Mapping ecosystem types by means of ecological species groups

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Abstract

A method is presented to deduce nation-wide maps of ecosystem types from FLORBASE. This national database contains data, per km², on the presence of indigenous plant species that grow in the wild. The ecosystem types on the maps are defined on the basis of abiotic factors that determine the plant species composition of the vegetation in the Netherlands: salinity, moisture regime, nutrient availability, acidity. Water management measures may cause changes in these four factors and, as a result, change the species composition of the vegetation. For the construction of the maps, species of the Dutch flora are first allotted to the ecosystem types. Then, on the basis of both the number and the indicative value of species, a botanical quality class of each km² is assessed for each ecosystem map. The boundaries of the quality classes are obtained by expert judgement. It is possible, however, to compute class boundaries with a mathematical procedure, also for grid cells larger than 1 km². The maps are corrected for regional differences in the detail of the plant inventories. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Mapping ecosystem types; FLORBASE; Ecological species groups

1. Introduction

In the Netherlands, nature is largely adapted to wet environmental conditions, as may be illustrated by typical landscapes, such as brook-valleys, swamp woodlands, fens, bogs, dune slacks, wet heathlands and salt marshes. This wet character is a result of the low level of the country, which causes the groundwater level to be rather close to the roots of the plants. However, especially during the second half of this century, groundwater levels have fallen, mainly as a result of intensified drainage of agricultural land and a steadily increasing abstraction of groundwater. To prevent the levels from becoming unacceptably low, Rhine and Meuse water has been let into the land. This river water is often ‘area-alien’, which means that its chemical composition differs from the original waters in the area (relatively high concentrations of Cl⁻, N, P, SO₄²⁻).

The fall in groundwater and the diversion of area-alien water have adversely affected ecosystems. Over the past few decades, this desiccation...
has been mentioned both by researchers and groundkeepers as one of the main causes for the deterioration of ecosystems. The Government decided to act: in 1990 the Dutch parliament adopted a resolution which stated that by the year of 2000, the desiccated area has to be reduced by at least 25%. Policy measures against desiccation were laid down by the Dutch Government in several policy documents, such as the National Policy Plan on Water Management (Ministerie van Verkeer en Waterstaat, 1997).

In order to carry out its nature conservation policy in the best possible way, the Dutch Government required information on the distribution of plant species and communities. The floristic database FLORBASE (Section 2) now provides these data, offering a full and up-to-date picture of the distribution of vascular plant species that grow in the wild. In a policy-supporting study, FLORBASE was used to construct nation-wide distribution maps, showing the botanical quality of some 28 ecosystem types (Witte and Van der Meijden, 1995; Witte, 1998). These maps serve as geographical input to the ecohydrological dose effect model for terrestrial nature (DEMNAT) (Witte, 1998; Van Ek et al., 2000). In DEMNAT, the vegetation is considered as representative of the biotic part of the ecosystem. There are two reasons for this approach: first, the relationship between the abiotic environment and plant life is quite direct, whereas the relationship between the abiotic environment and fauna is more indirect. And second, the value (expressed as a number) of an area for nature protection is usually deduced from the vegetation (Van Wirdum, 1986).

This paper gives a brief description of the methods that were used to construct the ecosystem maps. For more information refer to Witte (1998). In the following section we describe FLORBASE as well as the ecosystem classification we applied. In Section 3 we briefly describe the method used to construct the ecosystem maps. Some results are given in Section 4. This is followed by a discussion in which we focus both on the reliability of the methods and the applications of the maps.

2. FLORBASE and the ecotope system

2.1. FLORBASE

The database FLORBASE contains the observation records of all vascular plants that grow in the wild on a km² basis (Fig. 1). In our study FLORBASE-2c (released in November 1997) was used to construct ecosystem maps. It contains 6.4 million records from the period 1975–95, 2/3 of which were supplied by professional biologists and 1/3 by amateurs. The amateurs take a special interest in rare species, which is illustrated by the fact that they gathered half of the records on those species.

The data in FLORBASE have been taken from different inventories and therefore the database is likely to contain inventory effects, i.e. geographical differences in relation to the way the inventories were made, rather than to botanical differences. Inventory effects are clearly visible in Fig. 2, which shows the number of species per
species. One reason is that botanists often preferentially record rare and indicative species, because they have a special interest in such species. Another reason is that from the species that were only recorded on paper — and not stored digitally — especially the ecologically-indicative ones have been transferred into FLORBASE.

