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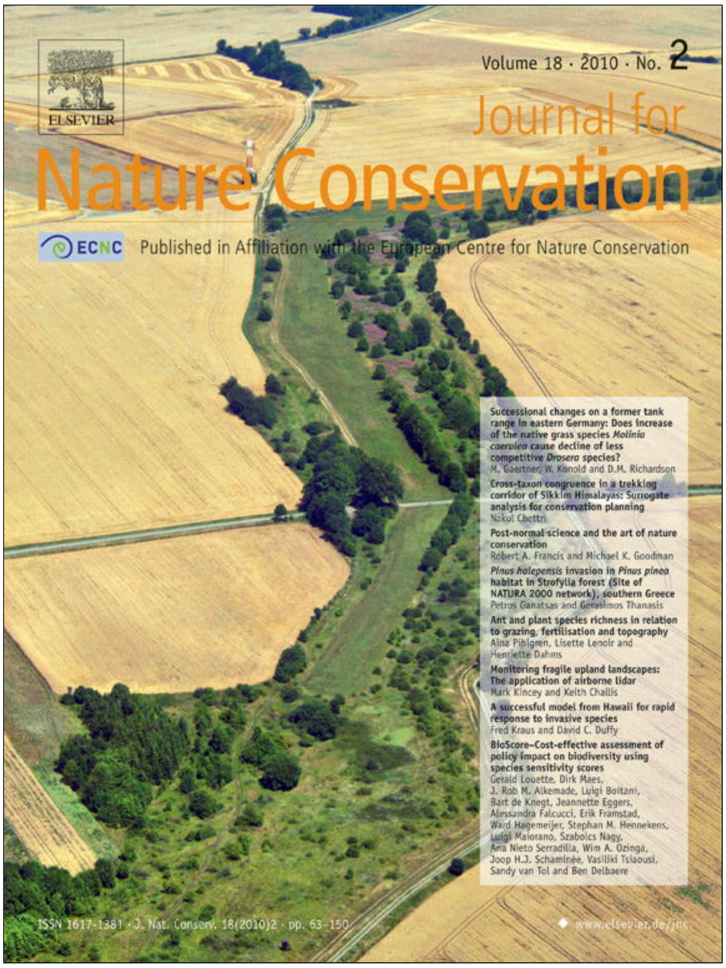
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Successional changes on a former tank range in eastern Germany: Does increase of the native grass species Molinia coerulea cause decline of less competitive Drosera species?
M. Gaertner, W. Konold and D.M. Richardson
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Post-normal science and the art of nature conservation
Robert A. Francis and Michael K. Goodman
Pinus halepensis invasion in Pinus pinea habitat in Strofylia forest (Site of NATURA 2000 network), southern Greece
Petros Ganatsas and Gerasimos Thanasis
Ant and plant species richness in relation to grazing, fertilisation and topography
Aina Pihlgren, Lisette Lenoir and Henriette Dahms
Monitoring fragile upland landscapes: The application of airborne lidar
Mark Kincey and Keith Challis
A successful model from Hawaii for rapid response to invasive species
Fred Kraus and David C. Duffy
BioScore–Cost-effective assessment of policy impact on biodiversity using species sensitivity scores
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BioScore–Cost-effective assessment of policy impact on biodiversity using species sensitivity scores

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A B S T R A C T

Human-induced pressures are known to be one of the main causes of biodiversity loss. In order to readily assess policy impacts on biodiversity, a cost-effective evaluation tool is developed, using species sensitivity scores. We demonstrate the potential effects of a selected policy option, being woody bioenergy crop production, on a wide range of species groups in Europe. Large-scale expansions of woody biofuel plantations would have a net negative effect on the species set covered in our study, with little variation among biogeographical regions, but with considerable differences among species groups. The evaluation tool enables policy makers to assess the potential impact of decisions on future biodiversity.

Introduction

For thousands of years human activities have had an impact on nature and biodiversity. Human-induced pressures are recognised to create ecosystem instability, mainly from biodiversity loss (Tilman et al. 2006; Western 2001). The key drivers for these losses are intensified agricultural production, increasing pollution load, transportation infrastructure, introduction of alien species, and overexploitation of resources (Araújo et al. 2006; Foley et al. 2005; Maes & Van Dyck 2001; Maiorano et al. 2008; Sala et al. 2000). Several studies have documented the negative impacts that these drivers may have on nature, e.g. declining species distribution areas and population sizes, the drop in local species richness, loss of habitats and invasion of alien species (Araújo et al. 2006; Biesmeijer et al. 2006; Delbaere 1998; EEA 2006a; IUCN 2006; Schtickzelle et al. 2006; Thuiller et al. 2005a, b). Aware of the harmful and often irreversible effects of human activities on biodiversity, special attention is currently being focused on biodiversity loss at policy level.

