ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/236200602

# Global warming changes the terrestrial flora of the Wadden Sea

**Article** · January 2011

CITATIONS
2

**1 author:**

Detlev Metzing
Carl von Ossietzky Universität Oldenburg
**53** PUBLICATIONS **104** CITATIONS

SEE PROFILE

**Some of the authors of this publication are also working on these related projects:**

Seed studies in Cactaceae View project

"Erosion der Artenkenntnis" - Situation und Strategien für eine Nachwuchsoffensive der Artenkenntnis View project

All content following this page was uploaded by Detlev Metzing on 29 May 2014.

The user has requested enhancement of the downloaded file.

# Global warming changes the terrestrial flora of the Wadden Sea

Detlev Metzing, Institute of Biology and Environmental Sciences, University of Oldenburg, D-26111-Oldenburg, detlev.metzing@uni-oldenburg.de

## 1. Introduction

Coastal regions are characterized by their high physical and biological diversity and are particularly vulnerable to global change effects (Holligan and Reiners, 1992; Sterr, 1998). Climate change will play a major role for structure, composition and function of coastal ecosystems in future. Plants are essential for structure and function of terrestrial coastal habitats. Coastal development, economic use, biodiversity as stability of dune and salt marsh ecosystems, too, depend on the presence and abundance of particular plant species. Direct (temperature) and indirect (e.g. change of precipitation, sea level rise, wind and water circulation, increasing storm events) consequences of the greenhouse effect will influence distribution patterns of species (and biocoenoses) at different spatial and temporal scales.

Previous studies about the impact of climate change at the coastal ecosystems focus mainly on sea level rise, changed flooding events and therefore on changes of sedimentation and erosion (cf. McLean and Tsyban, 2001). These indirect effects of climate change affect the distribution patterns of plant species and vegetation on a small scale (Metzing, 2006). If we focus on salt marshes, the zonal sequence of plant species is mainly dependent upon duration and frequency of tidal inundations, and hence a shift of vegetation zones towards land (or the dike), in vertical direction to the shoreline, has to be expected. Today the coast is largely embanked, and the dikes limit a shift in this direction. This may result in a loss of salt marsh areas.

Whereas sea level rise will affect the distribution of coastal species on a small scale, a large scale shift of distribution areas (scale > $10^5$–$10^6$ m, Metzing, 2006) is to be expected with climate change, in line with the often displayed correlation of climate and distribution (Pearson and Dawson, 2003). Usually, a northward shift of distribution boundaries accompanies climate warming (Gitay et al., 2002).

Because of the vast climatic gradients, climate change – as changes of temperature and precipitation – will affect distribution of species at a supra-regional scale. This paper describes the potential effect of global warming on the vascular plant flora of salt marshes of terrestrial ecosystems of the Wadden Sea.

## 2. Approach and methods

213 vascular plant taxa, characteristic for and/or occurring in terrestrial coastal habitats (mainly salt marshes and coastal dunes) of the German Wadden Sea and adjacent areas, were chosen to estimate their climatic sensitivity. Limitation of species numbers was necessary to keep the amount of data manageable. However, the selection is representative of the overall terrestrial flora.

In a first step, the climate variables have been determined. These are closely correlated to plant distribution patterns. Distribution data for the selected taxa have been taken from published distribution maps and other contributions (cf. Metzing, 2005 for sources). Climate data were obtained from the IPCC-Data Distribution Centre (for dataset construction see New et al., 1999) for the period 1961-1990 with a spatial resolution of 0.5° (an area of about 32 x 55 km in the study area). Additional climate indices, such as continentality, aridity, annual mean values, a.o. were calculated from the original data. The relevance of climatic factors for plant distribution patterns was tested by a DCCA in the program CANOCO 4.

In a second step, these climate variables have been used to determine the climatic envelope of each species. This is defined by the climatic space that corresponds to the geographic boundaries within which a plant taxon is considered to grow and reproduce under natural conditions (Box et al., 1993). For a first evaluation of the climatic sensibility of certain plant taxa, the climate envelopes have been plotted, as have the climate ranges of certain geographical areas in diagrams (= ecograms).

Further, the climate envelope model has been used to predict future distribution shifts based on given climate scenarios. Correlation of distribution patterns and climatic data by a niche based model allows prediction of area dislocations caused by climatic change for particular plant taxa. The data have been transferred to GIS (Idrisi), where distribution maps have been drawn for present climate, as well as for the climate change scenarios.

