0.1
SEDG (B1)	HadCM3	3.3	-0.8
GRAS (A1FI)	HadCM3	6.1	-0.8

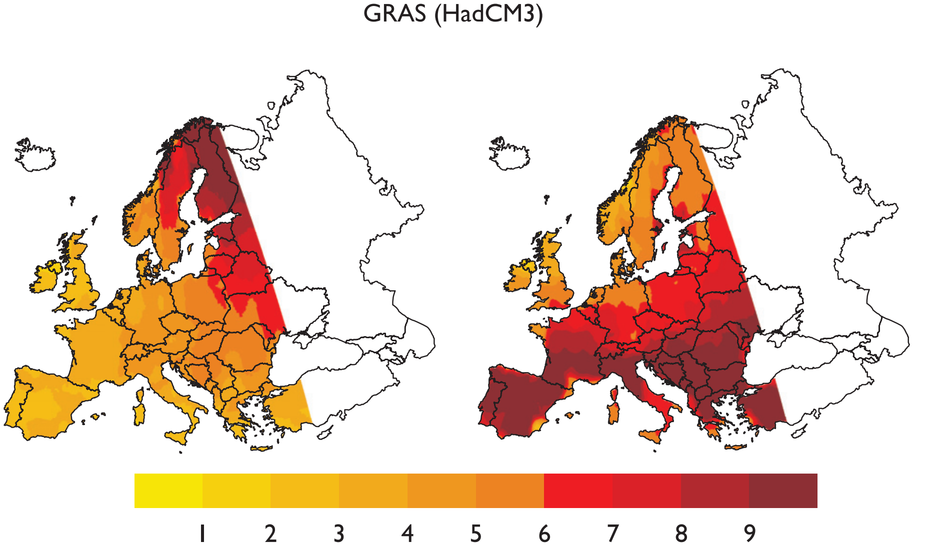

Figure 3. Change in air temperature (in °C) between the periods 1961–1990 and 2071–2100 in winter (December-February, left) and summer (June-August, right) for the GRAS scenario using the HadCM3 AOGCM with the A1FI emission scenario (taken from Fronzek et al. 2010).

The CSIRO2 model expects a similar temperature increase by 2100 (4.6° as compared to 5.0°), whereas the NCAR-PCM model results in a lower increase (3.0°) for the same scenario. The pattern of stronger warming in winter in North-East Europe and in summer in Southern Europe is consistent among all five climate scenarios (Fronzek et al. 2010).

The pattern of winter precipitation changes for the same scenario, again with the HadCM3 AOGCM, shows wetter conditions over nearly all of central and northern Europe and dryer conditions in southern Europe (Figure 4, left). Summer precipitation in this scenario decreases over large part of Europe with the only exceptions being Fennoscandia and parts of the Baltic countries (Figure 4, right). Averages for Europe shown in Table 2 do not convey these regional differences. Precipitation changes projected by the NCAR-PCM and CSIRO2 models show wetter conditions compared to the HadCM3 scenario (3.8% resp. 5.8% as compared to 0.1% increase averaged for Europe).

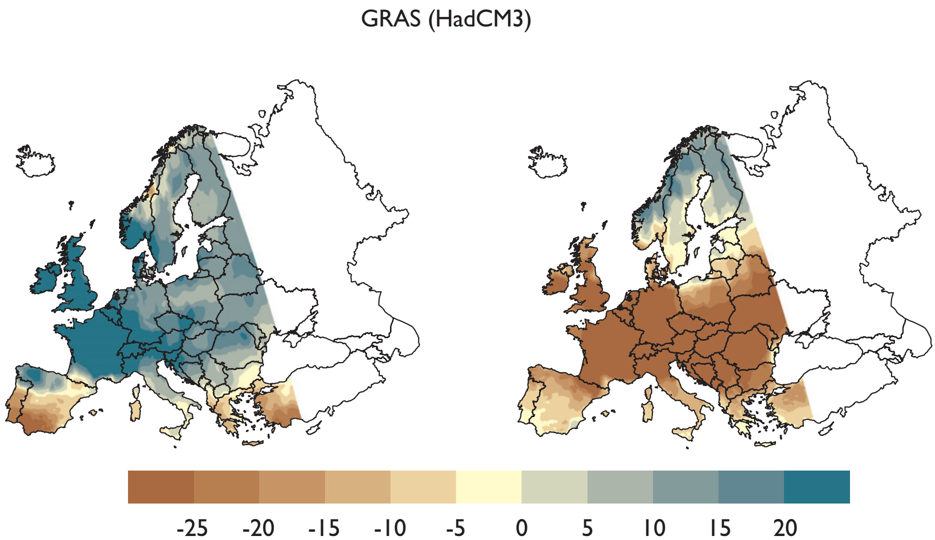

Figure 4. Relative change in precipitation (in %) between the periods 1961–1990 and 2071–2100 in winter (December-February, left) and summer (June-August, right) for the GRAS scenario using the HadCM3 AOGCM with the A1FI emission scenario (taken from Fronzek et al. 2010).

A further climate scenario (labelled GRAS-CUT) explores the impacts of a sudden collapse of the North-Atlantic thermohaline circulation (THC) that would cause a major cooling over north-western Europe.

Climate change impacts on biodiversity at large – with particular reference to ALARM results

Impacts of climate change on plants

A changing climate modifies the conditions which shape the physiological behaviour, the productivity and the ranges of many plants and thus, is expected to induce manifold reactions of climate sensitive species and ecosystems (e.g. Huntley et al. 1995, Sykes et al. 1996, Kappelle et al. 1999, Theurillat and Guisan 2001, Thuiller et al. 2005, Pompe et al. 2008). In recent years, an increasing number of ecological "fingerprints" of climate change impacts (Walther et al. 2001, Parmesan and Yohe 2003, Root et al. 2003) provide ground-truth data of observed changes in the behaviour and distribution of plant species (Walther et al. 2010). While a European scale analysis yielded strong impacts especially on Mediterranean and high mountain plant species (Thuiller et al. 2005, Rickebusch et al. 2008), a regional analysis from Germany showed specific vulnerability of plant species in the North-East and South-West of Germany due to increasing droughts (Pompe et al. 2008). Using this data and assigning the species to their habitat specific species pool (Pompe et al. 2010) found that the species pools of tall herb communities, bushes, and turfs near or above the treeline were most sensitive, followed by dwarf shrub communities below alpine areas. The species assigned to forb communities, forest grassland ecotones and tall herb slopes outside floodplains, plant cultures, and urban, commercial, and industrial areas were least negatively impacted by climate change.