The European Union (EU) has as a prime objective halting or significantly decreasing the loss of biodiversity by 2010 (CEC 2001, 2002; Duke 2005). In order to achieve this goal, the EU is keen to assess the impact of its policy measures on biodiversity levels using cost-effective tools (Delbaere 2006). Under the auspices of the European research project BioScore (Biodiversity impact assessment using species sensitivity scores, funded by the EC Sixth Framework Programme for Research and Technical Development) such a cost-effective tool is being developed, based on species-specific ecological requirements, to generate species sensitivity scores. Concurrently, research on the relationship between multiple pressures and biodiversity is being performed by BioScore's European sister project ALARM (Rounsevell et al. 2006; Settele et al. 2005; Spangenberg 2007).

A number of models have been developed to predict consequences of ongoing human driven processes under plausible

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scenarios. These predict either local biodiversity losses or changes in species distribution areas (e.g. Bakkenes et al. 2002; Bakkenes et al. 2006; Scholze et al. 2006; Thomas et al. 2004; Thuiller et al. 2005a, b). Most of these models rely on species-specific information, the so-called ecological requirements or ecological signatures of species. Depending on how the species' ecological signatures are obtained, it is possible to distinguish between deductive and inductive models (Corsi et al. 2000). Inductive models, of which there are numerous applications, determine ecological requirements of species by combining species occurrence data with values of concurrent environmental variables using a variety of statistical procedures (Elith et al. 2006; Guisan & Zimmermann 2000). Deductive models represent an alternative approach where expert knowledge and/or published data are used to determine the ecological signature of species (e.g. Maiorano et al. 2006). In both cases, the derived ecological signatures are used in Habitat Suitability Index analyses or equivalent procedures (e.g. Corsi et al. 2000; Guisan & Thuiller 2005; Heikkinen et al. 2007; Hickling et al. 2006; Hirzel et al. 2002; Titeux et al. 2004) to predict species suitability, their presence in the area under study or their incidence under particular scenarios of future environmental conditions (e.g. Rounsevell et al. 2006; Spangenberg 2007). Deductive models, with their generality, have the power to forecast potential species occurrences over large areas, encompassing much ecological variability across the study area (e.g. the scale of Europe), even when few or no data on species occurrences are available. This makes them especially suitable for human/policy impact assessment (Boitani et al. 2008; Corsi et al. 2000).

Although knowledge of species signatures should be based on direct measurements over a representative sample of survey sites or experimental units, this can be very time consuming, particularly over extensive study areas or for large numbers of species. Hence, the use of sensitivity scores may form a valid alternative for predicting policy impacts on biodiversity in a cost-effective way. Sensitivity scores typically link environmental pressures, i.e. consequences of policy measures, directly to the ecology of species and therefore have the advantage of being relatively simple and user-friendly. They have the benefit of simplifying values for a given attribute (e.g. dispersal distance) among species, by arbitrarily placing species into classes according to their tolerance levels for specific environmental pressures (e.g. degree of habitat fragmentation). Sensitivity scores have been widely applied in a number of research fields particularly medicine (e.g. Carnes et al. 2006; Pancorbo-Hidalgo et al. 2006; Suzuki et al. 2006), but have not been extensively used in environmental studies focusing on habitats (Angelidis & Kamizoulis 2005), or species and communities, with the exception of indexes for quality assessments of water courses based on aquatic macrobenthos organisms (Delbaere & Nieto Serradilla 2005; Hansen & Urban 1992; Horrigan et al. 2005; Santelmann et al. 2006; Scholes & Biggs 2005; Tucker & Evans 1997).

