Ecological Indicators for the Assessment of the Quality of Air, Water, Soil, and Ecosystems

Papers presented at a Symposium held in Utrecht, October 1982

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Ecological Indicators for the Assessment of the Quality of Air, Water, Soil, and Ecosystems

EDITORIAL

The present volume is based on papers presented at a Symposium held on 14 and 15 October 1982, in Utrecht, The Netherlands. This Symposium, organized by the Dutch Ecological Society, was devoted to 'Ecological Indicators for the Assessment of the Quality of Air, Water, Soil, and Ecosystems'.

It can be regarded as an answer to a part of the questions posed by the Board of INTECOL, the International Association for Ecology, concerning the ecosystem response to stress as measured by the persistence, resistance, and resilience of communities, and the development and value of indications of ecosystem condition.

Within an ecosystem, the stress of single species or of a part of the ecosystem can help to measure, evaluate, integrate, and predict the effect of both natural and man-made perturbations on the structure and function of this ecosystem. Many questions arise in this context: what is an ecosystem, what are its boundaries, how can we measure its natural or its stressed conditions, and what are the best indicators for such conditions?.

In this issue, firstly an elucidation is given of the concept of ecological indication, and the possibilities and difficulties in the use of bio-indicators, and the problems concerning the notion of quality. In the next sections, the ecotoxicology and the ecological indication for, respectively, air, soil, water, and even more complex ecosystems, are treated. To end with, some remarks from a governmental point of view on the possibilities of bio-indication. The different papers vary greatly in their character, ranging from a short introduction or the description of a planned sampling scheme, to a more or less extensive review of the pertaining literature or a thorough research paper.

This Symposium was supported financially by the Ministry of Public Health and the Environment.

We hope that this varied Dutch contribution will be of use to the international public.

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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.

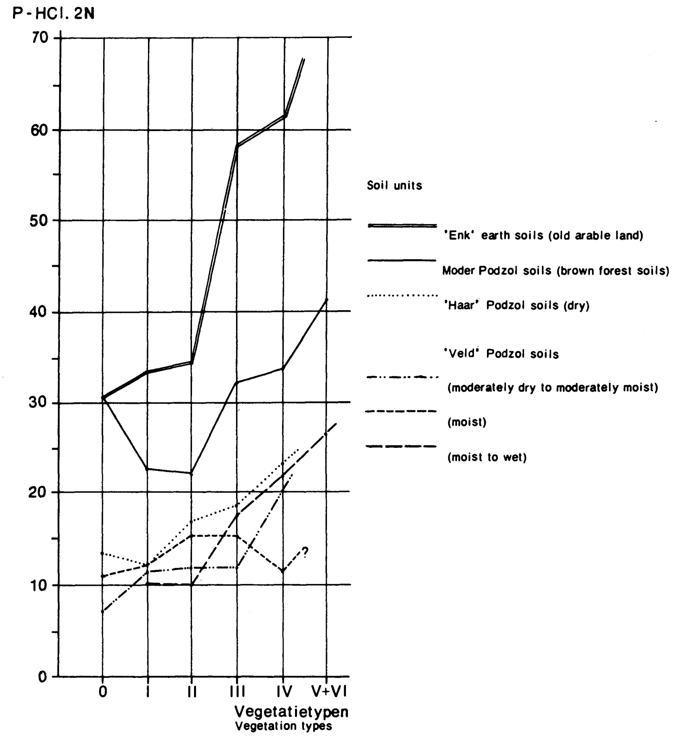

Fig. 1. The relation between P-HCl. 2N-value and the vegetation type on various soils units in Douglas forests in The Netherlands.

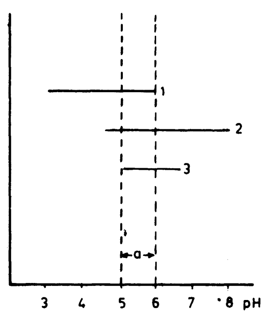

Fig. 2. Use of a few species for indication of an environmental factor. 1, 2, and 3: actual ecological amplitudes of three different species with respect to pH. (a) pH section covering the habitat of the three species.

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*.

* 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).

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THE NEED OF AN ECOLOGICAL QUALITY-CONCEPT*

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(Received November 1, 1982)

1. Indicators for Quality?

An indicator is something which makes visible, audible or perceptible which in itself is not visible, audible or perceptible. Many times indicators concern rather concrete matters, that might be experienced also in a more direct way. Acidity can be tasted, but a pH-meter is a better instrument. If such an instrument is not available the presence of *Sphagnum cuspidatum* tells, that the pH cannot be higher than 6.5. And when the accumulation of mercury in special tissues of fish constitutes a good reflexion of mercury content of water, the observation will be far easier.

