Potential impacts on important bird habitats in Eiderstedt (Schleswig-Holstein) caused by agricultural land use changes

Working Paper FNU-138

Christine Schleupner [a,b] & P. Michael Link [a]

[a] Research Unit Sustainability and Global Change, Hamburg University and Center for Marine and Atmospheric Sciences, Hamburg, Germany
[b] International Max-Planck Research School on Earth System Modelling, Hamburg, Germany

Correspondence to C. Schleupner:
Tel. +49 (40) 42838-7071
Fax +49 (40) 42838-7009
eMail: christine.schleupner@zmaw.de

Correspondence to P.M. Link:
Tel. +49 (40) 42838-7078
Fax +49 (40) 42838-7009
eMail: michael.link@zmaw.de

Abstract

Agricultural land on the Eiderstedt peninsula in Schleswig-Holstein (Germany) is traditionally dominated by extensively used grassland. These grassland areas are home to many (endangered) bird species, making Eiderstedt one of the prime bird habitats at the west coast of Schleswig-Holstein. Plans exist to convert large shares of grassland to arable farm land to grow crops needed in an intensified dairy production and for biofuels. In this study, three possible scenarios of agricultural land use change on Eiderstedt in the next couple of decades are developed. Using a *GIS*, the possible impacts of such conversions on breeding bird populations of four key species are determined. The results indicate that an increase of arable farm land to approximately two thirds of the whole agricultural area drastically reduces suitable bird habitat, thus considerably diminishing the number of breeding pairs supported by the environment. The ornithological impact is greatest if conversion takes place throughout Eiderstedt extending from already existing areas of arable farm land. But even though the reduction in suitable breeding habitat is less pronounced in the other scenarios, every one of them induces a severe pressure on populations of meadowbirds that rely on habitat on Eiderstedt for successful reproduction.

Key words

agricultural land use change, Eiderstedt, Geographic Information System, meadowbirds, Schleswig-Holstein

Introduction

The Eiderstedt peninsula at the west coast of Schleswig-Holstein (Germany) is a mainly agriculturally used land area which is also home to many bird species breeding along the shores adjacent to the Wadden Sea. Also, vast amounts of birds migrate through this region on their way from their wintering grounds in the south to the Arctic and back. Hötker et al. (2005) consider Eiderstedt to be one of the most important habitats for meadowbirds in whole Germany.

Currently, most of the agriculturally used land on Eiderstedt is extensively used grassland. In recent years, however, a growing share of the agricultural land is used as arable farm land to grow corn etc. because of an increase in demand for energy-rich food for cattle and fuel for biogas plants that are to be built in the area (Husumer Nachrichten, 2006). In addition, the extensively used grassland is more and more converted into intensively fertilized meadows for dairy production. Such large scale transformations of agricultural land are likely to have a considerable influence on those bird species that depend on grassland as breeding habitat (Bauer, 1997).

In this study, we determine the relationship between the occurrence of birds breeding on Eiderstedt and the characteristics of their breeding habitat. Using this information in a Geographic Information System (*GIS*), we assess the possible impacts of a continued agricultural land use change in the next two decades on the suitability of Eiderstedt as a principal breeding habitat for birds in Northern Germany and therefore on the expected abundance of breeding birds in this region.

Agricultural land use changes on Eiderstedt

The Eiderstedt peninsula is located at the west coast of Schleswig-Holstein (Germany). It lies between the river Eider and the city of Husum and extends into the North Sea (Fig. 1). Until the 11^{th} century Eiderstedt consisted of several smaller geest islands which became connected after the area was enclosed by dikes (Meier, 2001). Today, the Eiderstedt coastline is entirely protected by dikes.

Figure 1: The Eiderstedt peninsula.

The soil quality of the marshland is high (Feddersen, 1853; InfoNet Umwelt, 2007). But in order to utilize the land agriculturally, it is necessary to maintain a functioning drainage system. Besides a dense network of narrow trenches between the fields, parallel passing drills (in German: *Grüppen*) that additionally drain the grassland areas are typical for Eiderstedt (Fischer, 1997).

Up to the 18th century, cultivation of crops was one of the prime means of agricultural use of the land, but even though a large share of land was used as arable farm land, the predominant type of agricultural land was grassland. Around 1850, cattle farming increased in importance, as exports to the United Kingdom via the harbors of Tönning and Husum grew quickly (Hammerich, 1984). This called for a considerable extension of opportunities for grazing. In the following decades the share of grassland sometimes even exceeded 90 per cent (LVermA-SH, 2007a). After World War II the share of grassland on Eiderstedt decreased from close to 90 per cent to approximately 75 per cent in the 1970s (Tab. 1) and remained stable at this level until recently (Stat A Nord, 1950-2004).

year	total agricultural land area (ha)	share of grassland	share of arable farm land
1949	23,691	80%	20%
1960	23,264	84%	16%
1970	25,771	90%	10%
1979	25,973	80%	20%
1983	25,943	75%	25%
1987	25,504	74%	26%
1991	25,698	76%	24%
1995	25,504	78%	22%
1999	24,668	77%	23%
2003	24,016	73%	27%

Table 1: Agricultural land use on Eiderstedt from World War II until present (Stat A Nord, 1950-2004).

In recent years, the characteristics of cattle farming on Eiderstedt shifted towards a more intensive approach. Cattle for meat production generally remains in cow barns while the cattle used in dairy production is held on grassland, which is often heavily fertilized. The increased number of cattle held necessitates the growth large amounts of forage crops in adjacent areas, mainly corn. Since the total agricultural land area on Eiderstedt is limited, this led to a considerable increase in the share of arable farm land on Eiderstedt since 2003 and a concurrent reduction of grassland. Adventitiously, enhanced grassland conversion takes place because of fuel production for biogas plants.

The local farmers union plans to extend the amount of land used to grow forage crops to approximately two thirds of the agricultural land area in the next couple of decades (NABU, 2004). This plan is intensely debated and opposed by local environmental organizations who claim that such a large scale shift in land use not only alters the overall appearance of the whole region but also has devastating effects on the breeding bird colonies, as arable farm land on which corn is grown is much less suitable as habitat than extensively used grassland (Beintema, 1983). Therefore, realization of the farmers' plans would greatly impact the local carrying capacity of many (endangered) bird species.

Eiderstedt as important habitat for breeding and migrating bird species

Grassland is often an important substitute for lost natural habitats such as moors, salt marshes, or other wetlands. Eiderstedt offers ideal breeding conditions for meadowbirds owing to its large share of grassland and meadows with many ponds and drainage trenches that are extensively used by the local agriculture.

The Eiderstedt peninsula is an important breeding area of the Northern Lawping (*Vanellus vanellus*), the Eurasian Oystercatcher (*Haematopus ostralegus*), the Black-tailed Godwit

(*Limosa limosa*), and the Common Redshank (*Tringa totanus*) in Germany (Hötker et al., 2005). Despite considerable measures to protect the populations of these species, their abundance has decreased dramatically during the last few years. Northern Lawping and Common Redshank are considered to be endangered; the Black-tailed Godwit is even listed in the category of being severely threatened by extinction (Bauer et al., 2002; Knief et al., 1995). On the other hand, the abundance of the Eurasian Oystercatcher has increased recently.

The selected bird species depend on low and sketchy vegetation on wet meadows or marshes (Gillmor et al., 1998). Some prefer the proximity to open waters but all avoid fallow lands and cut meadows (Hoffmann, 2006). These species can also serve as indicators in land use intensity assessments (Beintema, 1983). While Eurasian Oystercatchers and Northern Lawping are also found on intensively used grassland and sometimes even breed on arable farm land, Common Redshank and particularly Black-tailed Godwit have higher demands regarding the quality of the grassland (Beintema, 1983; Hoffmann, 2006).

Methodology

Aims and methods

Conversion or the abandonment of extensively used grassland to either arable land, intensively used grassland or fallow land with forest succession can be observed throughout Europe. Such land use changes are often motivated by political decisions and demographic or socio-economic trends (Bauer et al., 2002). Regardless of the reason, a loss of valuable habitat can generally be registered as a consequence of such land conversion (EEA, 2004). This has implications for the ornithological fauna, which manifest themselves in the fact that many farmland bird species have been declared endangered species in Europe over the last few decades and that their decline has become an important conservation concern (Bayliss et al., 2005).

This study aims to improve the understanding of the potential impacts of land use changes on key species of the local bird fauna by exploring a set of possible land use development scenarios. We focus on four bird species with mapped field distribution as key species. The following key questions serve as guideline for the assessment:

1. Which processes cause the land use change and how can these be transformed into future land use scenarios?
2. How are the breeding habitats of the key species characterized and how can these be assessed concerning its site and habitat suitability?
3. To what extent do the habitats change qualitatively and quantitatively in the land use change scenarios?
4. What implications does this have on the key species?
5. Can general statements about grassland conversion be deducted from the findings?

Several empirical models already exist, which can be used to analyze the distribution and habitat suitability of species. Most of them model the potential distribution of certain single or multiple species (Bayliss et al., 2005; Cabeza et al., 2004; Manel et al., 1999; Seoane et al., 2004). Bayliss et al. (2005) use a multi-species approach that utilize Bayesian decision rules, others like Seoane et al. (2004) apply predictive habitat models or general linear models (*GLM*s) (Guisan et al., 2002; Granadeiro et al., 2004). In our assessment, the emphasis lies on the utilization of existing field data of bird occurrence and their extrapolation in accordance with different land use change scenarios. The analysis is conducted with *GIS*-based model that is explained in more detail below.

