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Statistical Classification of Terrestrial and Marine Ecosystems for Environmental Planning

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Abstract

Environmental planning is an instrument for the operationalisation of the precautionary principle in environmental law and, to this end, must rely on maps depicting the spatial patterns of ecological attributes of aquatic and terrestrial ecosystems and of environmental change effects, respectively. In this context, different mapping techniques are presented by example of three case studies covering terrestrial, coastal and marine environments. The first case study was selected to demonstrate how to compute an ecological land classification of Germany by means of CART. The resulting ecoregions were mapped by GIS. This CARTography enables to regionalise metal bioaccumulation data in terms of 21 ecological land categories and to prove the specificity of emission control measures as being part of environmental policies. The second investigation was chosen to apply for the first time in Germany the regionalisation approach to the research of climate change effects in terms of past, recent and potential future incidences of *Anopheles* sp. and malaria in Lower Saxony. To investigate whether malaria might be transmitted due to increasing air temperatures, data sets on past and future air temperatures were used to spatially model malaria risk areas. The third example demonstrates the transfer of the CARTography approach presented in the first case study from terrestrial to marine environments. We analysed the statistical relations between data on benthic communities and physical properties of their marine environments by means of CART and applied these rules to geodata which only describe physical characteristics of the benthic habitats. By this, those parts of the sea ground could be predicted where certain benthic communities might occur.

Keywords

CARTography, ecoregions, GIS, geostatistics, land classification

1 Introduction

1.1 Motivation

Environmental law is intended to assure human health and biodiversity. Environmental planning is one of the instruments to reach this goal by implementing the precautionary principle (von Schomberg 2006). To operationalise this legal principle, planning should be based on data describing the spatial patterns of terrestrial and marine habitats (sections 2.1, 4), their economic use and possibly related impacts in terms of exposure (section 2.2) and biological effects (sections 3.1 and 3.2). These data should cover the whole surface of the land or the ocean considered. But contrary to that need, many environmental data are sample point data. Thus, we need techniques to fill up the spatial gaps.

1.2 Goals of the study

This study should present statistical approaches that meet the methodical need described above. At first, a land classification was developed using surface data on basic characteristics of ecosystems (section 2.1) which, in combination with geostatistics and percentile statistics, further on was used to regionalise metal exposure data (section 2.2). Following the recommendation from Wiens (2002), this approach was then applied to marine environments (section 4). In consideration of the discussions about ecological impacts possibly linked with climate change these methods were supplemented

by a land classification according to the shifting plant phenology (section 3.1) and the risk of malaria transmission which up to the beginning of the 1950ties occurred in Germany along the coastal zones of the North Sea (section 3.2).

2 Ecological Land Classification

2.1 Method

One of the research topics of landscape ecology is land classification. In the first instance, land classifications were primarily used for geographical descriptions (Schröder et al. 2006). After World War II, Meynen et al. (1952-1962, 1959-1962) pointed out that ecological land classifications should be used for planning purposes. Since the 1980ies, land classifications were used to design ecosystem research and environmental monitoring in Germany and applied it in combination with geostatistics for the spatial generalisation of ecological sample point data (Schröder et al. 2003). Synopses on land classification approaches are given, amongst others, by Mabbutt (1968), Rowe and Sheard (1981), Schröder et al. (2006).

For mapping the ecoregions of Germany we decided on a classification by selected attribute values as for instance basic characteristics of ecosystems (soil texture, elevation, climate, potential natural vegetation) or ecological impacts in terms of exposure to contaminants and effects (parametric approach,

Mabbutt 1968). Furthermore, referring to the theory of hierarchy in ecosystems (Allen & Starr, 1982; Klijn & de Haes, 1994), we decided on Classification and Regression Trees (CART) to calculate the ecoregions of Germany within a GIS environment. To compute the spatial pattern of ecoregions, all data had to be at a 2 km x 2 km grid to correspond to the minimal, common spatial resolution of the primary data used for the respective mapping of soil texture, elevation, vegetation, and climate. Thus, for each of the 48 maps, there were 88,400 grid cells. All of the grid map data were then transferred into one table with 88,400 rows and, apart from the geographical coordinates, 48 columns for the ecological characteristics. The information from the cells of this table was then spatially classified by CART (Breiman et al. 1984) implemented in SPlus. The application of CART results in an ecological land classification which was then mapped by GIS techniques (Fig. 1 left). Each of the mapped land units can be statistically described according to the ecological characteristics used for the land classification. In Germany, this ecological land classification has gained a widespread application within the framework of different environmental monitoring programmes (Schröder et al. 2003, 2006; Schröder & Pesch 2006; Schröder & Schmidt 2007). One of such applications is the monitoring of metal accumulation in mosses.

2.2 Ecoregionalisation of Metal Bioaccumulation

Background and goal. Exposure data such as those on the bioaccumulation of metals in mosses should be related to ecologically defined regions (section 2.1) which are needed for the ecological interpretation of the environmental quality in terms of ecological stability and resilience (Ruxton 1968). Contrary to species which are used to indicate single aspects of habitat quality or pollution, ecoregions are more complex indicators which comprehensively describe the ecological coverage in terms of soil, vegetation, elevation and climate.

Materials and Methods. Since 1990, the European Heavy Metals in Mosses Surveys were performed every five years in 21 to 32 European countries. In Germany, moss samples were taken at 592 sites in 1990, at 1026 sites in 1995, and at 1028 sites in the 2000 campaign. The moss sampling was done according to UNECE (2001). This guideline should assure both quality and methodical comparability of the monitoring data and is therefore mandatory for the interpretation of spatial and temporal trends for the metal accumulation in mosses. *Pleurozium schreberi* (P.s.) (Brid.) Mitt., *Scleropodium purum* (S.p.) (Hedw.) Limpr., and *Hypnum cupressiforme* (H.c.) (Hedw.) were sampled by priority. In our study, 12 out of 40 metals measured were considered to be of special ecotoxicological significance: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe),

mercury (Hg), nickel (Ni), lead (Pb), antimony (Sb), vanadium (V), titanium (Ti) and zinc (Zn). To combine the metal contents measured in the mosses with ecoregions requires geostatistical surface estimation of the sample point measurements.