But speaking of indicators we mostly have other things in mind. In assessing the influence of the sea on inland waters chlorine concentrations can be measured by means of simple titrations. Nevertheless an impressive typology of brackish water exists, in which organisms function as an indicator for the 'degree of brackishness'. Many times we even experience that the assessment with the help of these organisms does not agree with that of our titrations (den Hartog, 1963). In such cases we tend to believe more in the values indicated by our organisms, rather than in the actual chlorine contents. We are not interested in chlorine as such, but in the response of the structure of the ecosystem as a whole, a response to the dynamics characteristic for a water which in some way is influenced by the sea. Brackish water shows its own character, and hence we attribute to it of its own quality.

With this description the concept of 'quality' is introduced. Quality is something which is not visible, audible or perceptible, but which can be made it by our indicators. We experience how behind the perceived reality another reality is hidden, an abstract reality, not of matters but of principles. Is 'quality' such a principle? Are we able, by looking to the things around us – plants, animals, communities, tissues, oxygen concentrations – to tell something about this difficult phenemenon 'quality'?

2. Quality, a Source of Concern. An Example

Recently the hydrobiologists of the Provincial Department for the maintenance of dikes, roads, bridges and the navigability of canals of Utrecht found a series of interesting diatoms in a ditch near the city of Utrecht. These diatom species belong to a community, normally found in a special type of shallow waters on pleistocene soils, called 'fens'. This

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watertype had formerly a modest distribution in the eastern part of The Netherlands but it has disappeared almost entirely by eutrophication. If the find had taken place in the eastern provinces, and in regions under the management of the State Forest Service, it would have been an argument to design the ditch as a nature reserve. But this was not the case. Moreover, the ditch was situated along a highway, in a region where activities, took place for the construction of a traffic junction. As a consequence of these activities, an old woodland area had been damaged seriously – a source of great concern during more than ten years for local environmental action groups (v.d. Pijl and Grimbergen, 1983). The construction of these traffic works has given rise to the occurrence of the very rare diatom species, to which justifiably is attached much value. The same activities, however, damaged a centuries old woodland. Is a highway under construction to be seen as a source of enrichment or impoverishment of the Dutch nature?

The problem is still more complicated. No fish was detected in the ditch. This might be natural, since the 'fens' in our eastern provinces are also mostly without fish. On the other hand, since water bodies along highways in general contain large amounts of lead, the water might be too poisonous for fish. In terms of environmental quality such ditches form an issue open for discussion. Nevertheless, the rare diatom species grow well, whether or not in reality lead loading is considerable. Heavy metals are not necessarily an impediment for natural diversity, certainly not in small organisms at a low organization level. Several researchers showed the existence of physiological races for temperature, pesticides, heavy metals and other phenomena. These races may behave differently under specific circumstances or replace each other. Especially in microorganisms such replacements may take place very quickly (Johnson, 1952; Moraitou-Apostoloupoulou and Verripoulos, 1978).

What is the quality of this ditch? 'Abominable' some experts argue. 'The water is full of lead, and nothing can be done with it'. 'But the absence of fish may be caused by other factors', other experts will assert. 'Possibly the relative paucity of nutrients causes the lack of fish. Besides, these ditches are not meant as a source for drinking water; many other things can be done with them'. The people who use mapping as a tool for assessing the environmental quality have another approach in their mind. Their main interest is the lock, stock and barrel of a piece of nature, for which lead is only one of the threats. In the present case nature is apparently able to face it. According to their standards the ditch has a good quality, since it contains a particular community. The members of the action group for saving the woodlands, however, do not have a single word of appreciation. Very few people are interested in diatoms, but the deterioration of the woodlands, closely connected with the existence of the ditch, concerns thousands of people. According to their ideas the ditch should never have been dug.

So many men, so many minds. They are all ecologists, speaking about the same matter. But their views differ from one to another. Discussing the notion of quality means ending up in a tangle of conceptions, misunderstanding, contraditions and prejudgements. Taking up the challenge is stirring up a hornet's nest.

3. Thinking of Quality in an Ecological Way

Is quality a principle of nature? Are we able by looking to the things around us, to tell something about this phenomenon? The example shows that quality is a hydraheaded monster. Will it be possible to survey all aspects in an encompassing view and to catch this view in a good definition?

The publication 'Language of the Landscape', set up by the working group on theories of the Society of landscape ecologists in The Netherlands (W.L.O.) defines quality as the relation between environmental requirements and accomplishment of functions (Schroevers, 1982). This definition shows, how quality in its last resort is of ecological nature. For, in what way we may think of the accomplishment of functions, ranging from playing football or windsurfing, up to the mere survival of the human species – the relationship with environmental requirements forms the central point, and what is more ecological than thinking of environmental requirements?

