Ecological Modelling 331 (2016) 160–172

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Using the Ecopath approach for environmental impact assessment—A case study analysis

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ARTICLE INFO

Article history:
Available online 21 October 2015

Keywords:
Ecospace
Natura 2000
Environmental impact assessment
Industrial area
Road
Wind turbine generator

ABSTRACT

If a proposed project or plan is likely to negatively impact a Natura 2000 site, it must undergo an environmental impact assessment. Article 6.3 of the Habitats Directive (92/43/EEC) clearly specifies the assessment procedure.

This case study presents the assessment of three different projects that might negatively affect a Natura 2000 site in Germany. The impacts of an industrial area, construction of a road and a wind power generator were investigated using the Ecospace habitat capacity model. The short and long-term effects of these projects were analyzed, considering cumulative effects of habitat loss, noise and light pollution on the environment. By applying Ecospace two alternatives were explored for each proposed project, thereby identifying the strategy with least impact and also determining the environmental damage and how it can be compensated.

This study demonstrates that the Ecopath approach is the number one tool for environmental management in the European Union, as it can deliver the results that are needed to meet all legal requirements and it is also able to solve 'on-going' problems, for example assessment of cumulative and in-combination effects, identification of effective mitigation measures and providing clear, objective conclusions

1. Introduction

The Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC) shall protect species and habitats in the European Union. Nature Conservation is leaning on two measures, namely the Natura 2000 network of protected habitats and specific species protection that covers over a 1000 animal and plant species, which are listed in the Directives.

In Germany, a total of 4606 Natura 2000 areas had been established until 2014, covering an area of 5.4 million hectares (BfN, 2014). However, today only 28% of protected habitats and 25% of listed species are in a good condition (Dröschmeister et al., 2014). The major threats to biodiversity are known, like agriculture and habitat loss (Dröschmeister et al., 2014). To ensure that project or plans that cause habitat loss do not negatively affect a Natura 2000 site, they must undergo an environmental impact assessment. Article 6.3 of the Habitats Directive (92/43/EEC) clearly specifies the assessment procedure. First, a project is screened and if it can be concluded that there are no negative impacts, authorization may be granted. If negative effects cannot be ruled out, the project has to undergo an appropriate assessment. Here, all cumulative and in-combination effects with other projects have to be assessed and effective mitigation measures might be identified. Only if all negative effects can be ruled out or removed, the authorization may be granted. Apparently the majority (61%) of projects in Germany has been screened out, as "they posed no problem" and in Baden-Württemberg even 90% of projects were not relevant to Natura 2000 areas (Sundseth and Roth, 2013). The Minister of Environment stated in 2007 that "to date the nature conservation Directives have not been prevented any single significant economic development in Germany" (Sundseth and Roth, 2013). Obviously there is a conflict, as nature is mostly in a bad condition, but projects are said to pose no problem in Germany. It is unclear, why the impacts of many projects do not need to be assessed, but there is also a problem with the projects that do undergo an impact assessment. There are "on-going" problems with the environmental impact assessment procedure that might explain the bad environmental condition in Germany (Sundseth and Roth, 2013). Major problems were: poor quality of impact assessments, clear conclusions were missing, assessment of cumulative effects and in-combination effects was needed, mitigation measures were not identified properly, lack of skills or knowledge, lack of understanding key terms, lack of sufficient ecological data and the assessment of significance of impacts was too subjective (Sundseth and Roth, 2013). In Germany, the Federal Agency for Nature Conservation recommends the application of case conventions, which are spatial benchmarks, to assess the

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http://dx.doi.org/10.1016/j.ecolmodel.2015.09.022
0304-3800/

significance of impacts (Lambrecht and Trautner, 2007; Lambrecht et al., 2004). However, there is reasonable doubt that these spatial benchmarks are able to assess significant impacts (Fretzer and Möckel, 2015). Thus, they do not fulfil the requirements of the European Court of Justice (Fretzer and Möckel, 2015). The Court required certainty that a Natura 2000 site is not negatively affected, if authorization of a project is granted.

Habitat loss is a major threat to biodiversity in Germany and the German government is willing to reduce habitat loss (Dröschmeister et al., 2014), but more projects are planned that might cause further degradation of protected species and habitats.

According to the Federal Ministry of Transport, Germany has one of the densest road networks in Europe, covering 12,917 km of autobahn plus 39,400 km of state roads. Germany will further invest approximately 47 billion Euros in road construction projects over the next years (BMVI, 2010). More roads are being built and planned, as traffic is expected to further increase in the next decade (BMVI, 2010). The ecological effects of roads cause substantial damage to wildlife (Forman and Alexander, 1998; Spellerberg, 1998) and also affect endangered species, such as the red kite (*Milvus milvus*) (Mammen et al., 2014).

Renewable energy projects, such as wind farms, also threaten biodiversity by negatively affecting bats and birds, for example the red kite (*M. milvus*) (Mammen et al., 2014). In 2014 over 24,000 wind energy plants had been raised in Germany and the importance of energy from wind power is expected to increase by 143% in 2030 (BMWI, 2014).

If there is overwhelming public interest, all these projects may be realized even if there are negative effects on Natura 2000 sites (Article 6.4, Habitats Directive). The environment in Germany is not in a good condition (Dröschmeister et al., 2014) and further biodiversity loss will affect the next generations (Essl et al., 2015), so we have to find a way to plan and build these projects without causing environmental damage. These projects need to be assessed properly and if negative effects occur, they have to be effectively compensated on site.

There is "still a real need to set up a more systematic consistent framework" for impact assessment in Europe (Sundseth and Roth, 2013) and other promoted frameworks haven't been able to fill this gap (Fretzer and Möckel, 2015; Masden et al., 2010; Villarroya and Puig, 2010).

This approach presents Ecospace and its habitat capacity feature as a feasible framework for impact assessment. By using a simple, theoretical model that presents one protected habitat type, such as the woodrush beech forest (listed habitat type No. 9110) and two protected species, such as the stag beetle (*Lucanus cervus*) and the red kite (*M. milvus*), three different types of projects are investigated here: a planned industrial area, construction of a road and a wind turbine generator. By applying Ecospace, two alternatives were explored for each proposed project, thereby identifying the strategy with least impact and also determining the environmental damage and how it can be compensated. This study will demonstrate that the Ecopath approach, in particular, the Ecospace/habitat capacity feature, is able to solve common on-going problems with the environmental impact assessment procedure and hence, improve the implementation of both Directives.

2. Material and method

2.1. Ecopath, Ecosim and Ecospace

Ecopath is a quantitative modelling technique that describes the biomass flows between functional groups (Christensen et al., 2005). A functional group can consist of a single species or a population, a taxonomic family or several taxa, for example, both single species (e.g. red kite, *M. milvus*) and broad taxonomic groupings (e.g. gastropods) form functional groups. Through Ecosim, dynamical simulations of the mass-balanced Ecopath model over a defined time period can be run to investigate alternative management policies, for example hunting or fishing policies (Christensen et al., 2005). The consumption rates in Ecosim, Q_{ij}, are based on the 'foraging arena' concept, which states that not all individuals are equally vulnerable to predation. The biomass (B_i) is divided into a vulnerable and an invulnerable component (Christensen et al., 2005). These vulnerabilities are assigned to each predator–prey relationship during the process of model calibration. The set of differential equations is solved in Ecosim using an Adams–Bashford integration routine (Christensen et al., 2005). Ecospace represents biomass dynamics over two-dimensional space and time (Walters et al., 1999). The user can develop a two-dimensional map by defining rectangular grids of cells. Each cell is assigned to a different habitat type and within each cell, the biomass densities are treated as homogenous for trophic interactions, fishing or hunting and movement calculations (Walters et al., 1999). Emigration flows occur from the four surrounding cells that border the cell. Emigration rates to the "outside world" (i.e. to the space outside the boundaries of the grid) are assumed to be compensated by immigration rates from that outside world (Walters et al., 1999).

Based on the spatial-temporal model of Ecospace, the habitat capacity approach drives the foraging capacity of functional groups from the cumulative impacts of multiple environmental factors, for example temperature, noise and light pollution (Christensen et al., 2014). For each environmental factor, an environmental preference function is defined and for each grid cell, a specific habitat capacity value is defined as the product of the environmental preference values. Thus, the biomass distribution for the functional group is derived as a function of the environmental preference functions combined with food web interactions and anthropogenic effects, like hunting or fishing.