Despite work on the impact of specific pressures on species or via indicators, e.g. climate change on plants (Bakkenes et al. 2002; Normand et al. 2007), habitat fragmentation (Henle et al. 2004), agriculture on farmland birds (Butler, Vickery, & Norris 2007), nitrogen on butterflies (Oostermeijer & van Swaay 1998), few studies have combined multiple pressures on distinct groups of species with the objective of assessing wider biodiversity (Santelmann et al. 2006; Verboom et al. 2007). Multispecies approaches, compared to single species or single taxa approaches (Fleishman et al. 2005; Maes & Van Dyck 2005), have the distinct advantage of serving as a 'conservation umbrella' facilitating a complementary, integrated picture of the quality and/or status of a location/region. The concept of the Biodiversity Intactness Index (Mace 2005; Scholes & Biggs 2005; with refinements made by Faith et al. 2008; Rouget et al. 2006) focuses on these same features, combining large species numbers, specific impacts and land use types into one single relative measure of the status of biodiversity with respect to an ideal (pristine) state.

In the BioScore project, our objective is to integrate data on the impact of a large set of pressures derived from European Community policies on various species groups (mammals, reptiles, amphibians, birds, butterflies, vascular plants, freshwater fish, and aquatic macrobenthos) at the geographical scale of Europe, by developing an evaluation tool based on species sensitivity scores. We demonstrate how the proposed tool can be used to measure biodiversity impacts linked to the implementation of large-scale biofuel production (second generation bioenergy crops) in Europe (Righelato & Spracklen 2007). In doing so, we present the expected beneficial/detrimental effects on a selected subset of biodiversity under this scenario in the different biogeographical regions. Finally, we discuss how the findings may support policy makers to assess their choices in order to sustain biodiversity in the future.

Methods

The evaluation tool developed by BioScore consists of a number of steps that follow the DPSIR framework (Driver, Pressure, State, Impact, Response) (EEA 1998) (Fig. 1). As a first step, environmental pressures are derived from selected policy sectors and related to Community policy instruments. These pressures are translated into scenarios of environmental change. In the second step, species are linked to the identified environmental pressures using environmental variables, and their ecological characteristics, such as optimal habitat type, and dispersal capacity. These measures are then summarised into sensitivity scores based mainly on expert judgment and information in the published literature. The scores are then translated into spatially explicit models that can be used to predict changes in the distribution/occurrence of species linked to the different scenarios resulting from different Community policies. The resulting outcomes should allow policy makers to evaluate the biodiversity impact of the current and planned policy measures, and plan alternative actions in the future.

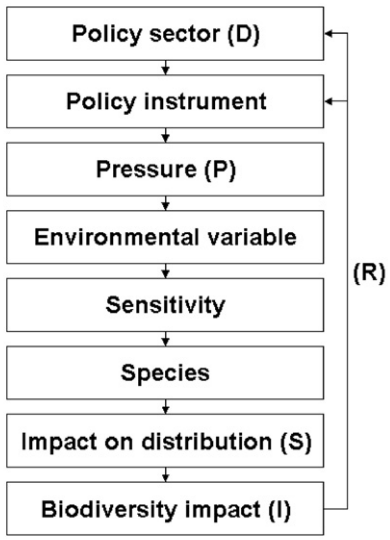

Fig. 1. Diagram of the method framework applied in BioScore (DPSIR: Driving Forces, Pressures, State, Impacts, Responses).

Focal species

Due to the large number of species in Europe (see databanks of Fauna Europaea and Flora Europaea), it is impracticable to use the entire biota of the EU. Therefore, we have selected a set of focal species among mammals, reptiles, amphibians, birds, butterflies, vascular plants, freshwater fish, and aquatic macrobenthos. In doing this, we followed the selection criteria proposed by Maes and Van Dyck (2005). For each species group we only retained species for which enough information was available on potential effects of the selected environmental pressures. This information was gathered from a variety of sources (i.e. books, original and review papers, expert judgment questionnaires, and existing databases). Subsequently, we retained species with an intermediate level of rarity based on distributions. For species groups, such as butterflies, where relatively detailed distribution maps are available at the scale of Europe, species were retained when they occurred in 10–20% of the surface area in at least one of the biogeographical regions in Europe. The regions follow the classification defined by the European Environment Agency (Alpine, Anatolian, Arctic, Atlantic, Black Sea, Boreal, Continental, Macaronesia, Mediterranean, Pannonian, Steppic) (EEA 2006a). For species groups where no detailed distribution information was available, we limited our selection of species to those present in a specific biogeographical region and not covering the entirety of Europe. For vascular plants, with more than 15,000 species in Europe (excluding small apomictic taxa), we used the 'target species approach' as developed by Ozinga & Schaminée (2005) to reduce this large number to a meaningful subset, focusing on species of conservation concern. For future analyses, we expanded the list of threatened plants to include a number of butterfly host plants. Ultimately, we retained a set of 754 species that are fairly equally spread over all six species groups considered. This species set covers most of the variety in terrestrial biotope types, life history traits, distribution ranges, conservation classes, etc. and can be considered a representative sample of (terrestrial) European biodiversity (Table 1). Furthermore, these groups are the only groups for which sufficient distribution data are available on a European level.