On the basis of long-term phenological records, trends in the response of living organisms to climatic changes can be tracked. Evidence that events in spring have been happening earlier in recent decades arises from a wide range of species and across a wide range of geographic locations. Despite some inconsistencies in the numeric values of the data, an overall trend of 2.3 days per decade towards an earlier onset of spring has been documented (Parmesan and Yohe 2003). Fewer phenological data are available for the fall season. However, the few data sets that include phenophases in both spring and autumn reveal a trend towards a prolongation at both ends of the season and thus, an extension of the growing season (Walther 2004). The observed lengthening of the growing season is based on terrestrial phenological data records with satellite observations of leaf area index anomalies over the past two decades (e.g. Lucht et al. 2002).

In addition to phenological changes, climate warming is also expected to shift the margins of species ranges or boundaries of biomes (e.g. Huntley et al. 1995, Sykes et al. 1996). Evidence for species range shifts has been reported from various habitats (Walther et al. 2010). The period of milder winter conditions since the 1970s for example is in temporal synchrony with a major phase of spread and establishment of thermophilous evergreen broad-leaved species on sites with former deciduous forest vegetation south of the Alps (Walther et al. 2002, Walther and Berger 2010).

In analogy, the partial replacement of neighbouring altitudinal belts is reported by Penuelas and Boada (2003) from north-eastern Spain. This upward shift of vegetation belts is ascribed to the rising annual temperature of 1.2–1.4 °C during the last 50 years with the main increase in the last 30 years. In the Arctic, Cornelissen et al. (2001) suggest a climate-induced change in species composition of arctic plant communities with declining macrolichen abundance as a consequence of the increased abundance of vascular plants. An analogue process of increasing species number and frequency is found at the altitudinal margin of plant life. In the Alps, e.g. Hofer (1992) and Grabherr et al. (1994) provide data on increasing species abundance and richness of plants on high mountain tops showing the overall trend of an upward shift of the alpine-nival flora, which is attributed to the observed warming in climate in these areas. A recent update of the flora of high mountain peaks in the Swiss Alps based on the Hofer (1992) revealed that the trend of increasing species numbers in the summit areas continues and might even have been accelerated in the last decade (Walther et al. 2005b).

The biotic response to thirty years of enhanced global warming has become perceptible and substantial. An overwhelming number of studies provide evidence for climate change impacts on species, communities and ecosystems (Hughes 2000, McCarty 2001, Walther et al. 2002, Root et al. 2003, Parmesan 2006, Walther 2010; for plants see also Walther 2004). In the long-term perspective, the biotic implications of climate change and its evolutionary consequences depend on both the magnitude and rate of global warming as well as on the development of other human influences on biological systems such as habitat conversion, overexploitation and pollution (e.g. Leemans 2001, Travis 2003). It is the combination of these influences that also determines the full extent of the impact of climate change on plants.

Of particular relevance for dragon- and damselflies are studies on climate change impacts on aquatic plants, as these are the core resources for oviposition. Heikkinen et al. (2009) present the northern spread of the invasive aquatic plant *Elodea canadensis* in Europe, which is fostered by climate change effects. The expansion of this plant may favour the expansion of damsel- and dragonflies showing endophytic oviposition, and in fact in Scandinavian countries *Calopteryx* species show an expansion to the north (Ott 2010b).

On the other hand, the decrease of the water soldier (*Stratiotes aloides*) in northern Germany in recent years, which seems to be a combined effect of climate change and eutrophication, has an immediate impact on the populations of the endangered and protected Green Darter (*Aeshna viridis*), a dragonfly which lays its eggs only into this plant.

Impacts of climate change on animals

As for plants there is already strong scientific evidence of the impact of climate change on animals in Europe. During the 21st century rapidly shifting climate zones and rising sea levels will put increasing pressure on species already under threat for other reasons. Among the many examples of climate change effects are: i) phenological changes such as earlier first appearances of British butterflies in the summer (Roy and Sparks 2000) or general changes in the phenology for dragonflies (Ott 2001), ii) northward expansion of many species (Parmesan and Yohe 2003), in particular for Mediterranean dragonflies (Ott 2001, 2010a, 2010b), iii) spreading of sea shell animals (e.g. the barnacle *Balanus perforatus*) from warmer seas around SW England 100 km eastwards up the Channel (Hiscock et al. 2004), iv) overwintering of migratory water birds from the Arctic along the North Sea coast rather than the milder western seaboard of Britain (Robinson et al., 2005), v) microevolutionary adaptations such as diet expansion of a butterfly in response to climate change (Thomas et al. 2001), vi) local extinction of low elevation butterflies in the southern parts of their geographical range (Hill et al. 2002), and (vii) changes in the structure of local bird and butterfly communities (Devictor et al. 2008, Van Swaay et al. 2010), as well as for dragonfly communities (Ott 2007b).

One of several studies from within the ALARM project (Araujo et al 2006) has shown that projected climate change could trigger massive range contractions among amphibian and reptile species in the southwest of Europe. The authors projected distributions of 42 amphibian and 66 reptile species 20–50 years into the future under 4 emission scenarios proposed by the Intergovernmental Panel on Climate Change and

3 different climate models (HadCM3, CGCM2, and CSIRO2). The researchers found that increases in temperature are not likely to constitute a major threat to amphibian and reptile species in Europe. Indeed, a global cooling scenario would be much worse. However, increases in aridity could trigger contractions in the distributions of nearly all species occurring in the southwest of Europe, including Portugal, Spain and France. Impacts in these three countries are not trivial because, together, they hold 62% of the amphibian and reptile species present in Europe. The high proportion of amphibian and reptile species occurring in these three countries is due to the key role played by the Iberian Peninsula as refugia against extinctions during past glacial periods. With projected climate changes these hotpots of persistence might be at risk of becoming hotspots of extinction (see Araujo et al. 2006 for further details).