To predict dislocation of distribution areas, two scenarios are used, based on the global model ECHAM4/OPYC3. These have been regionalised by statistical downscaling for the German coasts. According to these scenarios, an increase of annual temperature of 2.5 K and a 15% increase of winter precipitation up to the year 2050 are assumed in the worst case (+ 1.5 K and 7.5%, resp. best case; for temperature, these scenarios equal the B2-mid scenario resp. the A2-high scenario, cf. Hulme and Sheard 1999).

## 3. Results

A correspondence analysis (DCCA) confirmed the high correlation of temperatures and distribution patterns, while this relationship is less distinct for precipitation. Ecograms based on temperature and precipitation have shown, too, that in comparison to temperature, the precipitation factor is less decisive for the distribution patterns in the Wadden Sea area (this is different for areas with warmer climates and higher aridity, e.g. in the subtropics!). Therefore for further analyses (ecograms, models) precipitation could be neglected, and only temperature variables has been chosen (mean temperature of January, July and year). The combination of January and July temperature includes the factor thermic continentality, defined by a high annual temperature range.

Plotting the climate space covered by a species against the climate space of definite geographical regions allows for a first estimation of whether future climatic conditions will fit the climate envelope of the species. In Figure 1, the climatic space covered by *Leymus arenarius* (Sand Lymegrass; Poaceae) is shown in regard to January and July mean temperature. It is obvious that future climate at the German coast (as predicted by the climate scenario) will result in no overlap with the climatic envelope of *Leymus arenarius* any more.

The ecograms are an appropriate tool for a first estimate of whether the climatic conditions in a given area may be sufficient for a given species even when the climate changes. From this data, the species that are potentially threatened by the predicted climatic changes in a given area can be ascertained. But the ecograms tell us only roughly in which direction dislocations of distribution boundaries will happen. A more detailed idea can be given by modelling the distribution areas, based on the predicted climate change and the climate envelope.

To test the used model, maps based on the climate envelope were also prepared for present climatic conditions. "Present" means the period 1961-1990 of the underlying climatic data. Moreover, it is the same time span in which the used distribution maps were published. An example of *Leymus arenarius* is shown again in Figure 2. It shows the present distribution area of the species in Europe and the modelled species range (climatic envelope shape) for different scenarios. The modelled area reflects the present distribution area quite well. Even for the best case scenario there will be no suitable climatic conditions at the German coast for this species. The worst case scenario predicts a potential loss of *Leymus arenarius* for the Wadden Sea when temperatures increase by 2.5 K, which is predicted in the worst case scenario up to 2050.

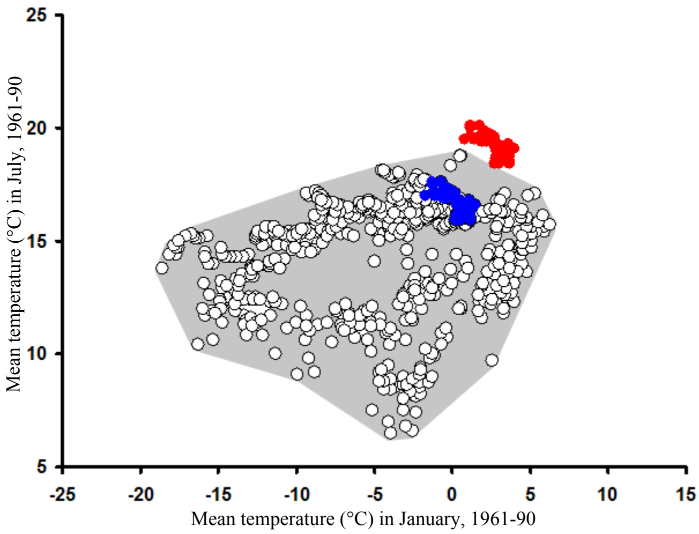


Figure 1: Ecogram of the climatic envelope for *Leymus arenarius* (Poaceae) for January and July temperature. Each point represents climate values of a grid rectangle with a geographical extension of 0.5° x 0.5° where the species is present. The present climatic space (time period 1961-1990) of the German coastal area is indicated by blue spots. The red spots reflect the climate which will prevail at the German coast in 2050 according to the worst-case scenario: 2.5 degree increase in summer and winter temperature. The grey area circumscribes the climate envelope of the species.