Sensitivity scores

Theoretically, all ecological characteristics of a species, from survival to successful reproduction, can contribute to sensitivity scores for assessing changes in ecological variables. Information such as optimal habitat type, dispersal capacity, minimal area requirements, preferred soil texture, sensitivity to exploitation pressures, can all be applied in habitat modelling when the necessary maps (e.g. land cover, soil) and models (e.g. measures of sensitivity to climate change) are available. In practice, sensitivity scores apply a limited range of values to a given ecological attribute usually by designation of arbitrary classes. Despite the loss of information, data and measures become easier to handle, and general patterns can be more easily derived for large numbers of species over large areas, even if limited information is available. The most widely used system based on sensitivity scores in ecology/conservation is probably the scoring system developed for vascular plants of Central Europe (Ellenberg et al. 1992). Although it is largely based on expert judgment, there is strong experimental evidence of its accuracy, with several studies reporting a close correlation between average indicator values and corresponding measurements of environmental variables (e.g. Schaffers & Sýkora 2000; Thompson et al. 1993).

Table 1
For each species group presented: the total number of species occurring in Europe (Total number), the number of species where enough ecological data are available to meet the selected pressures (Number with data), and the number of species retained after the additional criteria of being a focal species for at least one biogeographical region (Retained number).

	Total number	Number with data	Retained number
Mammals	295	60	60
Reptiles	217	30	28
Amphibians	88	20	20
Birds	526	478	179
Butterflies	576	152	77
Vascular plants	15974	3000	390
Freshwater fish	450	216	216
Aquatic macrobenthos[a]	–	–	–

[a] For aquatic macrobenthos there are only data available on the family level (66 families).

Scenario of bioenergy crop production

In order to mitigate climate change, several initiatives have been undertaken for reducing net additions to greenhouse gases in the atmosphere. Bioenergy production, from annual and perennial plants and trees, is usually considered a key solution for achieving this target (Baral & Guha 2004; Kirschbaum 2003). Herein, we present an example to illustrate how species sensitivity scores can be applied for assessing policy impact on biodiversity. As a case study, we focus on the policy scenario of large-scale second generation bioenergy crops cultivation throughout Europe. Second generation bioenergy crops can involve woody species, mainly willow *Salix* spp. and poplar *Populus* spp., which are harvested over a short rotation cycle of about 10 years (Perttu 1999). Through new processes, yet to be developed commercially, such crops may be converted into biofuels. The future extent of woody bioenergy crop production in the different biogeographical regions of Europe is still uncertain (EEA 2006b; Rounsevell et al. 2006), but in presenting our case study the assumption is made that such crops will be cultivated on a large scale across Europe. The most important environmental pressure relating to bioenergy production is land use change, with previously non-forested lands being covered by woody species, resulting in young forest plantations. It is expected that this type of land use change will mainly arise from the conversion of open agricultural land, and abandoned land that will be taken back into production. Loss of existing forest is foreseen to be minimal in this context (EEA 2006b; Götmark et al. 2005; Read 1997; Smeets et al. 2007).

Species can be linked directly to the impact of this policy by assigning sensitivity scores to the different land use classes (Corine Land Cover; Nunes de Lima 2005) in which they are known to occur. Many different possibilities are available but we adopted the following scheme based on four ranks: 0, the species is indifferent to a change or loss in that class of land cover type; 1, the species shows little responses to a reduction of that class of land cover type; 2, the species is moderately sensitive to a loss of that class of land cover type; and 3, the species is closely associated to that class of land cover type and highly sensitive to its loss. For vascular plants, a slightly different approach was taken. We used the Natural Habitat Types of the Habitats Directive as basis for our scoring system, instead of Corine Land Cover data. For each biogeographical region, we used sensitivity scores to classify species in three categories: 1-species with high sensitivity scores (scores 2 and 3) for the land use class 'forests'; 2-species with high sensitivity scores (scores 2 and 3) for the land use class 'agricultural land' and 'abandoned land'; and 3-species which are more or less indifferent to land cover types. In this way it was possible to distinguish between species that are strongly dependent on forest and woodland for their survival, species that are strongly dependent of the more open landscape for their survival, and species with both high and moderate sensitivity scores for the land use classes forest and agricultural – abandoned land (supplementary material concerning the classification of species is available in Appendix A). We considered in the analyses only species groups affected by terrestrial land use change, excluding freshwater fish and aquatic macrobenthos organisms that cannot be easily linked to land use change.