GIS methods have already been used in some studies to determine species distributions. E.g., Thompson et al. (2004) identify locations of potential breeding sites of curlews and Powell et al. (2005) analyze species distributions using biotic and abiotic factors to predict former ranges of species. They also demonstrate that simple rule-based non-statistical models can be effective tools for such applications. However, the integration of scenarios into *GIS*-based modeling of species habitats has been often neglected so far. This necessary step forward, which allows the application of the results in effective land use planning and conservation management, is taken in this study.

Data and software used in the assessment

In order to be able to determine the potential impacts of future land use changes on the breeding populations of the bird species in question, it is necessary to look at the historic land use development as it defines the current situation on Eiderstedt. This is done using survey data on agricultural production in Schleswig-Holstein provided by the Statistics Department Nord, which allows us to assess the period from the end of World War II until present (Stat A Nord, 1950-2004). Together with *GIS* data on current land use on Eiderstedt, provided by the Landesamt für Natur und Umwelt des Landes Schleswig-Holstein (LVermA-SH, 2007b) and data on the abundance of key bird species breeding in the area (Hötker et al., 2005) it is possible to relate the preferred breeding habitats to agricultural land use decisions. *ArcGIS* 9.1 and 9.2 as well as the analysis tools V-late and Hawths Analysis Tools (2006; Tiede, 2005) are used in this assessment.

The development of agricultural land use in recent decades is extended into the future for another 20 years. The projections are based on political intentions to drastically increase the share of arable farm land up to two thirds of all agricultural land on Eiderstedt (NABU, 2004) and assumptions about the possible patterns of land use change. As these changes alter the suitability of the land to serve as breeding habitat for meadowbirds, they can be expected to have a profound influence on the number of breeding pairs on the peninsula. The extent of the ornithological impact is quantified using a measure of dynamic habitat sensitivity of the potential breeding areas.

The Habitat-Sensitivity-Index as measure of biotope quality changes

We developed an assessment scheme to determine how landscape changes affect the characteristics of breeding habitats of birds. This scheme includes the transformation of ecological facts, effects and connections into indices that can be used in an objective interpretation (see Bastian & Schreiber, 1999; Weis, 2007). The habitat assessment relies on a combination of specific algorithms that allow integrative and complex statements (Bastian, 1997). Together with the results of the scenario analysis, these statements are projected into future conditions and compared with each other. This allows assessments of the impact potential of land use change and the sensitivity of the landscape. The following equation provides the basis of the habitat assessment. The habitat sensitivity (*HaSI*) of each patch of land *i* is a combined measure of three key indices: the proximity index (*PX*), the neighborhood quality index (*NI*), and the patch size index (*SCI*). *DI* denotes the habitat demand index.

$$HaSI_i = \frac{\sum_i \left(PX_i, NI_i, SCI_i\right)}{3} \forall DI \in \left[4,5\right] \quad (1)$$

A fundamental element influencing habitat sensitivity is the development of the suitability of land as ornithological habitat. It is described by a habitat demand index (*DI*). This index measures the suitability of a number of land cover parameters for selected breeding birds. Sites that have a relatively unfavorable natural character but serve as habitat for the majority of breeding birds can receive a fairly high index value as well. The supply (of nature) is related to the demand of the potential user (in this case endangered bird species).

The analysis of the habitat demand of selected bird species is based on the procedure of a habitat suitability analysis conducted by Lang & Blaschke (2007). The data used here are adapted from occurrence maps of selected breeding birds of 2001. Spatial land use and biotope data are from 1991 and 2002. In our analysis, we determine the preferred habitats of the selected bird species. In a first step, the occurrence data are intersected with the biotope and land use maps to identify the preferred habitat types. The results, which are expressed as proportional shares, are subsequently transformed into ordinal classes with five categories, the *DI*. Because we use data on breeding birds only, it is necessary to supplement the data with further information from literature (Morrison et al., 1992; Gillmor et al., 1998; Gruber, 2006; Hoffmann, 2006) to avoid uncertainty errors as described in Lang & Blaschke (2007). The *DI* categorizes the degree of general habitat suitability, which is the basis for further analyses. The resulting list of suitable and therefore valuable habitats for the selected bird species is space independent and yields information on a functional level. Biotope types with a *DI* of 4 and 5 (suitability level of 60-100%) are considered to be potentially extraordinary or very suitable habitats, whereas a *DI* of 3 (suitability level 40-60%) refers to conditionally suitable or partially suitable habitats. *DI*s of 2 and 1 (suitability level 0-40%) are unsuitable as habitats for the selected bird species and are omitted in the following model analysis.

The results gained above are spatially transformed to fit the biotope data of Eiderstedt and the areas with high habitat suitability, i.e. a *DI* of 4 or 5, are selected for further analysis. These particularly suitable habitats are the basis for the isolation assessment via the proximity index (*PX*) (Gustafson & Parker, 1992). The proximity evaluation is conducted with the tool V-late (Lang & Tiede, 2003) for *ArcGIS* and allows the rating of individual patches of land according to its functional network with the surrounding habitats (Kiel & Albrecht, 2004). The *PX* distinguishes between space dispersal and clustered distribution of habitats by considering the size as well as the distance of the patches, as both quantities are important for the assessment of habitat complexes. We use 2002 as base year with a buffer of 250 m for the *PX* evaluation. The results are transformed logarithmically and split into five classes (based on Weis, 2007). For comparability, the same divisions are applied in the subsequent scenario analyses. The index decreases the smaller the area and/or the higher the distance to similar patches of land becomes. The index value is highest if a patch is surrounded by and/or extending towards nearby biotopes of the same kind (Lang & Blaschke, 2007). Table 2 shows the classification scheme of the *PX*.

index	*PX*	*BQ*	*NI*	*SCI (ha)*
1	0.000 - 1.231	roads, other paved areas	0.0 - 2.0	0.0 - 2.0
2	1.232 - 2.569	settlements, arable farm land	2.1 - 2.5	2.1 - 10.0
3	2.570 - 3.453	intensively used grassland	2.6 - 3.2	10.1 - 40.0
4	3.454 - 4.211	extensively used grassland, beaches, dunes, ponds	3.3. - 4.0	40.1 - 100.0
5	4.212 - 6.078	marsh land, salt marshes, forests, open water	4.1. - 5.0	> 100.0

Table 2: Index classes of different biotope types on Eiderstedt used in the analyses.

Another important aspect in the evaluation of habitat sensitivity is the character of the environment (Bastian, 1997), since it also plays a role in the habitat choice of the bird species (Newton, 2003). In our assessment this is denoted by the neighborhood index (*NI*). It is assumed that the NI, and therefore the attractiveness of the area for the selected bird species, declines with a diminishing quality of the surrounding environment. We follow the assessment of Weis (2007). The *NI* can only be calculated if the following information on habitat quality is given.

The quality of the neighborhood is determined by the *BQ* index (cf. Schlüter, 1987). The *BQ* consists of an assessment of all characteristics of an area under utilization-specific aspects. This index value is represented by a combination of the hemeroby index (*HI*) and an index of the conservation value (*CI*).

$$BQ = \frac{HI + CI}{2} \tag{2}$$

Hemeroby is based on vegetation and depends directly on human utilization intensity and pressure. It assesses how pristine a considered biotope is, given the influence of anthropogenic cultivation present. Schlüter (1987) developed a scale to rate biotopes based on their vegetation. For our purposes, this scale is adjusted to yield five index classes by aggregating two levels into one index class. Generally, open waters do not fit into this scheme. However, the North Sea and the river Eider are included in our assessment and rated as *HI* = 5 because these waters are of significance for the adjacent salt marshes and the bird species considered in this study. The index values for the open water are also important to prevent a bias in the classification of the *NI*. The *HI* is closely connected to the biological regulation and regeneration capacity. The lower the *HI*, the more limited the regulation and regeneration potential of the biotope is. This allows inferences about the ecological stability of assessed landscapes.

In addition to the *HI*, the *CI* is a second measure of biotope quality. Each biotope is evaluated according to its general importance for species and biotope conservation. We apply the assessment scheme presented in Bastian & Schreiber (1999) which is adapted to fit our model. The base data are provided by a biotope map of 1991 (LANL, 1993) that is classified in a *GIS*. As before, index values between 1 and 5 are assigned to each biotope type based on its general conservation value. Table 2 lists the classification schemes of habitat quality for each biotope type. The characteristics of all index classes are described in Table 3.

index	*PX*	*NI*	*HaSI*
1	isolation of small habitat patch is extremely high	quality of the surrounding area is extremely unfavorable	extremely low bird habitat quality. No ecological value for selected bird species.
2	high isolation or very small habitat patch	neighboring areas of worse ecological quality	low habitat quality with minor value for selected breeding birds
3	medium isolation or medium sized habitat patches	medium neighboring quality	medium habitat quality but still of value for selected bird species
4	habitat patches build small complexes or are of bigger size	good biotope quality of the neighborhood	good habitat quality with significant value for selected breeding birds
5	very high complexity or extending patch size	excellent biotope quality of the surroundings	excellent habitat quality with very high ecological value for selected breeding birds

Table 3: Description of index values.

To obtain the *NI*, a buffer of 250 m is applied to all areas. The area-relevant mean value of *BQ* is determined for each patch (Bastian, 1997). The difference between the *BQ* of the habitat and that of its surrounding is a measure of the quality of the neighborhood (Weis, 2007). It is expressed in five index classes.