Just as amphibians, also dragonflies will of course show similar reactions and serve as an "indicator", as well as a "victim": higher temperatures during summertime and warmer winters (see chapter on climate change scenarios) will lead to many biological effects (e.g. change in the phenology, trend to an increased expansion, invasion of southern species, elimination of cold stenotherm species; see Ott 2001), weather extremes at a local or regional scale will lead to droughts in certain biotopes and eliminate all species of a water body or region or alter the communities (see Ott 2010b) and extreme storms can lead to long distance drifts of individuals and new areas may be readily occupied by a species.

In general all changes of the distribution of amphibians will alter also the dragonfly communities, as amphibians and dragonflies are prey and predators at the same time: dragonfly larvae prey on tadpoles and adult frogs prey on damsel- and dragonflies (Ott 2001).

In contrast, impacts of climate change on butterflies are projected to be more severe. Under an extreme GRAS scenario (climate corresponds to IPCC SRES A1FI) over 95 per cent of the present land occupied by 70 different butterflies would become too warm for continued survival. The best case SEDG scenario (A2) sees 50 per cent of the land occupied by 147 different butterflies would become too warm for them to continue to exist there. Many butterflies will largely disappear from where they are regularly seen now (Settele et al. 2008, 2009).

Butterflies are a typical prey for damsel- and dragonflies, but a decrease of butterflies will probably have only little effect on them, as butterflies will not in general be eliminated and dragonflies also can easily switch to other prey (e.g. Diptera).

In general, looking to the future, wild plants and animals will go extinct in some places unless they can keep pace with the rapidly changing climate. While some mobile species can do this, other, less mobile and stenoecious species, will find it much more difficult. There is also a concern that biodiversity may be affected in multiple ways because of other responses to climate change, such as increased demand for water, leading to drying out of rivers and wetlands.

The reactions of single species can have severe cascading effects on higher organisational levels of biodiversity. Since single species react individualistically to climate change, this will ultimately lead to the generation of novel communities (Walther

2010). These novel communities will be characterised by the disruption of currently existing species interactions and the potential of new interactions (Schweiger et al. 2010a). During the ALARM project Schweiger et al. (2008) showed that the future overlaps of climatically suitable areas of the monophagous butterfly *Boloria titania* and its larval host plant *Polygonum bistorta* may virtually disappear from where they presently co-exist and allow co-occurrence only in distantly located areas, whereby the ability to colonise these areas is questionable for both plant and butterfly. In a follow up study Schweiger et al. (2010b) showed that such mismatches are not the case for every species. In fact most butterfly species are supposed to be not limited by the distribution of their host plants and thus future mismatches are not an issue for them. However, there are several species which are to a certain extent limited by their host plants and for them future mismatches are indeed a serious issue. Of particular concern in this context are species that utilise range limited host plants.

Such mismatches of interacting species are not restricted to pairwise interactions but can expand to whole interaction networks as has been reviewed by Schweiger et al. (2010a). Although, the architecture of such networks and their redundancy and flexibility might impede cascading extinctions (Hegland et al. 2009, Memmot et al. 2004, Vilà et al. 2009), such buffer capacities are not unlimited and will not necessarily circumvent severe changes in species interactions and the consequent species extinctions (Memmott et al. 2004, Fortuna and Bascompte 2006). Further, changes in community composition and species interactions can, especially in combination with additional pressures (see below) lead to severe consequences for ecosystem services (Potts et al. 2010). This is in particular true for wetland ecosystems, where dragonflies are excellent indicators for the effects of climatic changes (Ott 2001, 2008b, 2010b).

Dragonflies only have a limited dependency on plants, but very much on waters, its quality and quantity. Alterations of the water level lead to changes of the dragonfly community (e.g. favour eurycious species and eliminate mooreland species, see Ott 2007b, 2010b) or could lead to invasions by Mediterranean species which previously did not inhabit these water bodies (e.g. by *Lestes barbarus* or *Ischnura pumilio*, see: Ott 2006, 2008a). If the water level recovers due to an increased precipitation the old dragonfly communities may recover as well and the new species may leave again, but it also could lead to an irreversible change and new aquatic communities (Ott 2010b, unpubl. data).

Multiple risks for biodiversity: Climate change in interaction with other pressures

In addition to climate change, global change creates many drivers that affect biodiversity (e.g., Potts et al. 2010, Schweiger et al. 2010). Among the most important drivers are land-use change with the consequent loss and fragmentation of habitats (Westphal et al. 2003, Tscharntke et al. 2005, Schweiger et al. 2007, Öckinger et al. 2010); increasing pesticide application and environmental pollution (Rortais et al. 2005, Dormann et al. 2007); alien species (Stout and Morales 2009, Walther et al. 2009, Vilá et al. 2010); and the spread of pathogens (e.g., Cox-Foster et al. 2007). These drivers are often in conflict with desired ecosystem services. Sustaining pollination services, for instance, is for sure highly desired by both conservationist and farmers, but it is often decreased as a consequence of other demands such as increasing agricultural production. Habitat loss and fragmentation are generally thought to be the most important factors driving pollinator declines (Brown and Paxton 2009). In addition, increased use of insecticides can cause pollinator mortality by direct intoxication (Alston et al. 2007). Increased herbicide and fertiliser use can affect pollinators indirectly by decreasing floral resource availability (Gabriel and Tscharntke 2007, Holzschuh et al. 2008).

All these drivers act simultaneously and very likely synergistically on local communities (Tylianakis et al., 2008). So far, most studies have analysed specific drivers in isolation, and therefore evidence of interactive effects is scant. However, in a recent review within ALARM Schweiger et al. (2010) show that the effects of multiple interacting pressures can be contrasting. In the face of climate change, alien species can serve as additional pollen and nectar sources (Stout and Morales 2009) or pollinators (Goulson 2003). Such species can thus substitute otherwise lost functions. On the other hand, alien species can lead to reduced reproductive success and population declines of native pollinators by competitive displacement of native plants (Traveset and Richardson 2006) or by high levels of resource competition among native and alien pollinators (Matsumura et al. 2004, Thomson 2006).

Yet, knowledge about the relative contribution and the importance of interactive pressures is an indispensible precondition to understand current and to predict future changes in biodiversity and resulting ecosystem services.