2.2. Model development

The Ecospace scenarios performed in this study are based on a published basic Ecopath model that describes a terrestrial ecosystem before the construction of a planned industrial area (Fretzer and Möckel, 2015). This theoretical Ecopath model consists of 31 functional groups and includes a protected species, the stag beetle (*Lucanus cervus*) and a listed habitat type (a woodrush beech forest, habitat type no. 9110) that are both protected by the Habitats Directive and a species protected by the Birds Directive (red kite, *M. milvus*) and agricultural areas, cultivating grass. 11% of the modelled area is covered by woodrush beech forest, 42% is covered by grassland and the remaining 47% of the area are covered by forest, which also includes the stag beetle habitats (Fig. 1). All functional groups in the forest habitat also appear in the stag beetle habitat. The functional groups of the woodrush beech forest habitat are labelled with its habitat number, such as 9110 (Table 1).

The agricultural area is depending on several factors like the application of fertilizer, pesticides, herbicides, irrigation and number of harvests (Benton et al., 2002) and therefore, the agricultural functional groups were highly simplified, only representing a harvest and faunal group for each crop (Fretzer and Möckel, 2015). However, for an appropriate impact assessment the agricultural food web and its impacts on site should be part of the model.

2.3. Data input

The development of the input parameters for the different functional groups will not be repeated here, but all details were already published (Fretzer and Möckel, 2015). The Ecospace analysis is

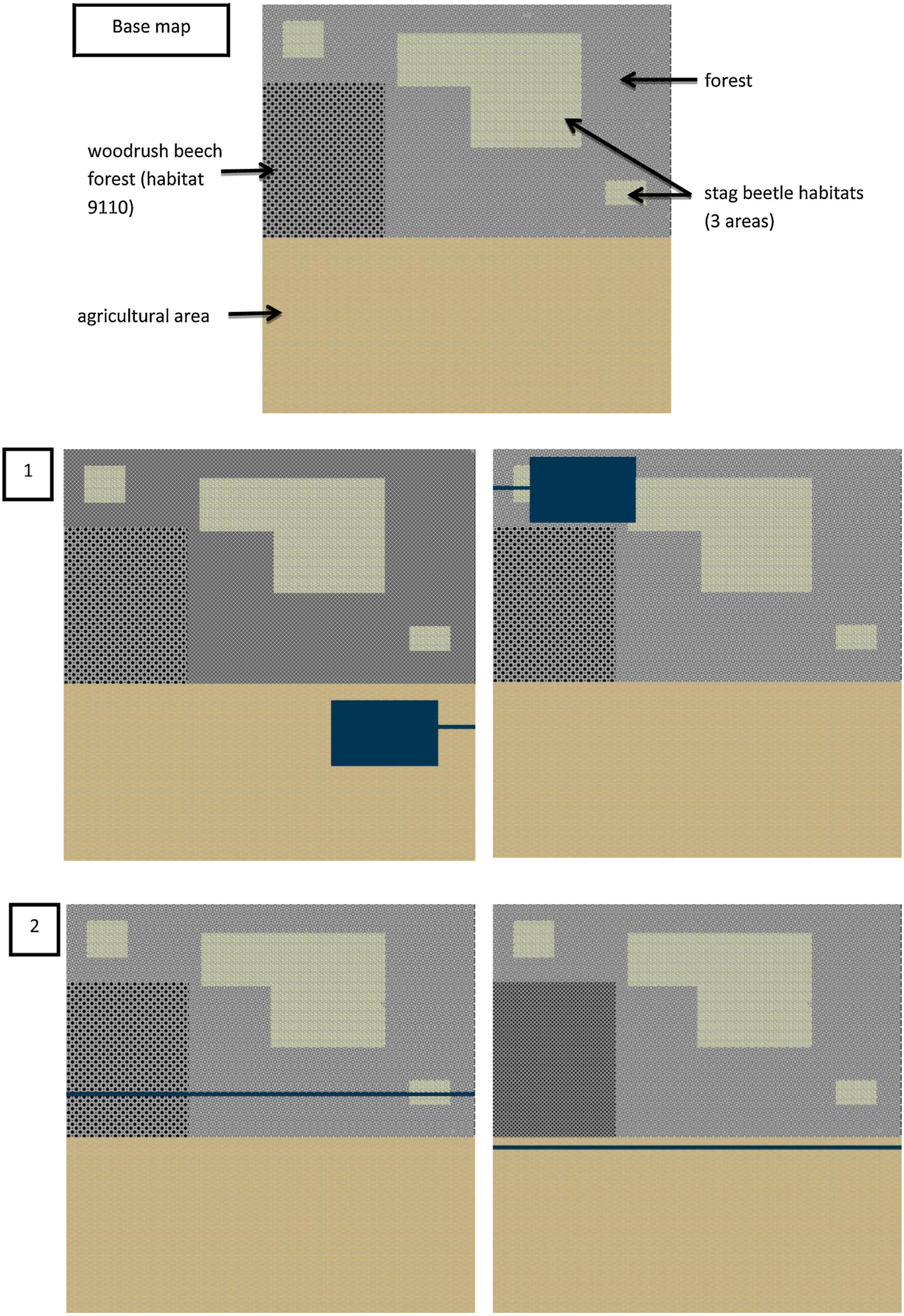

Fig. 1. The Ecospace base map is used for testing the different scenarios (projects in dark color) of a planned industrial area (1), the construction of a road (2) and a wind turbine (3) in locations A (left) and B (right); The wind turbine generator system consisted of the wind turbine and its access road. All projects were identical in size in both scenarios A and B.

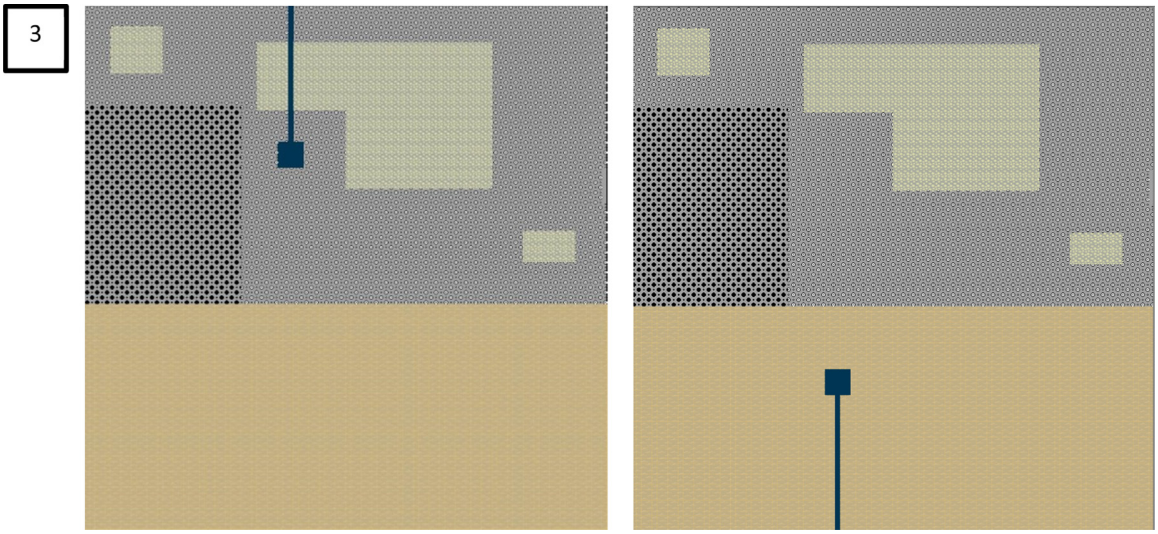

Fig. 1. (*Continued*).

Table 1
Presenting the changes in biomass of all functional groups in the model under the Ecospace scenarios presented in Fig. 1. The percentage change in biomass was calculated by comparing the different scenarios to the basic ecosystem presented in the base map (Fig. 1).