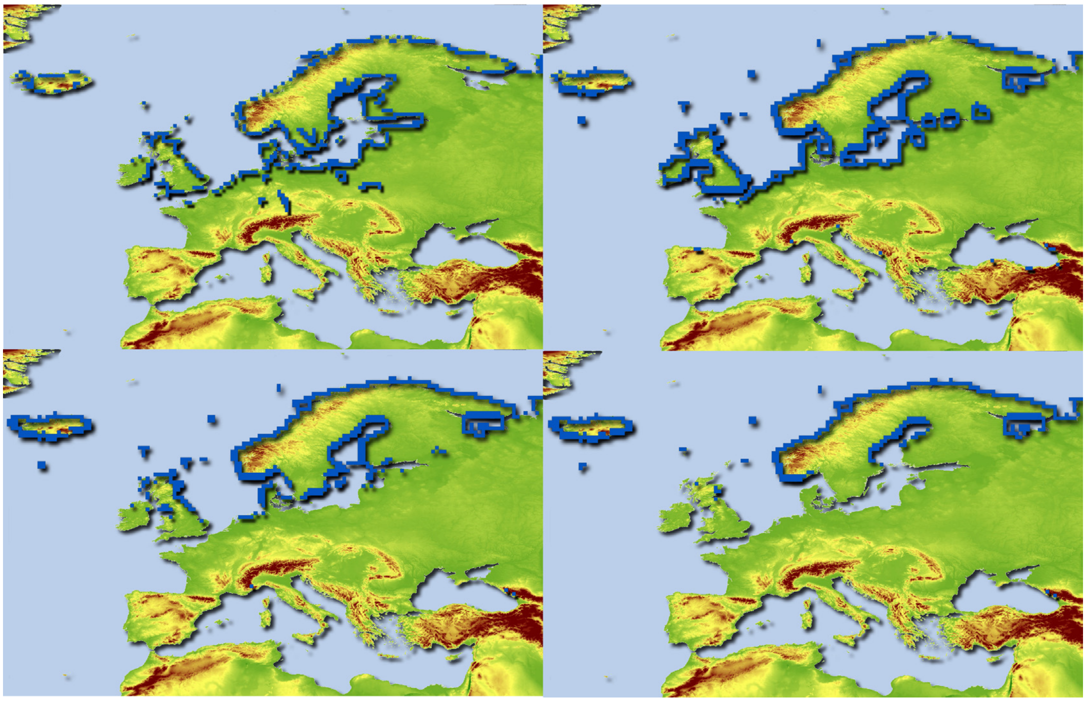

Figure 2:
Distribution of *Leymus arenarius* in Europe (top left), modelled distribution range (climatic envelope) along the coast for various scenarios: recent climate (top right), scenario 1 (+ 1.5 K, best case; bottom left), scenario 2 (+ 2.5 K, worst case; bottom right); the distribution area is marked in dark blue.

Climate change will not only affect a loss of biodiversity. Species with a more southerly range may spread into the Wadden Sea area. Such an example may be *Erica cinerea* (Bell heather, Ericaceae). This species is not present at the German Wadden Sea, but grows in dune heaths of the Dutch Wadden Sea islands Texel and Terschelling. According to the analysed data, the winter temperature is the limiting factor at the eastern distribution border. Increasing winter temperatures may allow the species to expand their distribution range eastwards (Figure 3).

Under a high scenario (warming of 2.5 K up to 2050), the climate envelopes for about 55 species (26%) of the species show either an expansion or a reduction within the area of the Wadden Sea coast. About 33 species (16%) of plant species in the Wadden Sea may be lost, according to our model results. There will be a significant impact of climate change on the biodiversity of coastal areas.