Another derivative can be made from this definition. Quality is an interpretation. It tries to fit a given situation, something we percieve or experience in nature, into a framework, made by ourselves through active thinking. Such a framework may be based upon natural principles. The hydrobiologists of the Department of Public Works in the Province of Utrecht could give their ditch the qualification 'fen', in agreement with the distribution of their organisms which are generally restricted to 'fens'. If so, they relate their findings to an abstract, typological model. Researchers, who are well up in this approach, often tell that they want to see quality only as a 'situation' (De Lange and De Ruiter, 1977). In my opinion this is not appropriate, for they do interpret. But their interpretation deals with qualitative properties, and does not want to judge about 'good' or 'not good', to evaluate. The functions to be accomplished are considered only as scientific, cultural ones. Everybody will agree that the study of these properties and their interpretation represents a task to the science of ecology. But it remains an open question to what extent the man in the street will be interested in it.

The largest number of ecologists prefer another approach. The standard situation as mentioned in the definition means more to them: it is a situation which they consider more or less as a target ideal. The water in the ditch shows uncommon features and hence they are inclined to consider its presence as valuable. If we interpret the definition in this way we end up in a social discussion. We make decisions on good and bad and leave the path of science.

In this issue most ecologists write about quality in this sense. According to their ideas scientific insights and methods allow them to speak about good and bad. But the problem is more complicated. Most scientists do handle decisions on quality, but they do not define their subject – even stronger: they do not want to define it. They resist the so-called 'objective' way, in which values of nature were expressed formerly. 'Forget this', they say: 'Leave it to democracy to indicate desirabilities. We can give standards and methods to measure. We attend on very concrete functions of nature as they are seen and understood by everyone. If we think of quality it concerns the very direct wishes of man with respect to nature, such as production of crops, availability of water for drinking; aims which concern our health and our economy. If we speak about indicators, we have measuring methods in our mind to judge about these matters (Meelis and Ter Keurs, 1976). The point of view concerns a banishment of the concept of quality from the ecology. Mostly this referes to definitions used in policy-making by the government, the European Economic Community or the Council of Europe. Partly this proceeding is correct. Judgements of value do not belong to the field of science. But this does not imply automatically, that ecologists have to restrict themselves to technical, methodological implementation with respect to functions as an answer to decisions made by others. In that case they forget their 'Landscape-language' definition, in which accomplishment of functions is related to environmental requirements. In the last resort the statements on 'good' or 'not good' concern a 'to be or not to be', and we may say that this is an ecological statement. In such a respect the situation for man is not different from those of the three-horned stickleback, the green woodpecker or the buttercup.

But man has different ways in which he claims his environment. This is a starting point for conflicts of interests. The example of the Utrecht ditch showed some of them. Ecologists are not able to dispose of these conflicts. But they can indicate how they all have to do with survival. They can show how conflicts of interest can be appeased for the short term, but how these activities give rise to new problems in the long term; problems connected with the survival of mankind. Thinking in this way we must admit, that the conflicts really concern ecological boundaries, not differing from those in sticklebacks, woodpeckers or buttercups. Ecologists can speak in a meaningful way about quality, not by telling what is good or bad, but by delivering arguments needed for judgements; arguments mainly applying for the long term. In its utmost consequence the delivery of a scientific basis for our thinking of values constitutes the only important thing they have to offer to the world. Human culture is the search for a balance between the desirable and the possible. Opposite the question: 'What do we want to achieve?' at any moment the question ought to be asked: 'What are the consequences if things go wrong?' This balance is rather disturbed now, as we are all aware of. Very little attention is paid to the latter question, if compared to the violence of the obtainable in an economy of growth. It is a question of quality, and the criteria for this come at long last from ecologists. Ecologists who do not admit it avoid their responsibility. They suggest to give it to democracy, but in fact they give it to the opportunistic strategies of current economy. And as there is no opposition, those strategies will pretend to be necessary for the constitution of our picture of the future world. We simply have to look around, e.g. to the ways in which a problem as unemployment is attacked, and to see the arguments, used by economists from left to right in the political spectrum. In the battle for nature the latter is always a closing entry rather than a basic condition. Leading politicians eagerly listen to experts, as we know. But why don't they come to ecologists?

4. The Social Meaning of an Ecologically Defined Quality

The Proposed Program for the sanitation of surface waters of 1975 (I.M.P.) introduced the word Ecological Function (I.M.P., 1981). Engineers charged with the responsability for the quality of surface waters had some troubles with the traditional, pragmatical approach, in which the water is alotted a number of functions for human life: drinking, fishing, cooling, water for agriculture, for industrial processes and so on. 'Water is not an addition sum of separate functions', they stated. 'Water is something living, with its own laws and regulations, and we have to face it that way.' Although the word is not appropriate – ecology is a science, not a human target –, it was a progressive touch and ecologists appreciated it. But, unfortunately the elaboration of this new notion is far from being progressive. It is my thesis, that the tackling of the problem, meant as a fundamental one, is in fact to be seen as a form of 'nostalgism'. Biologists are requested to assess the 'naturalness' of our waters and they try to give an answer by looking to the past. The year 1900 is more or less regarded as a breaking point. Before that year man lived in peace with nature, and the decline began after it. The wish, implicitly expressed in the approach, is a return to former situations. Is not that a form of nostalgism? It is, however, a misconception. People of former centuries did not live in peace with nature. Their way of interacting with nature differs from ours, but the source of this difference has to be sought in different economical structures, not in another ethic. Nature, on the other hand, is in our time not less 'natural' than it was 50 or 100 yr ago. It is the self-evident response on human activities, expression of economical processes. Poppies and camomilles along the borders of the highway belong to the economy of today and they form a spontaneous reaction on its processes, more natural than the heath tracks for instance, which have to be kept free from birches and grasses with much cost and much pain.