From the sample point measurement data interpolated surface maps were calculated by applying geostatistical methods (Schröder and Pesch 2006). According to Olea (1999), the spatial autocorrelation of the sample point data on the metal accumulation in mosses was examined and modelled by variograms. The model function was used for the surface estimation of the sample point data by means of kriging. The quality

of estimation was proved by cross-validation. The geostatistical computations were run by use of ISATIS (Bleignes et al. 2001). The variogram analysis was performed according to Olea (1999).

Whereas geostatistics served to spatially synthesise site specific data on metal accumulation, the subsequent calculation of accumulation indices should integrate the metal specific information into a comprehensive exposure (PEC) indicator. For this, the metal specific surface estimations on bioaccumulation were aggregated to ordinal indices by percentile statistics (Schröder and Pesch 2006).

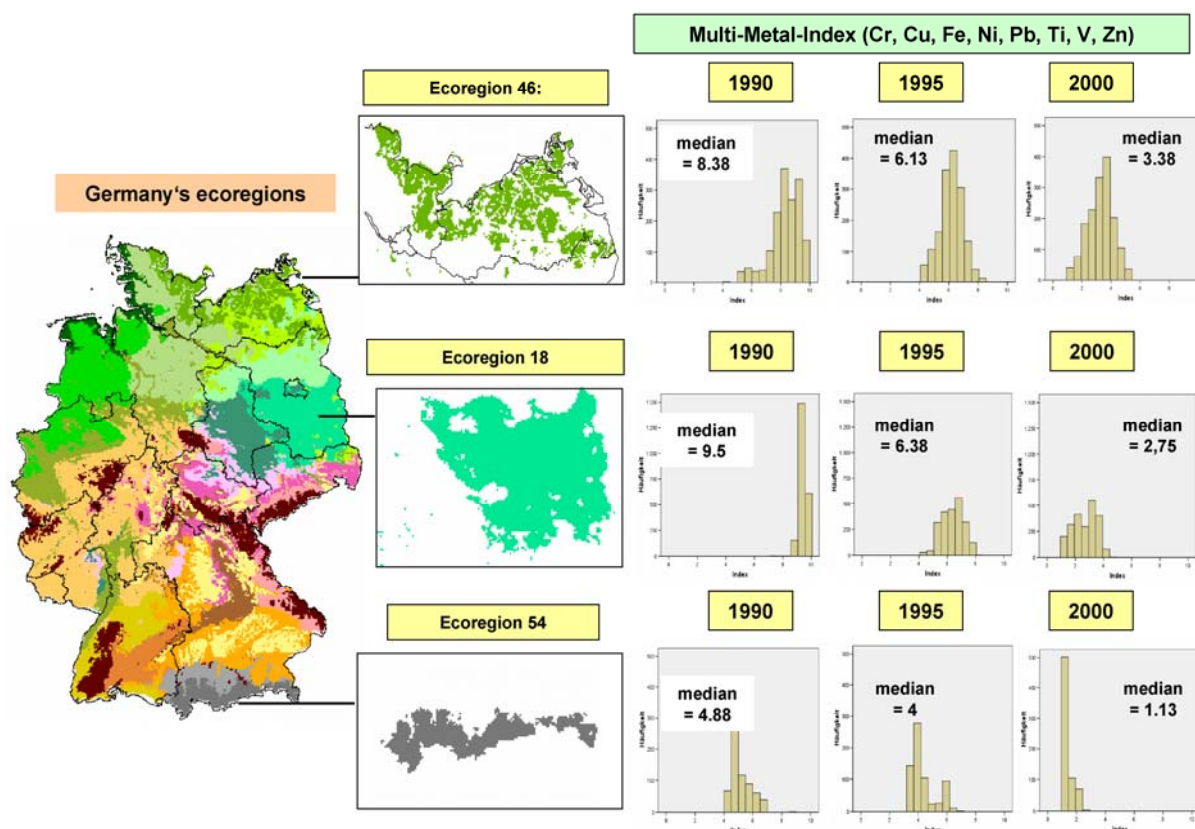


Figure 1: Temporal development of the accumulation of metals in mosses within ecoregions

Results. To comprehend the temporal development of the metal bioaccumulation in terms of ecoregions, the statistical distribution of the exposure index on the metal elements Cr, Cu, Fe, Ni, Pb, Ti, V, Zn was calculated for each ecoregion. These metals were investigated in each of the campaigns 1990, 1995 and 2000. As exemplarily shown for ecoregions 18, 46 and 54 in figure 1 the frequency distribution curves of the metal accumulation indices move towards the lower index values from 1990 to 1995 to 2000. The strongest decrease in atmospheric metal accumulation can be observed for ecoregion 19 located in former East Germany (from 9.5 in 1990 to 2.75 in 2000).

Discussion. In addition to this analysis of regional patterns of metal bioaccumulation Schröder et al. (2007) proved local variations in metal concentrations in mosses to depend mostly on different moss species, potential local emission sources, canopy drip and precipitation. Mainly the moss species, potential emission sources around the monitoring sites, canopy drip and precipitation were proved to cause the spatial variability of the metal accumulation. Furthermore, different techniques for digestion and analysis were identified to influence the measurements across the national borders of Austria, the Czech Republic, Germany, Italy, Slovakia, Slovenia, Poland, and Switzerland. However, geostatistical analyses did not ascertain discontinuities of metal bioaccumulation at the national borders due to different analytical techniques, as other factors mentioned

above could be found to be more important in explaining the variation in metal concentrations in mosses. Schröder et al. (2007) discuss these findings against the background of the respective international literature.

3 Land Classification by Biological Effects Monitoring

3.1 *Ecoregionalisation of Shifting Plant Phenology Due to Climate Change*

Background and goal. The current climate change exceeds the natural variation during the last thousand years. EEA (2004) identified 22 climate change states and impact indicators, including air temperature and plant phenology. The global annual mean temperature has increased by about 0.7° C whereas the European mean raised by 0.95° C in the last hundred years. From 1990 to 2100, the air temperatures are expected to further increase by 1.4° C to 5.8° C globally and by 2.0° C to 6.3° C in Europe. These changes have altered plant performance. For instance, the average annual growing season in Europe was extended by about 10 days between 1962 and 1995. While success in modelling phenology at the species level has been achieved, the prediction of regional plant phenological variations related with climate change is still a problem. This is mainly due to the fact that phenological data are often collected apart from the sites where meteorological and any other relevant environmental parameters are recorded. Thus, the

extrapolation of values obtained at the local scale to broader scales is the precondition for mapping and modelling plant phenological changes occurring at the regional level.

