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Characterizing the change of land-use based on flora: applicaton for EIA and LCA

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Abstract

The environmental impact of land-use can be expressed in terms of a change in biodiversity of flora. We present two models that characterize the negative effects of land-use: a model on the basis of species richness; a model on the basis of the rarity of ecosystems and their vascular plants. Each of those models may serve in the EIA (environmental impact assessment) of the urban and rural planning of expanding cities, industrial areas, road infrastructure, etc. Moreover, these models might be applied by LCA practitioners to incorporate the aspect of land-use in the environmental assessment of a specific product design. The results of both models have been applied in practice. Maps of The Netherlands are provided for both models: the map based on the rarity of ecosystems differentiates the best of what experts (biologists and ecologists) define as botanical quality of nature; the methodology is operational in The Netherlands and might be applied to other countries as well, however, detailed botanical information is required the map based on species richness has a weaker compliance with the botanical quality of nature, however, the model can more easily be applied to a wider area of the world, since indicative data about species richness is available on a global scale. The so called 'eco-costs of land conversion' is proposed as a single indicator, being the marginal costs of prevention (or compensation) of the negative environmental effects on biodiversity caused by change of land-use. These 'eco-costs of land conversion' for the botanical aspects are part of the much broader model of the eco-costs/value ratio, which has recently been published in this journal [Vogtländer et al., Journal of Cleaner Production 2002;10:57–671]. © 2002 Published by Elsevier Science Ltd.

Keywords: Land-use; Eco-costs; EVR; EIA; LCA; Single indicator; Botanical value; Biodiversity

1. Introduction

1.1. Land-use, sustainability, EIA and LCA models

1.1.1. The need for a characterization system for land-use in EIA, and its use in LCAs

The increasing use of land for urban areas, industrial areas, road infrastructure, etc., [2] is a major cause of degradation of the biodiversity in our environment [3]. In the last decades there has been a growing concern among EIA and LCA practitioners and spatial planning experts about this negative aspect of a growing population and a growing economic wealth [4–8].

It is obvious that, in future planning, the use of land should be optimized as much as possible by making more intensive (e.g. compact) use of cities and industrial areas. In a lot of cases, however, expansion of cities and industrial areas cannot be avoided. In such cases decisions have to be taken on how and where the expansion is planned. This issue is relevant in the field of EIA as well as LCA:

- in the field of EIA and spatial planning of urban and rural areas, it is relevant how to expand built-up areas with a minimal degradation of nature [8–10];
- in the field of LCA, it is relevant to incorporate the

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negative aspects of 'land-use' in the analyses of product-service systems [11–14].

The important aspect of the increased use of land is that the environmental impact (degradation) of it depends on *where* the land-use (or the change in land-use) takes place, since the environmental impact of change of land-use highly depends on its exact location. This applies to a global as well as a local scale:

- on a global scale: the botanical value[1] of tropical rainforests is quite different from that of the deserts;
- on a local scale: the botanical value can be quite different over relatively short distances of a few kilometres, e.g. near dunes, rivers, moors, coastlines, etc.

The local differences of the botanical value of land create a variety of opportunities in *spatial planning* of densely populated areas: relatively small changes in spatial planning can often save valuable areas of botanical nature. A characterization system of botanical value can guide governments in such cases to find better solutions in a structural way.

The high variety of botanical value on a local scale is an opportunity as well for engineers of new *production systems* (facilities) of companies: they can influence the LCAs of their production systems in a positive way by taking the botanical value of land into account in site selection studies.

For the *materials* in a LCA, it does make sense to apply a global weighed average of the land-use parameters of mines (in the case of metals), and of forests (in the case of wood from natural rainforests).

1.1.2. Two characterization systems of biodiversity of flora: 'species richness' and 'rare ecosystems'

There are many aspects of land-use in respect to the subject of sustainability [11,12,15]. In this paper we will focus on one aspect, i.e. on the 'botanical value' since this is the only type of characterization system which is currently operational [11]. We will examine two types of characterization systems for botanical value:

- a coarse system, based on the number of vascular plant species in a certain area: the system of the 'species richness';
- a more subtle system, based on the relative species richness of ecosystems as well as the diversity and rarity of ecosystems: the system of the 'rare ecosystems'.

For each typical case, one has to make a choice between these systems (otherwise it would lead to double counting of the effect on botanical value). Each system has its pros and its cons, see Table 1. The system on 'rare ecosystems' has been judged by experts on flora. They concluded that 'rare ecosystems' is a better indicator for botanical value than species richness [18].

1.1.3. Creating a single indicator for the LCA, based on conversion or occupation

The LCA methodology provides a structured way to characterize the environmental burden of conversion and occupation of land. The normal route to develop one single indicator for land-use in LCA comprises two steps:

Step 1 Define a category indicator, based on the characterization model (ISO 14042). For land-use such a category indicator can be expressed in 'equivalent m^2': 'equivalent m^2'='actual m^2'×'quality factor'Note that the quality factor is the ratio between the actual quality and the reference quality, and that the equivalent m^2 refers, in our case, to a certain botanical quality of land, the norm for quality.

