PRINCIPLES OF BIO-INDICATION*

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1. Some Concepts

1.1. 'Indication' and 'quality'

The concept indication as used in this series of papers points to making visible what is not immediately perceptible. In this case the non-immediately visible is the quality of air, water, soil and the living world which surrounds us, in short: our environment the ecosystem on which also man depends. One can try to find indicators which tell us directly something about the quality, i.e. the usefulness, resp. harmfulness for a certain purpose. However, one might be content with the indication of environmental factors which are not the quality itself, but which decide the quality indirectly such as moisture content, composition of minerals and the like.

In other words, one can apply the indication with two different incentives:

– in order to gain more knowledge on the indicated item in pure scientific sense;

– in order to be able and judge the quality of the indicated item (applied research).

The latter goes further than the former as it requires a presumption on good and evil and even a consideration of society. In this paper we restrict us to the indication as such. Schroevers (1983) will elaborate the conception of quality in a social context further on in this issue.

1.2. Indicators, criteria, and norms

Literally indication means: 'pointing out'. For instance, the hands of a clock, the needle of a manometer, are indicators. To be able to point out: A criterion is necessary such as a unit of time in case of a clock, unit of pressure in case of the manometer, percentage of moisture in case of a hygrometer, etc.

Next one needs a norm in order to be able to interpret what the registration means for the purpose for which it is indicating. (Van Leeuwen (1981c) argues that these concepts sometimes are confused).

The criteria are closely linked with the type of indicator and can vary from the colour of a tissue, the attitude of a leaf, to the species composition of an entire ecosystem expressed in quantitative or qualitative units.

The norm is either the quality as a whole, but in most cases the critical (marginal) values of an agent deciding the quality. The latter can be abiotic environmental factors

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such as water, nutrients, poisonous matter and the like. With a 'neutral' attitude there is no question of a clear norm, one ascertains only a situation.

1.3. Biological indication

Biological indication is making use of relatively easy, observable reactions of living matter as indicator. This matter may be parts of organisms up to total ecosystems. This is opposite to more or less direct measurement of these environmental factors themselves. Biological indication has been applied for a very long time. Within living memory hunters, shepherds and farmers have recognized the quality of land by the growth of plants and by the behaviour of animals, when they choose the place of their settlements, their huntinggrounds, their fields and pastures.

Pellerwoinen, the Finnish mythological figure, sowed Alder on the wet spot, Fir on the dry spots and the Finns knew so. The pre-technological people of Western Africa still recognize good soil by the Gau-tree (*Acacia albida*), the Gaya-grass (*Andropogon gayanus*) and also the Roan-antelope (*Hippotragus equinus*).

Biological indication is possible because there are 'correlative complexes' (relation-systems), in which the behaviour, the form, the existence of biological features of various kinds are connected causally, direct and indirect, with actions of the environment. These actions can be abiotic in nature (heat and cold, dryness and wetness, the presence of minerals which are necessary or poisonous) but also of biological nature such as grazing, trampling, manuring by animals. In all cases the main law in ecology holds (good): for each action one can distinguish a minimum required and a maximum tolerated. Between these is the optimum level for the influence of each environmental factor. With minerals an excess of the maximum tolerable is called: poisoning. Being insufficient to the minimum requirement is called: deficiency. There are in general poisonous doses, rather then real poisons. Notably the plant-nutrients such as nitrogen, potash, phosphor can be deficient, but also poisonous, dependent on the doses.

2. Why Biological Indication?

Why would one use *biological* indicators even for physical and chemical measurable factors? There are *six reasons*:

– Often it concerns cumulative processes of strongly fluctuating factors which can not be measured by one single observation using a chemical or physical method. The classical examples are groundwater, presence of nitrogen in soil and climate properties.

– Physical and chemical methods may be too time-consuming and/or too costly to repeat them often in space and time. For instance, gradients and processes in the vegetation or fauna can help to extrapolate a limited number of physical/chemical measurements in space and time. Important examples are soil qualities, climate zones.