Materials and Methods. To solve this type of difficulties we used geostatistical approaches to preliminary assess whether temporal and spatial trends can be identified and to evaluate the relationships between the records of air temperature and phenological traits of 15 plant species collected throughout Germany by the German Meteorological Service (Deutscher Wetterdienst DWD). The air temperature data were recorded across Germany at 675 sites, according to standardized methods (WMO 1996). The plant phenology was monitored away from those sites at up to 6,400 sites from all over Germany following a standard protocol (DWD 1991). The phenological network provides data on 269 plant species with a dense geographical and ecological coverage of Germany. We concentrated on four phenological phases (Blooming (B), leaf unfolding (L), ear formation (E), and sprouting in May (S)) monitored at up to 1,279 sites with regard to 15 species reported to be valuable indicators of the initiation of springtime (DWD 1991): *Acyras* (B), *Aesculus hippocastanum* (L, B), *Anemone nemorosa* (B), *Betula pendula* (L), *Crataegus laevigata* (B), *Galanthus nivalis* (B), *Picea pungens* (S), *Prunus avium* (B), *Quercus robur* (L), *Ribes rubrum* (B), *Ribes uva-crispa* (B), *Salix caprea* (B), *Secale cereale* (E), *Syringa vulgaris* (B), *Taraxacum officinale* (B). The beginning of the phases is indicated

as 'days after the beginning of the calendar year'.

The data involving the onset of the above mentioned spring phases and plant species and the air temperature monthly mean averages were compiled. Two time intervals (1961-1990 and 1991-2002) were considered to evaluate whether significant changes have occurred with regards to both air temperature and the onset of spring plant phenological phases. Annual air temperature averages for both periods were calculated. The Mann-Whitney-U-test was used to determine whether the selected phenological traits were significantly different in both periods, alpha was set at 0.05 for all comparisons. Since the meteorological and phenological networks did not match spatially, surface estimation methods were needed to ensure a valid spatial correlation of both datasets. Geostatistics enable to correlate measurement data of incongruent monitoring networks, as Kriging provides for each site-specific measurement value an estimate on the measurement of the complementary monitoring network. Thus, in this investigation each site-specific meteorological measurement was correlated with a site-specific phenological estimate, and, vice versa, each meteorological estimate was spatially related to a phenological measurement. The raw data from the meteorological and the phenological networks, the related surface estimations, and a map on land coverage (Keil et al. 2005) were integrated into a GIS (ArcView GIS 3.3). From the land cover map the for-

ested areas were extracted and linked to the monitoring sites.

Results. On average the onset of plant spring phases occurred six days earlier in the 1991-2002 period when compared to the 1961-1990 interval. The spring phases of the 15 plant species appeared to be related with air temperature records. As can be seen in figure 2 (left) the long term annual mean raised from 8.3° C (1961-1990) to 9.1° C (1991-2002). The highest temperatures were measured along the Upper and Lower Rhine Valley in the western part of Germany and in the lowlands of northern Germany. The highest increases were recorded in the low mountain ranges in central and south-eastern Germany.

The phenological phases of the forest trees investigated did not reveal a clear spatial pattern and thus no surface estimations were calculated. Future studies should involve alternative geostatistical methods and the most frequent forest tree species in Germany, *Picea abies*, *Fagus sylvatica*, and *Pinus sylvestris*. In this investigation *Syringa vulgaris* (common lilac) was used as an indicator of potential phenological effects of global warming in forested areas as it was monitored at 98 % of the phenological sites located in forests and it showed the highest spatial autocorrelation in comparison to all the species mentioned above. Also, this species matched the overall mean of the air-temperature shifts of the examined spring phases of the 15 plant species involved in this study showing a low standard deviation. The blooming of *Syringa vul-*

garis was monitored at 1,222 (1961-1990) and 1,020 (1991-2002) locations, respectively. 637 and 311, respectively, of these monitoring sites were situated in forested areas.

On average, the blooming of *Syringa vulgaris* at all sites began 134 days after New Year's Day during the 30 year's period, whereas in the 1990ties flowering started after 128 days. The beginning of blooming revealed similar patterns in the forested sites when compared with non-forested sites, with average values for the 1961-1990 and 1991-2002 terms of 136 days and 129.5 days, respectively. Thus, since the last 12 years the blooming of *Syringa vulgaris* occurred 6 and 7.5 days earlier at all sites and inside forests, respectively, than during the former period. The spatial patterns of the onset of the flowering of this species were strongly correlated with the spatial structure of air temperature. Accordingly, the shifting of spring time towards the beginning of the year was less pronounced in the coastal zones in northern Germany and the highlands than in the areas along the Rhine river and the lowlands.

Discussion. The quality of the databases of phenological traits and air temperature described in the Materials and Methods section and the geostatistical approach followed in this case study proved to adequately solve some of the methodological problems previously detected regarding the regional assessment of global change impact on plant phenology. However, other issues should be considered in future when assessing the re-