Step 2 Define a single indicator of LCA by a so-called evaluation (or normalization) step. In this step, the purpose of the analysis becomes important: is the analysis *damage* based or *prevention* based and is the impact described in terms of *occupation* or *conversion* (change) of land? The evaluation step of the eco-costs, as described in this article, is based on prevention (or compensation) of conversion of land.

Section 2 of this article will show how Step 1 is applied to the botanical value of land in terms of species richness or in terms of rare ecosystems.

Section 3 of this article will provide a method to arrive at a single indicator for land-use in the LCA (Step 2) is provided.

Section 4 gives a short discussion on results of both characterization systems, and gives conclusions with regard to further applications.

2. Characterizing the botanical value of land

2.1. The characterization system and the category indicator for 'species richness'

Species richness is characterized by the number of species of vascular plants S in a certain area A. It is one of the most applied measures of characterizing the botanical aspects of land in LCAs [11]. For many Western European countries, data on S are available. For The

[1] The botanical value of land is defined by a combination of completeness and rarity of the ecosystems [18], see also Section 2 of this publication for details.

Table 1
Advantages and disadvantages of the two characterization systems of biodiversity of flora

The system of the 'species richness'	The system of the 'rare ecosystems'
Advantages:	*Disadvantages:*
–It is the most commonly applied characterization system in the world of LCA practitioners [11–13]	–It is not yet commonly applied in the world of LCA and EIA practitioners.
–It is relatively simple and straightforward [14] and data are available in many regions; when they are not available, it is feasible to gather indicative data or to predict the main characteristics based on general observations.	–The system is more complex and less easy to comprehend (a reasonable level of biological as well as mathematical knowledge is required); moreover, this system requires more detailed information about the flora.
Disadvantages:	*Advantages:*
–*All* species add to the result in a positive sense, including the species that are part of disturbances (for instance: a heather has a higher species richness when it contains a weed).	–It only takes species into account that are indicative of the ecosystems considered (i.e. species which are valuable).
–Certain highly valued but nevertheless species-poor ecosystems (bogs, salt marshes, drifting sand dunes, heathlands) get a valuation which is too low.	–It uses the relative species richness of ecosystems, so that ecosystems that are species-poor by nature do not get a valuation which is too low.
–The system does not account for the fact that some species (especially the rare and threatened ones) are valued higher by nature conservationists than other species.	–It takes the rarity of ecosystems into account (and, indirectly, also the rarity of species thatoccur in those ecosystems).

Netherlands, field data are available on a grid of 1 km^2, see Fig. 1. This map has been derived from FLORBASE. FLORBASE is a database with counted species of vascular plants in the wild at a national grid of 1 km^2 , 35 000 km^2 in total. This database is a compilation of data from the Provinces, land owning organizations and institutes and from private persons.

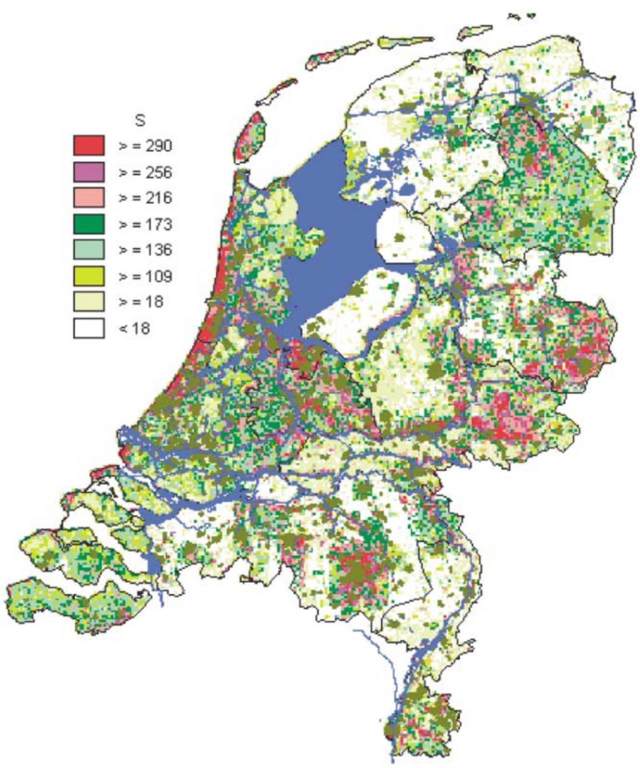

Fig. 1. The species richness, *S* (of 1 km^2) , in The Netherlands. Cumulative areas (percentage of total) for *S*: >290, 5%; >256, 10%; >215, 20%; >173, 35%; >136, 50%; >109, 60%; >18, 80%; <18, 100%. Note: cities and industrial areas have a brown colour.

We express land-use in terms of 'actual m^2 '×'quality factor' of land before and after the change. The quality factor is defined as the counted total number of vascular plant species, *S*, divided by the quality norm for it, S/S_{ref}. We now introduce the category indicator for species richness of land, SRI ('species richness indicator'), which is calculated as the area *A* (m^2) multiplied by the quality factor for it, S/S_{ref}:

$$\mathrm{SRI} = A \times \frac{S}{S_{\mathrm{ref}}}. \tag{1}$$

So SRI is expressed in terms of 'equivalent m^2 of nature'. Note that S and S_{ref} have to be both defined for the same area (e.g. the number of species at 1 km^2).