The size of a patch is also of importance when considering its neighborhood. The larger the habitat the less is it influenced by its surroundings. To integrate the habitat size, the area of each habitat is determined and categorized by five area size classes *SCI* (Tab. 2).

The *HaSI* integrates all elements described above and allows an assessment of the state of the landscape with special consideration of the necessities of the selected breeding bird species. The *HaSI* is first determined for the base year 2002, which is the reference for the comparison with the different scenarios of land use development on Eiderstedt.

Implications for bird populations

Occurrence maps of the selected bird species are intersected with the *HaSI* index values to determine the mean breeding pair density for each *HaSI* class (Tab. 4). Because the bird data only maps occurrence within the dikes, the outer salt marshes are excluded from further analysis. It is assumed that these areas, which often have the highest abundance of breeding birds, remain stable in size and carrying capacity. Under the condition that bird abundance per unit area is time independent, we incorporated the results into the scenarios, allowing calculations of the potential reduction of breeding pairs of the selected species. This assessment is conducted for each single bird species separately but also for all four species densities taken together.

Scenarios

In our assessment we assume that the plan to drastically increase the amount of arable farm land on Eiderstedt is realized within the next couple of decades. Since the propositions do not contain any information on which areas are to be converted, three different patterns of land use change are considered in this analysis. They are shown in Figure 2 together with the current agricultural land use on Eiderstedt (Fig. 2a).

In the first pattern of land use change, land is primarily converted along the main roads through Eiderstedt and preferably in only recently diked marshland (Fig. 2b), as the crops to be grown on the converted land need to be transported efficiently to the sites at which they are processed. Growing the crops as closely as possible to already existing infrastructure makes this task significantly easier. The second pattern is based on the assumption that it is best to grow crops on large continuous patches of land. Therefore, in this pattern land is primarily converted in areas around currently existing arable farm land (Fig. 2c). The third pattern of conversion follows the premise that the less remote an area of land is, the more useful it is to be used for crop production. Since the Eiderstedt peninsula is connected to the rest of Schleswig-Holstein only in the east, this pattern of land use change converts grassland to arable farm land from east to west (Fig. 2d). Further details about these scenarios are given in Link & Schleupner (2007).

Results

The agricultural land use patterns resulting from the planned conversion are identified for all scenarios. Afterwards, possible impacts on the populations attempting to breed on Eiderstedt are determined by considering the previously obtained information on the breeding habitat preferences of the bird species assessed.

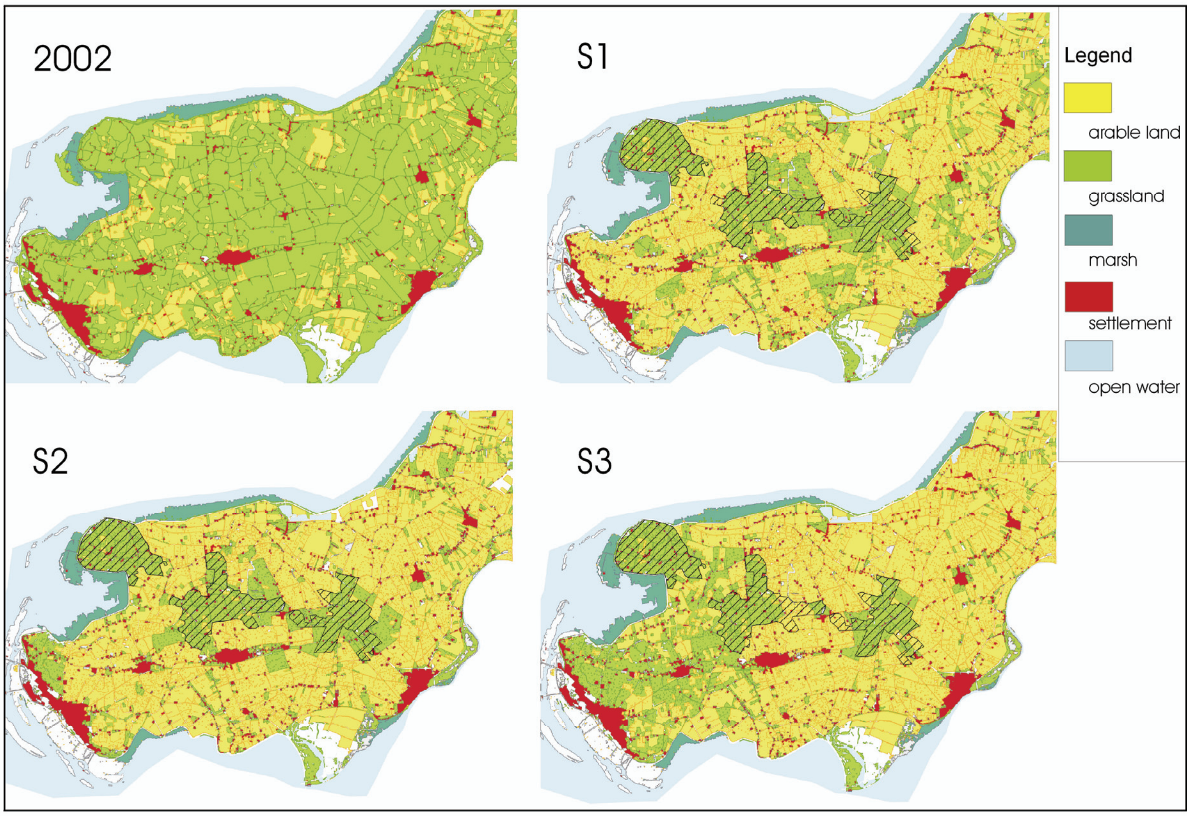

Figure 2: a) land use on Eiderstedt in 2002; expected land use on Eiderstedt in the late 2020s if land use change occurs b) along main roads and newly diked areas (*S1*), c) around already existing arable farm land (*S2*), d) from east to west (*S3*).

Depending on the pattern of land use change, the scenarios lead to considerably different distributions of agricultural areas on Eiderstedt approximately two decades into the future. If the land use change originates from the main roads through Eiderstedt (scenario *S1*), patches of grassland remain throughout Eiderstedt (Fig. 2b). These are generally detached from one another, except for the areas around the three bird sanctuaries, in which larger uniform areas of grassland remain intact. These serve as primary breeding grounds for the remaining meadowbirds. It has to be noted that the political choice of declaring Westerhever a bird sanctuary is the only reason for not converting the northwestern tip of Eiderstedt into arable farm land.

The distribution of the remaining grassland in 2025 is similar in scenario *S2*, in which land use change radiates outward from already existing patches of arable farm land (Fig. 2c). The region north of St. Peter-Ording remains grassland and less land is converted in the vicinity of the two bird sanctuaries in central Eiderstedt. Patches converted to arable farm land are less fragmented, so that the degree of land use change appears to be even higher than in the previous scenario, even though this is not the case.

The resulting pattern is substantially different in scenario *S3*, which depicts a conversion of farm land progressing westwards (Fig. 2d). Practically all remaining grassland is located west of the town of Garding. Eastwards only bird sanctuary of Kotzenbüll remains more or less intact, even though it has to be noted that there is even some land use change within the two sanctuaries in central Eiderstedt, which is likely to have an adverse influence on the overall habitat quality of these two special regions. Another caveat is that large parts of the remaining grassland are in the vicinity of the towns of St. Peter-Ording and Tating, which are popular tourist destinations at the west coast of Schleswig-Holstein. High frequentation of the areas surrounding the breeding habitats by humans can artificially reduce breeding success even though habitat conditions might be superior to those in the other two scenarios.

In the next step of the assessment, each patch of land is characterized based on the classification criteria outlined above. This way it can be determined how the altered land use patterns in all scenarios influence the suitability of the land as breeding habitat for the various bird species.

The proximity index yields information about the isolation or complexity of habitats. The analysis reveals that in 2002 areas with a high *PX*, i.e. a high complexity of habitats, are evenly distributed across the peninsula. Only very small patches and adjacent salt marshes have lower index values. The results of the neighborhood quality evaluation show the same pattern except that the salt marshes now have highest index values. In contrast to 2002, the index values are much lower in all three scenarios, but there are clear differences between the three cases considered. It is striking that the values for the salt marshes remain unchanged with the exception of the *NI* in *S2*, in which they suffer from extremely reduced biotope quality in neighboring biotopes.