2.2. The ecotope system

There are many methods for defining ecosystem types, depending, for example, on study objectives and map scale. We used the ecotope system of Leiden University (Stevers et al., 1987; Runhaar and Udo de Haes, 1994), which we modified slightly for our study. The ecotope system contains a classification of ecosystem types on the basis of five operational factors that explain important differences in the species composition of the vegetation of the Netherlands: salinity, moisture regime, nutrient availability, acidity (all four abiotic) and vegetation structure (Table 1). For each of these factors, a number of classes have been distinguished. The factor moisture regime, for example, is divided into the classes aquatic, wet, moist and dry (Table 1). Climate is also an important factor that influences the vegetation both directly (e.g. through frost) and indirectly (e.g. through soil development). However, it has not been used as a classification characteristic here because within the Netherlands climate differences are small.

Combinations of classes result in the ecosystem types of the ecotope system. One ecosystem type is K23: a herbaceous vegetation (K) on a wet (2), nutrient-poor and alkaline (3) soil. By combining those classes that are abiotic, the site types of the ecotope system are obtained (example X28: wet, very nutrient-rich). Not all the theoretically possible combinations of classes have been distinguished as ecosystem types. Some combinations are ecologically irrelevant. For example, in ecosystems that are very rich in nutrients, the influence of acidity on the species composition is far less pronounced than in nutrient-poor ecosystems. Therefore, in very nutrient-rich ecosystems acidity has not been used as a classification characteristic. In addition, many combinations of

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**Table 1** Classification characteristics and classes of the ecotope system (Witte and Van der Meijden, 1995, modified after Runhaar et al., 1987)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Classes (symbol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>Fresh (–), brackish (b), saline (z)</td>
</tr>
<tr>
<td>Vegetation structure</td>
<td>Herbaceous (K), water (A), woods and shrubs (H)</td>
</tr>
<tr>
<td>Moisture regime</td>
<td>Water (1), wet (2), moist (4), dry (6)</td>
</tr>
<tr>
<td>Nutrient availability</td>
<td>Low (–), moderate (7), high (8), moderate to high (9)</td>
</tr>
<tr>
<td>Acidity</td>
<td>Acid (1), neutral (weakly acid) (2), alkaline (3)</td>
</tr>
</tbody>
</table>

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km² in FLORBASE. It appears that the rather uneven distribution of the numbers of species is mainly determined by the borderlines between provinces (Fig. 1 shows the provinces). However, regions with few data often contain many indicative species, and these are precisely the ones that are needed to construct the ecosystem maps. There are two reasons for the fact that less investigated km² contain relatively many indicative species. One reason is that botanists often preferentially record rare and indicative species, because they have a special interest in such species. Another reason is that from the species that were only recorded on paper — and not stored digitally — especially the ecologically-indicative ones have been transferred into FLORBASE.
classes do not occur in the Netherlands (for instance the combination ‘woods and shrubs’ — ‘saline’).

The ecotope system also contains an allocation of all plant species of the Dutch flora to ecological species groups (Runhaar et al., 1987; Runhaar and Udo de Haes, 1994). Each of these groups is composed of the plant species that are indicative of the corresponding ecosystem type. Species may be allotted to several ecological groups, allowing the system to take account of the indicative value of species. Hence, species that are very constrained in their site requirements are ascribed to one single ecological group, whereas less constrained species may be ascribed to many.

2.3. Environmental impact assessment and the ecotope system

The reason that, in this study, the ecotope system was used, is that — compared with other classification systems — it has a major advantage: the types have been defined according to abiotic factors that may be directly affected by environmental changes. As a result, the effects of these changes (e.g. eutrophication, desiccation and acidification) may be translated relatively easily into changes in the vegetation’s species composition. For example, Fig. 3 shows in a very simplified way how hydrological changes may adversely influence important operational factors of wet and moist ecosystems. This figure has been compiled from various sources (Etherington, 1982; Van Wirdum and Van Dam, 1984; Grootjans, 1985; Vermeer, 1985; Beltman and Grootjans, 1986; Koerselman, 1989; Roelofs, 1989; Barendregt, 1993; Koerselman and Verhoeven, 1995; De Mars, 1996; Runhaar and Van’t Zelfde, 1996).

A falling groundwater level may lead to shortages in the water supply to the vegetation and, as a result, to a physiological desiccation of the vegetation: species that are adapted to wet and moist environments will disappear. A groundwater fall may also cause increased aeration, which, in turn, promotes mineralization and, consequently, eutrophication. Hence, species characteristic for nutrient-poor sites will disappear. When organic matter is mineralized, protons are released and acidification of the soil takes place, causing species of neutral and alkaline sites to vanish.

The availability of phosphorus is largely regulated by adsorption on calciumhydroxydes (at pH > 6.5) and ironhydroxydes (pH < 6.5) (Stumm and Morgan, 1981). In this adsorbed form it is not available for plants. Hence, an influx of calcium or iron-rich water by upward seepage may lead to the development of mesotrophic and oligotrophic sites. Moreover, calcium and bicarbonate in upward seepage water form an important buffer against acidification by percolating rainwater. Hence, when the soil is originally influenced by lithotrophic upward seepage, a decreasing groundwater level may enhance both eutrophication and acidification. Of course, both effects may also take place when the intensity of upward seepage diminishes.