The environmental effect of the change of land-use is described now as

$$\Delta\mathrm{SRI} = A \times \frac{\Delta S}{S_{\mathrm{ref}}} \tag{2}$$

where Δ denotes the difference of *S* and SRI before and after the change.

For the quality norm of *S* in The Netherlands, S_{ref}, a value of 250 vascular plants species for 1 km^2 is proposed. *S* is >250 for 11% of the total area of The Netherlands. (Areas above 300 are very scarce: 4% , areas above 200 are quite common: 25% , see also Fig. 1.) For Germany, England and the northern part of France, the same quality norm of 250 species for 1 km^2 is proposed, since the species richness in these countries is in the same order of magnitude as in The Netherlands [16]. For species richness of other countries, see Appendix B.

2.2. Estimation of S in LCA

For EIA applications, S must be either available from a database, or must be determined in the field, since detailed data on local level is required for a sound analysis.

For LCA purposes, however, the exact location is often not — or not yet — known. In such a case, one might apply a methodology to assess S on the basis of the CORINE land classification [17] combined with the size of such an area of land. We propose a calculation system which is in line with the basic approach of the 'species-pool effect potential' of Köllner [13] and the Eco-indicator '99 of Goedkoop and Spriensma [14]. The results of such calculations, however, must be regarded as first order estimates, and must be interpreted with great care.

Köllner [13] analysed data on S of various types of land as a function of the size of that type of land, applying the following correlation of S:

$$S = S_{1\text{ ha}}(A_{\text{TA}})^b \quad (3a)$$

where:

- $S_{1\text{ ha}}$ is the counted number of species (vascular plants) on 1 hectare (=0.01 km^2) of a certain type of land;
- A_{TA} is the actual size of the total area (hectare) of that type of land;
- b is the 'species accumulation rate' (the slope of the correlation between the measured value of S and the size of the area on log–log paper).

Table 2 provides the data of Köllner [13] for $S_{1\text{ ha}}$ and b, and subsequent calculations of S for other areas, according to eq. (3a). The data of Köllner are based on sample sizes of 1–20 ha. Calculation of data by eq. (3a) is restricted to this range (1 ha$<A_{\text{TA}}<$20 ha), since further extrapolation is hardly allowed[2]. For areas $<$1 km^2, S_{ref} in eqs. (1) and (2) is proposed according to

$$S_{\text{ref}} = 137.5 \times (A_{\text{TA}})^b, \quad (3b)$$

where $b = 0.13$ (resulting in $S_{\text{ref}} = 250$ for 1 km^2) , see also Table 2.

Example[3]: When an area of 0.2 km^2 (=20 ha=200 000 m^2) is converted totally from 'industrial fallow' to 'industrial area' or to 'intensive meadow' , the net effect on SRI in terms of 'equivalent m^2 of nature' can be calculated as follows [applying eq. (1) and Table 2]:

- the SRI of the 'industrial fallow' is

$$A \times \frac{S}{S_{\text{ref}}} = 200000 \times \frac{191}{203} = 188817 \text{ equiv.m}^2;$$

- the SRI of the 'industrial area' is

$$A \times \frac{S}{S_{\text{ref}}} = 200000 \times \frac{155}{203} = 134783 \text{ equiv.m}^2;$$

- the SRI of the 'intensive meadow' is

$$A \times \frac{S}{S_{\text{ref}}} = 200000 \times \frac{53}{203} = 52217 \text{ equiv.m}^2;$$

- the net loss of *SRI*, ΔSRI, of the conversion of 0.2 km^2 'industrial fallow' to 'industrial area' is 54 034 equiv. m^2 of nature;
- the net loss of SRI, ΔSRI of the conversion of 0.2 km^2 'industrial fallow' to 'intensive meadow' is 136 600 equiv. m^2 of nature.

2.3. The characterization system and the category indicator for 'rare ecosystems'

'Species richness' as such, provides only a weak indication of the botanical value (the assumption is: "when there are many species, there is a fair chance that there are valuable species as well"). Therefore the more advanced model of 'rare ecosystems' has been developed, which is described in this section.

The botanical value of a piece of land can best be described by the methodology developed by Witte [18, 19]. This methodology takes the rarity of ecosystems and their plants into account. It is a logical step forward to distinguish between species which are important and species which are less important. Witte took 'rarity of the ecosystems' as a main measure of importance. Witte operationalized the methodology by means of the Dutch FLORBASE database.

The basic idea behind this methodology is that every specific ecosystem has its own specific types of vascular plant species. This method distinguishes 28 ecosystem types in The Netherlands. The methodology results in a score for 'botanical value of 1 km^2', Q :

$$Q = \sum_{i=1,28} V_i C_i \quad (4)$$

where V is a parameter for the rarity of an 'ecosystem type', 1$<V<$10; and C is a parameter for the relative species richness or 'completeness' (in that km^2) of an ecosystem type in terms of 'indicator species' for that ecosystem type (indicator species are species which occur only in one, two, or a maximum of three

[2] Above 1 km^2, the value of b will drop drastically to a value between 0.22 (for lower scores of S) and 0.12 (for higher scores of S), see also [18, 19] for his analyses of coefficient b.