Scenarios:	1A		1B		2A		2B		3A		3B	
Time period:	short	long	short	long	short	long	short	long	short	long	short	long
Group name:	% change in biomass											
Wild boar	415.2	2340.4	94.7	287.8	152.6	531.1	403.2	2229.0	174.7	627.4	197.4	627.4
Red deer	−6.5	−12.5	−13.9	−10.8	−50.0	−45.8	−32.5	−31.8	−5.6	−8.0	−4.5	−8.0
Roe deer	−1.6	3.9	−12.5	−10.6	−41.4	−41.4	−20.0	−17.9	−2.8	0.1	−0.6	0.1
Fox	14.0	49.3	28.3	20.4	−8.2	−12.2	−8.6	−9.4	38.7	26.5	40.0	26.5
Red kite	238.5	735.7	100.6	182.3	71.3	106.7	522.2	540.1	140.6	195.3	137.4	195.3
Birds	−27.8	2028.4	27.4	226.6	56.9	33.6	51.1	58.3	−1.7	−13.6	−9.9	−13.6
Small mammals forest	79.9	47.5	113.5	91.9	−4.9	−0.5	3.9	−1.0	109.7	105.4	109.7	105.4
Small mammals 9110	207.7	3560.9	122.2	549.8	87.4	813.3	86.2	694.0	209.8	1360.8	223.6	1360.8
Butterflies forest	0.7	−32.2	−6.7	−17.8	−23.0	−21.2	−7.2	−11.0	−7.2	−2.8	−8.1	−2.8
Butterflies 9110	15.3	46.6	−28.8	−70.0	−9.2	30.6	−36.0	−46.4	11.5	49.0	19.3	49.0
Hymenopterans forest	2.2	15.4	0.4	2.6	−46.9	−45.7	−47.8	−48.5	0.9	1.7	1.5	1.7
Hymenopterans 9110	−0.9	1.0	−1.7	−4.0	2.4	3.5	−1.4	1.3	−1.8	−2.4	−1.4	−2.4
Stag beetle	389.8	397.8	387.9	402.6	318.5	331.9	317.7	329.3	388.5	411.2	388.5	411.2
Beetles forest	0.6	582.5	−0.7	39.2	−24.8	−26.1	−19.0	−21.7	−1.8	−1.7	−2.3	−1.7
Beetles 9110	484.6	23732479.4	−8.5	484044.5	−11.9	32.5	−25.6	62.0	24.4	68.6	32.7	68.6
Bugs forest	1.6	69.0	−4.2	−7.5	−32.3	−28.3	−29.7	−25.0	−4.7	−4.6	−5.3	−4.6
Bugs 9110	17.2	235.6	−28.1	−47.4	0.4	69.5	−40.7	262.2	−1.0	29.3	9.1	29.3
Arachnids forest	2.6	−10.3	−3.7	−18.4	−52.7	−51.9	−47.2	−46.7	−4.4	−3.7	−4.7	−3.7
Arachnids 9110	16.5	28311.8	−4.0	1130.4	71.0	214.3	588.8	304816.0	6.5	20.0	14.9	20.0
Worms forest	−22.4	−23.9	−20.0	−19.6	−26.1	−28.6	−26.5	−29.7	−21.8	−21.2	−21.3	−21.2
Worms 9110	−1.7	−0.8	−2.1	1.2	40.5	73.9	39.6	74.0	38.2	69.4	38.4	69.4
Ground vegetation forest	−0.5	2.1	−2.6	0.4	−44.8	−41.6	−49.0	−48.8	−1.2	−1.0	−0.6	−1.0
Ground vegetation 9110	−4.1	−7.2	2.0	8.9	6.2	5.1	4.4	9.1	−3.4	−6.7	−3.9	−6.7
Trees forest	0.1	0.1	0.1	0.2	−1.8	−3.1	−1.9	−3.1	0.1	0.2	0.1	0.2
Trees 9110	−0.01	0.1	−0.1	−1.0	−0.1	−0.6	−0.2	−1.0	−0.1	0.0	0.0	0.0
Grassland fauna	0.7	0.8	−0.9	−1.0	−0.6	−0.7	0.9	0.3	−0.2	0.0	0.1	0.0
Grassland harvest	−0.3	0.02	0.5	0.7	0.4	0.6	−2.3	−1.7	0.1	0.0	−0.1	0.0
Dead wood forest	0.01	0.3	0.1	0.3	−1.3	−2.3	−1.6	−2.6	0.1	0.2	0.1	0.2
Dead wood 9110	−0.2	−0.5	0.4	0.0	0.7	−0.2	0.5	−0.1	−0.2	−0.6	−0.3	−0.6
Detritus	0.1	1.3	0.4	0.7	−3.0	−4.8	−3.9	−6.1	0.3	0.2	0.2	0.2
Detritus 9110	−0.1	28.7	0.1	1.6	42.7	73.8	42.1	73.7	40.9	69.6	40.9	69.6
Total system biomass	0.1	37.9	0.2	1.0	−0.9	−1.5	−1.2	−1.6	1.1	1.8	1.1	1.8
Woodrush beech forest (all 9110 groups in Table combined)	−0.04	225.1	−0.1	4.0	6.0	10.0	5.9	12.3	5.7	9.9	5.7	9.9

Scenario 1: planned industrial area in locations A and B, Scenario 2: planned road construction in location A and B, scenario 3: planned wind turbine generator and its access road in locations A and B. *Short:* presenting short-term results after 5 years, *Long:* presenting long-term results and the scenario was run for ten years.

based on fitting procedure that was performed to demonstrate that Ecospace is more appropriate for an environmental impact analysis than spatial benchmarks (Fretzer, 2015). The vulnerability settings identified in this fitting procedure were also applied here (Fretzer, 2015).

The red kite is protected in the European Union, however it is heavily impacted by humans (Knott et al., 2009; Mougeot et al., 2011) and in Saxony–Anhalt, Germany the main recorded causes of death were electrocution (35%), collisions with traffic (22%), birds were shot dead (17%) and poisoned (3%) (Mammen et al., 2014).

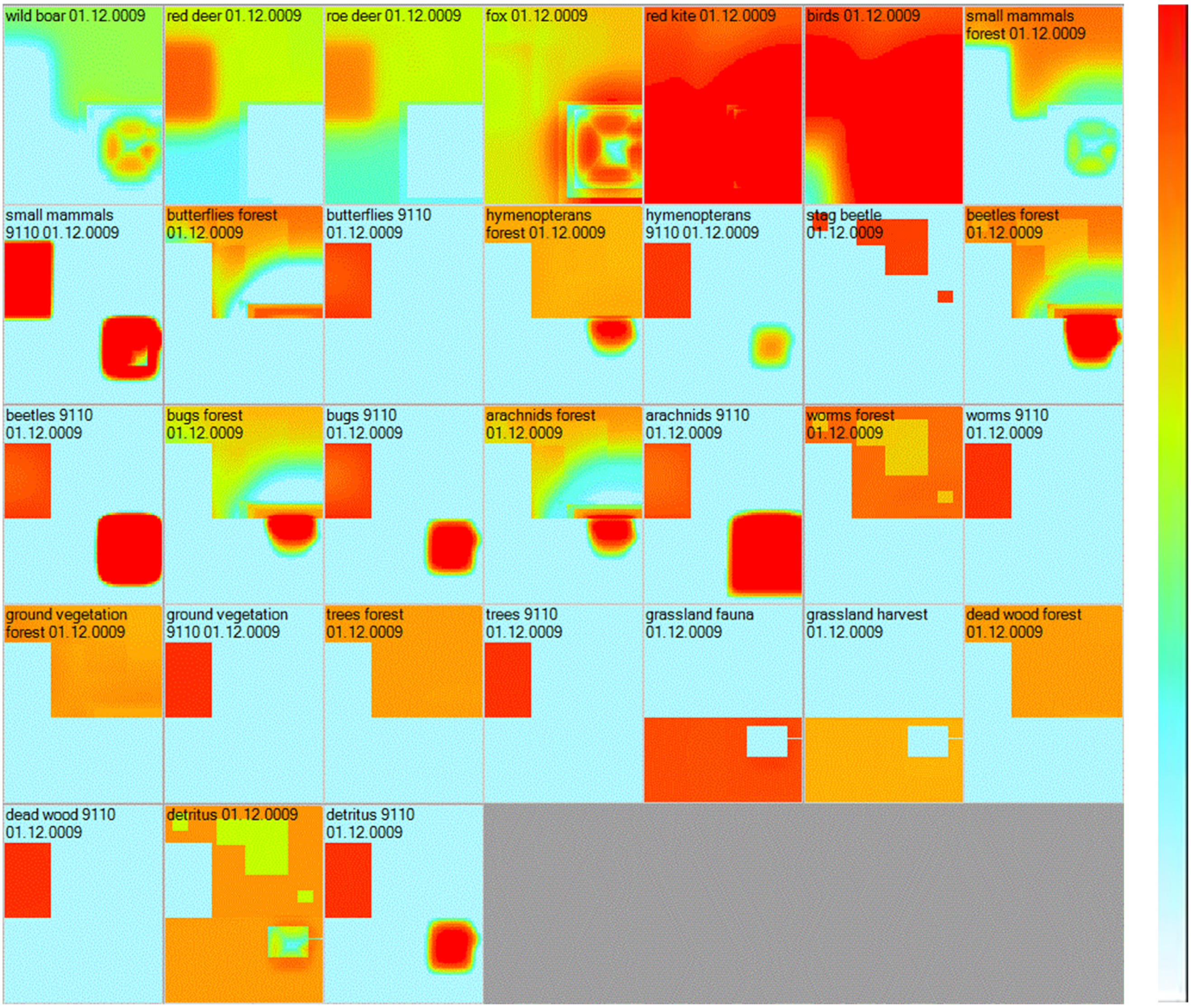

Fig. 2. Presenting relative spatial biomass distributions of all functional groups after the construction of an industrial area in location A (see Fig. 1). Biomass values ranged from high (red) to low (blue and white). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Primary and secondary poisoning are main threats to red kite populations (Knott et al., 2009; Mammen et al., 2014; Mougeot et al., 2011). It was assumed that these statistics represent the composition of total mortality of red kite in Germany. These anthropogenic impacts are included here in this model by considering the loss of red kite biomass as hunting bag. Thus, 20% of the input biomass (0.003 t km^{-2} per year) was assigned to the hunting fleet, which equals 0.0006 t km^{-2}.