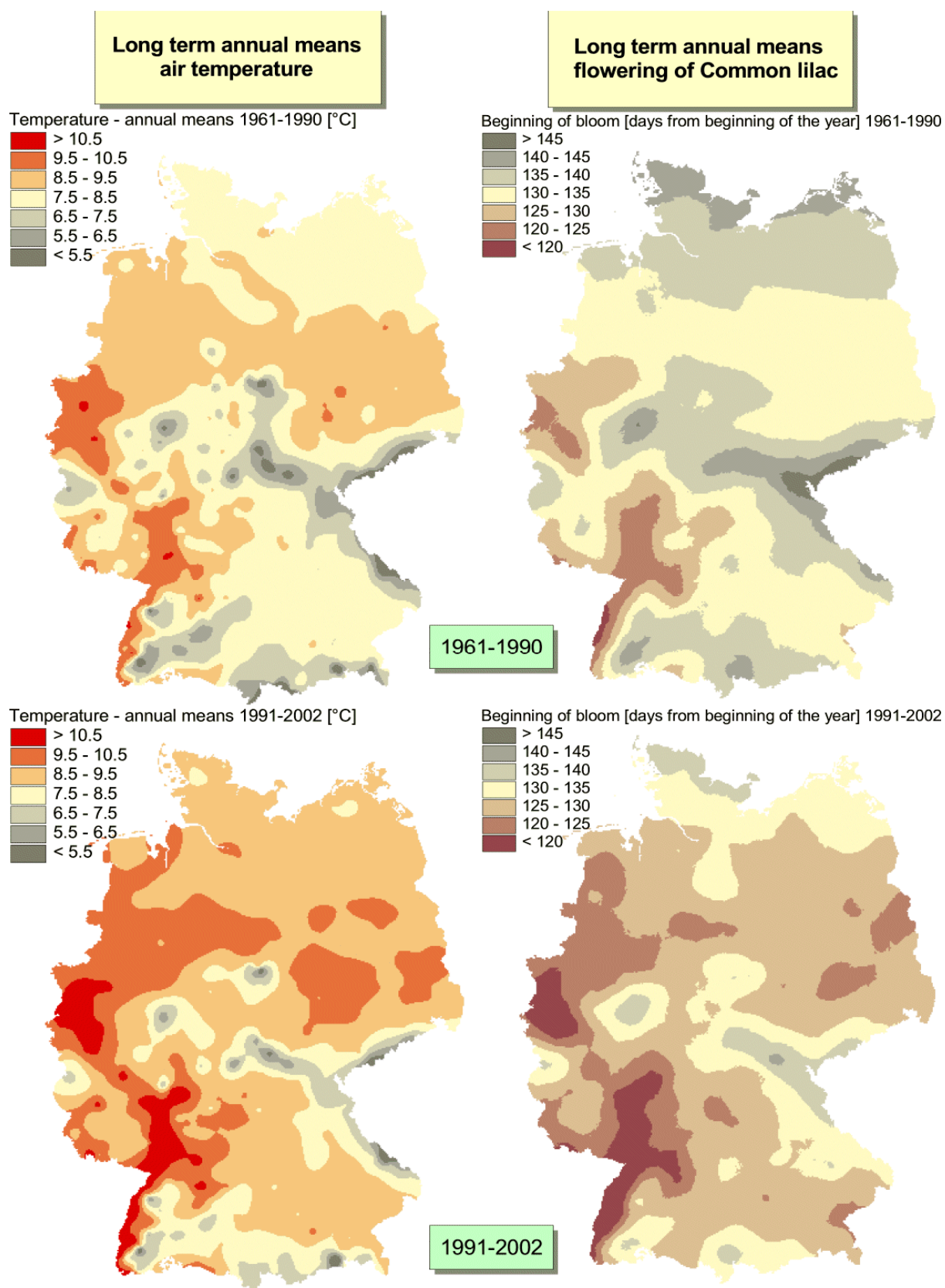


Figure 2: Shift in air temperature and the beginning of flowering of *Syringa vulgaris* in Germany 1961-1990 and 1991-2002

gional implications of climate change on plant phenology. For instance, Badeck et al. (2004) found the differences in trend estimates to be caused by the disparity of the relative number of observations in higher and lower latitudes, the involvement of different taxa or groups of phases and the varying length of the time series analysed. Moreover, global change encompasses more parameters than just air temperature and their regional patterns should be taken into account to avoid the usage of their global-scaled averages. In addition, the relationship between climate change and phenological traits other than spring phases should be also taken into account as well as the impacts on vector borne diseases.

3.2 Regionalisation of Potential Climate Change Related Malaria Transmission

Background and goal. Climate change could not only affect the plant phenology but also the geographic distribution of animals like such which can transmit diseases. *Anopheles sp.* mosquitoes can host and transmit malaria pathogens as for instance *Plasmodium vivax*. In Lower Saxony, malaria occurred until the 1950ies. Today, Anopheles mosquitoes are present in Lower Saxony (Wilke et al. 2006). Thus, the question arises whether a malaria transmission due to increasing air temperatures could take place if the pathogen is introduced again. To answer this question, a comprehensive concept is needed integrating: (a) data on past and present incidences of those vectors which, pro-

vided certain boundary conditions are given, could transmit malaria in Germany; (b) data on habitat properties; and (c) data on past and future air temperature. The risk mapping in our investigation was restricted to air temperature data which was applied to a formula modelling the basic reproduction rate of *Plasmodium vivax* hosted and transmitted by *Anopheles atroparvus*.

Materials and Methods. Data processing and risk assessment were based on two data sources. The taxonomy of the respective species, the name of the locality, and the Gauß-Krüger coordinates of Anopheles findings up to the 1950ies were collected from literature. The respective and supplementary information was collected from a digital database which contains, amongst others, Anopheles findings from 1985 up to today. Air temperature data from 54 observation sites in Lower Saxony were provided by the German Weather Survey (DWD). The computations refer to the following periods: 1947-1960, 1961-1990 and 1985-2004. The beginning of the latter period was set to 1985 instead of 1991 because the digital archive starts with representing findings of Anophelinae larvae in 1985. Accordingly, calculations were processed based on the respective best case and worst case scenarios for the years 2020, 2060, and 2100 published by the IPCC (2001).

The site specific data on air temperature were transformed to surface grids by means of variogram analysis and kriging estimation.

To this end we used FUZZEKS (Piotrowski et al. 1996). The geostatistically calculated surface air temperature maps were used for a GIS-based risk modelling of a climate warming induced outbreak of malaria tertiana in Lower Saxony by the basic reproduction rate (R_0). R_0 models the average number of secondary infections produced when a single infected individual is introduced into a potential host population in which each member is susceptible. If $R_0 \geq 1$, the disease will proliferate indefinitely, if $R_0 < 1$, the disease will die out (Martens et al. 1999). The calculations resulted in temperature maps, maps on areas at risk of malaria outbreak and maps on the duration of the transmission periods of the tertian malaria pathogen due to measured air temperatures from 1947 to 2004 and future temperatures estimated according to IPCC (2001).

Results. The computations revealed that from 1947 to 2004 in most regions of Lower Saxony the dominant transmission period was about two months (74-82 % of the territory, Table 1).