[3] This example is a calculation on the so called 'first order effect'. For more complex situations, where the so called 'second order effects' play a role, see [15]. It doubtful, however, whether or not these complex 'second order effects' make sense in practice [15].

Table 2
Values for $S_{1\ \mathrm{ha}}$ and b according to [13] (S rounded off in units of 5), and predictions of data for S and S_{ref} of other area sizes by eqs. (3a) and (3b)

				Species richness predicted with eq. (3)			
CORINE No.[a]	Land type	$S_{1\ \mathrm{ha}}$	b	$S_{2\ \mathrm{ha}}$	$S_{5\ \mathrm{ha}}$	$S_{10\ \mathrm{ha}}$	$S_{20\ \mathrm{ha}}$
1.1.1	Continuous urban	10	?	?	?	?	?
1.1.2	Discontinuous urban	55	0.38	72	101	132	172
1.1.3	Urban fallow	90	0.18	102	120	136	154
1.2.1	Industrial area	80	0.22	93	114	133	155
1.2.2.2	Rail area	80	0.22	93	114	133	155
1.2.5	Industrial fallow	105	0.20	121	145	166	191
1.3.4	Mining fallow	85	0.28	103	133	162	197
1.4.1	Green urban	80	0.34	101	138	175	222
1.5	Built-up land	0	0.00	0	0	0	0
2.2.1.1	Conventional arable	10	0.45	14	21	28	39
2.2.1.2	Integrated arable	10	0.50	14	22	32	45
2.2.1.3	Organic arable	25	0.45	34	52	70	96
2.3.1.1	Intensive meadow	15	0.41	20	29	39	53
2.3.1.2	Less intensive meadow	40	0.38	52	74	96	125
2.3.1.3	Organic meadow	45	0.40	59	86	113	149
3.1.1	Broad-leafed forest[b]	245	0.13	268	302	330	362
–	Swiss low lands	270	0.13	295	333	364	399
–	$S_{\mathrm{ref.}}$(S_{ref}=250 for 1 km^2)	137.5	0.13	150	169	185	203

[a] Numbers according to CORINE [17] Note: ? means that extrapolation is not possible.
[b] Köllner gives b=0.36, but this value results in unrealistic data; b=0.13 is proposed.

ecosystems), $0<C<1$. The summation is to cope with the cases where there are more than one ecosystem within 1 km^2. The way V and C of eq. (4) are calculated is briefly described in Appendix A.

Witte tested several valuation formulas by showing maps of the province of Utrecht (NL) to experts in the field of botany. He asked them, single blind (it was not explained to the experts how these maps had been calculated), which map they preferred. Maps based on the species richness S did not score well. The maps based on Q scored the best.

Such a map for Q in The Netherlands is shown in Fig. 2. In the discussion of Section 3.2 we will show that this map differentiates much better than the map of Fig. 1.

To arrive at a botanical value in 'equivalent m^2' we propose a national quality norm for Q on the basis of "what is rare (in The Netherlands) ?". Such a norm, $Q_{\mathrm{threshold}}$, has been determined by a Pareto analysis on all data for The Netherlands [15] (note that such a norm is basically a political choice):

$$Q_{\mathrm{threshold}} = 3.3$$

see the map of Fig. 2. The botanical value Q is >3.3 for 20% of the total area of The Netherlands.

Equivalent to eq. (1), the category indicator for botanical rarity of land, ERI ('ecosystems rarity indicator'), will be expressed in terms of the area, A (m^2), multiplied by $(Q/\ Q_{\mathrm{threshold}})$.

$$\mathrm{ERI} = A \times \left(\frac{Q}{Q_{\mathrm{threshold}}}\right). \quad (5)$$

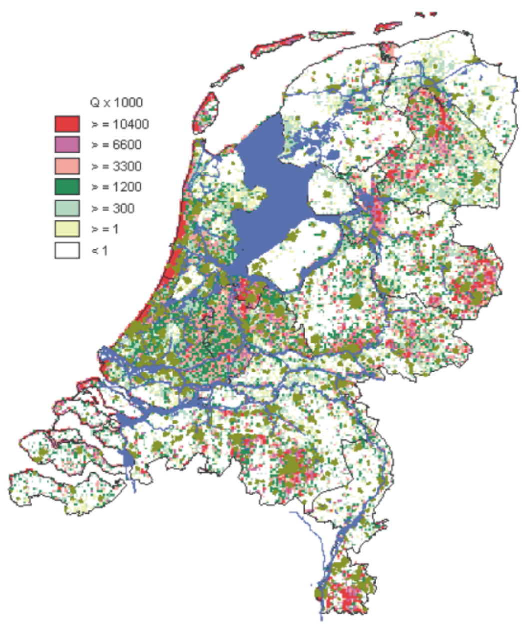

Fig. 2. The botanical value, Q (of 1 km^2) , in The Netherlands. Cumulative areas (percentage of total) for Q×1000: >10 400, 5%; > 6600, 10%; >3300, 20%; >1200, 35%; >300, 50%; >1, 60%; <1, 100%. Note: cities and industrial areas have a brown colour.