Nature was rich in 1900. The natural diversity was undeniably much higher than it is now, especially in The Netherlands. To draw this fact into our memories does no harm. Diversity is a good criterion for a 'general ecological function', but the use of the past as a standard is a wrong way. Better is, to develop an understanding, how diversity comes off, how human activities influence it and how this phenomenon is related to other features of nature, features to which man attaches much value. If this understanding is obtained, the insights in 'quality' can guarantee new developments. They will be progressive.

If nutrients penetrate into a bog region by means of human activities, some new species will occur which have never been there, like reed and nettles. Here an external dynamic force has increased the diversity of the bog. In this way eutrophication, entrance of minerals can achieve the fixation of new species, and the question whether nettles or orchids are concerned makes only a gradual difference. This is the way we have to understand the origin of our beautiful haymeadows, known as 'bluegrasslands', and of the Desmid-richness as we find it in our Brabant 'fens'. Diversity and unaltered virgin nature are not an unbreakable unity; the relationship between man and nature is of another character. A certain amount of human influence – say 'disturbance' – may benefit species richness, and it is not 'man' who spoils the matter, but rather a process which has become beyond control. In such a picture man is not contrary to nature. There are many resemblances and a failed economy could be the reason why things fail in nature. This conception is meaningful to our quality concept. It implies that old values, due to old economic structures never come back, when they have disappeared. It also expresses, however, how new economic relations may create new chances for nature. Ecologists would be able to indicate the opportunities and to describe the conditions for it. Would not that be a better starting point for an 'ecological function'?

5. A Picture for the Future

Imagine that all those people concerned with the problem of the ditch in Utrecht decide to come together and to discuss their conflicts. They look upon their differences as unsatisfying, whereas they have the same target in their mind. What could be the course of such a conversation? The specialist on lead will be originally only interested in the question, whether the absence of fish would be a good indicator or not. Of course he understands the interests of others, but he does not look upon his experiences as a contribution to these interests. But the diatom specialists make him doubt. Lead – and for other alien matters the same will apply – may attack a community radically, but it does not necessarily do so. Theoretically we can imagine that small amounts of lead may be favourable for the growth of diatoms in that it may suppress other harmful factors. In certain regions in neighbouring countries a particular lead flora is found (Ernst, 1965). Influence of a poisoning substance like lead may stay for a long time unnoticed, and suddenly the community may collapse, if other changes occur. We speak about 'synergism' which clarifies nothing, but which shows how the problems of lead and those of diatoms are connected. The troubles between the diatom specialists and the 'Friends of the Woodland' are of a more serious nature. But they find a common viewpoint with respect to the scale in which processes take place. Large scale processes may have a beneficial influence in certain cases on small scale structures; parts of a region may profit from them. The 'Friends' acknowledge it. Of course the controversies remain, when the interests are brought into the discussion. But some understanding glimmers. The main conclusion, drawn from the discussion is, that differences in the valuations proceed from functional restrictions and choices in scale; whereas in some way the different approaches tell the same story. All participants agree in the recognition that the balance as a whole is a negative one, due to a 'too much' of dynamics, in some way connected with 'too much' of energy. But in certain places, where nutrients are withdrawn a 'too little' may serve as a source of new biological richness. In spite of contradictory propositions in actual situations the empirical experience of the contributors has led to such a common insight.

The way of thinking exposed in this little fantasy is a valuable one, worthwile to be elaborated. Such an enterprise is, however, impossible to undertake within the scope of this paper. Firstly we have to give an analysis of the origin of the Dutch landscape through the ages (Schroevers, 1980). In this way we can learn, why special plants and animals are found in special regions. Secondly we have to relate these findings to economic developments, in particular the development of 'production forces', e.g. to the use of energy. Thirdly we have to handle the problem of scale, which teaches us, when alterations have to be seen as an enrichment or as an impoverishment. And finally we have to clarify the relationship between diversity and productivity, as an understanding of mutual connection between functions. The considerations brought together will lead to an ecological model for quality. Such a model may help to convince policy-makers and economists. It may be used in discussions on future strategies. But its construction is not simple. It is by far not enough, if some ecologists, accidentally brought together, devote some meetings to the subject, as described here. And when the model is constructed, its value has been admitted, many interests have to be changed, much struggle must occur. We hope, however, to have made one thing clear: the question for an ecological quality concept appears to be an important question. We have to search for an answer.