– Sometimes the quantity and/or intensity of the working agent is thus (low) that chemical and physical assessments are very complex and at any rate not accurate enough. With biological indication often gradients can be indicated. By chemical/physical measurements of the extremes of such a gradient the bio-indication can then be relatively quantified.

– Sometimes the combination of effects is more important than the separate factors. For instance, the indication of soil moisture is always a reaction on the total availability of water in the ground, not on the easy measurable phreatic level only. Fertility indication is in most cases a combined reaction on Potash, Mn, N, PH etc. The total effect can be different from the mere sum of all separate actions (synergy).

– It is also important to realize that various factors are very difficult to measure with respect to their proper direct (operational) action. Van Wirdum (1981) distinguishes between 'operational' and 'conditional' factors. The latter are complex circumstances to which the concerning real operational factors are connected directly or indirectly, but which are not the real agents themselves*. In various cases it may be stated that the proper operational actions are still unknown. By measuring the effect one gets a more realistic image than by measuring some 'pretended' agents themselves. Moreover the so-called direct measurements are in essence extremely rough. For instance, what is the relation between the *subtle* process of the actual ion-exchange between soil and plantroot, compared to the coarse chemical methods to determine these ions after demolition by grinding fine with *fierce* force of soil samples, then devoid of structure and life?

Examples are the relation between texture and fertility and humidity of soil as indicated by the vegetation. Fertility depends on availability of diverse nutrients of which the quantity and availability (absorption complex) is related to the texture. Moisture-holding capacity is especially determined by the structure which is again connected to certain extent by the texture. Thus texture is a simple conditional factor. Structure and making of the absorption complex inclusive the reaction on this by the plants is a complicated conditional situation which determine diverse operational effects.

By Bannink *et al.* (1973) an other example is given of the difficult measurableness of operational factors such as the phosphate-supply in forest grounds. It appears that within a definite type of soil, a clear correlation exists between the 2N–HCl. solvable phosphate both with the growth of planted trees and the spontaneous forest floor-vegetation. The relation appears to exist on three groups of different soil types: 'plaggenboden' (old arable land), 'brown forest' soils and a group of '(veld)podzol' soils, on the understanding that in each of the three (groups of) soil types a correlation exist between P and vegetation. An absolute correlation between P and vegetation type (neither tree production) does not exist however. Evidently the measured quantity of phosphate is not identical with the 'operational' quantity. Other factors, specific for each type of soil, under which probably the form in which humus and iron are present in the soil, define the operationality of the phosphate, which is defined only coarsely via a rough method of destruction and subsequent dissolution in relatively strong acids (2N–HCl.)*.

It is also generally known that a total N percentage of the soil can hardly reflect

* See for this 'positional' factors Section 5.3.