The best case scenario 2020 is based on a

predicted temperature increase of about 0.3° C. The areas where no transmission of tertian malaria is possible together with the areas of one month duration represent less than one percentage of the territory (Table 1). The remainder of the country is divided equally in transmission areas of two and three months. While the first is located in the northern and southern parts, the latter is a central broad belt from the west to the east of Lower Saxony.

In the 2020 worst case scenario, expecting an air temperature rise of 0.9 °C, the disease might be transmitted to four months (0.1 %) for the first time. In the whole territory of Lower Saxony a transmission is expected to be possible, a transmission period of three months is the most frequent (93.9 %). Only 6.0 % of the territory of Lower Saxony exhibit a transmission period of two months (low mountain range in the south and spots in the north).

The best case-prediction 2060 equals the 2020 worst case, i.e., the temperature rise is expected to be 0.9 °C. The IPCC (2001) pre-

no. of months period (projected temperature rise)	0	1	2	3	4	5	6	sum (%)
1947-1960	0.90	1.30	81.60	16.20	0.00	0.00	0.00	100.00
1961-1990	2.30	0.90	74.80	21.90	0.00	0.00	0.00	100.00
1985-2004	0.50	0.10	74.40	25.10	0.00	0.00	0.00	100.00
2020 (+0,3 °C)	0.10	0.10	49.90	49.90	0.00	0.00	0.00	100.00
2020 (+0,9 °C)	0.00	0.00	6.00	93.90	0.10	0.00	0.00	100.00
2060 (+0,9 °C)	0.00	0.00	6.00	93.90	0.10	0.00	0.00	100.00
2060 (+3,3 °C)	0.00	0.00	0.00	1.30	4.00	94.70	0.00	100.00
2100 (+1,4 °C)	0.00	0.00	1.90	76.50	21.60	0.00	0.00	100.00
2100 (+5,8 °C)	0.00	0.00	0.00	0.00	0.00	43.90	56.10	100.00

Table 1: Temperature dependent length of potential malaria transmission in Lower Saxony and related area coverage percentage

sumes a worst case temperature rise of 3.3 °C in 2060. Thus, the transmission map of that year reveals that Lower Saxony is almost totally situated with five months of transmission (94.3 %). Again, only the highlands in the south and the coastal zone in the north differ (3-4 months).

The 2100 best case scenario estimates a minimum climate warming of 1.4 °C and includes September as the fourth month of a potential transmission of malaria. The main transmission period is three months (76.6 %). Regions with four months of transmission (21.4 %) are expected to be located in a broad belt in the south and in the southwest part of Lower Saxony. At that time, also coastal areas at the North Sea will be included and tidal mud flat islands, too. The worst case calculation is based on a temperature rise of +5.8 °C. Given this, Lower Saxony is divided into two parts of transmission length: The western part reveals a predicted transmission period of six months (55.8 %). A disease spread period of five months (44.2 %) can be found within the rectangle of the river Weser in the northwest and the waterway 'Mittellandkanal' in the south. Another such area covers the low mountain range in the south of Lower Saxony.

Discussion. Several *Anopheles* findings which were documented since 1985 in the digital archive mentioned above overlap with those regions with the highest risk of a *Plasmodium vivax* transmission. Recent studies

gave evidence that *Anopheles atroparvus* and *Anopheles messeae* are still present in the coastal areas (Wilke et al. 2006) where malaria tertiana occurred up to the 1950ties (Weyer 1956). For these regions the best case scenario 2060 resulted in a four months risk of transmission. Thus, if the pathogen will be introduced and will still be able to be transmitted by mosquitoes, malaria could be transmitted. The calculations corroborate investigations from Krüger et al (2001) which give evidence that although malaria is not an endemic disease in Germany, the risk of an autochthon transmission does exist. Pathogens of the respective malaria types enter the country most likely by infected travellers and by mosquitoes from endemic areas. In a comparison of 16 European countries, Germany reported 150 (i.e. 24.3 % of all) cases of tertian malaria between 1999 and 2003 (Mühlberger et al. 2004).

The investigation revealed areas in Lower Saxony which are susceptible for a new tertian malaria outbreak transmitted by *Anopheles atroparvus* due to their monthly mean temperatures. The calculations corroborate that although malaria is not an endemic disease in Germany, the risk of an autochthon transmission does exist (Krüger et al., 2001). Pathogens of the respective malaria types enter the country most likely by infected travellers and by mosquitoes from endemic areas.

Schröder and Schmidt (2007) detailed the presented investigation by combining the

kriging maps depicting the potential temperature dependent transmission with an eco-regionalisation and by discussing the respective literature. Following this, non-climatic factors should be examined closer. However, as there is no explicit evidence so far that climate warming will not influence the distribution of malaria, there is a need for research in areas like Lower Saxony that are located in potential future risk zones for malaria transmission. Some European countries like Great Britain or Italy have already undertaken studies in that field, concluding that climate warming would increase the transmission potential. In Germany, there is no risk assessment present until now, which identifies hot spot areas where a re-entry of malaria is likely to happen.

The model applied in this investigation is the basic reproduction rate which considers the daily survival probability of the examined species to determine the endemicity levels because it depends on average temperature values. The basic reproduction rate is an established method to determine the risk of malaria transmission (Martens et al. 1999), but the formula has also some deficits. The relationship between climate and transmission potential of malaria is still only partly understood. Furthermore, in addition to meteorological factors, disease transmission dynamics are influenced by many other factors concerning the hosts, vectors and ecosystems and the interactions among them (Martens et al. 1999). Variables which can play a significant role in the complex dy-

namic process of disease spread estimation were excluded, like, e.g., precipitation, humidity, availability of breeding sites, hygiene, and medical supply and other ecological factors determining the developmental process of the mosquitoes. If the only criterion of a malaria transmission is temperature, malaria wouldn't have become eradicated in Europe, as demonstrated by the risk modelling. It would be wrong to confuse the modelling results with reality. It should rather be considered as an approximation and a helpful tool to determine and control areas at risk of malaria transmission. The impact of climate change poses enormous challenges to scientists because of the considerable amount of complexity and uncertainty: The same environmental change can have quite different effects in different places or times. Nevertheless, the public and the decision-makers are seeking from scientists estimates of the likely consequences for the ecosystems and populations. This needs the investigation of the short- and long-term dynamics of complex systems and requires an interdisciplinary approach integrating, amongst others, the fields of biogeography, ecology, and both medical and social sciences.