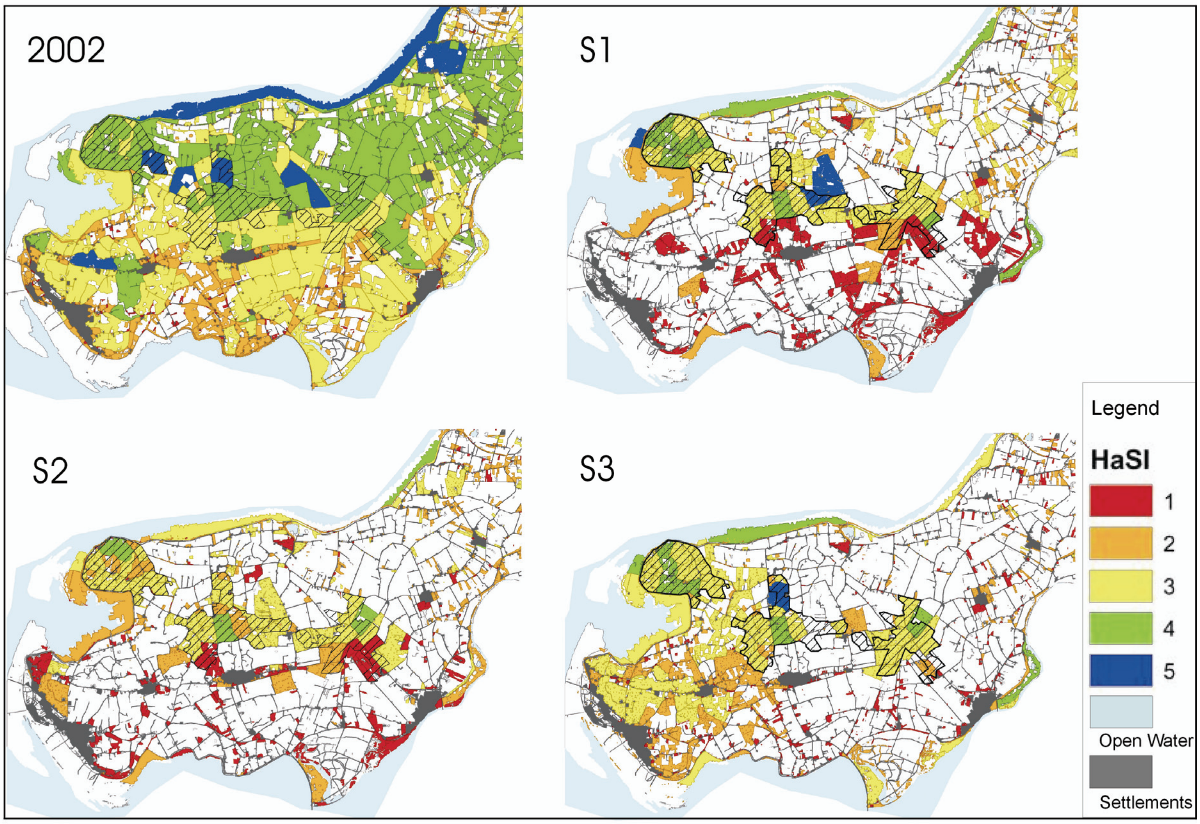

Figure 3: the *HaSI* for a) 2002, b) scenario *S1*, c) scenario *S2*, d) scenario *S3*.

After integrating all intermediate results into the *HaSI* equation, it is possible to draw conclusions about changes in habitat quality. *HaSI* ranges from 1 to 5, with class 1 referring to the lowest possible habitat quality with almost no ecological value for the selected breeding birds. The *HaSI* for 2002 and for the three scenarios is illustrated in Figure 3. In 2002, there were 26 132 ha of valuable habitats for the selected birds. This amounts to 70% of the total land area of Eiderstedt. The habitats are evenly distributed throughout the peninsula. Seven patches of land are rated with the highest *HaSI* value of 5. These are the salt marshes along the northern coast, as well as patches situated in the northern half of Eiderstedt. Only one of these patches is located in the southwestern part close to St. Peter-Ording. The habitats in the northern and eastern part of the peninsula obtained mainly high *HaSI* values of 4, whereas the lower values of 2 and sometimes of 1 are generally found in the south.

bird species	*HaSI*	density	2002	*S1*	*S2*	*S3*
all species	1	0.04	4	87	62	20
	2	0.47	1164	619	877	1042
	3	1.21	11235	3272	3358	4179
	4	1.87	17252	1343	720	1180
	5	2.84	3240	903	0	372
	total		32895	6224	5017	6793
Eurasian Oystercatcher	1	0.03	3	64	47	15
	2	0.12	292	158	224	266
	3	0.31	2973	838	860	1195
	4	0.52	4804	373	200	328
	5	0.65	740	207	0	85
	total		8812	1640	1331	1889
Common Redshank	1	0	0	0	0	0
	2	0.02	58	26	37	44
	3	0.06	564	162	167	231
	4	0.13	1160	93	50	82
	5	0.23	265	73	0	30
	total		2047	354	254	387
Black-tailed Godwit	1	0	0	0	0	0
	2	0.03	86	40	56	67
	3	0.08	732	216	222	308
	4	0.19	1652	136	73	120
	5	0.37	420	118	0	48
	total		2890	510	351	543
Northern Lawping	1	0	0	0	0	0
	2	0.09	230	119	168	200
	3	0.24	2208	649	666	925
	4	0.34	3148	244	131	215
	5	0.67	765	213	0	88
	total		6351	1225	965	1428

Table 4: The average breeding pair density for each habitat sensitivity index (*HaSI*) class (breeding pairs/ha) and the total expected bird abundance in all scenarios.

The three scenarios of possible development of agricultural land use are now compared to the reference state of 2002. Besides the reduction of total suitable habitat area, changes in *HaSI* of the remaining suitable breeding habitats are evident. Only in scenario *S3* one of the former patches with an index value of 5 remains, all others are either converted into arable farm land or have a deteriorated *HaSI*. In *S1*, the most suitable habitats shift towards the center of Eiderstedt. In *S2*, areas with the highest *HaSI* no longer exist and also the second highest index class is only found in four areas. Table 5 shows the share of the area for each *HaSI* class. It highlights the differences between all three scenarios but also gives the overall proportional changes in habitat quality. The area of habitats with lowest *HaSI* increases considerably in all scenarios. While in 2002 only 0.4% of the area is rated with *HaSI* of 1, the amount of land in this category increases to 7% in *S3*. In *S1* it even reaches nearly one third of the demanded area. The most dramatic change occurs with land that is fairly well suited as breeding habitat (*HaSI* = 4): In 2002, 41.5% of the total area are of this habitat quality, whereas after the presumed land use change only 6 to 10 % of the remaining area are still well suited as breeding habitat. To sum up, in all three scenarios large amounts of previously highly suitable habitats are degraded to sites with medium or low habitat value.

HaSI	2002	*S1*	*S2*	*S3*
1	0.4	30.1	23.6	6.9
2	11.1	18.2	28.4	30.2
3	41.8	37.4	42.2	52.5
4	41.5	9.9	5.9	8.6
5	5.1	4.4	0	1.8

Table 5: Shares of land area (%) in each *HaSI* class in the three scenarios and the reference year.

The results of the habitat sensitivity analysis are used to obtain average breeding pair densities of the selected bird species for each *HaSI* class. First of all, the breeding pair density is determined for each bird species and in total for the base year 2002. The breeding pair density of all four species considered is positively correlated with the *HaSI* (Tab. 4). This is a very convenient finding, as it also verifies the methodology of the *HaSI* evaluation. Only few Eurasian Oystercatchers breed on patches with a poor *HaSI*, while all other birds prefer higher quality habitats. Assuming that the bird densities remain stable for each *HaSI* category, it is possible to calculate the potential abundance of breeding birds in each scenario. Table 4 gives an overview of the breeding pair density per HaSI and the resulting bird abundances. The scenarios point to considerable impacts on breeding habitats caused by large scale agricultural land use changes: There is not only a loss of total habitat area of approximately two thirds, but also a shift in the quality of the habitats. With bird densities remaining constant over time, a decrease in bird abundance of more than 60% can be expected. Compared to the 32 895 breeding pairs of all four bird species in total in 2002, the number of pairs should decrease to about 11 000 pairs. The actually determined expected number of breeding pairs shown in Table 3 is even lower since the reduction in suitable land area brings about a decline in quality of the remaining habitats. The number of breeding pairs declines by another 50% in some scenarios due to this additional effect.

Discussion and conclusion

One aim of this study is to pinpoint the potential impacts of land use changes to species habitats of agricultural landscapes. In contrast to other studies that often model species habitats based on past or present habitat conditions (e.g. ´Bayliss et al., 2005; Seoane et al., 2004; Thompson et al., 2004) this assessment considers potential future land use changes. This necessitates the use of special scenarios to spatially extrapolate the landscape changes, which methodologically extends already existing habitat suitability models.

Agricultural land on the Eiderstedt peninsula is traditionally dominated by extensively used grassland even though the share of grassland in relation to arable farmland was fairly variable in the past. The knowledge of past land use changes and its regional causes are important for the development of future scenarios. The scenario analysis applies three possible paths of land use development on Eiderstedt in the next couple of decades. In all of them the share of arable farm land ends up at two thirds of the entire agricultural land of the peninsula. Our assessment demonstrates the possible ecological impacts of such land use change. The results show that the pattern of agricultural land conversion has a great influence on the ornithological species composition in this area. It is our intention to raise the awareness about the potential implications to the environment that might be caused by political decisions. Therefore, the three scenarios purposefully represent very far-reaching developments. But even though the scenarios appear extreme, they are by no means unrealistic, as they are based on real statements by local interest groups that traditionally have a strong influence on decisions in regional politics in northern Germany.

The main difference between the three scenarios lies in the degree of fragmentation of the remaining grassland patches and their location. A conversion of agricultural land starting along existing roads leads to the highest degree of fragmentation, which potentially reduces the quality of the unconverted grassland as potential breeding habitat for birds. On the other hand, a conversion to arable farm land from east to west leaves intact larger areas of grassland in western Eiderstedt but the value of the bird sanctuary near Kotzenbüll is reduced due to its isolation and large shares of the remaining breeding habitats lie in the vicinity of a major tourist destination, which is likely to lead to considerable anthropogenic disturbances.