So ERI is expressed in terms of 'equivalent m^2 of rare ecosystems'.

The basic idea about the threshold value is that if $Q/Q_{\mathrm{threshold}}$ is >1, the botanical value of nature is of such an importance that these areas have to be protected (never be converted).

3. A single indicator for land-use in the LCA

3.1. Land conversion as a basis for evaluation

The physical impact of land-use can be described in terms of:

- *conversion* (change, transformation) of the use of land (with the dimension of m^2);
- *occupation* of land for a certain activity (with the dimension of: m^2 year).

These two aspects of land use have both been proposed by the SETAC Working Group on Impact Assessment in 1996, see also [11]. In formula these are:

$$\text{land conversion impacts} = \text{area } A \times \text{ quality difference} \quad (6)$$

$$\text{land occupation impacts} = \text{area } A \times \text{ time } t \times \text{quality}. \quad (7)$$

Both equations can be combined with eqs. (1) and (5), since SRI and ERI denote the quality (in terms of equivalent m^2 of botanical value). Occupation addresses the impacts of using land, whereas conversion focuses on the impacts of changing the use of land. As the impacts of conversion are considered more relevant than those of occupation [3], we will focus here on the *conversion* impacts.

The basic idea of *conversion* of land, with the dimension of (m^2), is that the 'quality of land' is deteriorated when people start to use land. Nature is being destroyed and the environment is degraded at the moment urban and industrial areas or railway and road infrastructure is expanded ('greenfields' are becoming 'brownfields'). The conversion of land causes depletion of scarce 'nature', similar to the resource depletion of materials when virgin materials are used for products.

When a new production facility is planned in a renovated building, the consequence of the *conversion* approach is that there is no conversion of land (land is re-used, or 'recycled', similar to the approach of the recycling of materials). So the conversion approach in LCA is stimulating the use of existing facilities, instead of creating new facilities on new land. The conversion approach is focussed on the prevention of the *expansion* of industrial and urban areas: when all economic activities stay within the existing boundaries, there is no impact in terms of conversion.

Land-use described in terms of *conversion* of land is appropriate to analyse design alternatives for governments (spatial planning) and manufacturing companies (site selection).

3.2. The eco-costs for 'species richness' and 'rare ecosystems'

The conversion of a category indicator into the single indicator of the EVR model, the eco-costs, is based on either the prevention costs or the compensation costs of degradation of 'nature'. Compensation means here that somewhere else an extra area of protected nature will be created.For $(Q/Q_{\text{threshold}}) < 1$, compensation is regarded as feasible as well as realistic. For $(Q/Q_{\text{threshold}}) > 1$, compensation is not a realistic option (in such a case the 'rare ecosystems' is of exceptional botanical value), so conversion is forbidden (i.e. conversion must be prevented).

The costs related to the creation of a protected nature area (i.e. the compensation costs) are estimated at:

- 3.5 Euro per m^2 to buy the land (price of agricultural land in the Western part of Europe in 2000);
- 0.5 Euro per m^2 for the conversion costs [21].

The resulting total costs of compensation, the eco-costs of species richness as well as the eco-costs of rare ecosystems, are 4 Euro per equivalent m^2 of nature.

In formula:

$$\text{eco} - \text{costs of species richness} = \Delta\text{SRI} \times 4 \text{ (Euro) for } \frac{Q}{Q_{\text{threshold}}} < 1 \quad (8a)$$

or

$$\text{eco} - \text{costs of rare ecosystems} = \Delta\text{ERI} \times 4 \text{ (Euro) for } \frac{Q}{Q_{\text{threshold}}} < 1 \quad (8b)$$

where Δ SRI (or Δ ERI) is the difference between SRI (respectively ERI) before and after the conversion.

Eq. (8) might be applied to The Netherlands, Belgium, Germany, England and the northern part of France, see [16]. For other countries in the world, a preliminary calculation method of the eco-costs is proposed in Appendix B.

4. Evaluation

4.1. Discussion

The issue of land-use in terms of conversion of land is often a complex problem of contradicting interests of the stakeholders who are involved. The current policy in most western countries is to empower local authorities to meet the needs of their communities. The result, however, is a highly fragmented structure of decision making, with little or no co-ordination to consider regional and long term consequences [8]. 'Not in my back yard' (NIMBY) discussions do often prevail. In such a situation there is a need for a structured approach in EIA of the land-use conversion.

To quantify the ecological effect of land-use, two aspects play a role:

- the area (km^2) of the land which is to be converted,
- the quality of the land of that area.

Biodiversity is one of the important aspects of that quality. It is obvious that biodiversity is about the diversity of flora as well as fauna. Vascular plant diversity is an obvious proxi upon which to base a practical indicator of the biodiversity of flora, since vascular plants play a key role in ecosystem functions. Moreover, diversity and completeness of ecosystems seems to be reasonably well correlated with species diversity (including fauna) in general [12]. One may conclude that both methods (the 'species richness' model as well as the 'rare ecosystem' model) can provide a proxi for biodiversity in EIA and LCA calculations on land-use. Note that the methods can also be applied to EIA calculations with regard to compensation measures (losses in one area might be compensated by creation of a natural area elsewhere).