New developments in relation to dragon- and damselflies

In the course of the project, ALARM was enlarged and partners from other continents have been included. With this expansion the ALARM approach had to be tailored for the respective regions, which in the context of dragon- and damselflies was particularly the case for research in Asia and Africa.

For Asian rice-growing systems a close collaboration with IRRI was started to analyse long-term trends in the biodiversity of natural enemies of rice pests, with a particular focus on parasitoids (by applying and adjusting the ALARM field site network approach, compare Grabaum et al. 2006). A further aim was to look into the options to develop appropriate sustainability indicators for rice growing systems, where in particular dragon- and damselflies might play a key role and where we have a direct field for the further application of the research results (Heong et al. 2010).

In southern Africa, there are many narrow range endemics that are at risk from the effects of global climate change. Among these are *Colophon* beetles (Samways 2005) and certain dragonflies. One species of dragonfly, only discovered in 2003, is *Syncordulia serendipitor*, which lives in primary high elevation streams (Samways 2008). With global change, it appears to have nowhere to go. However, genetic work has indicated that this species diverged 60 million years ago (Ware et al. 2009), and it has seemingly survived climate changes in the past, some of which have been very rapid. This leads to the speculation that perhaps even some narrow range endemics are physiologically adapted to climate change. But then perhaps in the past the overall population size and hence genetic variation, was greater, enabling the species to survive climatically difficult times. There is some evidence for this among some other, more widespread, odonate species in southern Africa. There is remarkable elevational tolerance among some species, enabling them to survive at higher or lower elevations according to the prevailing climatic conditions (Niba and Samways 2006), even in the case of some endemic species (Samways and Niba 2010). Other species show great plasticity in their ability to expand their geographic ranges and colonize water bodies during wet phases of El Niño cycles, then shrinking back to predictably wet refugia in the dry phases (Samways 2010). As this is a common phenomenon, there appears to have been strong selection pressure on a whole range of species to survive stressful climatic conditions. These shifts in population presence can be so extreme, that in the case of one species, *Aciagrion congoense*, it appeared as a new national record to South Africa in 2000, apparently driven south by floods in Mozambique. It then became the dominant damselfly at iSimangaliso Wetland Park in 2001. However, a few years later, after an extended dry spell, it again disappeared from South Africa. The point here is that at least in this part of Africa, there is some evidence that odonate species are to some extent already honed to tolerate some anthropogenic climate change.

Within ALARM the effects on dragonflies were mainly studied in Germany and Europe: here the waters in the Palatinate (Germany) and the Gran Sasso area (Italy) were studied. It could be shown that the general trends for dragonflies (e.g. range expansion of Mediterranean species, alteration in the phenology, changes in the aquatic communities, decrease of stenoecious species, see Ott 2001, 2008b), which have already shown earlier, still continued and the expansion is an ongoing and European wide process (Ott 2010a, 2010b). In general biodioversity will increase, but in the medium term there will probably be a decrease, as stenoecious species, such as alpine and mooreland species, will decrease due to the negative effects on their biotopes. In the Mediterranean the lack of water, in particular in intensively used areas, will lead to the decrease and eventual extinction of many species (e.g. species of running waters).

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References

Alexander LV, Zhange X, Petersonn TC, Caesar J, Gleasonn B, Klein Tank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research 111: doi:10.1029/2005JD006290.

Alston DG, Tepedino VJ, Bradley BA, Toler TR, Griswold TL, Messinger SM (2007) Effects of the insecticide phosmet on solitary bee foraging and nesting in orchards of Capitol Reef National Park, Utah. Environmental Entomology 36: 811–816.

Araújo MB, Thuiller W, Pearson RG (2006) Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33: 1712–1728.

Benedetti F, Colombo C, Barbini B, Campori E, Smeraldi E (2001) Morning sunlight reduces length of hospitalization in bipolar depression. Journal of Affective Disorders 62: 221–223.

Brown MJF, Paxton RJ (2009) The conservation of bees: a global perspective. Apidologie 40: 410–416.

Carson C, Hajat S, Armstrong B, Wilkinson P (2006) Declining vulnerability to temperature-related mortality in London over the 20th century. American Journal of Epidemiology 164: 77–84.

Chloupek O, Hrstkova P, Schweigert P (2004) Yield and its stability, crop diversity, adaptability and response to climate change, weather and fertilisation over 75 years in the Czech Republic in comparison to some European countries. Field Crops Research 85: 167–190.

Conti S, Meli P, Minelli G, Solimini R, Toccaceli V, Vichi M, Beltrano C, Perini L (2005) Epiderniologic study of mortality during the Summer 2003 heat wave in Italy. Environmental Research 98: 390–399.

Cornelissen JHC, Callaghan TV, Alatalo JM, Michelsen A, Graglia E (2001) Global change and arctic ecosystems: is lichen decline a function of increases in vascular plant biomass? Journal of Ecology 89: 984–994.

Cox-Foster DL, Conlan S, Holmes EC et al. (2007) A metagenomic survey of microbes in honey bee colony collapse disorder. Science 318: 283–287.

Devictor V, Julliard R, Couvet D, Jiguet F (2008) Birds are tracking climate warming, but not fast enough. Proc Biol Sci. 275: 2743–2748.

Dormann CF, Schweiger O, Augenstein I et al. (2007) Effects of landscape structure and land-use intensity on similarity of plant and animal communities. Global Ecology and Biogeography 16: 774–787.

Epstein PR (2000) Is global warming harmful to health? Scientific American 283: 50–57.

Epstein PR (2002) Climate change and infectious disease: Stormy weather ahead? Epidemiology 13: 373–375.

Epstein PR (2005) Climate change and human health. New England Journal of Medicine 353: 1433–1436.

Euskirchen ES, McGuire AD, Kicklighter DW, Zhuang Q, Clein JS, Dargaville RJ, Dye DG, Kimball JS, McDonald KC, Melillo JM, Romanovsky VE, Smith NV (2006) Importance of recent shifts in soil thermal dynamics on growing season length, productivity, and carbon sequestration in terrestrial high-latitude ecosystems. Global Change Biology 12: 731–750.

Fanslow G (2006) Thinking outside the box. Rice Today (October – December 2006), 45–46.

Folland CK, Karl TR, Christy JR, Clarke RA, Gruza GV, Jouzel J, Mann ME, Oerlemans J, Salinger MJ, Wang S-W (2001) Observed climate variability and change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (Eds) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 99–181.