The potential environmental impacts of the land use conversion differ depending on the resulting distribution pattern of agricultural land. The ornithological impacts are quantified using the *HaSI* assessment scheme. Such *GIS*-based modeling techniques that rely on rule-based parameter combinations are considered to be effective tools in this context (Powell et al., 2005; Thompson et al., 2004). The *HaSI* scheme is validated using bird abundance maps. The methodology of the *HaSI* assessment has a high accuracy because the *HaSI* values correlate well with the observed breeding pair density data of the selected bird species. In regions with a high *HaSI* the breeding bird density is also highest and a low *HaSI* corresponds to a low breeding pair number. Assuming a time independence of the species-specific breeding bird densities, the potential development in the number of breeding pairs supported by the habitats on Eiderstedt can be evaluated.

The potential decline in breeding pairs is particularly strong for Common Redshank, the species with the lowest abundance to start with (cf. Tab. 4). In all scenarios, its reduction is above average, making the species highly endangered of extinction in this region if breeding habitats were to be reduced as projected. The more abundant species appear to be slightly more resilient to the altered extent of suitable breeding habitats. Both the Eurasian Oystercatcher and the Northern Lawping partly offset the reduced habitat availability by increasingly utilizing land area with only marginal suitability for breeding.

However, since the number of breeding pairs of all species assessed is reduced drastically in all three scenarios, it can be deduced that the overall quality of the Eiderstedt peninsula as habitat for meadowbirds deteriorates considerably. The main reasons are the increasing isolation of suitable breeding areas and the increasing likelihood of disturbances by anthropogenic activities. The results indicate that not even the declaration of the three bird sanctuaries on Eiderstedt can offset this development since the suitability of these areas as breeding habitat is also critically impaired owing to the land conversions in the neighborhood of these protected sites. Therefore, buffer zones around these bird conservation areas are of paramount importance to preserve the existing habitat quality.

The same holds for the salt marshes outside the main dikes, where the highest bird densities are generally observed. For these areas, suitable conditions for breeding need to be present in the adjacent hinterland as well if their overall quality as ornithological habitat is to be maintained. The importance of an intact neighborhood is augmented if the impacts of sea level rise on the salt marshes are considered as well. Because of impossibility of retreat due to anthropogenic infrastructure such as dikes, an accentuated erosion of the salt marshes might take place, leading to the deterioration or complete loss of the potentially most valuable breeding areas for meadowbirds. The hinterland on the Eiderstedt peninsula could serve as highly suitable substitution habitat, but only if current conditions are preserved.

Based on the results of this assessment it is possible to identify the characteristics of an optimal bird conservation area on this peninsula, considering not only the habitat suitability for bird species, but also respecting the recent and future socio-economic developments of the local actors via participatory analyses. This study serves as a starting point for such assessments as it provides a model to analyze the potential impacts of land use changes. Moreover, the utilization of scenarios as presented here can help improve the efficiency of integrated land use planning and conservation management of landscapes. By considering potential landscape developments, such scenarios allow the formulation of optimal targets for a given region.

The scenario analysis illustrates that a much smaller number of breeding birds will be supported by the remaining suitable habitats if land use changes occur as projected. Today, many farmers argue that a distinct expansion of arable farming is the only way to survive economically and that shifts in the overall structure of the regional agriculture necessitate these conversions. However, the Eiderstedt peninsula is not only an agricultural region but also a famous tourist destination because of its vast grassland areas and high densities of breeding or migrating birds. It is likely that large scale conversions of grassland to arable farm land also have an influence on the appearance of the Eiderstedt landscape to visitors. An assessment of the impacts of land use change on tourist activities on Eiderstedt is beyond the scope of this analysis and will be conducted in a separate study. Future assessments of land use change on Eiderstedt will further enhance the understanding of the impacts of planned land conversions, so that hopefully, farmers, birds, and tourists will all find or retain their optimal niches on Eiderstedt in the next decades without having to experience too extensive economic and ecological losses.

Acknowledgements

The land use change assessment is based on previous analyses by the Landesamt für Natur und Umwelt des Landes Schleswig-Holstein, which we can gratefully utilize in this study. The authors would like to thank Dr. E. Tschach for providing the digital base maps and the land use data. Data on bird abundance were provided by the Naturschutzbund Deutschland, Bergenhusen, Germany. The *GIS*-Software *ArcGIS* 9 has been kindly sponsored by the ESRI-Absolventenprogramm. This case study contributes to the EU-project *GEOBENE* (Global Earth Observation – Benefit Estimation: Now, Next and Emerging, FP6).

References

Bastian, O. (1997). Gedanken zur Bewertung von Landschaftsfunktionen – unter besonderer Berücksichtigung der Habitatfunktion. In O. Bastian & U. Schreiber (Eds.), NNA-Berichte, 3 (pp. 106-125). Schneverdingen, Germany (in German).

Bastian, O. & Schreiber, K.-F. (Eds.) (1999). Analyse und ökologische Bewertung der Landschaft (2nd ed.). Heidelberg, Germany: Spektrum Akademischer Verlag (in German).

Bauer, H.G., Berthold, P., Boye, P., Knief, W., Südbeck, P. & Witt, K. (2002). Rote Liste der Brutvögel Deutschlands, 3. überarbeitete Fassung. Berichte zum Vogelschutz, 39, 13-60 (in German).

Bauer, P. (1997). Die Brutvögel Mitteleuropas: Bestand und Gefährdung (2nd ed.). Wiesbaden, Germany: AULA-Verlag (in German).

Bayliss, J.L., Simonite, V. & Thompson, S. (2005). The use of probabilistic habitat suitability models for biodiversity action planning. Agriculture, Ecosystems and Environment, 108, 228-250.

Beintema, A.J. (1983). Meadow Birds as Indicators. Environmental Monitoring and Assessment, 3, 391-398.

Cabeza, M., Araújo, M.B., Wilson, R.J., Thomas, C.D., Cowley, M.J.R. & Moilanen, A. (2004). Combining probabilities of occurrence with spatial reserve design. Journal of Applied Ecology, 41 (2), 252-262.

European Environment Agency (EEA) (ed.) (2004). EEA Signals 2004. Copenhagen. http://www.eea.eu.int.

Feddersen, F. (1853). Beschreibung der Landschaft Eiderstedt. Tönning/Altona, Germany: Schlüter Verlag (in German).

Fischer, L. (Ed.) (1997). Kulturlandschaft Nordseemarschen. Bredstedt/Westerhever, Germany: Nordfriisk Instituut (in German).

Gillmor, R., Hillcoat, B., Roselaar, C.S., Vincent, D., Wallace, D.I.M., Wilson, M.G., Snow, D.W. & Perrins, C.M. (1998). The Birds of the Western Palearctic. Volume 1: Non-Passerines, Volume 2: Passerines. Oxford, UK: Oxford University Press.

Granadeiro, J.P., Andrade, J. & Palmeirim, J.M. (2004). Modelling the distribution of shorebirds in estuarine areas using generalised additive models. Journal of Sea Research, 52, 227 – 240.

Gruber, S. (2006). Habitatstrukturen in Nahrungsrevieren jungeführender Kiebitze (*Vanellus vanellus L.*) und deren Einfluss auf die Reproduktion. Kiel, Germany: Dissertation Christian-Albrechts-Universität zu Kiel (in German).

Guisan, A., Edwards Jr., T.C. & Hastie T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological Modelling, 157, 89-100.

Gustafson, E.J. & Parker, G. 1992. Using an index of habitat patch proximity for landscape design. Landscape and Urban Planning, 29, 117-130.

Hammerich, H. (1984). Eiderstedts Landwirtschaft – gestern und heute. Husum, Germany: Husum Druck- und Verlagsgesellschaft (in German).

Hawths Analysis Tools (2006). http://www.spatialecology.com/htools

Hoffmann, J. (2006). Schlupferfolgskontrolle von Wiesenlimikolen im Naturraum Eiderstedt. Trier, Germany: Diplomarbeit Biogeographie Universität Trier (in German).

Hötker, H., Köster, H. & Thomsen, K.M. (2005). Wiesenvögel auf Eiderstedt und in der Eider-Treene-Sorge Niederung/Schleswig-Holstein im Jahre 2001. Corax, 20, 1-17 (in German).

Husumer Nachrichten (2006). Gemeindevertretersitzung der Gemeinde Osterhever. Article published March 14, 2006. Husum, Germany (in German).

InfoNet Umwelt (2007). http://www.umwelt.schleswig-holstein.de (last visited June 25, 2007).

Kiel, S. & Albrecht, K. (2004). Großräumige Landschaftsbewertung mit landscape metrics im Praxistest – ein Methodenvergleich. In J. Strobl, T. Blaschke, & G. Griesebebner, Angewandte Geoinformatik 2004. Heidelberg, Germany: Herbert Wichmann Verlag (in German).

Knief, W., Berndt, R.K., Gall, T., Hälterlein, B., Koop, B. & Struwe-Juhl, B. (1995). Die Brutvögel Schleswig-Holsteins – Rote Liste. Kiel, Germany: Landesamt für Naturschutz und Landschaftspflege Kiel (in German).

Landesamt für Naturschutz und Landschaftspflege Schleswig-Holstein (LANL) (1993). Landesweite Biotopkartierung – Kreis Nordfriesland. Kiel, Germany (in German).