Summary

Quality assessments with respect to our environment are done in many different ways. Generally these assessments are connected with functions which the environment has to accomplish for man. These are partial approaches in which some characteristics are selected from the complex reality. Although such assessments are useful for the solution of conflicts, they are insufficient for long term strategies. We need a view on the totality, the 'self-ordering' of nature. Judgements based upon such a concept can be placed opposite the economical ones, which follow conscious ordering by man. Quality concepts like these can have a meaning in different fields:

– In conflicts between interests. Many times we are aware that ecological arguments are much stronger than we are able to express. A universal concept helps to find a reconciliation of points of view.

– In current quality-assessments. By comparing them to a universal concept we can experience the opportunities for the long term in short-term solutions.

– In policy-making we are overflowed almost daily by economic value concepts pretending to be all-embracing. Ecologists have to counter them.

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In this paper the word 'fen' is used in order to avoid linguistic problems. The Dutch word for the mentioned watertype is 'ven' (plur. 'vennen'). The word refers to small ponds on pleistocene soils with a more or less strongly fluctuating water level. 'Fen' and 'ven' are not completely synonymous.

ECOTOXICOLOGY AND ENVIRONMENTAL QUALITY*

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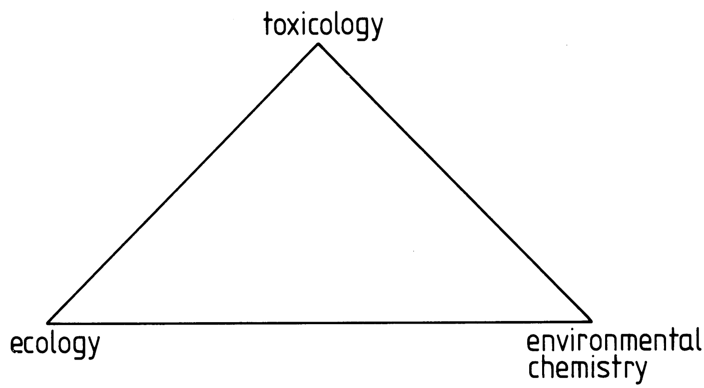
The use of the word ecotoxicology has become common practice in recent years. The objectives of ecotoxicology are clear, it concerns the study and judgment of possible noxious effects of chemicals on ecosystems. It is a multidisciplinary field of science which comprises toxicology, environmental chemistry and ecology as outlined in the triangular diagram below.



Toxicology is concerned with effects at the level of the individual organisms in a population of a species. It requires knowledge and insight in the fields of physiology, pathology, biochemistry, immunology and other basic sciences dealing with the functioning of man and other organisms. Environmental chemists measure the occurrence of chemicals in the environment and analyse processes related to their distribution, deposition and degradation. These scientists are generally trained in analytical chemistry, biochemistry and microbiology. Working together toxicologists and environmental chemists are able to judge whether exposure of organisms under natural circumstances may reach levels at which toxic effects are likely to occur. Whether or not such effects may have consequences for the populations of the organisms concerned or for other organisms in an ecosystem is a matter covered by ecology. An ecologist is a biologist with a special knowledge in fields like life-cycle biology, nutrient cycles in nature, population dynamics and other matters required for the elucidation of relations among

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species and their abiotic environment. Ecotoxicologists mastering the whole field probably do not exist, unless one identifies these scientists either as toxicologists with some feeling for environmental chemistry and ecology or as ecologists with some feeling for toxicology and environmental chemistry. An environmental chemist cannot easily become labelled as ecotoxicologist because of a lack of background in physiology and general biology.

The contribution of toxicology to the evaluation of ecotoxicological risks consists of a qualitative (type of effect) and quantitative (dose/concentration-effect and time-effect relationships) registration of the effects of chemicals per species. In that way the potential vulnerability of species and taxonomic groups can be assessed. From a toxicological point of view relative vulnerable species could be seen as indicator species. Organisms of these species are the first where effects are likely to show up after the use or disposal of chemicals under practical circumstances. These effects could be an incidence of mortality, changes in reproduction parameters, organ weights and the activity of certain enzymes and for instance cytogenetic effects. The indicator function may also be measurable at the population level in case the effects have consequences for the age composition or size of populations. However, this does not happen always. It is possible for instance that an increased rate of mortality is compensated by an increased rate of reproduction or by an immigration of individuals from other places. In these situations population parameters cannot be used as indicators.

The other contributions to this section will illustrate how ecotoxicological indicators can be used in studies on environmental quality.

ANIMAL INDICATORS FOR SIDE-EFFECTS OF CHEMICAL VECTOR CONTROL

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Abstract. In many places in the tropics pesticides are applied in the natural environment to control insects either for crop protection, or for human health. The present study concerns the side-effects of insecticides that are applied in West Africa against tsetseflies (*Glossina* spp), which are the vectors of human and animal sleeping sickness. Pyrethroids and endosulfan were sprayed either by helicopter or by ground spraying on riverine forests and on forests around villages.