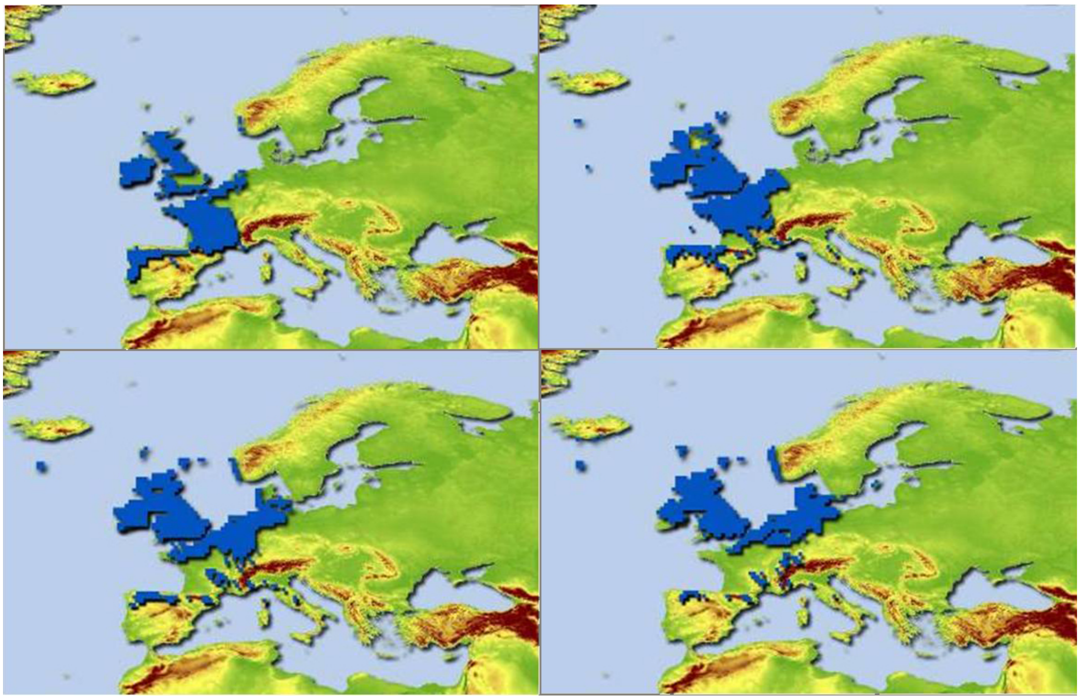

Figure 3:
Distribution of *Erica cinerea* in Europe (top left), modelled distribution range (climatic envelope) along the coast for various scenarios: recent climate (top right), scenario 1 (+ 1.5 K, best case; bottom left), scenario 2 (+ 2.5 K, worst case; bottom right); the distribution area is marked in dark blue.

The number of taxa with regressive distribution areas is higher than this of the taxa with progressive ranges. According to this simplified interpretation, we would have to expect a decrease of the total species number, hence a lower phytodiversity (species diversity). But incoming taxa, not present at the German coasts up to now, should also be considered. Where could these taxa – new for the German coastal flora – come from? Coastal areas, which have exactly the same temperature ranges for January, July and the whole year as predicted for the German coast do not exist in Central- and Western Europe. Coastal areas with at least similar climate can be found at the coasts of The Netherlands up to N-France and SE-England. It has to be assumed that coastal taxa predominantly will spread along the coastline to the German coast. The immigration of species from the Mediterranean area or the Black Sea coast would require long distance dispersal across the European continent. This is not impossible, but much less probable (however, the intentional or unintentional introduction of diaspores by men and the transport over long distances may happen and facilitate the establishment of alien plants). Plant species could invade even from inland areas of East- and Central France, but the successful establishment of non-coastal plants in maritime habitats is less probable.

## 4. Discussion

The models show the direction, distances, and rates of potential distribution shifts which are necessary to stay in equilibrium with climatic conditions. But an inherent characteristic of ecological systems is the delayed response to changing environmental conditions (IPCC, 2002). The real change of distribution patterns will be different for the different taxa, which will react individually and show different migration rates (Huntley, 1991).

Progressive (immigration) and regressive (extinction, emigration) migration have to be distinguished. Whereas immigration is limited by potential dispersal rate and the ability to establish, grow and complete the life cycle in new sites, withdrawal is dependent on delayed mortality and extirpation caused by hardiness and long life-cycles. Generally the colonization of new areas is a lengthy process; hence a delayed response to climate change has to be assumed for most species (Jackson and Overpeck, 2000).

Coastal habitats provide more favourable conditions for dispersal than habitats of other regions, for instance cultivated landscapes, settlement areas, or high mountains. At the coast, most habitats are less fragmented over great distances and are arranged in linear order, so no significant dispersal barriers exist to stop migration along the coast. This is in particular true for the habitats of the drift-lines and salt marshes, less distinct for dunes. Disseminules of many coastal plant species, mainly those of the salt marshes, drift-lines and fore- and yellow dunes, are well adapted to dispersal by sea water and may float over longer time periods and distances (Chang, 2006). On the other hand, plant species strictly confined to coastal habitats can't withdraw to inland habitats if environmental conditions (here: climate) become unsuitable at the coast. However, in general the conditions for progressive distribution shifts are rather favourable at the coast. The way that individual species respond will result in new species combinations, and changed biotic interactions.

In view of the predicted climate change, the climate factor will gain a higher relevance on future plant distribution in comparison with other causes of declining or enlarging distribution ranges (dispersal of neophytes, destruction of habitats, agriculture, land use change). The results of this study allow interpreting and discriminating potential causes of future flora changes.

From the human view, there is a special interest in these species, which play a key role either in the ecology of dunes and salt marshes, or in coastal defense. Such species with a predicted retreat in the Wadden Sea are e.g. *Leymus arenarius* and x *Calammophila baltica*. These species are planted for coastal defense purposes in yellow dunes ("Weißdünen"). *Empetrum nigrum* is another species, where the models predict an extinction in the Wadden Sea up to 2050 (worst case scenario, +2.5 K). The loss of this species will change the appearance and function of brown dunes at the islands conspicuously.