Results

Large-scale woody bioenergy crop production is likely to lead to changes in general biodiversity levels measured in terms of the relative numbers of species affected. Based on their sensitivity to the assumed land use change, the net effect of massive woody bioenergy crop production would be negative (28% will be negatively affected while around 10% would experience beneficial effects; averages over species groups) (Fig. 2). Impacts are almost uniformly distributed over the biogeographical regions, with negative effects lowest in the Boreal (12%) and highest in the Anatolian region (41%) (Fig. 3). When analysing the effects for the different species groups separately, some considerable differences among groups, but also among regions for the different groups, come to light. Negative effects are strongest for reptiles, butterflies and birds (Fig. 2 and Table 2); 40% of reptile species diversity would be negatively affected in all regions. Considering butterflies, detrimental effects would be evident for some 35% of the species in the Atlantic, Continental and Mediterranean regions, and for 25% of species in the Boreal region. Bird species would experience negative influences mostly in the Mediterranean region where more than 35% of the species would be affected by the predicted changes. Beneficial effects are generally low for all species groups, except for vascular plants, where around 30% of the species would benefit over most biogeographical regions. As a consequence a net percentage of plant species would profit from the woody bioenergy

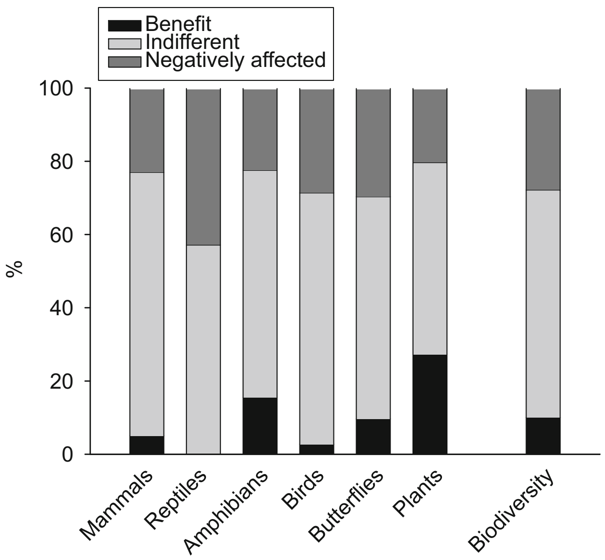

Fig. 2. Proportion of species that will benefit, are indifferent, and will be negatively affected under a scenario of massive woody bioenergy crop production for the different species groups, as well as biodiversity in general (average over all groups and biogeographical regions) in Europe.

scenario. Overall, amphibians and vascular plants would be less affected by this important land use change (overall effect lower than 10%).

Discussion

The tool developed in the BioScore project and applied to our case study indicates the potential of sensitivity scores to assess current and future policy impacts on biodiversity in a cost-effective way. We have been able to show how the potential effects of policy options (e.g. substantial woody bioenergy crop production) on biomes may be projected in a relatively simple way. For a wide variety of species groups, land use changes are linked to preferences of species for habitat types, and impacts per region can be assessed given that scenarios of change are available. Our method has the advantage of applying a multi-species approach in which policy impacts are assessed for a larger fraction of biodiversity. Hence, patterns will be more robust than would be the case when using single species or single species groups (Maes & Van Dyck 2005). The use of species sensitivity scores in our scheme has the added benefit of simplifying values for a given attribute among species, by using expert opinion to classify species according to their tolerance level for certain environmental pressures. As a result, data become much easier to handle, and general patterns can be extracted for large numbers of species, even when no detailed information is available.