The prediction of environmental change and its health impacts encounters several difficulties. Some of them are scientific ones and refer to deficient understanding of actual processes. Some of the uncertainties are related to the modelling of the linkage between the increase of air temperatures and humidity on the one hand and the mosquito breeding,

survival and biting behaviour. Some uncertainties pertain to what can be foreseen about future emissions of greenhouse gases. And, finally, there is uncertainty arising from data collection.

Malaria incidence is hugely influenced by prevailing climate. However, malaria incidences correlate with per capita income, too. Apportioning malaria causality between environment and socio-economic conditions is, therefore, problematic. The difficulty of modelling the impacts of global (environmental) change processes on human health is that it has to cope with a variety of processes that operate on different temporal and spatial levels and differ in complexity: Modelling has to connect processes that differ by nature, such as physical processes, monetary processes, social processes and policy processes. Furthermore, modelling has to deal with the fundamental question if relations between the malaria transmissions and associated factors at one spatial and temporal scale hold at larger or lower scale levels. Despite the limitations of the modelling, models draw attention to the climate change-related impacts and point out the relative importance of the factors. This could help to increase the understanding of the climate change impacts, and identify gaps in data and knowledge needed to improve the analysis of these effects.

4 Ecological Classification of Marine Habitats

Background and goal. According to Wiens (2002), the land classification approach outlined in section 2.1 was applied to marine environments. Currently, several national and international projects aim at mapping benthic habitats in the North Sea (ICES 2005, 2006). One outcome of these activities is the European Nature Information System (EUNIS). EUNIS provides a complex hierarchy of rules for characterising and mapping habitats in both terrestrial and marine environments. But the application of EUNIS is faced with the problem to make available and adjust marine data to the according classification rules. The goal of this investigation was to present a benthic habitat mapping concept which follows the approach outlined in section 2.1 and thus should be structured hierarchically and based on objective methods and available data.

Materials and Methods. The data on eight benthic organisms from 182 sample sites taken from Rachor and Nehmer (2003) do not spatially coincide with the approximately 235000 sample point data on salinity, temperature, silicate, nitrate, and ammonium at the interface water body / sediment, and on grain size ranges (0-63 μ , 63-2000 μ) which were made available from the ICES Data Base, the Marine Environmental Data Base

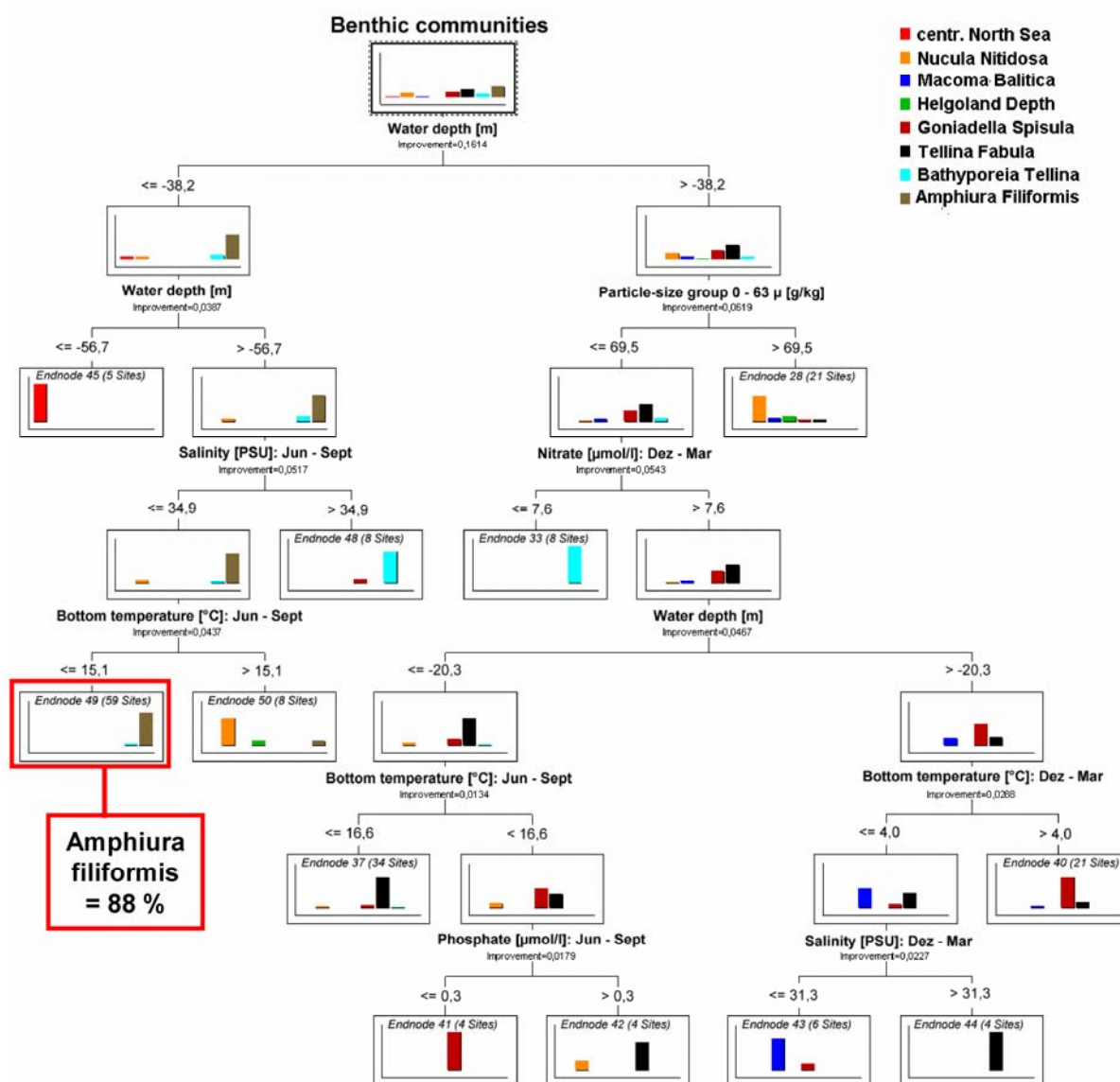


Figure 3: Decision tree for the occurrence of benthic communities in the North Sea