Because of the complexity of the terrestrial and aquatic ecosystems under study, a selection was made of populations in which side-effects were assessed (so-called indicators). Fish and benthic arthropods were studied in the rivers; Diptera, Hymenoptera and spiders in the forest. Observations on short-term effects revealed the most vulnerable populations (indicators for effects) depending on the insecticide and the method of application. Long-term studies, up to two years, revealed the differences amongst these populations in ability to recover from local depletion. The populations which recovered most slowly were regarded as indicators for recovery.

Differences in hydrological regime between climatic zones are regarded to be highly related to differences in vulnerability of ecosystems to irreversible damage by pesticides.

1. Introduction

Pesticides are applied at a large scale to the natural environment for the control of some vectors and agricultural pests. Examples of vector control in Africa are:

- *onchocerciasis* or riverblindness: the larvae of the vectors, *Simulium damnosum subspp.*, are controlled by spraying rivers,
- *schistosomiasis* or *bilharzia*: standing and running waters are treated against the vectors, snails of the genera *Bulinus* and *Biomphalaria*,
- *tryanosomiasis* or sleeping sickness: forests and grassland are sprayed against tsetseflies.

Some examples of the agricultural pests are:

- locusts: wadis and oases are sprayed,
- grain-eating birds, especially *Quelea spp*: trees and other nesting sites are treated.

In all these cases alternative control methods are too expensive or not operational. However, the executing authorities are in general very inclined to avoid environmental damage. This is obtained by adapting the pesticide and the application method to the specific environmental situation. However, the environment where control campaigns are carried out varies from area to area. Therefore a thorough knowledge of the effects of the used pesticides is required from as many different situations as possible.

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The present study concerns the effects of chemical control of tsetseflies in Upper Volta and the Ivory Coast from 1978 to 1981. Because of the experimental character of the campaigns, they were executed on a limited scale (100–500 km^2) and with more than one insecticide. The experiments were carried out under responsibility of the World Health Organisation and the Food and Agricultural Organisation.

The treated habitats were gallery forests along rivers and forests around villages. The treatments were directed to the resting sites of the flies. Both residual and knock-down methods were tested. The former method requires one to three treatments, the latter one five to seven treatments at 10–20% of the residual insecticide dosage.

2. Measuring of Ecological Damage

For the observations on side-effects, acute damage and long-term effects were studied by sampling natural populations. The sampling period is determined by the time needed for recovery. Damage is not always separable from the variations caused by all other affecting factors, either because the side-effect are extremely small (Russell-Smith, 1982) or the methods used are not sensitive enough (Müller *et al.*, 1980).

Because of the complexity of the ecosystem at the studied habitats (the vegetation, the forest bottom and the water) the observations were restricted to a limited number of species, considered as indicators for ecological damage. These species are relatively easy to recognize and to sample at a large scale. They are of ecological importance, and they have a specific sensitivity for the used pesticide. The value of indicators for a side-effect is distinguished from that of the many known other ecological indicators by the strict necessity of timeseries of observations. The latter give information on the abiotic and biotic environment by their presence or absence at direct observation. In the case of a small number of sequential treatment (1 to 4, depending on the temporal variation of the sampled taxa), data from a treated zone should be compared to those from a control zone. To be suitable to serve as a control zone requires intensive preceding research. However, the longer the period over which effects can be observed, the more the value of the control zone diminishes. This problem can partly be met by selecting more than one control zone. After a certain period of time recovery can be observed in most cases. From then on populations fluctuations in the treated zone coincide with those in the control(s). Another approach is possible when the treatment is repeated many times (5 or more). In this case changes in numbers of a taxon may coincide significantly with the treatments, and no data from a control zone are required.

From earlier observations by Koeman *et al.* (1978), Takken *et al.* (1981) and Smies *et al.* (1980), it appeared that endosulfan and pyrethroids, applied at dosages which were effective against *Glossina* spp, did not affect warm-blooded animals, Takken *et al.* (1981) found that insects and aquatic crustacean populations were affected by pyrethroids. However, no data were available on long-term effects and on the specific sensitivity of species, genera or families.

The equipment used for the sampling of the populations studies was standardized and fabricated locally. In the forest pitfall traps and malaise traps were used for edaphic and flying arthropods, respectively. The correlations of the sampled numbers of several groups of organisms and environmental factors have been calculated in order to minimize variation between the traps. Thus 10 malaise traps and 30 pitfall traps per running kilometer of gallery forest met the requirements. During the sampling period of 1980/81 50 malaise traps and 150 pitfall traps were put into position at different sites at the Ivory Coast. In the water scoopnets, casting-nets and drag-nets for fish were used; driftnets and plankton-nets for insects and shrimps, and artificial substratums for benthic insect larvae. The artificial substratum consisted of concrete blocks that were suspended in the water. All methods which required human activity were standardized for time and hour of the day. The fishing methods were applied for the collection of qualitative data. When necessary visual observations on acute effects were made.