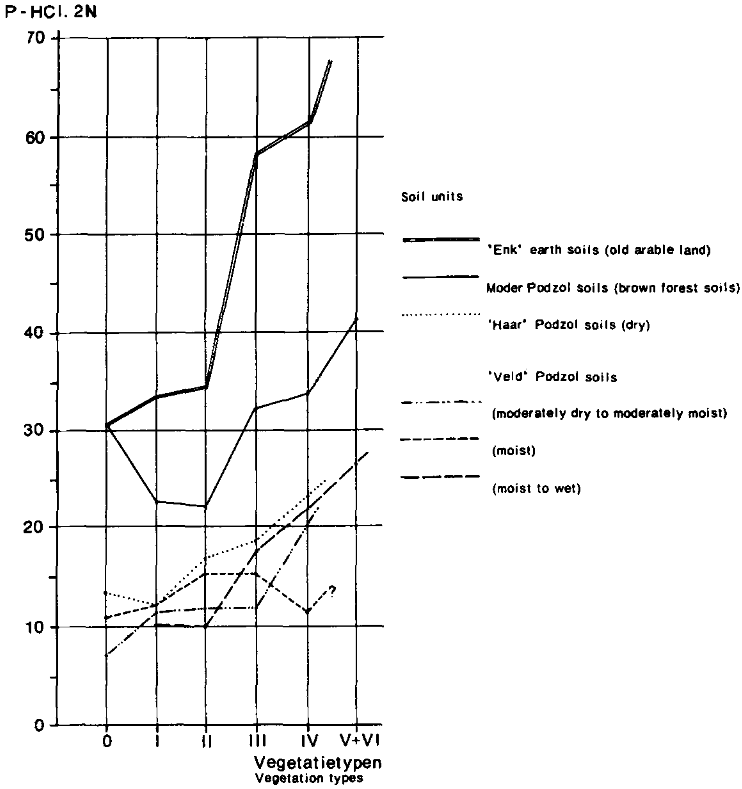

Fig. 1. The relation between P-HCl. 2N-value and the vegetation type on various soils units in Douglas forests in The Netherlands.

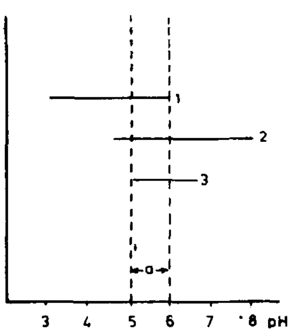

Fig. 2. Use of a few species for indication of an environmental factor. 1, 2, and 3: actual ecological amplitudes of three different species with respect to pH. (a) pH section covering the habitat of the three species.

anything of the operational availability of this nutrient, although here also, high values tend to indicate to probably better availability than low values. This follows also from the observation that the decomposition of organic matter with higher percentage of nitrogen proceeds also often more rapid than that of organic matter with a high C/N ratio. Experiments are required to find out to what extent the differences in vegetation indicate phosphate and/or nitrogen or something else. From fertilizer tests it appears that phosphate application can cause the differences in vegetation of the kind mentioned before. Agricultural fertilizing advise is usually given empirically. The chemical analysis of soil can only be used if one takes into account all kinds of conditional factors.

– Finally there is a sixth important argument for biological indication. This can be formulated, one should *'ask the patient herself how she is feeling'*. This often is done whenever the quality of a certain environment for the means of indication itself or related processes of live is concerned, or for the total ecosystem of which the means of indication is a main attribute. Such is the case e.g. if spontaneous vegetation in forests, arable fields and pastures are concerned. For deciding the actual situation this is the ideal way of doing.

However, there are also *disadvantages*: A patient may not know about 'why' he feels good or bad and 'what there is to be done'. In order to state the latter further investigation is necessary, in order to assess what factor is too much or too little (and how much the excess or shortage is).

Indeed, biological indication is often lacking quantitative data. In general, a combination of biological and chemical/physical methods is the most ideal way.

3. Biological Indicators

Bearers of life are, in the order of successive integration levels, macro-molecule, organelle, cell, tissue, organ, organism, population, community, ecosystem, biome. In practice all these 10 levels are used for indication.

So chromosome structure is already useful to indicate the action of poisonous matter (macro-molecule and organelle), see Everts in this issue. At the other side of the scale is the biome, the complex ecosystem which implies broad climate zones or lifezones (e.g. Holdridge, 1959). The integration levels most frequently used for indication are, however, tissues and organs, organisms (plant and animal taxa) and communities (viz. vegetation types). Tissues are used especially for indication of true pollution. The criterium is deterioration, the measure is the intensity. The determination of the content of poisonous material adsorbed to plant tissues such as bark of trees or moss (*Sphagnum*) which are specially exposed to poisonous air in bags, tends already to non biotic means of indication.

* The various ways of solving phosphate, P-citron, P. Al, P. water appear to be all just approximations. They never are really revealing the operational quantity. Even if they approach the ideal, the content of P in natural soils may be so low that the determination figures do lie in the range of determination errors. Only in arable soils relative high P contents are available even in poor soils. For these the existing methods give acceptable results.

The *Avena* coleoptyle method (Went) to determine phytohormones (auxine) is a well-known example of using an organ as indicator. The wilting of leaves of young sunflower plants as a measure for moisture tension (pF) is an other example and also for 'using the patient to show how he/she is feeling him(her)self'.