The inlet of surface water may lead to eutrophication, especially of aquatic ecosystems, since this water — in many cases from the rivers Rhine and Meuse — is often rich in phosphorus and nitrogen. Even when nutrient concentrations are low, the inlet-water may stimulate mineralization, leading to ‘internal eutrophication’. An explanation for this phenomenon is that the inlet-water often has a higher pH than the original water. More-

![Fig. 3. Main effects of hydrological changes on important operational factors of wet and moist sites, harmful to the vegetation (Witte, 1998). Direction of change indicated by arrows: (↑) increase, (↓) decrease.](image-url)
3. Method to construct ecosystem maps

The ecosystem maps were made in three steps. The first step involved the allocation of species to ecosystem types by means of indicator values. The higher the indicator value (v) of a particular species, the more indicative that species is for the ecosystem type in question. Table 2 lists, for example, the ecological species group of ecosystem type K21 (herbaceous vegetation on a wet, nutrient-poor and acid soil). In Table 2 Andromeda polifolia has an indicator value of 1 as this species is unique for K21, whereas Carex curta has a v = 1/2, because it also belongs to another ecosystem type.

The inventory of the Netherlands has not been carried out with the same intensity everywhere, causing the distribution maps that are directly based on FLORBASE to show inventory effects. Therefore, a second step was needed, involving the completion of species by means of gap-filling in every ecological group. This method is based on the phenomenon that some species may function as guiding species for other species. If a guiding species is found somewhere, the presence of its accompanying species may be taken for granted. Gap-filling led to a second flora database, which is more complete and, as a result, yields ecosystem maps that are more reliable. Fig. 4 shows for every km² the number of species that were added to FLORBASE by means of gap-filling. The gap-filling is highest when special efforts have been taken to collect or digitize data about indicative species: e.g. in the southern provinces. Where there are few gap-fillings or none at all, there may be two reasons for this: either the area has been examined especially well, so that there is no need for gap-filling, or it has been examined very poorly, so that gap-filling cannot take place for lack of guiding species.

In the third step, ecosystem maps were derived from the gap-filled database. For this, the indicator values per km² were added up for every ecological species group, resulting in an indicator value score S that provided information about the presence and the botanical quality of the ecosystem type in question. If, for example, in a certain km² the species C. curta, Drosera intermedia,
Eriophorum angustifolium and Rhynchospora fusca occur, then $S$ of $K21$ in that square amounts to 2 and $5/6$ (Table 2 : $1/2 + 1 + 1/3 + 1$). No direct use can be made of this score for the distribution maps because the ecological species groups differ in the number of ascribed indicator species, as well as in the spectrum of indicator values. Besides, there are differences in the number of indicator species that may actually be expected to occur within a km². Nevertheless, the indicator value score may indicate botanical quality differences within an ecosystem type, even though a comparison between the ecosystem types cannot directly be made. To reflect this, three threshold values $T$ were introduced, dividing the indicator value scores into four botanical quality classes. These threshold values have been determined for every ecosystem type. Scores that are lower than the first threshold value $T_1$ are disposed of as ‘noise’. Only when the score surpasses $T_1$, may the ecosystem type be accepted to be present and may it be used as a measure for botanical quality. The second, third and fourth classes in relation to the threshold values have been given the qualifications ‘low’, ‘high’ and ‘very high’. The threshold-values of ecosystem type $K21$, for instance, are $T_1 = 2.0$, $T_2 = 4.5$ and $T_3 = 7.0$. Therefore, with $S_{K21} = 25^6$, the botanical quality of $K21$ in the km² is classified as ‘low’.

4. Some results

In this section we present three out of the 28 ecosystem maps. In order to illustrate the full character of the maps, we will not show the whole of the Netherlands, but focus on some provinces instead (Fig. 1 shows the provinces).

Fig. 5 gives the distribution of ecosystem type $K21$ (herbaceous vegetation on a wet, nutrient-poor, acid soil) in the province of Drenthe. The botanical quality classes ‘noise’, ‘low’, ‘high’, and ‘very high’ are indicated by the colors grey, blue, yellow and red, respectively. Km² which after gap-filling contain less than 50 species have been omitted (‘insufficient data’). Regional surface waters (generally small rivulets) are indicated by blue lines.
The relatively species-poor vegetation is mainly found in bogs and wet heathlands, dominated by *Ericaceae* and *Sphagnum* species. With respect to its water supply, ecosystem type K21 is completely dependent on precipitation. Therefore, it is found in the more elevated recharge areas in between the brooks, where rain water infiltrates. The 'wet' character of K21 is related to the occurrence of a perched water table, which in most cases is the result of a shallow layer of boulder clay.