A new Ecospace base map was developed, which allowed testing different scenarios on a larger spatial scale (Fig. 1). In each scenario, the impacts of the planned projects were analyzed in two locations, investigating short- and long-term impacts, after five and ten years, respectively. Different environmental impacts were included in the different scenarios, like habitat loss, noise and light pollution. Pollution and chemical contamination, caused by industry or roads, were not investigated here.

The feeding behavior of birds and mammals is impacted by pollutants like noise and light at night (Bird et al., 2004; Francis et al., 2012; Longcore and Rich, 2004; Siemers and Schaub, 2011). Thus, the foraging response of these functional groups was presented by a sigmoid curve, with zero feeding at highest disturbance level and normalizing feeding rates with increasing distance. Invertebrates are also able to detect light (Longcore and Rich, 2004) and noise (Morley et al., 2014), but it was unclear if their feeding behavior was affected.

It was assumed that the impact of light and noise pollution was equally strong and the noise effect of the wind turbine was assumed to be far less, ranging from 0 to 3, than the impact of roads or the industrial area, where the pollution ranged from 0 to a maximum value of 5 (Fig. 2). It was also included in the habitat capacity feature that the forests diminished the extend of the pollution zone, which was greater in grassland.

In contrast to the planned industrial area, the road and wind turbine cause death through collisions and take faunal biomass out of the system. Thus, they were implemented in the scenarios as additional fleets.

Road collision data was found on the internet for wild boar, red and roe deer for the entire area of Hesse in Germany (Hessen, 2014), which presents 16,632 km of road. Based on this data, the biomass killed by road collisions was estimated with 0.005 t km^{-2} for wild boar, 0.001 t km^{-2} for red deer and 0.011 t km^{-2} for roe deer. These values represent between 1.2 and 2.9% of the input biomass of these groups and therefore, a mean value of 2% was applied to estimate the fox biomass killed by road collisions with 0.0002 t km^{-2}. A study

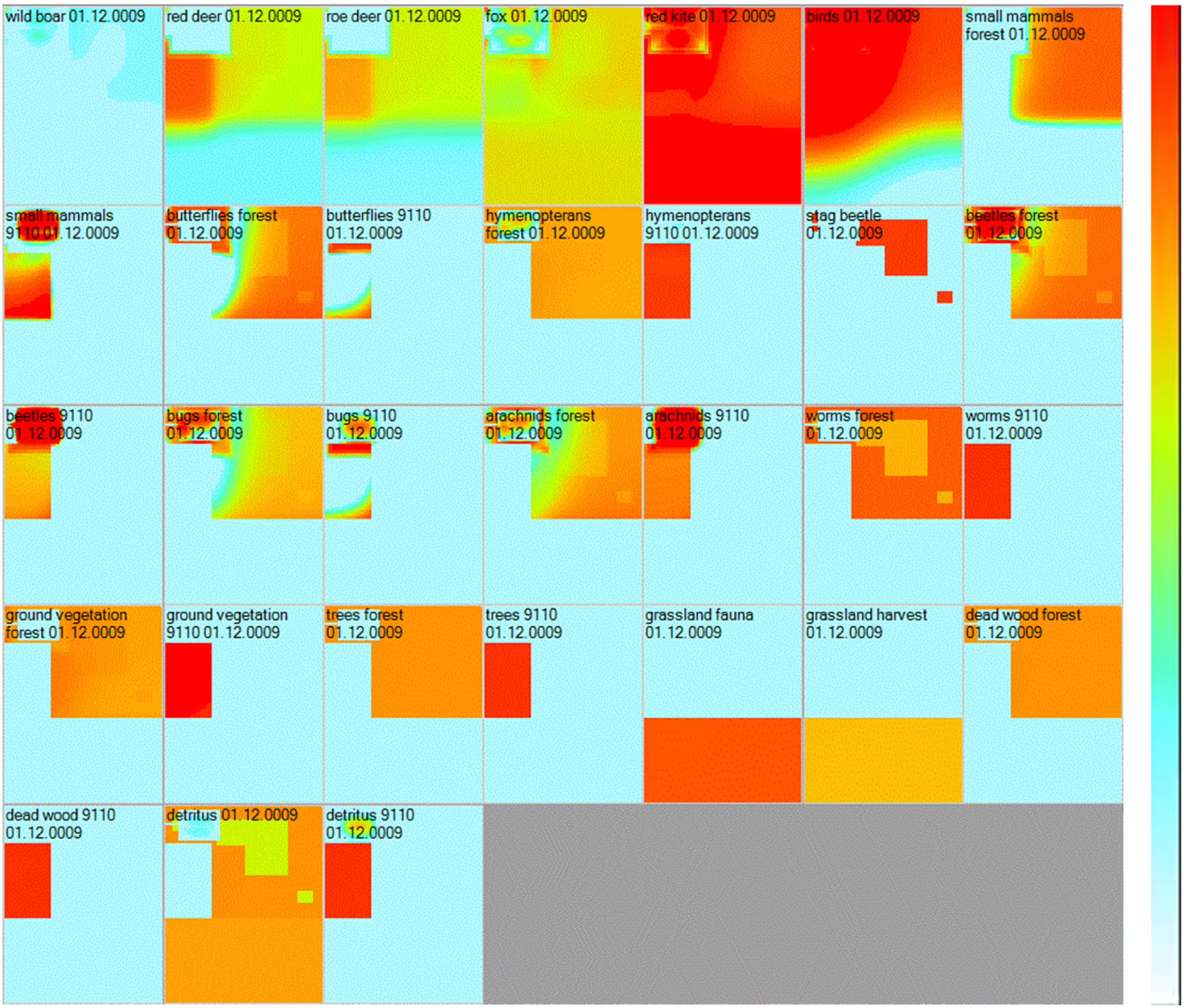

Fig. 3. Presenting relative spatial biomass distributions of all functional groups after the construction of an industrial area in location B (see Fig. 1). Biomass values ranged from high (red) to low (blue and white). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in Germany demonstrated that 22% of dead red kites were killed by traffic collisions (Mammen et al., 2014) and thus, it was assumed in this model that 22% of the input biomass of red kite were killed in road accidents (model entry 0.0007 t km^{-2}). The road kill of birds varied in the literature (Erritzoe et al., 2003; Pickles, 1942) and here, it was assumed that 7.3% of the bird biomass were killed on the road (Pickles, 1942), which equaled 0.006 t km^{-2} per year.

In scenario A (Fig. 1), the road runs through the forest habitat (60% of road length), the woodrush beech forest (30% of total road length) and the stag beetle habitat (10% of road length). All functional groups in the forest habitat also appear in the stag beetle habitat. The road kill biomass values of these different functional groups were adjusted according to the percentage of total road crossing their habitat. Based on data from the literature, it was estimated that 2.9% of input biomass of small mammal groups were killed by traffic (Pickles, 1942) (adjusted model entry: small mammals forest: 0.012 t km^{-2}, small mammals 9110: 0.001 t km^{-2}). Flying insects are also killed by traffic and a study found that 7% of adult butterflies were killed by vehicles on a road (Munguira and Thomas, 1991). This percentage was also used in this model to estimate the annual biomass of all flying insect groups killed on roads. The model data were: butterflies forest 0.085 t km^{-2}, butterflies 9110: 0.040 t km^{-2}, hymenopterans forest 0.201 t km^{-2}, hymenopterans 9110: 0.089 t km^{-2}, stag beetle: 0.0003 t km^{-2}, beetles forest: 0.052 t km^{-2}, beetles 9110: 0.023 t km^{-2}, bugs forest: 0.004 t km^{-2} and bugs 9110: 0.011 t km^{-2} per year.

It was difficult to estimate the biomass of agricultural fauna killed on road, as this functional group includes species of different taxa (Fretzer and Möckel, 2015). However, based on data found in literature (Erritzoe et al., 2003; Munguira and Thomas, 1991; Pickles, 1942) it seemed appropriate to estimate the road kill biomass of agricultural fauna with 7% of input biomass, which equaled 2.470 t km^{-2} per year.

After the road kill was added to the basic Ecopath model, the model needed to be rebalanced and the P/B ratio of four insect groups were increased by 10% to reach a new state of equilibrium. These insect groups were stag beetle and in the woodrush beech forest habitat (habitat 9110) the groups of beetles, bugs and hymenopterans.