Comparison of Figs. 1 and 2 and reveals that there seems to be a correlation of the data of the two methods *on a regional level* ("when the species richness *S* is high, the botanical value *Q* is also high in most of the cases").

However, when those maps are analysed in detail *on a local level*, differences between the two methods can be very significant. Details are given here for the northern part of The Netherlands: the islands above the Waddenzee (Terschelling, Ameland, Schiermonnikoog, Rottemerplaat and Rottemeroog). See Figs. 3 and 4. It is evident that parts of these islands score low on the species richness map (Fig. 3), but high on the rare ecosystems map (botanical value, Fig. 4). An example is the island of Rottemerplaat (Fig. 5), a protected area because of its high quality of nature: $Q>10.4$, however, S is only between 136 and 109 species at 1 km^2! Therefore, local assessments of change of land-use in EIA must always be done by means of the method of the 'rare ecosystems'. For regional assessments, however, the model of the 'species richness' is accurate enough to provide data with regard to alternative solutions in spatial planning. So both methods can be valuable tools in the decision making process of EIA.

In most LCA studies, local details are not known, so data on 'species richness' are fair enough as a proxi for the botanical aspects of land-use.

4.2. Conclusions

With regard to EIA and the rare ecosystems model:

1. The rare ecosystems indicator is more adequate for EIA than the species richness indicator, since the rare ecosystems model provides better data to base decisions on with regard to spatial planning on a local scale
2. Obtaining the detailed data on the flora which is required for the rare ecosystems model, might be a problem in some parts of the world. The complexity of the calculation method might also be regarded as a disadvantage of the model.

With regard to EIA and the species richness model:

3. For EIA on the scale of big regions (i.e. >5000 km^2), the species richness model might be a practical choice for making comparisons between alternative solutions,
4. Data required for the species richness model is available in most of the situations.

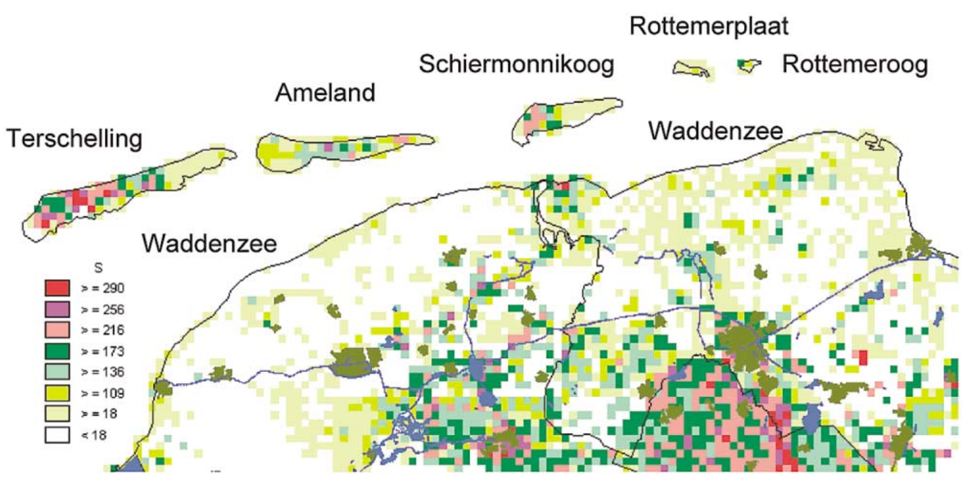

Fig. 3. The species richness, *S* , in the northern part of The Netherlands.

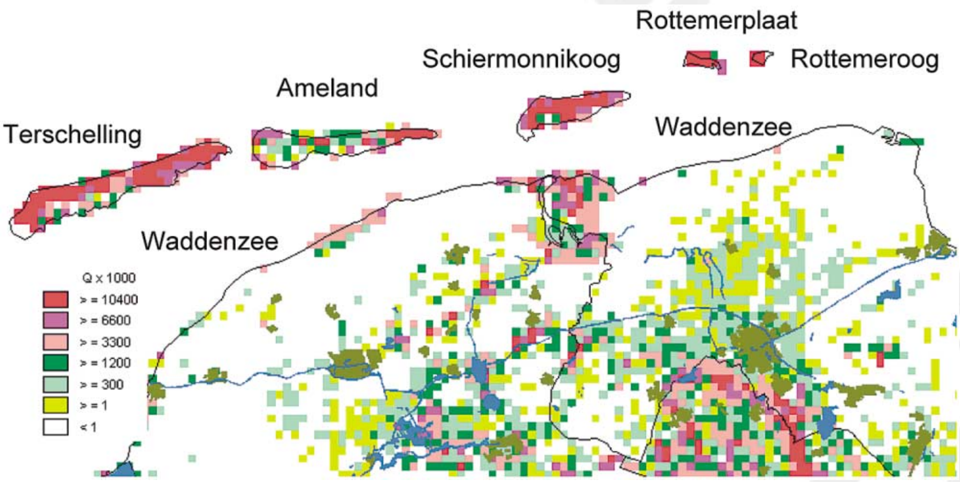

Fig. 4. The botanical value, Q , in the northern part of The Netherlands.