Landesvermessungsamt Schleswig-Holstein (LVermA-SH) (2007a). Digitale Topographische Karte 1:25000 – Vorläufige Ausgabe (DTK25-V) of the Preußische Landesaufnahme 1878, pages 1518, 1519, 1617, 1618, 1619, 1717, 1718, and 1719.

Landesvermessungsamt Schleswig-Holstein (LVermA-SH) (2007b). Digitale Topographische Karte 1:25000 – Vorläufige Ausgabe (DTK25-V) of 2002, pages 1518, 1519, 1617, 1618, 1619, 1717, 1718, and 1719.

Lang, S. & Blaschke, T. (2007). Landschaftsanalyse mit GIS. Stuttgart, Germany: Ulmer Verlag (in German).

Lang, S. & Tiede, D. (2003). V-Late Extension für ArcGIS – vektorbasiertes Tool zur quantitativen Landschaftsstrukturanalyse. ESRI Anwenderkonferenz 2003 Innsbruck. Innsbruck, Austria: ESRI, CD-ROM (in German).

Link, P.M. & Schleupner, C. (2007). Agricultural land use changes in Eiderstedt: historic developments and future plans. Coastline Reports, 9, 197-206.

Manel, S., Dias, J.-M. & Ormerod, S.J. (1999). Comparing discriminant analysis, neural networks and logistic regression for predicting species distributions: a case study with a Himalayan river bird. Ecological Modelling, 120, 337-347.

Meier, D. (2001). Landschaftsentwicklung und Siedlungsgeschichte des Eiderstedter und Dithmarscher Küstengebietes als Teilregion des Nordseeküstenraumes, Teil 1 und 2. Bonn, Germany: Habelt Verlag (in German).

Morrison, M.L., Marcot, B.G. & Mannan, R.W. (1992). Wildlife-habitat relationships: concepts and applications. Madison, WI, University of Wisconsin Press.

Naturschutzbund Deutschland (NABU) (2004). Resolution NABU Landesvertreterversammlung: Eiderstedts Grünland muss erhalten bleiben! http://www.nabu.de (last visited June 15, 2007) (in German).

Newton, I. (2003). The Speciation and Biogeography of Birds. London, UK: Academic Press.

Powell, M., Accad, A. & Shapcott, A. (2005). Geographic information system (GIS) predictions of past, present habitat distribution and areas for re-introduction of the endangered subtropical rainforest shrub Triunia robusta (*Proteaceae*) from south-east Queensland Australia. Biological Conservation, 123, 165-175.

Schlüter, H. (1987). Der Natürlichkeitsgrad der Vegetation als Kriterium der ökologischen Stabilität der Landschaft. In A. Miyawaki (Ed.), Vegetation ecology and creation of new environments (pp. 93-102). Tokyo, Japan: Tokai University Press (in German).

Seoane J., Bustamante J. & Díaz-Delgado, R. (2004). Competing roles for landscape, vegetation, topography and climate in predictive models of bird distribution. Ecological Modelling, 171, 209-222.

Statistisches Amt für Hamburg und Schleswig-Holstein (Stat A Nord) (1950-2004). Statistische Berichte zur Landwirtschaft in Schleswig-Holstein auf Gemeindeebene, multiple volumes. Kiel, Germany (in German).

Thompson, S., Hazel, A., Bailey, N., Bayliss, J. & Lee, J.T. (2004). Identifying potential breeding sites for the stone curlew (*Burhinus oedicnemus*) in the UK. Journal for Nature Conservation, 12, 229-235.

Tiede, D. (2005). V-Late – Vector-based Landscape Analysis Tools. http://www.geo.sbg.ac.at/larg/vlate.htm

Weis, M. (2007). Entwicklung von Landschaftsleitbildern für multifunktionale ländliche Räume. Ein landschaftsökologischer Ansatz auf Basis multitemporaler Landnutzungsdaten sowie sozio-ökonomischer Nutzungsszenarien am Beispiel von Hinterzarten im Hochschwarzwald. Freiburg, Germany: Dissertation Universität Freiburg (in German).

Working Papers

Research Unit Sustainability and Global Change

Hamburg University and Centre for Marine and Atmospheric Science

Schleupner, C. and P.M. Link (2007), *Potential impacts on bird habitats in Eiderstedt (Schleswig-Holstein) caused by agricultural land use changes*, **FNU-138** (submitted)

Link, P.M. and C. Schleupner (2007), *Agricultural land use changes in Eiderstedt: historic developments and future plans*, **FNU-137** (submitted)

Anthoff, D., R.J. Nicholls and R.S.J. Tol (2007), *Global Sea Level Rise and Equity Weighting*, **FNU-136** (submitted)

Schleupner, C. (2007), *Wetland Distribution Modelling for Optimal Land Use Options in Europe*, **FNU-135** (submitted)

Mayor, K. and R.S.J. Tol (2007), *The Impact of the EU-US Open Skies Agreement on International Travel and Carbon Dioxide Emissions*, **FNU-134** (submitted)

Schneider, U.A., M. Obersteiner, and E. Schmid (2007), *Agricultural adaptation to climate policies and technical change*, **FNU-133** (submitted)

Lychnaras, V. and U.A. Schneider (2007), *Dynamic Economic Analysis of Perennial Energy Crops - Effects of the CAP Reform on Biomass Supply in Greece*, **FNU-132** (submitted)

Mayor, K. and R.S.J. Tol (2007), The Impact of the UK Aviation Tax on Carbon Dioxide Emissions and Visitor Numbers, **FNU-131** (submitted)

Ruane, F. and R.S.J. Tol (2007), *Refined (Successive) h-indices: An Application to Economics in the Republic of Ireland*, **FNU-130** (submitted)

Yohe, G.W., R.S.J. Tol and D. Murphy (2007), *On Setting Near-Term Climate Policy as the Dust Begins the Settle: The Legacy of the Stern Review*, **FNU-129** (forthcoming, *Energy & Environment*)

Maddison, D.J. and K. Rehdanz (2007), *Happiness over Space and Time*, **FNU-128** (submitted).

Anthoff, D. and R.S.J. Tol (2007), *On International Equity Weights and National Decision Making on Climate Change*, **FNU-127** (submitted).

de Bruin, K.C., R.B. Dellink and R.S.J. Tol (2007), *AD-DICE: An Implementation of Adaptation in the DICE Model*, **FNU-126** (submitted).

Tol, R.S.J. and G.W. Tol (2007), *The Stern Review: A Deconstruction*, **FNU-125** (submitted).

Keller, K., L.I. Miltich, A. Robinson and R.S.J. Tol (2007), *How Overconfident Are Current Projections of Anthropogenic Carbon Dioxide Emissions?*, **FNU-124** (submitted).

Cowie, A., U.A. Schneider and L. Montanarella (2006), *Potential synergies between existing multilateral environmental agreements in the implementation of Land Use, Land Use Change and Forestry activities*, **FNU-123** (submitted)

Kuik, O.J., B. Buchner, M. Catenacci, A. Goria, E. Karakaya and R.S.J. Tol (2006), *Methodological Aspects of Recent Climate Change Damage Cost Studies*, **FNU-122** (submitted)

Anthoff, D., C. Hepburn and R.S.J. Tol (2006), *Equity Weighting and the Marginal Damage Costs of Climate Change*, **FNU-121** (submitted)

Tol, R.S.J. (2006), *The Impact of a Carbon Tax on International Tourism*, **FNU-120** (*Transportation Research D: Transport and the Environment*, **12** (2), 129-142).

Rehdanz, K. and D.J. Maddison (2006), *Local Environmental Quality and Life Satisfaction in Germany*, **FNU-119** (submitted)

Tanaka, K., R.S.J. Tol, D. Rokityanskiy, B.C. O'Neill and M. Obersteiner (2006), *Evaluating Global Warming Potentials as Historical Temperature Proxies: An Application of ACC2 Inverse Calculation*, **FNU-118** (submitted)

Berrittella, M., K. Rehdanz and R.S.J. Tol (2006), *The Economic Impact of the South-North Water Transfer Project in China: A Computable General Equilibrium Analysis*, **FNU-117** (submitted)

Tol, R.S.J. (2006), *Why Worry about Climate Change? A Research Agenda*, **FNU-116** (submitted, *Review of Environmental Economics and Policy*)

Hamilton, J.M. and R.S.J. Tol (2006), *The Impact of Climate Change on Tourism in Germany, the UK and Ireland: A Simulation Study*, **FNU-115** (submitted, *Regional Environmental Change*)

Schwoon, M., F. Alkemade, K. Frenken and M.P. Hekkert (2006), *Flexible transition strategies towards future well-to-wheel chains: an evolutionary modelling approach*, **FNU-114** (submitted).

Ronneberger, K., L. Criscuolo, W. Knorr and R.S.J. Tol (2006), *KLUM@LPJ: Integrating dynamic land-use decisions into a dynamic global vegetation and crop growth model to assess the impacts of a changing climate. A feasibility study for Europe,* **FNU-113** (submitted)

Schwoon, M. (2006), *Learning-by-doing, Learning Spillovers and the Diffusion of Fuel Cell Vehicles*, **FNU-112** (submitted).

Strzepek, K.M., G.W. Yohe, R.S.J. Tol and M. Rosegrant (2006), *The Value of the High Aswan Dam to the Egyptian Economy*, **FNU-111** (submitted, *Ecological Economics*).

Schwoon, M. (2006), *A Tool to Optimize the Initial Distribution of Hydrogen Filling Stations*, **FNU-110** (*Transportation Research D: Transport and the Environment*, **12** (2), 70-82).