Two scenarios were tested here (Fig. 1). In location A the road passes through two forest habitats, whereas in position B it crosses agricultural land from East to West. In location A, it was assumed that only functional groups inhabiting the area are killed by road and thus, the road mortality of agricultural fauna was set to zero. In

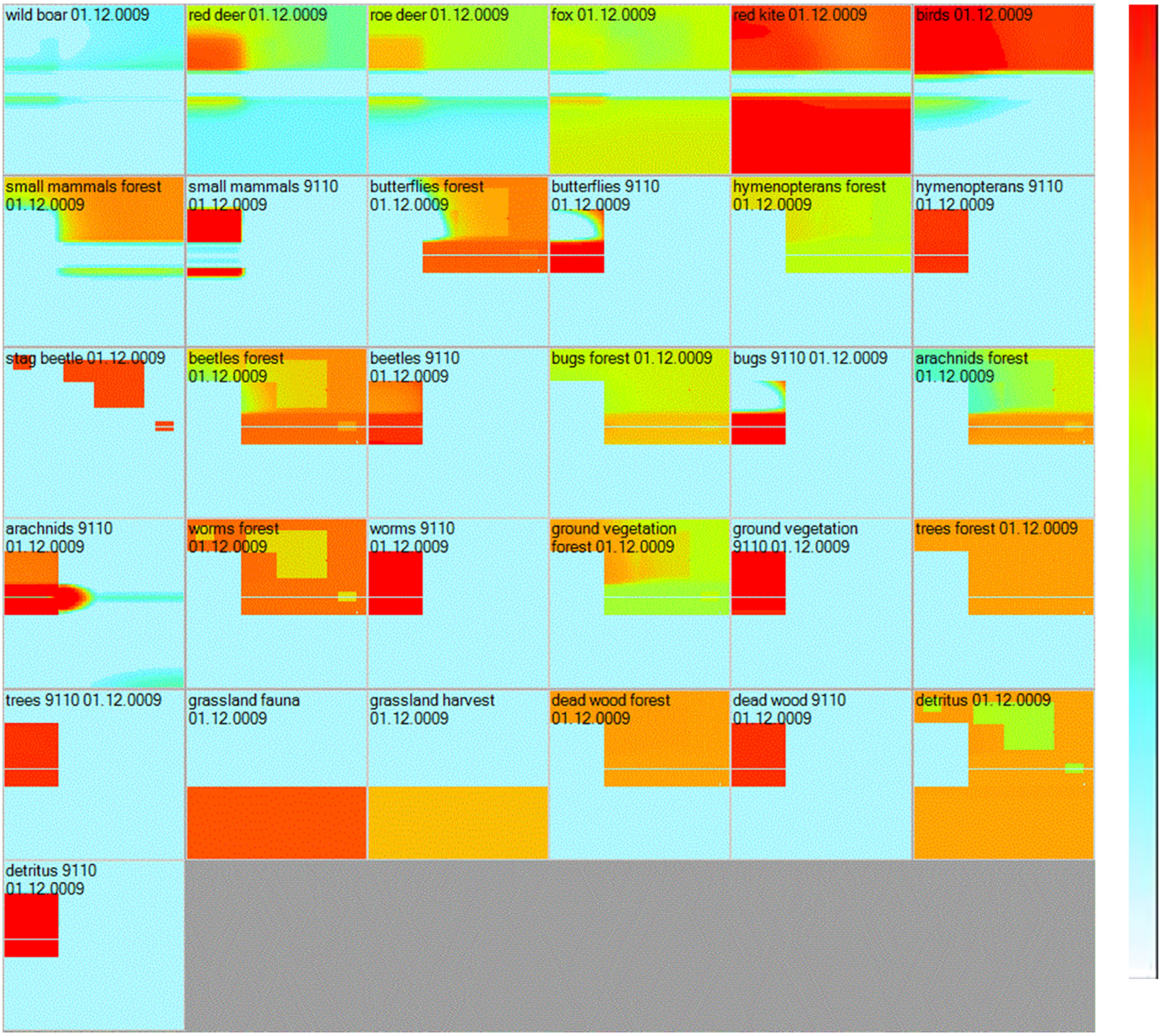

Fig. 4. Presenting relative spatial biomass distributions of all functional groups after the construction of a road in location A (see Fig. 1). Biomass values ranged from high (red) to low (blue and white). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

location B, only agricultural fauna was directly affected by road collisions and thus, the road mortality of functional groups inhabiting the forest habitats was set to zero.

Wind turbines vary in size and in this model, a rather large turbine was built with approx. 90 m in diameter. The height of the tower was not specified in this two-dimensional Ecospace scenario. An additional fleet was added to the basic Ecopath model to consider the biomasses lost to wind turbine collisions. It was assumed here that 2% of the initial red kite biomass was lost to turbine collisions. This seemed to be appropriate, as 2% of dead red kite were found dead because of collisions (Mammen et al., 2014). Birds were also affected by the wind turbine collisions in this model. Collisions per turbine vary greatly depending on its location and season (Drewitt and Langston, 2006). Thus, it was assumed that 0.5% of the initial bird biomass were affected by collisions, which is slightly less than birds getting killed by traffic. Consequently, the bird biomass lost to turbine collision is fairly high, but is accepted here for testing a worst case scenario in Ecospace. After adding the additional fleet wind turbine, the Ecopath model was still in balance and no further adjustments were made. It was assumed here that mortality caused by wind turbine was constant over time, even though studies demonstrated that birds adapt to wind farms and fly around the area, thus avoiding collisions (Desholm, 2006). It was also assumed that only mammal and bird groups were disturbed by the noise of the wind turbine, which affected their feeding behavior, showing a sigmoid feeding response that reached a normal level with increasing distance from the turbine. The wind turbine causes less noise than a busy road or industrial area and thus, the noise levels ranged from 0 to a maximum value of 3.

There is no reason, why insect groups should be repelled by the tower and tower foundation of the wind turbine and so, this area is accessible by insect groups in the Ecospace model.

3. Results and discussion

3.1. Industrial area

After the construction of the industrial area in location A (Fig. 1), the mammal and bird groups will avoid the area being driven away by light and noise pollution. The low abundance of predators