Fortuna MA, Bascompte J (2006) Habitat loss and the structure of plant-animal mutualistic networks. Ecology Letters 9: 281–286.

Fronzek S, TR Carter, Jylhä K (2010) Scenarios of Climate Change for Europe. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammer V, Klotz S Kühn I (Eds) Atlas of Biodiversity Risks. Pensoft, Sofia-Moscow, 68–71.

Gabriel D, Tscharntke T (2007) Insect pollinated plants benefit from organic farming. Agriculture, Ecosystems and Environment 118: 43–48.

Gillett NP, Zwiers FW, Weaver AJ, Stott PA (2003) Detection of human influence on sea-level pressure. Nature 422: 292–294.

Gordo O, Sanz JJ (2005) Phenology and climate change: a long-term study in a Mediterranean locality. Oecologia 146: 484–495.

Goulson D (2003) Effects of introduced bees on native ecosystems. Annual Review of Ecology, Evolution and Systematics 34: 1–26.

Grabaum R, Hammen VC, Kühn I, Klotz S, Settele J, Biesmeijer JC, Wolf T (2006) The European Field Site Network of the ALARM Project - Cross Border GIS Solutions for Research. In: Karrasch P (Ed) Nature protection: GIS. International Symposium on Geoinformatics in European Nature Protection Regions, Proceedings, TU Dresden, 149–156.

Grabherr G, Gottfried M, Pauli H (1994) Climate effects on mountain plants. Nature 369: 448.

Grize L, Huss A, Thommen O, Schindler C, Braun-Fabrlander C (2005) Heat wave 2003 and mortality in Switzerland. Swiss Medical Weekly 135: 200–205.

Hammen VC, Biesmeijer JC, Bommarco R, Budrys E, Christensen TR, Fronzek S, Grabaum R, Jaksic P, Klotz S, Kramarz P, Kröel-Dulay G, Kühn I, Mirtl M, Moora M, Petanidou T, Pino J, Potts SG, Rortais A, Schulze CH, Steffan-Dewenter I, Stout J, Szentgyörgyi H, Vighi M, Vujic A, Westphal C, Wolf T, Zavala G, Zobel M, Settele J, Kunin WE (2010a) Establishment of a cross-European field site network in the ALARM project for assessing large-scale changes in biodiversity. Environmental Monitoring and Assessment 164: 337–348.

Hammen V, Biesmeijer JC, Bommarco R, Budrys E, Christensen TR, Fronzek S, Grabaum R, Jaksic P, Klotz S, Kramarz P, Kröel-Dulay G, Kühn I, Mirtl M, Moora M, Petanidou T, Pino J, Potts SG, Rortais A, Schulze CH, Steffan-Dewenter I, Stout J, Szentgyörgyi H, Vighi M, Vujic A, Westphal C, Wolf T, Zavala G, Zobel M, Settele J, Kunin WE (2010b) The ALARM Field Site Network, FSN. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kühn I (Eds) Atlas of Biodiversity Risk. Pensoft, Sofia-Moscow, 42–45.

Hegland SJ, Nielsen A, Lázaro A, Bjerknes AL, Totland O (2009) How does climate warming affect plant-pollinator interactions? Ecology Letters 12: 184–195.

Heikkinen RK, Leikola N, Fronzek S, Lampinen R, Toivonen H (2009) Predicting distribution patterns and recent northward range shift of an invasive aquatic plant: *Elodea canadensis* in Europe. BioRisk 2: 1–32.

Heong KL, Hijmans RJ, Villareal S, Catindig JL (2010) Biological Control ecosystem services in tropical rice. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kühn I (Eds) Atlas of Biodiversity Risk. Pensoft, Sofia-Moscow, 248–249.

Hill JK, Thomas CD, Fox R, Telfer MG, Willis SG, Asher J, Huntley B (2002) Responses of butterflies to twentieth century climate warming: implications for future ranges. Proceedings of he Royal Society of London, B 269: 2163–2171.

Hiscock K, Southward A, Tittley I, Hawkins S (2004) Effects of changing temperature on benthic marine life in Britain and Ireland. Aquatic Conservation: Marine and Freshwater Ecosystems 14: 333–362.

Hofer HR (1992) Veränderungen in der Vegetation von 14 Gipfeln des Berninagebietes zwischen 1905 und 1985. Berichte des Geobotanischen Instituts ETH, Stiftung Rübel, Zürich 58: 39–54.

Holzschuh A, Steffan-Dewenter I, Tscharntke T (2008) Agricultural landscapes with organic crops support higher pollinator diversity. Oikos 117: 354–361.

Hughes L (2000) Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution 15: 56–61.

Huntley B, Berry PM, Cramer W, McDonald AP (1995) Modelling present and potential future ranges of some European higher plants using climate response surfaces. Journal of Biogeography 22: 967–1001.

IPCC (2001) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (Eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 892pp.

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (Eds)] Cambridge Univ Press, Cambridge, UK, 1008pp.

Jones PD, Moberg A (2003) Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. Journal of Climate 16: 206–223.

Jonkman SN (2005) Global perspectives on loss of human life caused by floods. Natural Hazards 34: 151–175.

Kappelle M, van Vuuren MMI, Baas P (1999) Effects of climate change on biodiversity: a review and identification of key research issues. Biodiversity and Conservation 8: 1383–1397.

Kerr RA (2006) A worrying trend of less ice, higher seas. Science 311: 1698.

Kutz SJ, Hoberg EP, Polley L, Jenkins EJ (2005) Global warming is changing the dynamics of Arctic host-parasite systems. Proceedings of the Royal Society B - Biological Sciences 272: 2571–2576.

Leemans R (2001) The use of global-change scenarios to determine changes in species and habitats. Global biodiversity in a changing environment [Chapin FS III, Sala OE, Huber-Sannwald E (Eds)], Ecological Studies 152: 23–45.

Le Quere C, Raupach MR, Canadell JG, Marland G, Bopp L, Ciais P, Conway TJ et al. (2009) Trends in the sources and sinks of carbon dioxide. Nature Geoscience 2: 831–836.