In this case the organism reacts as a whole. The same holds for all kinds of tests for hormones and vitamines with various plant and animal species. Air pollution indication is mainly done with a limited group of species, be it again mainly through tissue reactions: *Petunia, Medicago, Urtica, Poa, Apium graveolens, Gladiolus* (special races) (see Posthumus in this issue). The herdsmen, farmers and hunters mentioned earlier distinguish usually species as indicators. The dutch name 'Zorggras' (sorrow grass) for *Holcus mollis*, points to the sorrowful situation in an agricultural sense, if this grass appears in the arable fields: a sign of depletion of fertility. The old farmer who says that he in pitch-darkness can tell where the best soils are by walking on his socks knows that thistles (*Cirsium arvensis*) only occur on the best soils, be it that it reveals a somewhat shoddy farmer. Still quite some criticism rose during recent decades parallel with the development of agro-chemistry and technology about these old 'farmers wisdom' and use of species as indicators. This criticism is partly justified (see Section 4, 5, and 6). The use of vegetation types represents a following level of integration. Part of the objections against the use of single species as indicator can be eliminated by using vegetation types (e.g. De Boer, 1983).

Growth and life forms are an important medium for bio-indication instead of species. One and the same species may indicate certain environmental conditions by its growth form (phenotype). This may be due to seasonal differences in climate at present or in the past. In subarctic and subalpine areas the form of trees may indicate thickness of the snow cover. The same species looks quite different depending on the influence of snow, the wind and the browse intensity.

Schreiber (1977) used the deformation of branches caused by frost damage to buds to indicate climatic fluctuations in the past. Growth rings in wood are used for the same purpose, but than for a much larger period.

Life forms are hereditary properties that can be interpreted as genetically fixed adaptations to the environment. Various lifeform systems do exist, and more could be thought off. The hydrotype systems of Iversen (1936) describes adaptations to the factor water. The spectrum of various types of adaptations can be used as a measure of the hydrological regime (compare Zonneveld (1959, 1960) and Zonneveld and Bannink (1960)). The system of Raunkiaer (1937) depends on the adaptation to the most unfavourable season (hibernation strategy). This characteristic makes it very suitable for climate indication, especially of biomes, but also of plant associations (see Section 5).

4. Limitations of the Use of Bio-Indication

The use of organisms as indicator is restricted by limitations arising from the four following main laws:

– The law of Baas Becking-Beyerinck: 'Everything (diaspores) is everywhere but the environment selects' confirms indicatory value on presence or absence of organisms but neglects the restrictions of accessibility.

– The law of the physiological (potential) and ecological (actual) amplitude. Competition and tolerance, priority and primarity determine also the occurrence of species (taxa).

– The law of relative site constancy (Walter). Species behave more critical towards a site factor the further they are removed from there optium (centre of their plant-geographical distribution area).

– The complex character of factors. Correlation with measured factors differs depending on interacting of other factors. The difficulty in measuring operational factors compared with conditional factors plays a role here, as well as synergy.

The first mentioned law of Baas Becking and Beyerinck only applies to organisms with very light and numerous diaspores. Even here the current windsystems cause differences in accessibility. For most other organisms various barriers like mountain chains and oceans hamper the transport. This means that a certain organism does not occur on many places where suitable niches are available. Competition is at least as important for the absence of a species at a certain site. Its place is occupied by another species because the latter is stronger, or because it was by chance just a bit earlier and strong enough to resist others, or because at that site an individual of another species as relict from a former succession stage is growing, which may be less suitable for the site, but for the time being holds itself (primarity). Competition, priority and primarity determine together the above mentioned law which states that the ecological (actual) and physiological (potential) site amplitude differ. This means that results of laboratory experiments with single or small group of plants may not be extrapolated to the field situation.

Nevertheless, one is used to distinguish e.g. nitrogen-indicators, moisture-indicators, etc. Even handbooks do exist with indication values for taxa, irrespective the competition circumstances (Ellenberg, 1974; Londo, 1975 and others). These lists are reasonably valid within the local area for which they are developed based on field experience (mainly estimation).