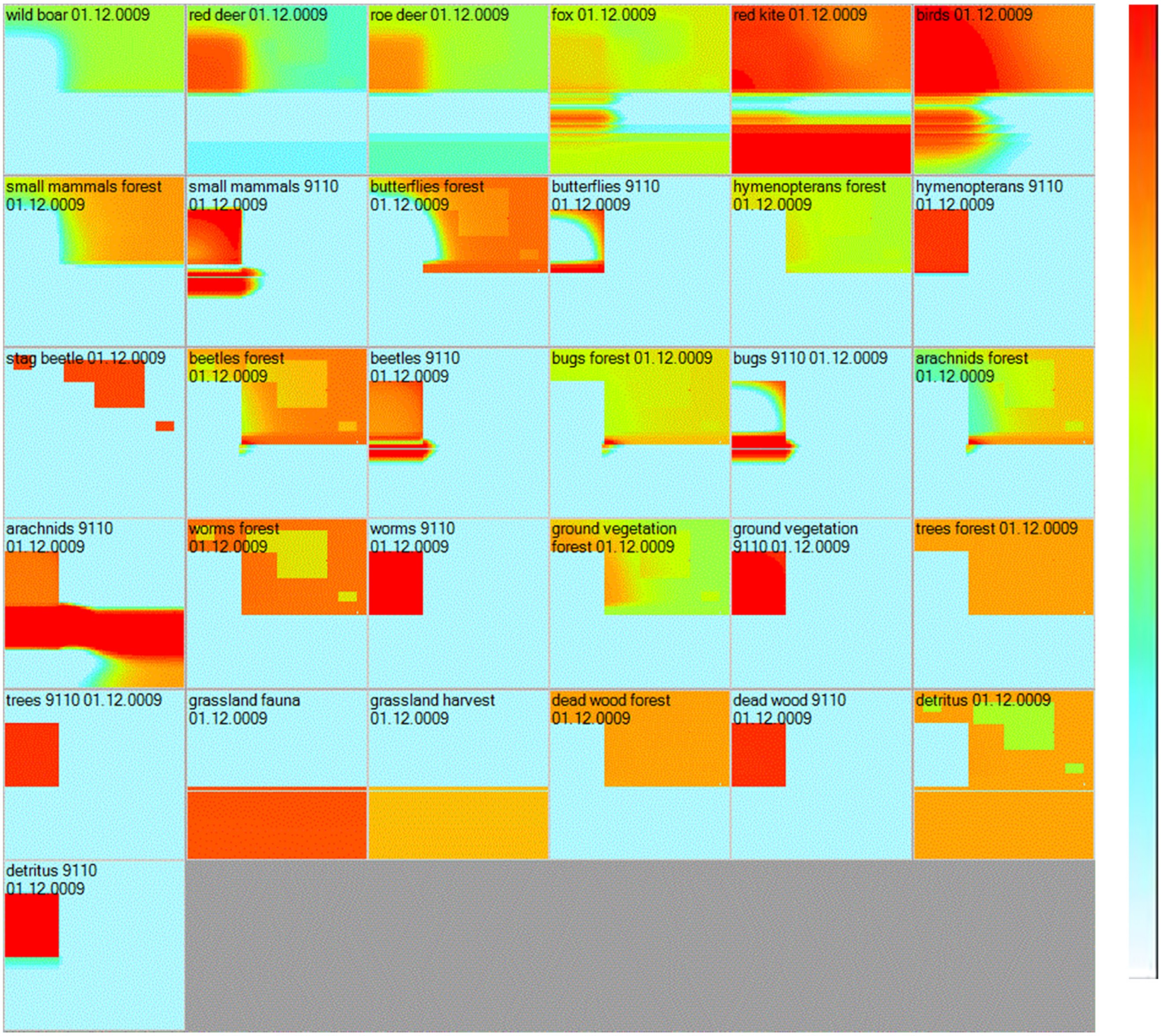

Fig. 5. Presenting relative spatial biomass distributions of all functional groups after the construction of a road in location B (see Fig. 1). Biomass values ranged from high (red) to low (blue and white). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

however, will lead to an increase in their insect prey groups. All groups of butterflies, beetles, bugs and arachnids will increase (Table 1). Even if the industrial area is so far away from the woodrush beech forest habitat, that it is not directly affected by pollution, this protected habitat type will decrease in the short-term by 0.04% compared to the ecosystem development without industrial area (Fig. 2). In the short-term the abundances of the stag beetle and red kite populations will increase and this increase will continue in the long-term (Table 1). In the long-term most groups will increase in this scenario, but red deer, the groups of butterflies and arachnids in the forest habitat, both worm groups and the ground vegetation in the woodrush beech forest habitat will decrease (Table 1). By looking at the spatial dispersal of all functional groups, it becomes apparent that the ecosystem will establish a carnivorous food web in the industrial area, driven by carnivorous insect groups, mainly beetles and arachnids, which will occupy the area to avoid predators (Fig. 2). Carnivorous insect groups will use the area as new habitat with woodrush beech forest groups (9110 groups in Table 1) being more successful in occupying the area than insects from the forest habitat (Table 1). Herbivorous groups, like butterflies, are not able to profit from predator avoidance in the industrial area (Fig. 2), as there is no food available in the new habitat.

The carnivorous insect groups are able to attract predators, mainly small mammals from the woodrush beech forest and also wild boar and fox are attracted and slightly increase in the area (Fig. 2).

In location B, red and roe deer, the groups of butterflies, beetles, bugs, arachnids and worms will decrease shortly after the construction of the industrial area (Table 1). Even though there was no logging of woodrush beech forest, trees in this habitat will decrease by 0.1% (Table 1). The protected forest habitat type will slightly decrease, whereas stag beetle and red kite show an increase in abundance (Table 1). Overall, the whole ecosystem will slightly grow by 0.2% in total biomass (Table 1).

In the long-term, the whole ecosystem will increase by 1% and the woodrush beech forest habitat will show an increase of 4% in biomass (Table 1). Also stag beetle and red kite will increase (Table 1). These results however have to be treated with caution. The industrial area in location B will lead to a very strong increase in beetle groups, which will result in higher abundances of their predators, e.g. small mammals of the woodrush beech forest (Table 1, Fig. 3). However, the small mammals from the forest are not able to benefit from this new prey source and even though some prey groups, like bugs, will migrate to the industrial area, there overall trend is negative (Table 1), which means the industrial habitat is not able to compensate the negative effects caused by pollution. The mammal and bird groups show a positive long-term trend, but their spatial distribution is limited by the impacts of the industrial area (Fig. 3). Even though wild boar increases compared to the basic ecosystem development, it will only occupy outer forest areas, which demonstrates a decrease in its favorable habitat (Fig. 3). Red and roe deer avoid the industrial area and mainly inhabit the woodrush beech forest, only the fox shows a greater spatial dispersal and also appears in the industrial area being attracted to the group small mammals 9110 (Fig. 3).

3.1.1. Which location should be chosen for the industrial area?

Location A

In location A, only 7 groups will show a negative response in the long-term compared to 11 groups in location B. In location A, the ecosystem in the model will establish a carnivorous food web, driven by carnivorous insects that will occupy the area to avoid their predators (Fig. 2). This new industrial habitat food web will boost other functional groups in the ecosystem, including the stag beetle, the red kite and the functional groups of the woodrush beech forest habitat (Table 1). However, the ecosystem can only establish the new industrial food web, if the animals are welcome and supported by the management. There must be no pesticides and rodenticides in the ecosystem, including the agricultural area, which has to be crossed to access the new industrial habitat. If appropriate structures are provided, like trees or food plants, the positive effect might expand to herbivorous groups and might even lead to a higher biomass push. Under these circumstances, the industrial area will cause no environmental damage and no compensation measures will be necessary.

If the farmer will not be willing to sell, it is important to point out, that even with a reduction of the grassland area, the harvest will slightly increase in the long-term by 0.02%. In this scenario A, the farmer will not lose any money, as the harvest biomass is not decreasing (Table 1).

To monitor the effect of the industrial area on the ecosystem, it is recommended to keep a check on the keystone species, such as the functional groups of both bird groups, beetles in the forest and fox (Fretzer, 2015). It is also suggested that the industrial area is sampled to examine and sustain the carnivorous food web in place.

3.2. Road

In location A, the road passes through forest, whereas in position B it crosses agricultural grassland (Fig. 1). The distance between these two alternative locations is small. Light and noise pollution in location B also affect the forest habitats.

At first glance, location A seems to be less destructive, as the total system biomass decreases by 0.9% after five years and in the long-term, it will decrease by −1.5%, whereas in location B, the total decline in biomass is −1.2% and −1.6%, respectively.

In location A, red kite and stag beetle will increase (Table 1). The functional groups of the woodrush beech forest (groups 9110 in Table 1) will also lead to an increase of the protected habitat by 6% and will even further increase with time (Table 1). This biomass increase is mainly driven by carnivorous and omnivorous insect groups that are attracted to the pollution zones near the roads, where they are safe from predation (Fig. 4). The foundations of the ecosystems are affected by the road construction in location A, as ground vegetation in forest declines by more than 40% and

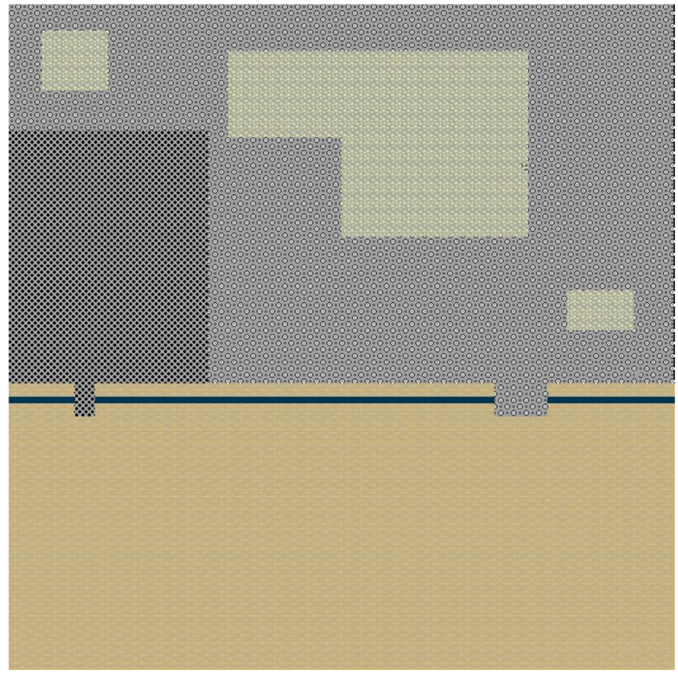

Fig. 6. Exhibiting the overpasses that were developed to compensate the ecological damage cause by the road construction in scenario B (see Fig. 1). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tree biomasses decline in both forest habitats (Table 1). The mammal groups, but wild boar increase in biomass (Table 1). Both bird groups increase in biomass. However, these effects are accompanied by indirect habitat loss and habitat fragmentation (Fig. 4). The area south of the road is less attractive or cannot be reached, as the road acts as barrier (Fig. 4). This is very obvious for birds, wild boar, red and roe deer (Fig. 4).