Le Tertre A, Lefranc A, Eilstein D, Declercq C, Medina S, Blanchard M, Chardon B, Fabre P, Filleul L, Jusot JF, Pascal L, Prouvost H, Cassadou S, Ledrans M (2006) Impact of the 2003 heatwave on all-cause mortality in 9 French cities. Epidemiology 17: 75–79.

Lucht W, Prentice IC, Myneni RB, Sitch S, Friedlingstein P et al. (2002) Climatic control of the high-latitude vegetation greening trend and Pinatubo effect. Science 296: 1687–1689.

Luterbacher J, Dietrich D, Xoplaki E, Grosjean M, Wanner H (2004) European seasonal and annual temperature variability, trends, and extremes since 1500. Science 303: 1499–1503.

Marion G, Grabaum R, Grescho V, Butler A, Bierman S, Douguet J-M, Hammen V, Hickler T, Hulme PE, Maxim L, Omann I, Peterson K, Potts SG, Reginster I, Settele J, Spangenberg JH, Kühn I (2010) Biodiversity Risk Assessment for Europe – Putting It All Together. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kühn I (Eds) Atlas of Biodiversity Risk. Pensoft, Sofia-Moscow, 252–253.

Matsumura C, Yokoyama J, Washitani I (2004) Invasion status and potential ecological mpacts of an invasive alien bumblebee, *Bombus terrestris* L (Hymenoptera: Apidae) naturalized in Southern Hokkaido, Japan. Global Environmental Research 8: 51–66.

McCarty JP (2001) Ecological consequences of recent climate change. Conservation Biology 15: 320–331.

Memmott J, Waser NM, Price MV (2004) Tolerance of pollination networks to species extinctions. Proceedings of the Royal Society B-Biological Sciences 271: 2605–2611.

Mitchell TD, Carter TR, Jones PD, Hulme M, New M (2003) A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100). Tyndall Centre Working Paper 55: 29.

Molin J, Mellerup E, Bolwig T, Scheike T, Dam H (1996) The influence of climate on development of winter depression. Journal of Affective Disorders 37: 151–155.

Nelson FE, Anisimov OA, Shiklomanov NI (2001) Subsidence risk from thawing permafrost - The threat to man-made structures across regions in the far north can be monitored. Nature 410: 889–890.

New M, Lister D, Hulme M, Makin I (2002) A high-resolution data set of surface climate over global land areas. Climate Research 21: 1–25.

New M, Todd M, Hulme M, Jones P (2001) Precipitation measurements and trends in the twentieth century. International Journal of Climatology 21: 1889–1922.

Niba AS, Samways MJ (2006) Remarkable elevational tolerance in an African dragonfly (Odonata) larval assemblage. Odonatologica 35: 265–280.

Öckinger E, Schweiger O, Crist TO, Debinski DM, Krauss J, Kuussaari M, Petersen JD, Pöyry J, Settele J, Summerville KS, Bommarco R (2010) Life-history traits predict species responses to habitat area and isolation: a cross-continental synthesis. Ecology Letters 13: 969–979.

Olsen B, Munster V, Wallensten A, Waldenstrom J, Osterhaus A, Fouchiewr R (2006) Global patterns of influenza a virus in wild birds. Science 312: 384–388.

Ott J (2001) Expansion of mediterranean Odonata in Germany and Europe – consequences of climatic changes - Adapted behaviour and shifting species ranges. In: Walter G-R et al. (Eds) (2001) „Fingerprints" of Climate Change. Kluwer Academic Publishers, New York, 89–111.

Ott J (2006) Die Südliche Binsenjungfer – *Lestes barbarus* (FABRICIUS, 1798) – erobert den Pfälzerwald (Insecta: Odonata: Lestidae). Fauna und Flora in Rheinland-Pfalz 10: 1315–1321.

Ott J (2007a) The expansion of *Crocothemis erythraea* (Brullé, 1832) in Germany – an indicator of climatic changes. In: Tyagi BK (Ed) Odonata - Biology of Dragonflies. Scientific Publishers (India), 210–222.

Ott J (2007b) Hat die Klimaänderung eine Auswirkung auf das Netz NATURA 2000? - Erste Ergebnisse aus Untersuchungen an Libellenzönosen dystropher Gewässer im Biosphärenreservat Pfälzerwald. In: Balzer S, Dietrich M, Beinlich B (Eds) Natura 2000 und Klimaänderungen. Naturschutz und Biologische Vielfalt 46: 65–90.

Ott J (2008a) Die Kleine Pechlibelle (*Ischnura pumilio*) (CHARPENTIER, 1825) in der Pfalz: ein Profiteur von Regenrückhaltebecken, Naturschutzgewässern und der Klimaänderung. Mainzer Naturwissenschaftliches Archiv 46: 233–261.

Ott J (2008b) Libellen als Indikatoren der Klimaänderung – Ergebnisse aus Deutschland und Konsequenzen für den Naturschutz. Insecta – Zeitschrift für Entomologie und Naturschutz 11: 75–89.

Ott J (2010a) The big trek northwards: recent changes in the European dragonfly fauna. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kühn I (Eds) Atlas of Biodiversity Risk. Pensoft Publishers, Sofia-Moscow, 82–83.

Ott J (2010b) Effects of climatic changes on dragonflies – results and recent observations in Europe. In: Ott J (Ed) (2010) Monitoring Climate Change with dragonflies. BioRisk 5: 253–286.

Overpeck JT, Otto-Bliesner BL, Miller GH, Muhs DR, Alley RB, Kiehl JT (2006) Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. Science 311: 1747–1750.

Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O (2010) Global pollinator declines: drivers and impacts. Trends in Ecology and Evolution 25: 345–353.

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37: 637–669.

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37–42.

Pascual M, Bouma MJ, Dobson AP (2002) Cholera and climate: revisiting the quantitative evidence. Microbes and Infection 4: 237–245.

Patz JA, Campbell-Lendrum D, Holloway T, Foley JA (2005) Impact of regional climate change on human health. Nature 438: 310–317.

Penuelas J, Boada M (2003) A global change-induced biome shift in the Montseny mountains (NE Spain). Global Change Biology 9: 131–140.

Perry RD, JD Fetherston (1997) Yersinia pestis - Etiologic agent of plague. Clinical Microbiology Reviews 10: 35–66.