– The law of relative site constancy is postulated by Walter (1973) especially for the phenomenon that many plants, originating from relatively humid climates 'withdraw' themselves from the dryer climates to local humid topoclimates and/or more humid soils.

An example is the galery forest along rivers in savannas with clear relation to the rainforest on the upland in the more humid tropical climates. Species growing at the fringes of their distribution areas, become in general more accurate indicators of certain environmental factors then they are in the center (Hengeveld and Haeck, 1982). Arable weeds are also good examples*.

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* The law of Lundegårdh-Mitcherlich pointing, that the more a factor is in the minimum, the stronger the influence of that factor on an organism is, plays a role here. The extreme of the latter is the well-known law of the minimum factor of Liebig, which plays an important role in indication. ►

– Finally the complex character of environmental factors with their interrelations, makes it very difficult to determine precise relations between species and the real operational factors. So certain species like *Eupatorium cannabinum*, *Epilobium hirsutum*, *Sambucus nigra* and *Fraxinus exelsior* react on nutrients liberated from rapid decomposing organic matter (N and P especial). This situation occurs in areas with strongly fluctuating eutrophic waters but also in soils rich in lime, far away from any groundwater influence.

By consequence the same species are found amoung the 'phreatophytes' indicating (fluctuating) groundwater and as lime-indicators as well. They do in reality 'simply' react on the operational factors phosphorus and nitrogen, which are both conditioned by rapid decomposing organic matter.

The answer to the restrictions mentioned in this chapter is the use of a combination of species instead of single ones, the use of vegetation types preferably in combination with other observable land attributes like relief and soils. This is treated in the next section.

5. Integrated Use of Plant-, Vegetation and Land Indication

5.1. Species combination as indication

The advantage of using more than one species as indicator is:

(a) By using more species, indication will be sharper, even if competition and synergy would not be of influence.

(b) By using more species local deviation in behaviour of one of the species will be less relevant.

(c) The vegetation unit as a whole points to a complex environmental situation, usually correlated with certain conditional factors. Certain operational factors may in turn depend on these conditional factors.

A combination of the use of vegetation units (possibly also land units) together with single species is the so-called 'Coincidence or Calibration' method introduced by Tüxen (1958) (Koinzidenzmethode, Eichungsmethode). By using the phytocoenological table- (or an other matrix-) method, the coincidence is assessed between the occurrence of a species and a factor considered as operational. These factors are physically measured (groundwater, N, P, K etc.) *within* a certain syntaxonomic vegetation unit (possibly also in combination with a soil unit or land use unit or landform). By doing this it is guaranteed that influences of competition and the law of relative site constancy will be considerably reduced.

Bannink *et al.* (1973, 1974) elaborated examples of these methods for groundwater indication and general chemical fertility by arable weeds and also forest floor vegetations of coniferous forest plantations in the Netherlands. In this way indicator species could be assessed, which could be allocated together in so-called ecological groups, composed of species (taxa) with similar ecological amplitude for certain environmental factors. By having a number of indicator plants for a certain factor one has a reasonably reliable means, because although on each concrete site certain species may be absent due to unknown reasons, still the others care for the indication. The value of indication by single species and vegetation units is also discussed by de Boer (1983) and Oosterveld (1983).

5.2. Structure and life form as indication

Structure and life form of vegetation are of high value for the purpose of indications. Only a few examples may be mentioned. Zonneveld (1959, 1960) gives examples of indication of hydrological factors such as duration, frequency of flooding and mechanical influence of currents on life forms that can be expressed as frequention diagrams per vegetation type. Not published studies by the same author (Zonneveld and Bannink, 1960) show clear correlation of Iversens and Raunkiear life forms with factors as (ground)water fluctuation, humus formation and sand deposition in inland dune and heathland areas in the Southwest Netherlands and Belgium. Climate indication in general by Raunkiaers life forms is very well-known.