(MUDAB) of the German Federal Maritime and Hydrographic Office (BSH) and the German Federal Environmental Agency (FEA) as well as the Institute of Marine Research (IfM) of University of Hamburg. Surface data on bathymetry was made available by the Alfred-Wegener-Institute. All data sets were integrated into a relational Database Management System. The geochemical measurement data was aggregated over a three year period from 1997 to 2000 accord-

ing to summer (June to September) and winter (December to March) months. This aggregation should assure a sufficient spatial and temporal coverage of the measurement values. The Geostatistical Analyst from ArcGIS 9.0 was used to calculate raster data on bottom water measurements on salinity, temperature, silicate, phosphate and nitrate as well as on grain size. The geostatistically estimated abiotic data and the bathymetry map were intersected with the sample site

specific data on benthic communities. This yielded a table with 182 rows and 14 columns representing X-/Y-coordinates, benthic communities, and 11 abiotic parameters. By defining the benthic communities as the target variable and the abiotic parameters as the predictor variables a decision tree was calculated by applying CART (Figure 3). The tree was grown in a way that the minimum number of cases per endnode did not exceed four. This corresponds to the number of sites belonging to the smallest benthic community which Rachor and Nehmer (2003) called Helgoland depth. Since the decision tree corresponds to a hierarchically ordered set of decision rules these were written into an SQL-statement and applied on the raster data available for the entire study area. Since each endnode was determined by decision rules, the tree could be applied to predict benthic communities at sites where such information was not available.

Results. By application of the procedure described above for all geostatistically estimated raster maps covering the North Sea, a predictive habitat map was calculated with respect to the possible incidence of the eight benthic communities defined by Rachor & Nehmer (2003) (Fig. 4). The possibility of the occurrence of each community can be derived from its percentage in the corresponding endnode of the CART dendrogram. Each of the twelve benthic habitats was described statistically with regard to the predictor variables used for the CART-analysis.

Discussion. Pesch et al. (2007) could show that the habitat mapping approach is in accordance with the existing knowledge about benthic habitats in the North Sea. The respective literature emphasize the bathymetry and the sediment conditions to be important for the density and distribution of benthic organisms or the composition of benthic habitat complexes. This corresponds to the results of the CART-analysis: Water depth and sediment (in terms of the particle size group 0 - 20 μ) were identified as predictors in the CART-tree that was calculated for the occurrence of benthic communities in the study area. Furthermore, temperature was found to be responsible for the spatial distribution of benthic communities.

With regard to the classification system derived by the CART-analysis the temperature conditions near the sea floor were taken twice to be the most important predictors for the benthic communities. Further, changes of the benthic populations among other things correlate with changes of the degree of eutrophication which might be the reason why the bottom water ammonium concentration was as a predictor in the CART analyses presented in this article. The meaning of bottom water salinity (chosen as a predictor) for the abundance of epibenthic organisms was proven in an investigation cited by Pesch et al. (2007).

As carried out above, the first methodological step to calculate a predictive benthic habitat map consisted in the geostatistical