Pompe S, Badeck F-W, Hanspach J, Klotz S, Thuiller W, Kühn I (2008) Projecting impact on plant distributions under climate change - a case study from Germany. Biology Letters 4: 564–567.

Pompe S, Hanspach J, Badeck F-W, Klotz S, Bruehlheide H, Kühn I (2010) Investigating habitat-specific co-occurrence of plant species under climate change. Basic and Applied Ecology 11: 603–611.

Pounds JA, Bustamante MR, Coloma LA, Consuegra JA, Fogden MPL, Foster PN, La Marca E, Masters KL, Merino-Viteri A, Puschendorf R, Ron SR, Sanchez-Azofeifa GA, Still CJ, Young BE (2006) Widespread amphibian extinctions from epidemic disease driven by global warming. Nature 439: 161–167.

Raper SCB, Braithwaite RJ (2006) Low sea level rise projections from mountain glaciers and icecaps under global warming. Nature 439: 311–313.

Rickebusch S, Thuiller W, Hickler T, Araujo MB, Sykes MT, Schweiger O, Lafourcade B (2008) Incorporating the effects of changes in vegetation functioning and CO2 on water availability in plant habitat models. Biology Letters 4: 556–559.

Robinson RA, Learmonth JA, Hutson AM, Macleod CD, Sparks TH, Leech DI, Pierce GJ, Rehfisch MM, Crick HQP (2005) Climate Change and Migratory Species, Defra, London. BTO Research Report 414.

Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C et al. (2003) Fingerprints of global warming on wild animals and plants. Nature 421: 57–60.

Rortais A, Arnold G, Halm MP, Touffet-Briens F (2005) Modes of honeybees exposure to systemic insecticides: estimated amounts of contaminated pollen and nectar consumed by different categories of bees. Apidologie 36: 71–83.

Roy DB, Sparks TH (2000) Phenology of British butterflies and climate change. Global Change Biology 6: 407–416.

Ruosteenoja K, Carter TR, Jylhä K, Tuomenvirta H (2003) Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios. The Finnish Environment 644.

Samways MJ (2005) Insect Diversity Conservation. Cambridge University Press, Cambridge, UK, 356pp.

Samways MJ (2008) Dragonflies as focal organisms in contemporary conservation bipology. In: Córdoba-Aguilar A (Ed) Dragonflies & Damselflies: Model Organisms for Ecological and Evolutionary Research. Oxford University Press, Oxford, UK, 97–108.

Samways MJ (2010) Impacts of extreme weather and climate change on South African dragonflies. In: Ott J (Ed) Dragonflies and Climate Change. BioRisk 5: 73–84.

Samways MJ, Niba AS (2010) Climate and elevational range of a South African dragonfly assemblage. In: Ott J (Ed) Dragonflies and Climate Change. BioRisk 5: 85–107.

Samways MJ, Osborn R, Hastings H, Hattingh V (1999) Global climate change and accuracy of prediction of species' geographical ranges: establishment success of introduced ladybirds (Coccinellidae, *Chilocorus* spp.) worldwide. Journal of Biogeography 26: 795–812.

Schiermeier Q (2003) Alpine thaw breaks ice over permafrost's role. Nature 424: 712.

Schijven JF, Husman AMD (2005) Effect of climate changes on waterborne disease in The Netherlands. Water Science and Technology 51: 79–87.

Schweiger O, Musche M, Bailey D et al. (2007) Functional richness of local hoverfly communities (Diptera, Syrphidae) in response to land use across temperate Europe. Oikos 116: 461–472.

Schweiger O, Settele J, Kudrna O, Klotz S, Kühn I (2008) Climate change can cause spatial mismatch of trophically interacting species. Ecology 89: 3472–3479.

Schweiger O, Biesmeijer JC, Bommarco R et al (2010) Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. Biological Reviews 85: 777–795.

Schweiger O, Heikkinen RK, Harpke A et al. (in press) Increasing range mismatching of interacting species under global change is related to their ecological characteristics. Global Ecology and Biogeography, DOI: 10.1111/j.1466-8238.2010.00607.x.

Settele J, Kühn E (2009) Insect conservation. Science 325: 41–42.

Settele J, Hammen V, Hulme P, Karlson U, Klotz S, Kotarac M, Kunin W, Marion G, O'Connor M, Petanidou T, Peterson K, Potts S, Pritchard H, Pysek P, Rounsevell M, Spangenberg J, Steffan-Dewenter I, Sykes M, Vighi M, Zobel M, Kühn I (2005) ALARM – Assessing LArge-scale environmental Risks for biodiversity with tested Methods. GAIA 14/1: 69–72.

Settele J, Kudrna O, Harpke A, Kuehn I, van Swaay C, Verovnik R, Warren M, Wiemers M, Hanspach J, Hickler T, Kuehn E, van Halder I, Veling K, Vliegenthart A, Wynhoff I, Schweiger O (2008) Climatic Risk Atlas of European Butterflies, BioRisk 1: 1–710.

Settele J, Kudrna O, Harpke A, Kühn I, Van Swaay C, Verovnik R, Warren M, Wiemers M, Hanspach J, Hickler T, Kühn E, Van Halder I, Veling K, Vliegenthart A, Wynhoff I, Schweiger O (2009) Corrigenda: Settele J et al. (2008) Climatic Risk Atlas of European Butterflies. BioRisk 2: 33–72.

Settele J, Spangenberg JH, Hammen V, Harpke A, Klotz S, Rattei S, Schmidt A, Schweiger O, Kühn I (2010) Assessing LArge-scale environmental Risks for biodiversity with tested Methods – the ALARM project. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kühn I (Eds) Atlas of Biodiversity Risk. Pensoft, Sofia-Moscow, 38–41.

Spangenberg JH (2007a) Integrated scenarios for assessing biodiversity risks. Sustainable Development 15: 343–356.

Spangenberg JH (2007b) Biodiversity pressures and the driving forces behind. Ecological Economics 61: 146–158.

Spangenberg JH, Fronzek S, Hammen V, Hickler T, Jäger J, Jylhä K, Kühn I, Marion G, Maxim L, Monterroso I, O'Connor M, Omann I, Reginster I, Rodriguez-Labajos B, Rounsevell M, Sykes MT, Vighi M, Settele J (2010) The ALARM scenarios. Storylines and simulations for analysing biodiversity risks in Europe. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammen V, Klotz S, Kotarac M, Kühn I (Eds) Atlas of Biodiversity Risk. Pensoft, Sofia-Moscow, 10–15.