In location A, all faunal groups but worms and arachnids were affected by road kill. After a decade, the total annual road kill amounts to 5.98 $\mathrm{t\,km^{-2}}$ per year, compared to 0.157 $\mathrm{t\,km^{-2}}$ taken by hunters. According to Ecospace, red kite are killed by the road with an annual road kill of 0.006 $\mathrm{t\,km^{-2}}$ per year and birds lose 0.004 $\mathrm{t\,km^{-2}}$ per year in road collisions.

In location B, the positive trend for the protected species and habitat are similar to location A, as stag beetle and red kite and the woodrush beech forest habitat increase in biomass (Table 1). Even though the road crosses only agricultural land, the ground vegetation in the forest habitat decreases by almost 50% in biomass and also trees decline slightly (Table 1). The road construction in location B will boost the biomasses of arachnids and worms in the woodrush beech forest habitat (Table 1). In the long-term, other groups in the protected forest habitat will revive, like beetles 9110 and bugs 9110 (Table 1). These groups, and in particular arachnids 9110, will use the road as corridor to enlarge their suitable habitat, spreading eastwards along the road (Fig. 5). Interestingly, the insectivorous groups in the forest habitat, for example bugs forest and arachnids forest, cannot profit in the same way (Fig. 5). In location B the road will also lead to habitat fragmentation and will act as a barrier for wild boar, red and roe deer and small mammals forest (Fig. 5). Small mammals 9110 are also present south of the road, but the group pays a high price for road crossing by losing 0.01 $\mathrm{t\,km^{-2}}$ per year to road collisions. The small mammals in the forest avoid the area south of the road (Fig. 4) and their biomass lost to road collisions is rather small with 0.00002 $\mathrm{t\,km^{-2}}$. In the long-term, the total annual biomass lost to road collisions in location B amounts to 0.175 $\mathrm{t\,km^{-2}}$.

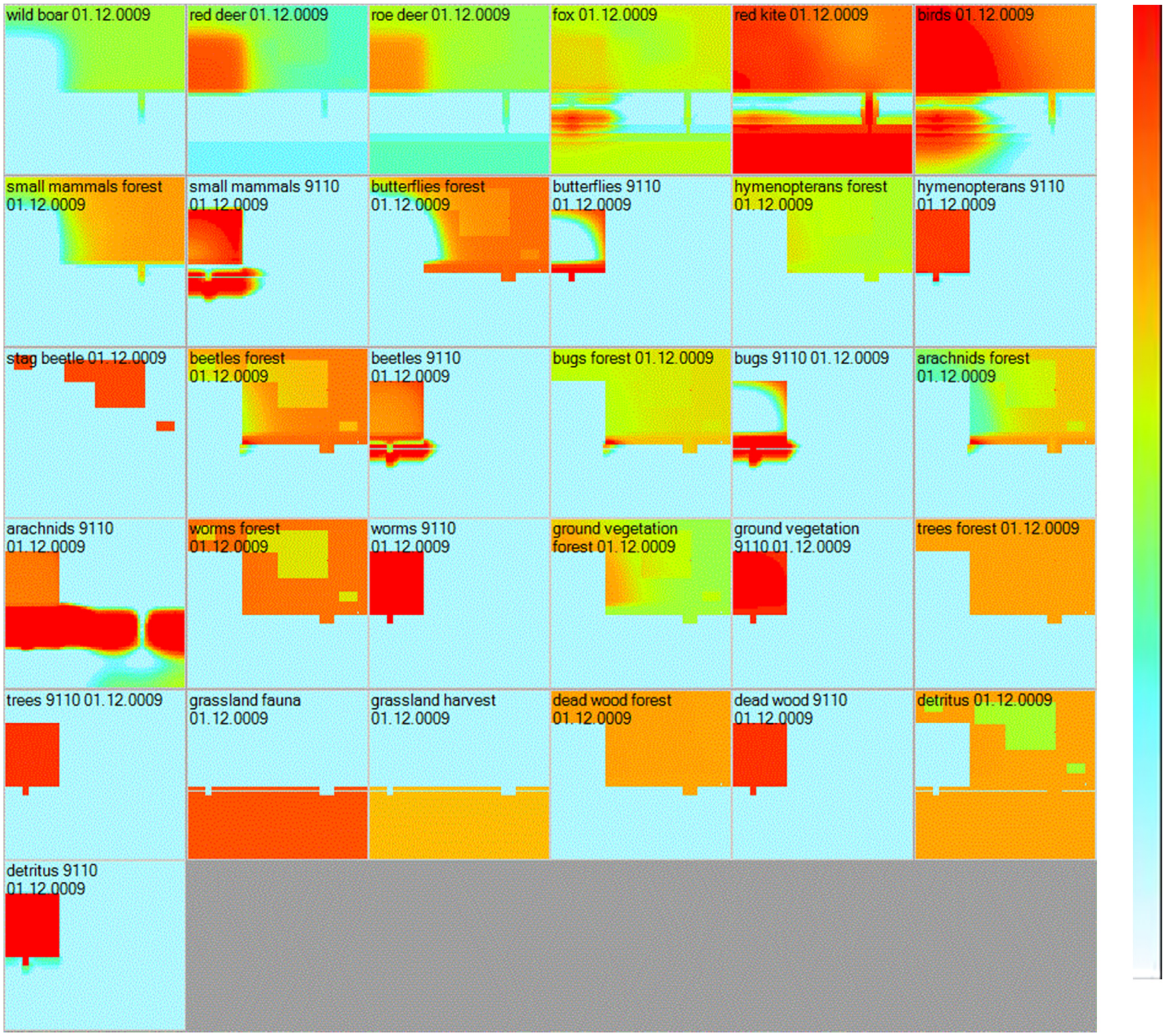

Fig. 7. Presenting relative spatial biomass distributions of all functional groups after the construction of two overpasses (Fig. 6) to compensate the damage cause by the construction of a road in location B (see Fig. 1). Biomass values ranged from high (red) to low (blue and white). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.2.1. Which location should be chosen for road construction? Location B.

There is a high tendency of 9110 groups to cross the road (Fig. 5), accompanied by a high biomass lost to road kill. In location A the road kill of red kite is 20 times higher than in location B. On the other hand, a road in location B kills ten times more birds than in location A. In location A birds are also affected by the barrier effect of the road. Thus, the two main problems with road construction are road kill and habitat fragmentation. Both effects are more severe in location A and thus, location B is less destructive for the environment.

How can we compensate the damage caused by the road in location B? Two different overpasses are developed in this scenario (Fig. 6). A small overpass connects the woodrush beech forest to the agricultural land. A second overpass connects the forest to the grassland area, but here noise and light pollution are diminished, for example by walls that are built on the left and right sides of the overpass (Fig. 6). In contrast to the small overpass of the woodrush beech forest, the silent and dark overpass is able to overcome the problem of habitat fragmentation (Fig. 7). Mammals and birds, in particular red kite, show a high biomass in the large overpass. Thus, it can be concluded that large overpasses without or minimized disturbance are suitable to connect habitat fragments and avoid the separation of populations. However, for some functional groups, like wild boar or deer, the overpass is not ideal, as their biomasses only increase slightly (Fig. 7). These results are in line with findings in the literature, which recommend large overpasses with minimum width of 30 to 50 m (Forman and Alexander, 1998), which means that the overpass in the model is not wide enough for some groups. It is known that birds cross barriers less often, when barriers are noisy (St. Clair, 2003). This can also be observed in the model, where red kite and birds avoid the small noisy overpass (Fig. 7). The small overpass in this Ecospace model was not able to overcome habitat fragmentation.

Road mortality depends on species behavior (Guinard et al., 2012) and environmental factors, like season (Hodson and Snow, 1965; Shuttleworth, 2001) and traffic intensity (Mazerolle, 2004). The mortality can be alleviated by speed reduction (Forman and

Alexander, 1998) and adjusting traffic intensity to breeding seasons.

The easiest way to find out, if the compensation measure was effective, is a long-term monitoring program covering the overpass and the area south of the woodrush beech forest, which present the most obvious changes in abundances.

3.3. Wind turbine

The construction of the wind turbine generator does not affect the spatial relative biomass distribution of the functional groups in the models, as we see for example in Fig. 5. Thus, the results are only shortly described here.

In location A, the wind turbine was placed in the middle of the forest, adjacent to the woodrush beech forest and stag beetle habitat (Fig. 1). All mammal and bird groups avoided the small area of the wind turbine and the invertebrate groups of the forest habitat only presented small biomass levels in turbine habitat. No group was attracted by this new habitat.