Tol, R.S.J., K.L. Ebi and G.W. Yohe (2006), *Infectious Disease, Development, and Climate Change: A Scenario Analysis*, **FNU-109** (forthcoming, *Environment and Development Economics*).

Lau, M.A. (2006), *An analysis of the travel motivation of tourists from the People's Republic of China,* **FNU-108** (submitted).

Lau, M.A. and R.S.J. Tol (2006), *The Chinese are coming – An analysis of the preferences of Chinese holiday makers at home and abroad*, **FNU-107** (submitted, *Tourism Management*).

Röckmann, C., R.S.J. Tol, U.A. Schneider, and M.A. St.John (2006), *Rebuilding the Eastern Baltic cod stock under environmental change - Part II: The economic viability of a marine protected area.* **FNU-106** (submitted)

Ronneberger, K., M. Berrittella, F. Bosello and R.S.J. Tol (2006), *KLUM@GTAP: Introducing biophysical aspects of land-use decisions into a general equilibrium model. A coupling experiment,* **FNU-105** (submitted).

Link, P.M. and Tol, R.S.J. (2006), *Economic impacts on key Barents Sea fisheries arising from changes in the strength of the Atlantic thermohaline circulation*, **FNU-104** (submitted).

Link, P.M. and Tol, R.S.J. (2006), *The Economic Impact of a Shutdown of the Thermohaline Circulation: An Application of FUND*, **FNU-103** (submitted).

Tol, R.S.J. (2006), *Integrated Assessment Modelling*, **FNU-102** (submitted).

Tol, R.S.J. (2006), *Carbon Dioxide Emission Scenarios for the USA*, **FNU-101** (submitted, *Energy Policy*).

Tol, R.S.J., S.W. Pacala and R.H. Socolow (2006), *Understanding Long-Term Energy Use and Carbon Dioxide Emissions in the USA*, **FNU-100** (submitted).

Sesabo, J.K, H. Lang and R.S.J. Tol (2006), *Perceived Attitude and Marine Protected Areas (MPAs) establishment: Why households' characteristics matters in Coastal resources conservation initiatives in Tanzania*, **FNU-99** (submitted).

Tol, R.S.J. (2006), *The Polluter Pays Principle and Cost-Benefit Analysis of Climate Change: An Application of* FUND, **FNU-98** (submitted, *Environmental and Resource Economics*)

Tol, R.S.J. and G.W. Yohe (2006), *The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test*, **FNU-97** (forthcoming, *Global Environmental Change*)

Berrittella, M., K. Rehdanz, R.Roson and R.S.J. Tol (2005), *The Economic Impact of Water Pricing: A Computable General Equilibrium Analysis*, **FNU-96** (submitted, *Water Policy*)

Sesabo, J.K. and R. S. J. Tol (2005), *Technical Efficiency and Small-scale Fishing Households in Tanzanian coastal Villages: An Empirical Analysis*, **FNU-95** (submitted)

Lau, M.A. (2005), *Adaptation to Sea-level Rise in the People's Republic of China – Assessing the Institutional Dimension of Alternative Organisational Frameworks*, **FNU-94** (submitted)

Berrittella, M., A.Y. Hoekstra, K. Rehdanz, R. Roson and R.S.J. Tol (2005), *The Economic Impact of Restricted Water Supply: A Computable General Equilibrium Analysis*, **FNU-93** (*Water Research*, **42**, 1799-1813)

Tol, R.S.J. (2005), *Europe's Long Term Climate Target: A Critical Evaluation*, **FNU-92** (*Energy Policy*, **35** (1), 424-434)

Hamilton, J.M. (2005), *Coastal Landscape and the Hedonic Price of Accommodation*, **FNU-91** (submitted)

Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), *Climate Preferences and Destination Choice: A Segmentation Approach*, **FNU-90** (submitted)

Zhou, Y. and R.S.J. Tol (2005), *Valuing the Health Impacts from Particulate Air Pollution in Tianjin*, **FNU-89** (submitted)

Röckmann, C. (2005), *International Cooperation for Sustainable Fisheries in the Baltic Sea,* **FNU-88** (forthcoming, in Ehlers,P./Lagoni,R. (Eds.): *International Maritime Organisations and their Contribution towards a Sustainable Marine Development*.)

Ceronsky, M., D. Anthoff, C. Hepburn and R.S.J. Tol (2005), *Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response* **FNU-87** (submitted, *Climatic Change*)

Zandersen, M. and R.S.J. Tol (2005), *A Meta-analysis of Forest Recreation Values in Europe,* **FNU-86** (submitted, *Journal of Environmental Management*)

Heinzow, T., R.S.J. Tol and B. Brümmer (2005), Offshore-Windstromerzeugung in der Nordsee -eine ökonomische und ökologische Sackgasse? **FNU-85** (*Energiewirtschaftliche Tagesfragen*, **56** (3), 68-73)

Röckmann, C., U.A. Schneider, M.A. St.John, and R.S.J. Tol (2005), *Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints,* **FNU-84** (forthcoming, *Natural Resources Modelling*)

Tol, R.S.J. and G.W. Yohe (2005), *Infinite uncertainty, forgotten feedbacks, and cost-benefit analysis of climate policy,* **FNU-83** (submitted, *Climatic Change*)

Osmani, D. and R.S.J. Tol (2005), *The case of two self-enforcing international agreements for environmental protection*, **FNU-82** (submitted)

Schneider, U.A. and B.A. McCarl, (2005), *Appraising Agricultural Greenhouse Gas Mitigation Potentials: Effects of Alternative Assumptions*, **FNU-81** (submitted)

Zandersen, M., M. Termansen, and F.S. Jensen, (2005), *Valuing new forest sites over time: the case of afforestation and recreation in Denmark,* **FNU-80** (submitted)

Guillerminet, M.-L. and R.S.J. Tol (2005), *Decision making under catastrophic risk and learning: the case of the possible collapse of the West Antarctic Ice Sheet*, **FNU-79** (submitted, *Climatic Change*)

Nicholls, R.J., R.S.J. Tol and A.T. Vafeidis (2005), *Global estimates of the impact of a collapse of the West Antarctic Ice Sheet: An application of FUND,* **FNU-78** (submitted, *Climatic Change*)

Lonsdale, K., T.E. Downing, R.J. Nicholls, D. Parker, A.T. Vafeidis, R. Dawson and J.W. Hall (2005), *Plausible responses to the threat of rapid sea-level rise for the Thames Estuary,* **FNU-77** (submitted, *Climatic Change*)

Poumadère, M., C. Mays, G. Pfeifle with A.T. Vafeidis (2005), *Worst Case Scenario and Stakeholder Group Decision: A 5-6 Meter Sea Level Rise in the Rhone Delta, France,* **FNU-76** (submitted, *Climatic Change*)

Olsthoorn, A.A., P.E. van der Werff, L.M. Bouwer and D. Huitema (2005), *Neo-Atlantis: Dutch Responses to Five Meter Sea Level Rise,* **FNU-75** (submitted, *Climatic Change*)

Toth, F.L. and E. Hizsnyik (2005), *Managing the inconceivable: Participatory assessments of impacts and responses to extreme climate change*, **FNU-74** (submitted, *Climatic Change*)

Kasperson, R.E. M.T. Bohn and R. Goble (2005), *Assessing the risks of a future rapid large sea level rise: A review,* **FNU-73** (submitted, *Climatic Change*)

Schleupner, C. (2005), *Evaluation of coastal squeeze and beach reduction and its consequences for the Caribbean island Martinique,* **FNU-72** (submitted)

Schleupner, C. (2005), *Spatial Analysis As Tool for Sensitivity Assessment of Sea Level Rise Impacts on Martinique,* **FNU-71** (submitted)

Sesabo, J.K. and R.S.J. Tol (2005), *Factors affecting Income Strategies among households in Tanzanian Coastal Villages: Implication for Development-Conservation Initiatives,* **FNU-70** (submitted)

Fisher, B.S., G. Jakeman, H.M. Pant, M. Schwoon. and R.S.J. Tol (2005), *CHIMP: A Simple Population Model for Use in Integrated Assessment of Global Environmental Change*, **FNU-69** (*Integrated Assessment Journal*, **6** (3), 1-33)

Rehdanz, K. and R.S.J. Tol (2005), *A No Cap But Trade Proposal for Greenhouse Gas Emission Reduction Targets for Brazil, China and India*, **FNU-68** (submitted, *Climate Policy*)

Zhou, Y. and R.S.J. Tol (2005), *Water Use in China's Domestic, Industrial and Agricultural Sectors: An Empirical Analysis*, **FNU-67** (*Water Science and Technoloy: Water Supply*, **5** (6), 85-93)

Rehdanz, K. (2005), *Determinants of Residential Space Heating Expenditures in Germany*, **FNU-66** (forthcoming, *Energy Economics*)

Ronneberger, K., R.S.J. Tol and U.A. Schneider (2005), *KLUM: A Simple Model of Global Agricultural Land Use as a Coupling Tool of Economy and Vegetation,* **FNU-65** (submitted, *Climatic Change*)

Tol, R.S.J. (2005), *The Benefits of Greenhouse Gas Emission Reduction: An Application of* FUND, **FNU-64** (submitted, *Global Environmental Change*)

Röckmann, C., M.A. St.John, U.A. Schneider, F.W. Köster, F.W. and R.S.J. Tol (2006), *Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions,* **FNU-63-revised** (*Fisheries Research,* **85**, 1-13)