However, we urge caution in interpreting our results. Due to the cost-effective approach of our method, only easily accessible and well delineated parameters can be applied in the calculation procedure. This inevitably results in coarse-scale information, producing relatively broad-scaled impact patterns. For instance, we did not take into account some parameters, such as climate models, dispersal problems, nuances in structure within habitat types, stochastic events, and interactions among species, which most likely influence species occurrences at fine scales (Bakkenes et al. 2002; Henle et al. 2004; Ozinga et al. 2005). Thus, our conclusions can only be drawn on the scale of biogeographical regions in Europe, and even at this level, care needs to be taken over interpretation as not all biogeographical regions will be suitable for woody bioenergy crop production, and there will be a high variability of biofuel production within given regions and under different scenarios of future development (Spangenberg 2007). Bioenergy crops are most likely to be produced in regions with appropriate climatic conditions, with soil, nutrients, temperature and precipitation acting as limiting factors (Perttu 1999). Also production can be regionally restricted when the demand for food, industrial round wood, traditional wood fuel, and the need to preserve existing forests for biodiversity protection is high (Smeets et al. 2007). As such, woody biofuel crop production in the near future is likely to be developed only the Boreal, Continental and Atlantic regions. Moreover, the degree of other types of land use change within biogeographical regions is not covered in our case study. Our method thus provides indications of the extent to which species groups are vulnerable to losses or gains of specific biomes. Nevertheless, we are confident that our results reflect what might happen if certain scenarios of second-generation woody bioenergy crops are implemented across Europe (Smeets et al. 2007).

From our model, it is expected that species will be negatively affected by the predicted land use changes under the bioenergy scenario. On average, 18% of the species will be negatively affected, with reptiles, butterflies and birds experiencing the most dramatic impacts. These groups all cover a large proportion of species associated with more open landscapes (Gasc et al. 1997; Tucker & Evans 1997; van Swaay & Warren 2006), a contrasting biotope to

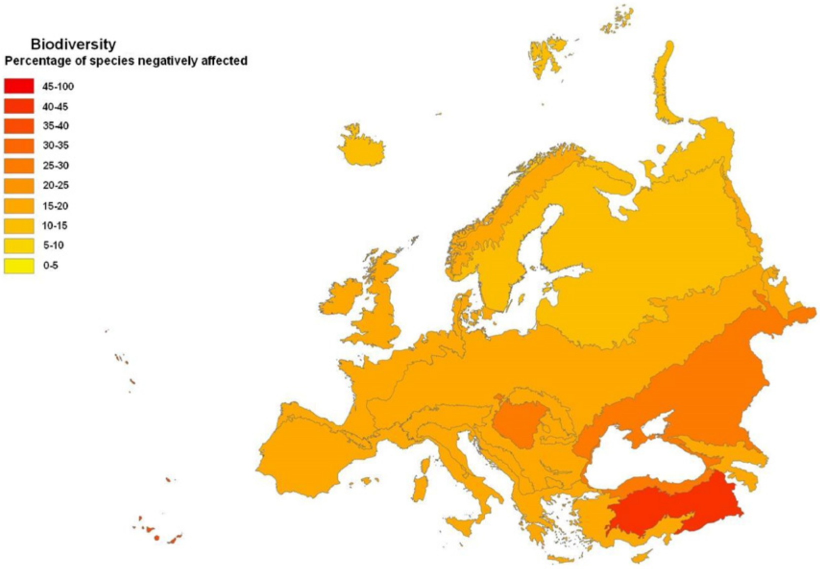

Fig. 3. Regional variation in the overall negative effect of an assumed massive woody bioenergy crop production on biodiversity in general (shown as the difference between the proportion of species negatively affected and the proportion of species which benefit).

Table 2
For each species group the percentage of species that will benefit (*B*), are indifferent (*I*), and that will be negatively affected (*N*) under a scenario of massive woody bioenergy crop production is presented for all biogeographical regions occurring in Europe, as well as over whole Europe.