On airphotos horizontal structural images (pattern) usually are informative. So dot-patterns, be it small vegetation elements in a homogene matrix, but also 'patchiness' (bare areas in a dense vegetation) indicate extreme conditions, like salinity or other extremely 'dynamic' factors. The vertical structure in forests is strongly related to the humidity regime via the climate. From the tropical rainforest towards the steppe via the savannes, one observes a gradual simplification of the structure. Half way forest vegetation composed by two or three strata predominate. To the humid side these grades via more strata into a complete, the space filling, profile of the ideal tropical rainforest where only the lowest strata are rather open.

Towards the dry side the tree (and shrub) layers become more and more open until only a grass/herb layer remains in steppe-like vegetations often also with annuals and xerophytic chamaephytes, along the fringes of the almost pure bare deserts. However, the use of structure as an indicator in detail is in many places hampered by the fact that human influence in the past and in an increasing way recently, has changed the structure so much that reliable observation becomes difficult. Floristic properties change also, but much slower and they still give better possibilities for indication.

5.3. Use of the land concept and positional factors

The use of the 'land'(scape) concept is a far reaching applicating of integrated ecological indication. Beside vegetation data abiotic land attributes as relief, soil, rock, groundwater etc. are utilized, together composing 'land units', at certain scale also called 'land systems'. These land units then are indicative for a whole series of properties that as 'qualities' are important for land evaluation (Zonneveld, 1979).

Another example is the 'lifezones' concept of by Holdridge (1959), where by means of a combination of climate stations – in which all kinds of data about temperature, temperature and precipitation are being measured – and vegetation classification the quantitative data over large areas are extrapolated. The same principle is applied with the UNESCO's bioclimatic maps.

The use of 'potential actions' (potentiële werkingen) (see Van Leeuwen, 1981b and Van Wirdum, 1981) as indication of the environment, depends also on the integration of abiotic land factors. Here we deal with spatial circumstances pointing to the existance of certain operational factors. The most simple example is the relief. The lowest places receive, due to gravimetrical powers material from above (water and/or nutrients).

In this respect Van Leeuwen (1966 and 1981a, b, c) proved that the potential value for natural values (diversity, occurrence of rare organisms) coincides with such gradient situations where an oligotrophic environment 'rules over' (is situated above) an eutropic environment. In the opposite situation, the eutrophic environment will spoil quickly the lower situated oligotrofic vegetation. The observation can be done by abiotic means (e.g. assessment that peat occurs above limestone) or biotic means (one maps the vegetation and by indication, one observes that an oligotrophic (peat) vegetation lays over a calciphylous vegetation). Then one can predict that the transitional zone will have the high valuable character or (it may be disturbed by present land use) at least the potention to develop in that direction.

6. Quantitative Versus Qualitative

In the foregoing the possibilities and restrictions of bio-indication have been discussed.

A warning has still to be given against efforts to use these on a too quantitative way. It may be clear from what is said, that real quantitative data, even those obtained with the most delicate chemical and physical methods, are difficult to assess, because of the fact that so many real operational factors are not liable for such measurements. This is contrary to some conditional factors of which the measurements, however, only supply indirect data.

Although the biological indicator may react directly to the operational factor, real quantitative results however, cannot be expected due to the complex nature of the cybernetic system of life and its communities. In most cases one should satisfy oneself with a diagnosis of what is happening. If real quantitative data are required in order to interfere into an ecosystem, a combination of bio-indication and physio-chemical assessment methods will be necessary in most cases. Still empirical work and experiments will be also unavoidable (see also Zonneveld, 1982).

References

Bannink, J. F., Leys, H. N., and Zonneveld, I. S.: 1973, 'Vegetation, Habitat and Site Class in Dutch Conifer Forests', *Versl. Landbouwk. Onderz.* 800, *Bodemk. Studies* **9**, Stiboka, Wageningen, 188 pp. (in Dutch).

Bannink, J., Leys, H. N., and Zonneveld, I. S.: 1974, 'Weeds as Environmental Indicators Especially for Soil Conditions', *Versl. Landbouwk. Onderz.* 807, *Bodemk. Studies* **11**, Stiboka, Wageningen, 88 pp. (in Dutch).