In location B, the wind turbine was placed on grassland. The biomass distributions of mammals and birds were driven by avoidance behavior resulting in very low biomasses at the turbine location. The bird group showed high biomass levels in the forest habitat, which decreased to lower biomass levels in the agricultural habitat. The turbine location is in the outer range of the ideal bird biomass distribution and so, only a small fraction of bird biomass is affected by the wind turbine in this scenario. The only group accumulating near the wind turbine was arachnids 9110, all other groups did not respond to the wind turbine habitat in any way.

3.3.1. Which location should be chosen for wind energy production? Location B

First of all, wind farms are mostly effective in open, exposed areas (Drewitt and Langston, 2006), which clearly favors location B in this study. However, the ecological long-term effects of the wind turbines in locations A and B do not differ (Table 1). There were no negative impacts on the protected species, such as the red kite and stag beetle, and on the woodrush beech forest habitat, which is represented by 9110 groups in Table 1. Birds will decrease by 13% over time, which is concerning. However, the biomass lost to collision is rather small with 0.00003 t km^{-2} per year. It is more likely that birds suffer from an increase in competitors, such as the groups of small mammals, which increase drastically in both forest habitats (Table 1). A food source, such as ground vegetation, decreases after the construction of the wind turbine (Table 1). Also, the fox increases in biomass, but it is unlikely that this predator is responsible for the decline in birds, as in the scenario of the industrial area fox and birds were able to increase at the same time (Table 1). Consequently, the main cause for bird losses might be that there is less food for birds and higher competition in this scenario. These effects can be easily compensated by planting and sustaining a major food source, such as the ground vegetation, in the area.

This bird loss can be compensated by further decreasing the impact of the wind turbine, for example adjusting the height of tower and blades, as birds seemed to be less disturbed by larger wind turbine generators (Hötker, 2006). Reducing mortality by applying light signals still needs more research, but it is known that changes in weather conditions and poor visibility enhance collision risk (Desholm, 2006). Also collision rates in migratory birds are higher in breeding seasons (Desholm, 2006). Thus, management can actively reduce bird mortality by considering these environmental factors and disable the turbine blades in times of bad environmental conditions. Surprisingly, even if collision mortality of birds is set to zero in location B, the biomasses of all groups will still be the same (Table 1). It should be mentioned that "no significant impacts on birds have been recorded at any of these wind farms" in UK (Drewitt and Langston, 2006), which is in line with the findings here, that collision mortality is not the main reason for bird decline.

To assess the effectiveness of these compensation measures, it is recommended to monitor ground vegetation and bird abundances in the forest areas.

4. Conclusions

If we really need more buildings, more roads and more wind turbine generators or even wind farms in Germany, it is absolutely essential to do a proper environmental impact assessment, as most protected habitats and species are not in a good condition (Dröschmeister et al., 2014). It was demonstrated here, how ecosystem models, in particular the habitat capacity feature in Ecospace, can be used to identify the project proposal that will cause least environmental damage (Table 1, Figs. 2–5). By applying this method, we can quantify the ecological damage and indicate effective compensation measures (Figs. 6 and 7), as well as appropriate monitoring programs. The Ecopath approach is able to assess scenarios that impact large areas, like construction of an industrial area (Figs. 2 and 3) or linear infrastructures, such as roads (Figs. 4 and 5) and even point pollution impacts caused by wind turbines (Table 1).

I would like to point out why this method is the appropriate "systematic consistent framework" (Sundseth and Roth, 2013) for managing Natura 2000 sites and for the assessment procedure.

For managing Natura 2000 sites, it is essential to define preservation goals and characteristic species of the area (Sundseth and Roth, 2013). Ecopath can identify the keystone species of the ecosystem according to their relative impact on the food web. It is important to assess the conservation status of a species. By applying Ecosim, the manager can identify if a species has reached a stable equilibrium state and in which direction it will develop in the future. It is required to determine tending strategies and the 'Mixed Trophic Impact' routine in Ecopath identifies the strategy that will lead to a biomass increase of the characteristic species. Ecospace can assess mitigation measures and also identify if a proposed project will affect the coherence of the Natura 2000 network. It was mentioned that "there is however no 'one size fits all' model for managing Natura 2000 sites" (Sundseth and Roth, 2013). But there is! Ecospace has no upper or lower space limits and can be used for terrestrial and aquatic Natura 2000 sites.

There are common 'on-going' problems with the environmental impact assessment procedure related to Natura 2000 requirements (Sundseth and Roth, 2013) and I will explain how Ecopath, Ecosim and Ecospace can solve them. First, the poor quality of impact assessments is a big problem. It is common in Germany to use verbal argumentation or spatial benchmarks to determine the environmental impact of a planned project, but there are scientific doubts that these methods can detect ecological damage and protect Natura 2000 areas (Fretzer and Möckel, 2015). The Ecopath approach however, is based on verifiable mathematical equations and hence, it has a very high quality. It has been developed and used for over 30 years and applies the best science available in ecosystem research. This method is based on mathematical equations, uses the best knowledge in science for its input parameters and one can perform a sensitivity analysis to diminish uncertainty. Thus, impact assessments based on the Ecopath approach represent the best scientific research available, which is the scientific level requested by the European Court of Justice (European Court of Justice, 24.11.2011–C-404/09, Rn. 99).

Stake holders need clear conclusions and Ecospace can provide clear conclusions, as the method will determine the magnitude of change for each functional group, for example in the unit t km^{-2}.

It is a major problem to assess cumulative and in-combination effects, but as presented in this study, the habitat capacity model can assess multiple cumulative effects, like habitat loss, noise and light pollution, as well as hunting or road kill or collisions with wind turbines. Often mitigation measures are not identified properly, but Ecospace is able to test different scenarios and identify appropriate measures for mitigation and compensation (Fig. 7).

Another problem is the ineffectiveness of assessments regarding plans, but as shown here, the Ecopath approach can easily consider the impact of hunting, fishing, agricultural activities and other human related impacts. For this underlying basic Ecopath model, hunting kill was considered in Ecopath (Fretzer and Möckel, 2015) and a long-term hunting data set was used to calibrate the model (Fretzer, 2015) and determine the vulnerability settings used in the Ecospace scenarios here in Table 1.

There is also a lack of skills and knowledge, a lack of understanding of key terms and a lack of expertise and capacity in competent authority (Sundseth and Roth, 2013). The Ecopath manual and scientific publications are publicly available. The lack of capacity should be no problem, as it is easier and quicker to assess the results provided by Ecospace (Table 1) than following pages of verbal argumentation. It was also criticized that the assessment of significance of impacts was too subjective, but the model approach provides quick, easy to understand and objective results, for example the decrease or increase of biomass (Table 1).

The last problem mentioned here is the lack of sufficient ecological data (Sundseth and Roth, 2013). For the Ecopath approach more data is needed compared to other methods (Fretzer and Möckel, 2015). However, the European Court of Justice required the best scientific knowledge and to raise the bar to this standard, we need sufficient ecological data. As this theoretical study demonstrated, data from the literature can be applied for parameter calculations until better data is available. The local authorities have to monitor Natura 2000 sites and report to the European Commission every six years (Dröschmeister et al., 2014). Thus, the authorities have to keep track and sample the areas. This data can be applied to manage the Natura 2000 site and support the assessment procedure.

The EU Commissioner for Environment, Maritime Affairs and Fisheries, Karmenu Vella, will sue Germany over weak conservation efforts, as Germany failed to sustain protected habitats and protected species and more than half of the Natura 2000 sites in Germany are not adequately protected and managed (Violation of contract No. 2014/2262, letter of formal notice received by German authorities 27th February 2015). If the Commission files a complaint before the European Court of Justice, the court decision may result in high penalty payments. Compared to high penalty payments and the ecological costs of biodiversity loss, establishing an effective management system for Natura 2000 sites based on the Ecopath approach is money well spent. This nullifies the argument that an ecosystem modelling approach is too expensive (Lambrecht et al., 2004) for environmental management and the impact procedure of Natura 2000 sites.

We have to improve the management and protection of Natura 2000 sites in Germany and the modelling approach presented here is the best scientific method for the impact assessment procedure on the market, as it solves all on-going problems (Sundseth and Roth, 2013). The authorities have to monitor and collect data in Natura 2000 sites anyway and this data can be used in the model for improving management and impact assessment. It will take longer to model a Natura 2000 site and analyze the impact assessment results than using verbal argumentation or case conventions. Also there will be a need for highly qualified ecosystem modelers. These factors will increase costs, but if the Ecopath approach is established as management tool and the model is set up, it will be easier to manage and monitor a Natura 2000 site and the Ecospace findings can be easily reported to the European Commission every six years.

Consequently, it is recommended here to use the Ecopath approach as "'one size fits all' model for managing Natura 2000 sites" and as "systematic consistent framework" for the Natura 2000 assessment procedure.

Acknowledgements

I would like to thank Martin Fretzer and Jeroen Steenbeek for their support. The project was privately funded.

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