Fig. 5. The island of Rottermerplaat.

With regard to LCA:

5. In LCA, the *species richness* model seems to be accurate enough as a proxi for biodiversity in most of the cases. Even eqs. (3a) and (3b) can be used to make an estimate of S (note that there are hardly any situations in EIA, where eqs. (3a) and (3b) can be considered as acceptable in terms of accuracy).

5. Uncited references

[20, 22–24]

Appendix A. Calculation of the botanical value, *Q*

The way V, C, and Q of eq. (4) are calculated is briefly described as follows (see [18] for details):

- ‘ecosystem types’ have been defined, based on the following four abiotic parameters: salinity (classes: fresh, brackish, saline); moisture regime (classes: water, wet, moist, dry); nutrient availability (classes: low, moderate, moderate to high, high); and acidity (classes: acid, neutral, alkaline). Combination of these parameters resulted in 28 ecosystem types relevant for the total Dutch area
- Groups of ‘indicator species’ have been defined for each ecosystem type. The ‘indicator value’, v, has been determined to describe the ecosystem–species relationship ($v = 1$ if a vascular plant occurs only in one ecosystem, $v = \frac{1}{2}$ if a plant occurs in one other ecosystem as well, $v = \frac{1}{3}$ if a plant occurs in three ecosystems, $v = 0$ if a plant occurs in more than three ecosystems).
- The indicator values v have been added up for all m species (vascular plants) in a km^2 belonging to a certain ecosystem, resulting in the ‘indicator value score’, R:

$$R = \sum v_{\mathrm{m}}$$

So R is a weighed number of indicator species in 1 km^2.

- The maximum R in the database was determined for each of the 28 ecosystems, being the value which is not surpassed in 99.8% (!) of the km-squares (to rule out extremities): $R_{0.2}$ (being the maximum practical weighed count of indicator species in 1 km^2).
- The parameter for the completeness, C, has been calculated for each km^2 in the database via a quite complex procedure. This calculation, however, can be approximated within 10% by:

$$C = 1 \text{ for } \frac{R}{R_{0.2}} > 0.72$$

(the km^2 is 'saturated' with indicator species or, in other words, its completeness is 'very high' when R is >72% of $R_{0.2}$)

$$C = 0 \text{ for } \frac{R}{R_{0.2}} < 0.43$$

(this threshold determines "whether an ecosystem may be said to be really present in 1 km^2 , instead of classifying its occurrence as 'noise' ")

$$C = \frac{R-0.43R_{0.2}}{0.29R_{0.2}} \text{ for } 0.43 < \frac{R}{R_{0.2}} < 0.72.$$

The linear range of C might look rather small, but when the results of the scores of C are drawn on maps of The Netherlands, the results appear to be surprisingly good in terms of relevant botanical information.

- Species in an abundant ecosystem type are less rare than species in a rare ecosystem type. Therefore, the second main parameter in the model, V, copes with the rarity of an 'ecosystem type'. V is a function of the occurrence of the ecosystem type in terms of the total weighed area AW (km^2) of that ecosystem type: $\mathrm{AW} = \sum(C \times \Delta A)$ where ΔA is 1 km^2 and the summation is for the total area of The Netherlands

$$V = \left(\frac{\mathrm{AW}_{\max}}{\mathrm{AW}}\right)^{0.63}$$

where AW $_{\max}$ is the occurrence $\sum(C \times \Delta A)$ of the most abundant ecosystem. Note: V has been slightly corrected for international rare ecosystems. V ranges in the database from 1 to 9.8.

- Finally, the importance of land, Q ('Botanical Value of 1 km^2'), can be calculated according equation:

$$Q = \sum(V \times C).$$

Note: the summation is used when there are more than one ecosystem type within 1 km^2.

Appendix B. Species richness of vascular plants on a global scale

Fig. 1 provides the data on species richness on the national level of The Netherlands. For other European countries between 46° and 57° latitude, Table 2 or local data might be applied, but what do we do in other areas of the world? Such a question is particularly of interest for the issues of land-use (land conversion) related to mining of minerals and fossil fuels and to production of wood from rainforests.

In literature, the species richness of vascular plants is provided on the basis of the number of species per 10 000 km^2 [16]. The number of species for The Netherlands are in the range of 1000–1500 per 10 000 km^2.

To make a preliminary estimate of the eco-costs of land conversion in other parts of the world, the following assumptions have been made:

1. $S_{10000\ \mathrm{km}^2} = 5 \times S_{1\ \mathrm{km}^2}$ ($S_{1\ \mathrm{km}^2} = 250$ for 1 km^2 corresponds with $S_{10000\ \mathrm{km}^2} = 1250$ for 10 000 km^2);
2. the quality norm of The Netherlands, $S_{1\ \mathrm{km\ nature}} = 250$ in eq. (3), is applied to the other areas as well (so there is one quality level of S for the whole world);
3. the eco-costs of species richness of 4 Euro per equivalent m^2 of nature, see Section 3.2, is applied to the other areas as well (that means that all areas in the world are valued at the same level, regardless of local conditions for marginal prevention or compensation costs);
4. the local number of species S before the conversion is the average number of S for the area;
5. $S = 0$ after the conversion (for mining as well as production of wood from rainforests).