3. Observed Ecological Damage

3.2. Aquatic habitats

Examples of effects on aquatic organisms which were observed after deltamethrin treatment are presented in the Figures 1 to 3. In Figure 1 the change in the natural daily drift of benthic organisms as a result of the treatments is given. The most obvious effect of the treatments is usually observed in ephemeropteran families, while Odonata appear to belong to the least sensitive groups. In Figure 2 the composition of the casualties which drift off after repeated spraying are given. Both crustaceans (shrimps) and the ephemeropteran family Tricorythidae have disappeared after the second treatment. The effect on Tricorythidae can also be seen in Figure 3, where the occupation by benthic organisms of artificial substratum is presented before and after treatment. After their tempory disappearence the Tricorythidae were found again at the end of the sampling season. Simulid larvae virtually disappeared after the spraying, but within one week the populations had recovered, consisting mainly of the youngest larval instars.

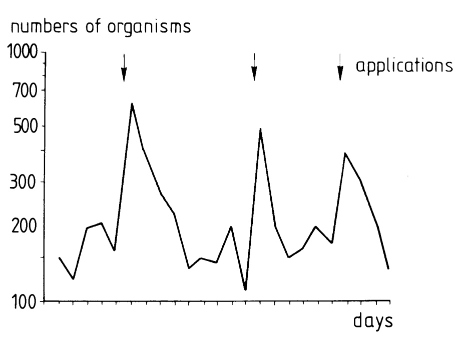

Fig. 1. Increase in the natural daily drift of the benthic arthropods as a result of insecticide applications.

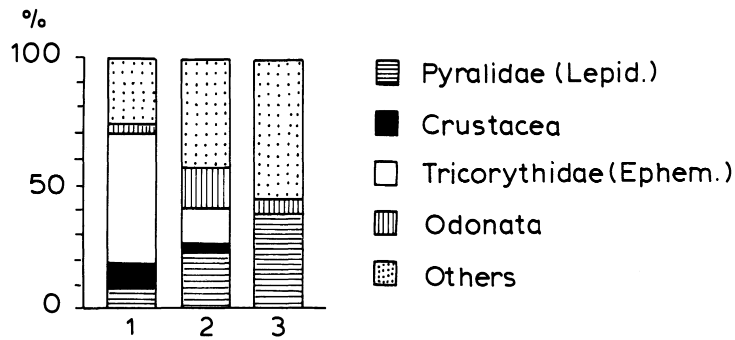

Fig. 2. Aquatic causualties of three treatments of the same river with deltamethrin.

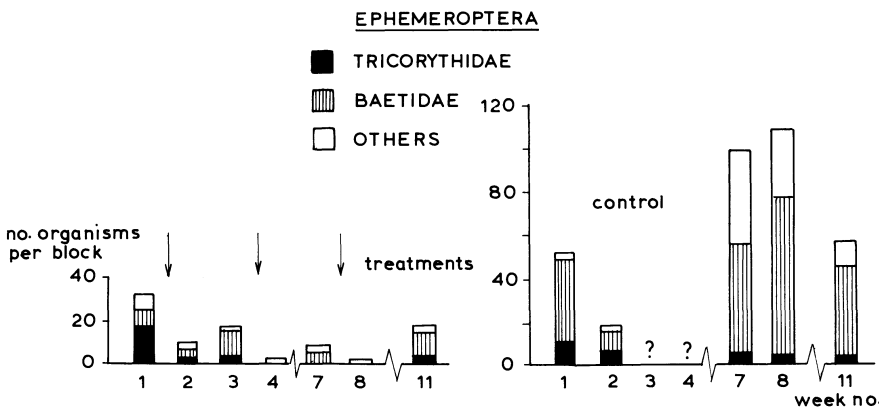

Fig. 3. Ephemeroptera on artificial substratum during a spraying cycle with deltamethrin (? = no data available).

The shrimp *Marcrobrachium vollenhovenii* was affected temporarily by deltamethrin, in that the animals showed abnormal behaviour or drifted off due to paralysis. Recovery occured within two days.

The following effects on fish were observed after the spraying of endosulfan. At a dosage of 100 g (active ingredient)/ha several dead animals were found, while at 200 g or more all fish were killed. Some Cyprinidae (*Epiplatys* spp. and *Aphyosemion* spp.) showed symptoms of poisoning earlier than the other fish species. *Tilapia* spp. and *Lates niloticus* (all young specimines) were the first ones to reimmigrate in a deserted river.

3.2. Terrestrial habitats

3–4.000 Arthropod species can be caught by pitfall and malaise traps in West Africa, part of which has been described in the literature.

We found about 130 species of spiders. The juveniles and adults of *Aporoptychus lamottei*, an orthognath spider of which only the females have been described, appeared to be particularly sensitive for deltamethrin, permethrin and cypermethrin. Six weeks after treatment, recovery of adult animals was observed. In the Diptera and Hymenoptera, the lowest taxonomic level that could be named under the given circumstances, was that of the families. Of one family, the Scelionidae, the genera could be studied. Permethrin had a significant effect on Chalcididae, Encyrtidae and Pteromalidae. The Braconidae were affected by cypermethrin initially, although recovery was observed three weeks after treatment. These hymenopteran families, which are all parasitic, are of economic importance.