Spangenberg JH, Carter TR, Fronzek S, Jaeger J, Jylhä K, Kühn I, Omann I, Paul A, Reginster I, Rounsevell M, Stocker A, Sykes MT, Settele J (in press) Scenarios for investigating risks to biodiversity: The role of storylines, scenarios, policies and shocks in the ALARM project. Global Ecology and Biogeography.

Stireman JO, Dyer LA, Janzen DH, Singer MS, Li JT, Marquis RJ, Ricklefs RE, Gentry GL, Hallwachs W, Coley PD, Barone JA, Greeney HF, Connahs H, Barbosa P, Morais HC, and Diniz IR (2005) Climatic unpredictability and parasitism of caterpillars: Implications of global warming. Proceedings of the National Academy of Sciences of the United States of America 102: 17384–17387.

Stout JC, Morales CL (2009) Ecological impacts of invasive alien species on bees. Apidologie 40: 388–409.

Sykes MT, Prentice IC, Cramer W (1996) A bioclimatic model for the potential distributions of north European tree species under present and future climates. Journal of Biogeography 23: 203–233.

Theurillat JP, Guisan A (2001) Potential impact of climate change on vegetation in the European Alps: A review. Climatic Change 50: 77–109.

Thomas CD, Bodsworth EJ, Wilson RJ, Simmons AD, Davies ZG, Musche M, Conradt L (2001) Ecological and evolutionary processes at expanding range margins. Nature 411: 577–581.

Thomson DM (2006) Detecting the effects of introduced species: A case study of competition between Apis and Bombus. Oikos 114: 407–418.

Thuiller W, Lavorel S, Araújo MB, Sykes MT, Prentice IC (2005) Climate change threats to plant diversity in Europe. Proceedings National Academy of Sciences of the United States of America (PNAS) 102: 8245–8250.

Traveset A, Richardson DM (2006) Biological invasions as disruptors of plant reproductive mutualisms. Trends in Ecology and Evolution 21: 208–216.

Travis JMJ (2003) Climate change and habitat destruction: a deadly anthropogenic cocktail. Proceedings of the Royal Society, B 270: 467–473.

Treydte KS, Schleser GH, Helle G, Frank DC, Winiger M, Haug GH, Esper J (2006) The twentieth century was the wettest period in northern Pakistan over the past millennium. Nature 440: 1179–1182.

Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. Ecology Letters 8: 857–874.

Tylianakis JM, Didham RK, Bascompte J, Wardle DA (2008) Global change and species interactions in terrestrial ecosystems. Ecology Letters 11: 1351–1363.

Van Swaay CAM, Harpke A, Van Strien A, Fontaine B, Stefanescu C, Roy D, Maes D, Kühn E, Őunap E, Regan EC, Švitra G, Heliölä J, Settele J, Musche M, Warren MS, Plattner M, Kuussaari M, Cornish N, Schweiger O, Feldmann R, Julliard R, Verovnik R, Roth T, Brereton T, Devictor V (2010) The impact of climate change on butterfly communities

1990–2009. Report VS2010.025, Butterfly Conservation Europe & De Vlinderstichting, Wageningen.

Vilà M, Bartomeus I, Dietzsch AC, Petanidou T, Steffan-Dewenter I, Stout JC, Tscheulin T (2009) Invasive plant integration into native plant–pollinator networks across Europe. Proceedings of the Royal Society, B 276: 3887–1674.

Vilá M, Basnou C, Pyšek P et al. (2010) How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Frontiers in Ecology and the Environment 8: 135–144.

Walther G-R (2004) Plants in a warmer world. Perspectives in Plant Ecology, Evolution and Systematics 6: 169–185.

Walther G-R (2010) Community and ecosystem responses to recent climate change. Philosophical Transactions of the Royal Society, B 365: 2019–2024

Walther G-R, Berger S (2010) Palms (and other evergreen broad-leaved species) conquer the north. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammer V, Klotz S, Kühn I (Eds) Atlas of Biodiversity Risks. Pensoft, Sofia-Moscow, 212–213.

Walther G-R, Burga CA, Edwards PJ (Eds) (2001) „Fingerprints“ of Climate Change - Adapted behaviour and shifting species ranges. Kluwer Academic/Plenum Publishers, New York, 338pp.

Walther G-R, Post E, Convey P, Menzel A, Parmesan C et al. (2002) Ecological responses to recent climate change. Nature 416: 389–395.

Walther G-R, Berger S, Sykes MT (2005a): An ecological ‘footprint’ of climate change. Proceedings of the Royal Society, B 272: 1427–1432

Walther G-R, Beißner S, Burga CA (2005b): Trends in the upward shift of alpine plants. Journal of Vegetation Science 16: 541–548.

Walther G-R, Roques A, Hulme PE, Sykes MT, Pysek P, Kühn I, Zobel M, Bacher S, Botta-Duka Z, Bugmann H, Czucz B, Dauber J, Hickler T, Jarosik V, Kenis M, Klotz S, Minchin D, Moora M, Nentwig W, Ott J, Panov VE, Reineking B, Robinet C, Semenchenko V, Solarz W, Thuiller W, Vila M, Vohland K, Settele J (2009) Alien species in a warmer world – risks and opportunities. Trends in Ecology and Evolution 24: 686–693.

Walther G-R, Nagy L, Heikkinen RK, Penuelas J, Ott J, Pauli H, Pöyry J, Berger S, Hickler T (2010) Observed climate-biodiversity relationships. In: Settele J, Penev L, Georgiev T, Grabaum R, Grobelnik V, Hammer V, Klotz S, Kühn I (Eds) Atlas of Biodiversity Risks. Pensoft, Sofia-Moscow, 74–75.

Ware MJ, Simaika JP, Samways MJ (2009) Biogeography, and divergence time estimation of the relic South African Cape dragonfly genus *Syncordulia*: global significance and implications for conservation. Zootaxa 2216: 22–36.

Westphal C, Steffan-Dewenter I, Tscharntke T (2003) Mass flowering crops enhance pollinator densities at a landscape scale. Ecology Letters 6: 961–965.