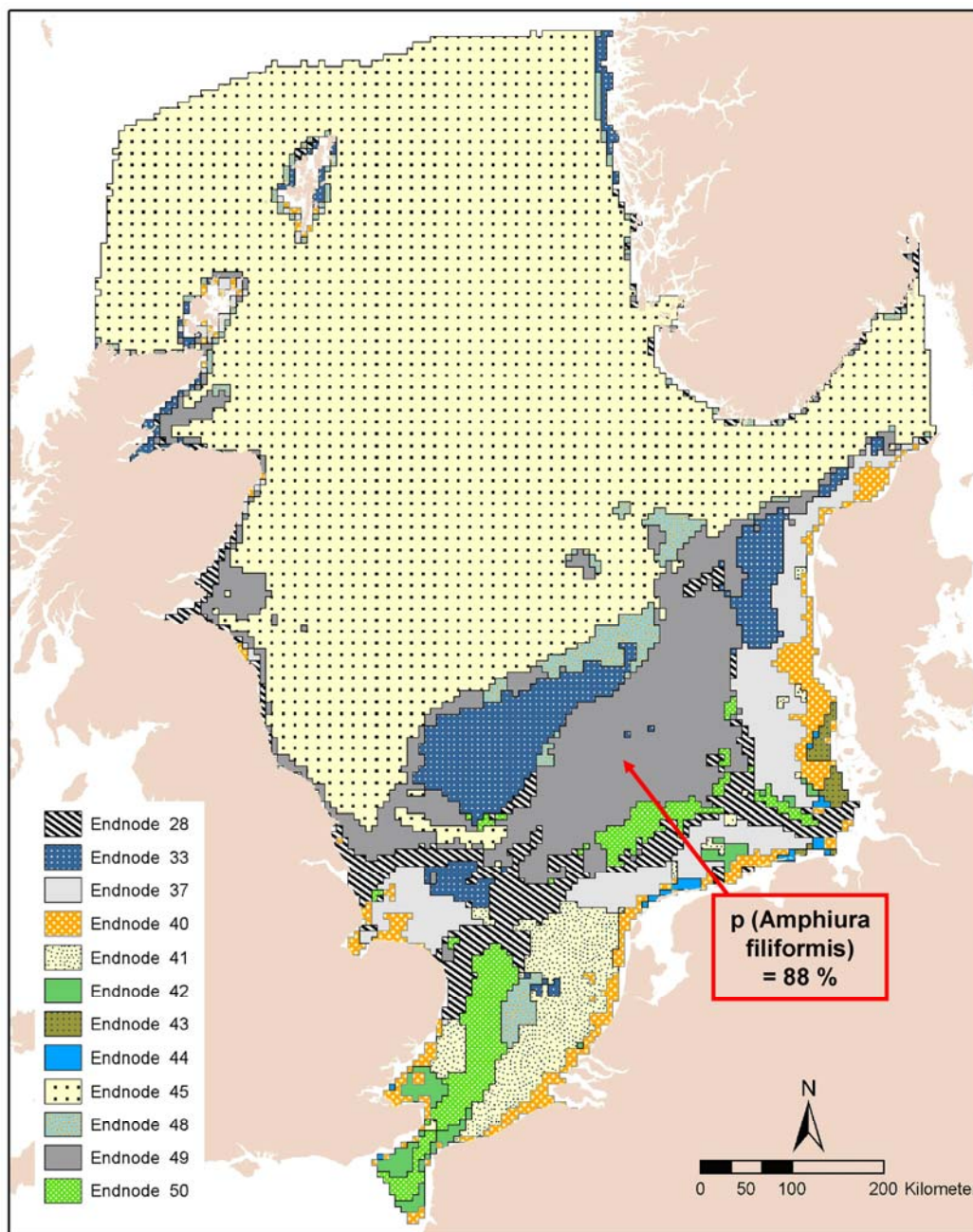


Figure 4: Predictive benthic habitat types for the North Sea derived with help of the decision tree in Fig. 3 - Each of the twelve decision tree endnodes corresponds to one of the benthic habitat types

analysis of abiotic measurement data that was aggregated according to four monthly time intervals within the year aggregated over a three years period from 1997 to 2000. Such aggregation was done with regard to two reasons: (1) to guarantee a sufficient coverage of measurement values across the

study area and (2) to cover a sufficiently long time period to characterise the abiotic conditions near the sea floor. To account for temporal variabilities of the abiotic parameters coefficients of variation were calculated at places where sampling was performed more than once between 1995 and 2000. In fur-

ther analysis, the benthic habitat map presented in this study has to be checked in terms of a sensitivity analysis regarding other methodological alternatives (Pesch et al. 2007). The classification technique CART is one of the most frequently applied decision tree algorithm although other such methods are available. In further studies the CART results should therefore be compared to other habitat maps calculated with help of decision tree algorithms like CHAID (Chi-squared Automatic Interaction Detector) or QUEST (Quick, Unbiased, Efficient Statistical Tree). Provided that predictive habitat maps are to be calculated for the abundance of chosen benthic indicator organisms multivariate regression could be applied as well. Furthermore, more emphasis should be laid on the calculation of raster maps with help of other geostatistical methods. In this study a univariate kriging method (ordinary kriging) was used to produce valid surface estimations. For future investigation bi- and multivariate kriging methods should be applied as well. Such methods account for secondary information that can be implemented in the estimation process. This might especially be of value for the calculation of a sediment map for the sea floor of the North Sea since the sediment distribution is one of the most important predictors to characterise the sea floor in terms of its biological properties. Existing measurement data on grain size ranges should be combined with available sedimentological maps to calculate the grain size maps at first and then to aggregate such maps with help of existing sedi-

mentological classification systems to an overall sediment map of the North Sea.

5 Conclusion

Ecoregions are more complex systems than species or population, integrating soils, vegetation, climate, and relief. They may indicate long-term effects (responses) as, e.g., structural and functional as resulting from bioaccumulation of contaminants. Such effects depend both on the stress intensity and on the ecological characteristics and related sensitivity of the land unit which is exposed. Mosses have been proven to serve as exposure indicators describing the geographical patterns of metal accumulation in terrestrial ecosystems. Exposure monitoring should enable a comprehensive assessment of the status of ecosystems and therefore monitoring networks should encompass the ecological coverage of the monitoring area in terms of different sensitivity. This helps to extrapolate measurement values from locations of small extent, such as, e.g., monitoring sites, to broader areas as, e.g., landscapes. The methodology presented in section 2 allows the calculation of metal-integrating exposure indices from measured metal concentrations and ways of generalizing the indices from the sampling sites to the ecoregions. Thus, finally, metals, time and space should be integrated to give a comprehensive description of the metal exposure in ecoregions over time.

The spatial resolution of the phenological data and of the air temperature records together with the geostatistical approach outlined in section 3.1 proved to adequately solve some of the methodological problems regarding the regional assessment of global change impact on plant phenology. However, other issues should be considered in the future when assessing the regional implications of climate change on plant phenology. Furthermore, global change encompasses more parameters than just air temperature and their regional patterns should be taken into account. Additionally, the relationship between climate change and phenological traits other than spring phases should be also taken into account. Particularly, the relationships between tree phenology and forest vitality should be clarified by means of multivariate statistics and dynamic modelling considering processes such as N-related ecosystem dynamics.

The investigation presented in section 3.2 enabled to regionalise and corroborate the risk of a malaria transmission (Hoshen & Morse 2004; Martens et al. 1999). The model applied in this investigation is the Basic Reproduction Rate which was combined with geostatistical estimation of measured temperature values and future scenarios. Species specific information is included in the model, although the relationship between climate and transmission potential of malaria is still only partly understood. Thus, just in terms of a potential temperature rise, and if so, only restricted to the range given by the

prediction of the IPCC (2001), the outcomes of the future transmission maps are correct. Other variables which play a role in the complex dynamic process of disease spread estimation were excluded, like, e.g., precipitation, humidity, availability of breeding sites, hygiene, and medical supply and other ecological factors determining the developmental process of the mosquitoes. If the only criterion of a malaria transmission is temperature, malaria wouldn't have become eradicated in Europe, as the transmission maps show. Present Anopheline larvae findings in Lower Saxony could be matched with past endemic malaria zones. Referring to the maps depicting the situation in former years, a maximum risk of a four months transmission period could be determined for parts of Lower Saxony, while in terms of the worst case scenarios the utmost duration of a proliferating malaria transmission could last from May to October.

The marine habitat map presented provides fundamental information for the sustainable management. Therefore the map is intended to be used for marine planning and management needs, such as the installation of offshore wind power plants or the declaration of protection zones (Lourie and Vincent 2004). Furthermore, marine habitat maps serve for the investigation of habitat preferences among demersal fish species and benthic invertebrates (Reiss & Kröncke 2005) and as a reference system to monitor the exposure of certain xenobiotica and the effects of climate change (Krupnick & Kress 2003;

Parmesan et al. 2005). Finally, benthic habitat maps can assist the planning and optimisation of environmental monitoring networks (Danielsson et al. 2004).



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