A completely different picture is given in Fig. 6, which shows the distribution of ecosystem type K27 (herbaceous vegetation on a wet, moderately nutrient-rich soil) in the province of Drenthe. The vegetation is relatively species-rich, and consists mainly of species from *Calthion* and *Philipendulon* grasslands (*sensu* the French–Swiss school of Braun-Blanquet). This ecosystem type is almost entirely restricted to relatively undisturbed brook valleys, which are fed by upward seepage of lithoclien groundwater, i.e. groundwater that is rich in calcium and bicarbonate. The groundwater has been enriched with these ions during its transport from the recharge area (with a.o. K21) to the discharge area.

The vegetation in the coastal province of Zeeland is influenced strongly by brackish and saline water. Along the coast, the vegetation may be in direct contact with seawater, whereas on the continent, upward seepage of saline groundwater may be the source of salt. Wet and moist ecosystems that are typical of fresh water, like K21 and K27, hardly occur in this province. On the other hand, brackish and saline ecosystems are relatively abundant. As an example, Fig. 7 shows the distribution of ecosystem type bK20 (herbaceous vegetation on a wet, brackish soil).

5. Discussion

5.1. How good are the maps?

The ecosystem maps and the various steps that were developed to obtain them have been thoroughly analyzed (Witte and Van der Meijden, 1995; Witte, 1998).

Ample attention was paid, for instance, to the question of whether gap-filling introduces more errors than corrections. To this end, various tests were developed. In one of the tests, for instance, species are randomly removed from a database. After gap-filling, it appears that the characteristics of the original database have returned (Fig. 8). These and other tests show that gap-filling is justified and that it considerably improves the ecosystem maps.

Also the way threshold values were established by expert judgement was examined. This judgement appears to have been systematic to the extent that an imitation by mathematical procedures is justified, not only for the km², but also for larger grid cells, measuring for instance 5 × 5 km². For the application of the ecosystem maps in policy analysis, such as is carried out with DEMNAT, this is a reassuring result. An inconsistent judgement, after all, could lead to the situation that regions with many over-estimated ecosystem types would dominate the model results. For example Fig. 9 shows the computed first and third threshold values plotted against the original threshold values, obtained by expert judgement.
The ecosystem maps have been compared to other data representative of the vegetation cover in the Netherlands, such as vegetation relevés. Insofar as the comparison permits conclusions, it may be stated that the maps are reliable. In particular the correspondence of the ecosystem maps with the site maps of Klijn et al. (1996, 1997) appeared to be very good. The site types of these maps were defined according to the same operational site-classes as those of the ecosystem types (Table 1), enabling a direct comparison.

Fig. 7. Botanical quality of ecosystem type bK20 (herbaceous vegetation on a wet, brackish soil) in the province of Zeeland. Based on FLORBASE-2c.

Fig. 8. Relation between original indicator value scores of ecosystem type K28 and: (A) mutilated scores; (B) gap-filled scores. After gap-filling, the scores more resemble the original values. RMS, root mean square of differences.
Finally, we questioned whether or not the eco-
tope system is suitable for a FLORBASE-aided
description of the vegetation of the Netherlands
(Witte et al., 1996; Witte, 1998). To this end, the
division into ecological species groups was com-
pared to the allotment of plant species to vegeta-
tion-units by Westhoff and Den Held (1969). The
division of Westhoff and Den Held is obtained by
the method of phytosociology ('French–Swiss
School' of Braun-Blanquet) and over the past few
decades, their publication has served as an impor-
tant work of reference for phytosociological re-
search in the Netherlands. The conclusion that
was drawn from the comparison is that the eco-
tope system is suitable for the FLORBASE-aided
description of the plant cover of the Netherlands.
More surprisingly, it appears to be of better use
for this purpose than the phytosociological divi-
sion by Westhoff and Den Held.

5.2. Applications

As we mentioned in Section 2, the maps serve
as a geographical input to the ecohydrological
model DEMNAT. Moreover, the ecosystem maps
have also been used in numerous water manage-
ment analyses on a regional scale (e.g. Klooster-
man et al., 1996; Hoogeveen and Vermulst, 1997).
Finally, we used the maps in a conservation
valuation study (Witte, 1996, 1998). In this study,
the 28 maps were combined into one single con-
servation value map by calculating one value per
kilometer square, which is based on: (1) the num-
ber of ecosystem types in a kilometer square, (2)
the botanical quality of these ecosystem types,
and (3) the potential conservation value of these
ecosystem types. Five experts in the field of
botany preferred this map to eight maps based on
other conservation valuation methods. Our con-
servation valuation method is used to evaluate the
ecological effects of water management, as calcu-
lated by the ecohydrological model DEMNAT.
Moreover, it was used to evaluate the environ-
mental effects of a proposed expansion of the
Dutch railway (Groen, 1997).

References