Boer, Th. A. de: 1983, 'Vegetation as an Indicator of Environmental Changes', *Environmental Monitoring and Assessment* **3**, 375–380 (this issue).

Ellenberg, H.: 1974, 'Zeigerwerte der Gefäszpflanzen Mitteleuropas' *Scripta Geobotanica* **9**, Göttingen, Verlag Erich Goltze. Z. Auflage 122 p.

Hengeveld, R. and Haeck, J.: 1982, 'The Distribution of Abundance, I. Measurements', *J. Biogeography* **9**, 303–316.

Holdridge, L. R.: 1959, 'Ecological Indication of the Need for a New Approach to Tropical Land Use', *Econ. Bot.* **13**, 271–280.

Iversen, J.: 1936, *Biologische Pflanzentypen als Hilfsmittel in der Vegetationsforschung'*, København, Levin & Munksgaard, 224 p.

Leeuwen, Chr. van: 1966, 'A Relation Theoretical Approach to Pattern and Process in Vegetation', *Wentia* **15**,25–46.

Leeuwen, Chr. van: 1981a, College syllabus, Technical Univ. Delft, 79 pp. (in Dutch).

Leeuwen Chr. van: 1981b, 'From Ecosystem to Ecodevice', Proc. Int. Congr. Neth. Soc. Landscape Ecology, Veldhoven: 29–34.

Leeuwen Chr. van: 1981c, 'Nature Technics', *Ecology and Nature Technics (5).* Tijdschrift Kon. Ned. Heidemij. 92 7/8: 297–306 (in Dutch).

Londo G.: 1975, Dutch list of hydro-, phreato- en aphreatophytes. Report RIN, Leersum, 52 pp. (in Dutch).

Oosterveld, P.: 1983,'Taraxacum Species as Environmental Indicators for Grassland Management', *Environmental Monitoring and Assessment* **3**, 381–389 (this issue).

Raunkiaer, C.: 1937, *'Plant Life Forms'.* Oxford, Clarendon Press, 104 pp.

Schreiber, K. F.: 1977, 'Landscape Planning and Protection of the Environment', *Appl. Sci. Dev.* **5**, 128–135.

Schroevers, P. J.: 1983, 'The Need of an Ecological Quality-Concept', *Environmental Monitoring and Assessment* **3**, 219–226.

Tüxen, R.: 1958, 'Die koinzidenzmethode-Eichung von Pflanzengesellschaften auf edaphischen Faktoren'. *Angew. Pflanzen-soziologie* **15**, 1–10.

Walter, H. (transl. by Joy Wieser): 1973, *Vegetation of the Earth in Relation to Climate and the Eco-Physiological Conditions*, Heidelberg Science Library.

Wirdum, G. van: 1981, 'Design for a Land Ecological Survey of Nature Protection', Proc. Int. Congr. Neth. Soc. Landscape Ecology, Veldhoven: 245–251.

Zonneveld I. S.: 1959, The Relation between Soil and Vegetation Research', *Boor en spade*, 35–58 (in Dutch).

Zonneveld, I. S.: 1960, 'A Study of Soil and Vegetation of a Freshwater Tidal Delta', *The Brabantse Biesbosch'*, Ph.D. Thesis, Wageningen. Med. Landb. Onderz. No. 65, 20 (in Dutch).

Zonneveld, I. S.: 1979, *Land(scape) Science and Land Evaluation*, ITC-textbook VII-4, 2nd edition, 134 pp.

Zonneveld, I. S.: 1982, 'Principles of Indication of Environment Through Vegetation', in L. Steubing and H. J. Jäger (eds.), *Monitoring of Air Pollutants by Plants. Methods and Problems*, Junk Publishers, The Hague.

Zonneveld, I. S. and Banninck, J. F.: 1960, 'Studies of Soil and Vegetation on the Dutch Part of the 'Kalmthoutse heide', Internal Report, Stiboka 2429, Wageningen.