	Mammals			Reptiles			Amphibians			Birds			Butterflies			Vascular plants		
	B	*I*	*N*	*B*	*I*	*N*	*B*	*I*	*N*	*B*	*I*	*N*	*B*	*I*	*N*	*B*	*I*	*N*
Alpine	5	72	23	0	57	43	15	60	25	2	68	30	10	56	34	30	54	16
Anatolian	5	72	23	0	57	43	16	63	21	1	61	38	–	–	–	5	49	46
Arctic	5	72	23	0	57	43	16	63	21	4	79	17	6	81	13	23	58	19
Atlantic	5	73	22	0	57	43	15	60	25	3	71	26	11	55	34	27	56	17
Black sea	5	72	23	0	57	43	16	63	21	2	67	32	4	64	32	32	52	16
Boreal	5	72	23	0	57	43	16	63	21	6	75	19	13	62	25	27	53	20
Continental	5	72	23	0	57	43	15	60	25	5	68	27	10	56	34	31	53	17
Macaronesia	5	72	23	0	57	43	16	63	21	0	76	24	–	–	–	–	–	–
Mediterranean	5	73	22	0	57	43	15	60	25	1	62	37	11	53	36	29	56	15
Pannonian	5	72	23	0	57	43	16	63	21	2	66	32	9	60	31	36	45	19
Steppic	5	72	23	0	57	43	16	63	21	3	65	32	11	60	29	32	49	19
Europe	5	72	23	0	57	43	16	62	22	3	69	29	10	61	30	27	52	20

For mammals and reptiles the same set of species was used for all biogeographical regions, thus leading to equal percentages.

the young forests which would be created under a bioenergy policy of woody crops. Our findings of detrimental effects caused by afforestation for these species groups are consistent with the general pattern found in some original environmental field and review studies (Goldstein et al. 2005; van Swaay & Warren 2006). Other authors present a somewhat different pattern for other species groups (Berg 2002; Dhondt et al. 2007; Santelmann et al. 2006), but then local biodiversity levels can indeed increase when new habitat types are created in a previously monotone landscape, due to the increase of mosaic structure, and thus suitable biotopes. However, at the wider regional scale of Europe, and certainly for species that are endemic to Europe, an overall negative effect will be the case, especially if large-scale bioenergy crop production is promoted. More specifically, our study suggests that the Boreal region will be least affected, while the Continental and Atlantic will be equally and somewhat more affected. The same holds for the Mediterranean region (Araújo et al. 2006), even though, as already pointed out above, massive woody bioenergy crop production is unlikely in this part of Europe. A remarkable fact is that an overall positive effect is predicted for vascular plants, with a substantial fraction of the species within the group being replaced as 20% will be negatively affected, while more than 25% will benefit), in contrast to the pattern for the other species groups. However, given that most of the plant species that we considered are of conservation concern, a possible bias in the analysis is possible.

According to our results, large-scale short-rotation woody energy plantations can lead to biodiversity loss and should therefore be planned carefully (Biemans et al. 2008; Cook et al. 1991; ten Brink et al. 2006). We agree that when short rotation bioenergy crops are properly managed (i.e. adequate weed control, preservation of existing sensitive habitats, promotion of small stands, use of several woody crop species, limited use of fertilisers; Perttu 1999), biodiversity levels may be slightly enhanced, but still this would not be enough to compensate for the loss of species from vanishing open habitats under the scenario assumed here. Even so, as it is obviously uncertain to what extent land use changes will occur, an a priori abandonment of woody biomass production as sustainable energy source may be premature.

In conclusion, the scheme presented here has clear potential for supporting policy makers in evaluating a wide variety of current policy measures, and in forecasting the likely impact on biodiversity under planned actions at a coarse scale. When existing maps, such as those for roads, land cover and elevation, as well as economic and land use models, such as GTAP (Global Trade Analysis Project; Van Meijl et al. 2006), CLUE (Conversion of Land Use Change and its Effects; Verburg et al. 2002), and IMAGE (Integrated Model to Assess the Global Environment; Bouwman et al. 2006), are linked to the highly accessible and elaborate details for around 800 species available in the BioScore database, more fine-scaled predictions can be obtained. The Biodiversity Intactness Index (BII) approach (Rouget et al. 2006; Scholes & Biggs 2005) together with its refined Biodiversity Representativeness Indices, using species-area relationships (Faith et al. 2008), provides a suitable scheme for the development of further cost-effective biodiversity assessment methods. Applying the BII (Biggs et al. 2008) to our data using a scenario in which 4% of the agricultural land will be converted to biofuel production, resulted in changes that were highly correlated with the observed trends in our study ($r = 0.99$, $p < 0.001$). The procedure used in our study, however, is independent of quantitative scenario's and aims at indicating species and regions that are likely to be sensitive to European policy decisions. Our method, therefore, provides an alternative approach, in particular for less well studied species groups allowing for the coverage of many species groups simultaneously (Fleishman et al. 2005), and will reflect policy impacts on biodiversity in a rapid and qualitative way.

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Appendix A. Supporting Information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jnc.2009.08.002.

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