Letsoalo, A., J. Blignaut, T. de Wet, M. de Wit, S. Hess, R.S.J. Tol and J. van Heerden (2005), *Triple Dividends of Water Consumption Charges in South Africa*, **FNU-62** (forthcoming, *Water Resources Research*)

Zandersen, M., Termansen, M., Jensen,F.S. (2005), *Benefit Transfer over Time of Ecosystem Values: the Case of Forest Recreation,* **FNU-61** (submitted)

Rehdanz, K., Jung, M., Tol, R.S.J. and Wetzel, P. (2005), *Ocean Carbon Sinks and International Climate Policy*, **FNU-60** (*Energy Policy*, **34**, 3516-3526)

Schwoon, M. (2005), *Simulating the Adoption of Fuel Cell Vehicles*, **FNU-59** (submitted)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2005), *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study*, **FNU-58** (submitted)

Bosello, F., R. Roson and R.S.J. Tol (2004), *Economy-wide estimates of the implications of climate change: Human health*, **FNU-57** (*Ecological Economics,* **58**, 579-591)

Hamilton, J.M. and M.A. Lau (2004) *The role of climate information in tourist destination choice decision-making,* **FNU-56** (forthcoming, Gössling, S. and C.M. Hall (eds.), Tourism and Global Environmental Change. London: Routledge)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), *The impact of climate on holiday destination choice*, **FNU-55** (*Climatic Change*, **76** (3-4), 389-406)

Bigano, A., J.M. Hamilton, M. Lau, R.S.J. Tol and Y. Zhou (2004), *A global database of domestic and international tourist numbers at national and subnational level*, **FNU-54** (forthcoming, *International Journal of Tourism Research*)

Susandi, A. and R.S.J. Tol (2004), *Impact of international emission reduction on energy and forestry sector of Indonesia*, **FNU-53** (submitted)

Hamilton, J.M. and R.S.J. Tol (2004), *The Impact of Climate Change on Tourism and Recreation*, **FNU-52** (forthcoming, Schlesinger et al. (eds.), Cambridge University Press)

Schneider, U.A. (2004), *Land Use Decision Modelling with Soil Status Dependent Emission Rates*, **FNU-51** (submitted)

Link, P.M., U.A. Schneider and R.S.J. Tol (2004), *Economic impacts of changes in fish population dynamics: the role of the fishermen's harvesting strategies*, **FNU-50** (submitted)

Berritella, M., A. Bigano, R. Roson and R.S.J. Tol (2004), *A General Equilibrium Analysis of Climate Change Impacts on Tourism*, **FNU-49** (*Tourism Management*, **27** (5), 913-924)

Tol, R.S.J. (2004), *The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of* FUND, **FNU-48** (forthcoming, *Mitigation and Adaptation Strategies for Global Change*)

Erdil, E. and Yetkiner, I.H. (2004), *A Panel Data Approach for Income-Health Causality,* **FNU-47**

Tol, R.S.J. (2004), *Multi-Gas Emission Reduction for Climate Change Policy: An Application of* FUND, **FNU-46** (forthcoming, *Energy Journal*)

Tol, R.S.J. (2004), *Exchange Rates and Climate Change: An Application of* FUND*,* **FNU-45** (*Climatic Change*, **75**, 59-80)

Gaitan, B., Tol, R.S.J, and Yetkiner, I. Hakan (2004), *The Hotelling's Rule Revisited in a Dynamic General Equilibrium Model*, **FNU-44** (submitted)

Rehdanz, K. and Tol, R.S.J (2004), *On Multi-Period Allocation of Tradable Emission Permits*, **FNU-43** (submitted)

Link, P.M. and Tol, R.S.J. (2004), *Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: An Application of* FUND, **FNU-42** (*Portuguese Economic Journal*, **3**, 99-114)

Zhou, Y. and Tol, R.S.J. (2004), *Evaluating the costs of desalination and water transport,* **FNU-41** (*Water Resources Research,* **41** (3), W03003)

Lau, M. (2004), *Küstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg,***FNU-40** (*Coastline Reports*, Issue 1, pp.213-224.)

Rehdanz, K. and Maddison, D. (2004), *The Amenity Value of Climate to German Households*, **FNU-39** (submitted)

Bosello, F., Lazzarin, M., Roson, R. and Tol, R.S.J. (2004), *Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise*, **FNU-38** (submitted, *Environmental and Resource Economics*)

Schwoon, M. and Tol, R.S.J. (2004), *Optimal CO_2-abatement with socio-economic inertia and induced technological change*, **FNU-37** (submitted, *Energy Journal*)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2004), *The Effects of Climate Change on International Tourism,* **FNU-36** (*Climate Research*, **29**, 255-268)

Hansen, O. and R.S.J. Tol (2003), *A Refined Inglehart Index of Materialism and Postmaterialism*, **FNU-35** (submitted)

Heinzow, T. and R.S.J. Tol (2003), *Prediction of Crop Yields across four Climate Zones in Germany: An Artificial Neural Network Approach,* **FNU-34** (submitted, *Climate Research*)

Tol, R.S.J. (2003), *Adaptation and Mitigation: Trade-offs in Substance and Methods,* **FNU-33** (*Environmental Science and Policy*, **8** (6), 572-578)

Tol, R.S.J. and T. Heinzow (2003), *Estimates of the External and Sustainability Costs of Climate Change*, **FNU-32** (submitted)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2003), *Climate change and international tourism: a simulation study,* **FNU-31** (*Global Environmental Change,* **15** (3), 253-266)

Link, P.M. and R.S.J. Tol (2003), *Economic impacts of changes in population dynamics of fish on the fisheries in the Barents Sea*, **FNU-30** (*ICES Journal of Marine Science*, **63** (4), 611-625)

Link, P.M. (2003), *Auswirkungen populationsdynamischer Veränderungen in Fischbeständen auf die Fischereiwirtschaft in der Barentssee*, **FNU-29** (*Essener Geographische Arbeiten*, **35**, 179-202)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – An Assessment of Structural Impacts on Decision-making Processes*, **FNU-28** (*Ocean & Coastal Management*, No. 48 (2005), pp. 115-159.)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – A Unique Approach?*, **FNU-27** (*China Environment Series,* Issue 6, pp. 120-124; http://www.wilsoncenter.org/topics/pubs/7-commentaries.pdf)

Roson, R. and R.S.J. Tol (2003), *An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem: A Comment*, **FNU-26** (*Integrated Assessment,* **6** (1), 75-82)

Yetkiner, I.H. (2003), *Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration*, **FNU-25**

Yetkiner, I.H. (2003), *A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions*, **FNU-24**

Schneider, U.A. and B.A. McCarl (2003), *Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry*, **FNU-23** (submitted)

Zhou, Y. and Tol, R.S.J. (2003), *The Implications of Desalination to Water Resources in China - an Economic Perspective*, **FNU-22** (*Desalination*, **163** (4), 225-240)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), *The Cyclical Advancement of Drastic Technologies*, **FNU-21**

Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness*, **FNU-20** (*Ecological Economics,* **52** 111-125)

Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, **FNU-19** (*Energy Policy,* **33** (16), 2064-2074).

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), *Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation*, **FNU-18** (submitted).

Schneider, U.A. and B.A. McCarl (2003), *Implications of a Carbon Based Energy Tax for U.S. Agriculture*, **FNU-17** (submitted).

Tol, R.S.J. (2002), *Climate, Development, and Malaria: An Application of* FUND, **FNU-16** (forthcoming, *Climatic Change*).

Hamilton, J.M. (2003), *Climate and the Destination Choice of German Tourists,* **FNU-15** (revised and submitted).

Tol, R.S.J. (2002), *Technology Protocols for Climate Change: An Application of* FUND, **FNU-14** (*Climate Policy,* **4**, 269-287).

Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (forthcoming, *Climatic Change*).

Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of* FUND, **FNU-12** (forthcoming, *Environment and Development Economics*).

Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (*Ecological Economics*, **54**, 397-416).

Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (*Resource and Energy Economics*, **27**, 1-17).

Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages – A Legal and Economic Assessment*, **FNU-9** (*Energy Policy*, **32** (9), 1109-1130).

Yohe, G. and R.S.J. Tol (2001), *Indicators for Social and Economic Coping Capacity – Moving Toward a Working Definition of Adaptive Capacity*, **FNU-8** (*Global Environmental Change*, **12** (1), 25-40).

Kemfert, C., W. Lise and R.S.J. Tol (2001), *Games of Climate Change with International Trade*, **FNU-7** (*Environmental and Resource Economics*, **28**, 209-232).

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), *Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions*, **FNU-6** (submitted).

Kemfert, C. and R.S.J. Tol (2001), *Equity, International Trade and Climate Policy*, **FNU-5** (*International Environmental Agreements*, **2**, 23-48).

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), *Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions*, **FNU-4**. (*Pollution Atmosphérique – Numéro Spécial: Combien Vaut l'Air Propre?*, 155-179).

Tol, R.S.J. (2000), *How Large is the Uncertainty about Climate Change?*, **FNU-3** (*Climatic Change*, **56** (3), 265-289).

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), *How Much Damage Will Climate Change Do? Recent Estimates*, **FNU-2** (*World Economics,* **1** (4), 179-206)

Lise, W. and R.S.J. Tol (2000), *Impact of Climate on Tourism Demand*, **FNU-1** (*Climatic Change*, **55** (4), 429-449).