It is more difficult to predict potential immigration than emigration, as potential invaders may come not only from coastal regions, but also from inland. These have been omitted in this study for methodological reasons. The balance of immigration and local extinction will determine a loss or gain of biodiversity. There is no reason to assume that species loss will be retarded by climate change – many studies prove the opposite (Gitay et al., 2002).

For evaluation and optimization of such model predictions it is urgent to establish monitoring projects. e.g. floristic mapping of selected areas or remote sensing of *Empetrum* heaths. Regular monitoring makes it possible to detect future developments and to organize possible management actions. The models show which species are probably most sensitive to increasing temperatures; these taxa may serve as indicator species in monitoring plant species distribution. Moreover, indicator species should be easily identifiable to get sure data. Suitable indicator species are listed in Table 1.

## 5. Conclusion

The model, based on climate envelopes of the plant species, predicts shifts of distribution ranges within the Wadden Sea area for more than a quarter of the considered taxa. This will change floristic composition and biodiversity remarkably. Some species will be lost, others may immigrate into the Wadden Sea area. A regular and standardized monitoring of the (plant) species inventory (floristic mapping, incl. or only indicator species) is essential to detect realized distribution shifts as well as to verify/optimize models and predictions.

| |
|---|
| ×*Calammophila baltica* (R) |
| *Empetrum nigrum* (R) |
| *Lathyrus japonicus* (R) |
| *Leymus arenarius* (R) |
| *Polygonum maritimum* (P) |
| *Euphorbia paralias* (P) |
| *Calystegia soldanella* (P) |
| *Crithmum maritimum* (P) |
| *Cynodon dactylon* (P) |
| *Glaucium flavum* (P) |
| *Tuberaria guttata* (P) |
| *Ulex europaeus* (P) |
| *Lagurus ovatus* (P) |

**Table 1:** Suitable indicator species of climate change in the Wadden Sea area. R = species with predicted regressive distribution areas, P = species with predicted progressive distribution areas

## References


Box E. O., Crumpacker D. W., and Hardin E. D., 1993. A climatic model for location of plant species in Florida, U.S.A. Journal of Biogeography, 20, 629–644.

Chang E. R., 2006. The role of dispersal constraints in the assembly of salt marsh communities. PhD thesis, University of Groningen.

Gitay H., Suárez A., Watson R. T., Dokken D. J. (eds.), 2002. Climate change and biodiversity. IPCC Technical Paper V. Intergovernmental Panel on Climate Change: Geneva.

Holligan P. M., and Reiners W. A., 1992. Predicting the responses of the coastal zone to global change. Advances in Ecological Research 22: 211–255.

Hulme M. and Sheard N., 1999. Climate Change Scenarios for Germany. Climatic Research Unit, Norwich, UK.

Huntley B., 1991. How plants respond to climate change: migration rates, individualism and the consequences for plant communities. Annals of Botany, 67, 15–22.

Jackson S. T., and Overpeck J. T., 2000. Responses of plant populations and communities to environmental changes of the late Quaternary. Paleobiology, 26, 194–220.

McLean R. F., and Tsyban, A., 2001. Coastal zones and marine ecosystems. In: Houghton J. T., Ding Y., Griggs D. J., Noguer M., van der Linden P. J., Dai X., Maskel, K., and Johnson C. A., (eds.), Climate Change 2001: The scientific basis. Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change: 343–370. Cambridge University Press: Cambridge [a. o.].

Metzing D., 2005. Küstenflora und Klimawandel – der Einfluss der globalen Erwärmung auf die Gefäßpflanzenflora des deutschen Küstengebietes von Nord- und Ostsee. PhD thesis, University of Oldenburg, Germany.

Metzing D., 2006. Natur im Einfluss des Klimawandels – wie verändern sich Flora und Fauna. Bremer Beiträge für Naturkunde und Naturschutz, 8, 31-49.

New M., Hulme M., and Jones P., 1999. Representing twentieth-century space-time climate variability. Part I: Development of a 1961–90 mean montly terrestrial climatology. Journal of Climate, 12, 829–856.

Pearson R. G., and Dawson T. P., 2003. Predicting the species of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography, 12, 361–371.

Sterr, H., 1998. Gefährdung in den Küstenregionen. In: Lozán J. L., Grassl H., and Hupfer P., (eds.), Warnsignal Klima: 248–253. Wissenschaftliche Auswertungen, Hamburg.

View publication stats