Applying eqs. (3) and (4) under the aforementioned conditions results in:

$$\text{eco} - \text{costs of species richness} \quad (9)$$

$$= A \times 4 \times \frac{S_{10000\ \mathrm{km}^2}}{250 \times 5} \text{ (Euro)}$$

where A is the area which is disturbed by the conversion, and $S_{10\,000\ \mathrm{km}^2}$ is from [16].

Rainforests in Panama, Bolivia, Peru and Cameroon have a very high species richness: $S_{10000\ \mathrm{km}^2} = 5000$. The eco-costs of species richness are for these areas 16 Euro per m^2. The eco-costs of rainforest in e.g. New guinea, Indonesia, Congo and Colombia are slightly lower: 12.8 Euro per m^2. Data on other countries in the world are provided in [15].

Appendix C. Other characterization systems for conversion of land in the EVR model

For land-use within the EVR model, the following four main 'endpoint categories'[4] have been proposed with regard to sustainability (subjects which need to be protected) [15]:

1. 'habitat for plants, animals and other species' with biodiversity as an important impact category', with either 'species richness' or 'rare vegetation' as the most important indicators (indicators for fauna are still under development);
2. 'local habitat for the human being' with 'scenic beauty' as the main 'impact category';
3. 'food and energy production' with 'net biomass production' as the main 'impact category';
4. 'H_2O cycle function' with 'filter capacity', 'water storage' and 'desiccation' as the main 'impact categories'.

This is depicted in Fig. 6.

The endpoint category 'habitat for plants' (the subject of this paper) is basically a proxi for 'habitat for flora and fauna'. The basic idea is that, when vascular plants are safeguarded, the fauna will be safeguarded as well [12].

The endpoint category 'local habitat for people' is regarded as one of the important sustainability issues (our world is not only for flora and fauna, but for us, human beings, as well) . The impact category of 'scenic beauty' is related to urban and rural planning. The basic idea is that the human being has the fundamental right to experience the pleasure of 'nature' (natural beauty, scenic beauty of landscapes and other visual and recreational aspects of parks and landscapes). The 'greenfields' have to be planned not far from the cities, since the need for travelling over long distances has to be kept to a minimum. Scenic beauty is considered as an elementary aspect of the human welfare, it should be protected, and it is therefore a sustainability issue. Another aspect of 'local habitat for people' is related to the 'eco-costs of noise' of the EVR model.

The endpoint category 'food and energy production' has had a lot of attention in literature, with 'biomass production' as the main 'impact category' [11].

The endpoint category 'H_2O cycle function' is complex and divers [26]. It seems especially important for spatial planning issues. For the specific situation of Dutch polders, a characterization system has been developed [15]. The main functions of land in the H_2O cycle are the filtering (cleansing) function and the storage function of fresh water. Unfortunately, the importance of these functions were neglected for decades. Only recently is there sufficient awareness that these functions are real sustainability issues, and that 'water management' is an indispensable activity for the future.

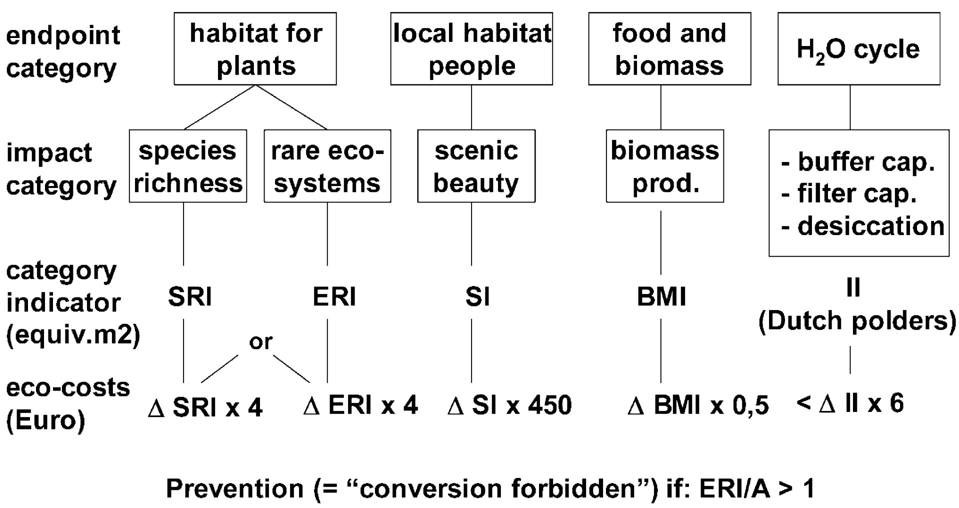

Fig. 6. The four subsystems for land-use in the EVR model.

[4] The idea of 'endpoint category' has been introduced in the LCA methodology to define the major areas of protection with respect to sustainability [25].

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