Deltamethrin had a marked effect on muscidae. As *Glossina* spp. are muscid flies, a specific effect of delthamethrin on this family may indicate a certain selectivity towards the target-species.

4. Other Risk Factors

The described effects only form a part of the risks to which the ecosystems concerned are exposed. Unabridged application of agricultural chemicals, but also the frequent abuse for fishing purposes, threaten of ecosystems. Also the construction of dams may result in irreversible losses. In the case of *M. vollenhovenii* it may block the passage to brackish coastal waters, where it reproduces. Furthermore the control of tsetseflies, especially in potential cattle breeding areas, leads to serious disturbance of the fauna and the vegetation.

5. Recovery from Damage

As illustrated, several mechanisms for recovery can be observed. The young larvae of *Simulium damnosum* hatched from unaffected eggs after depletion of the older population. Tricorythidae recovered by drifting in from untreated areas. Recovery of *Aporoptychus lamottei* occurred by reimmigration from adjacent untreated fields. The capacity to recover after damage may differ considerably between related species. The small shrimp *Caridina africana* (<4 cm) which disappeared after deltamethrin spraying, recovered in one year over 40 km of river. The larger shrimp *Macrobrachium raridens*, which is slightly less sensitive than *C. africana* was not observed until two years after its extinction in the same stretch of river.

It appears that in certain situations it is not only worthwhile to recognize indicators for an effect (like *C. africana*) but also indicators for recovery (like *M. raridens*). The latter group consists of those species in the affected taxa of which recovery requires more time than for the remaining species.

In Figure 5 the effect of a pesticide on the numbers within a group of organisms is illustrated by means of a diagram. The curve is a simplification of the effects which were observed in the field. The height of the curve, the distance $N_a - N_c$, which determines to which extent the effect is observed, depends on the heterogeneity of the group of

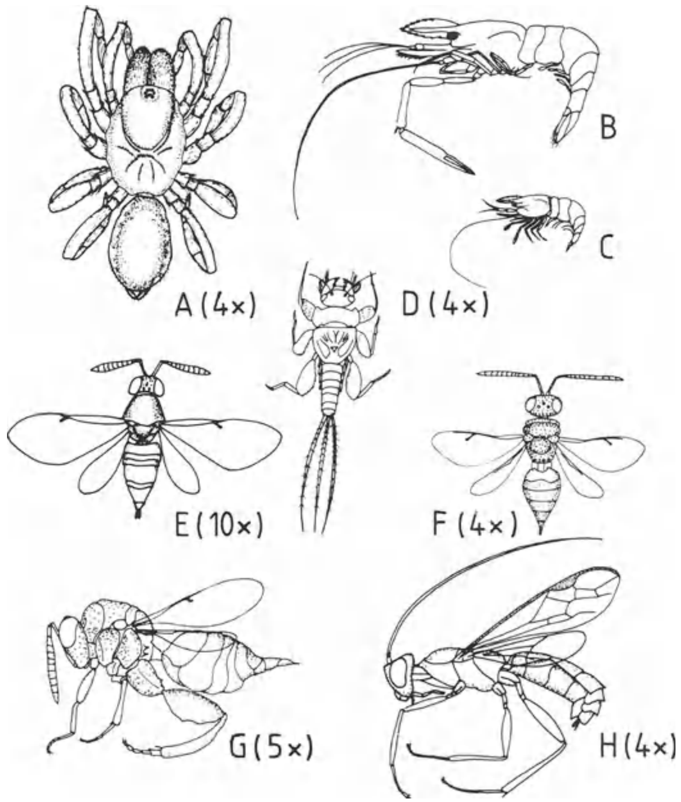

Fig. 4. Indicators of side-effects of insecticide treatments and recovery. A, *Aporoptychus lamottei*; B, *Macrobrachium raridens*; C, *Caridina africana*; D, *Tricorythus* sp.; E. Encyrtidae gen. sp; F, Pteromalidae gen. sp; G, Chalcididae gen. sp; H, Braconidae gen. sp.

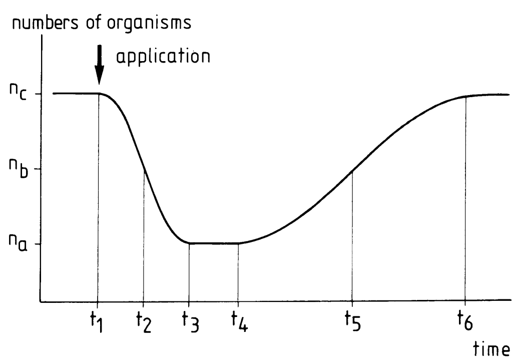

Fig. 5. Diagram of an effect of a pesticide on a natural community or population.

organisms studied. The higher the number of species (or subspecies, ecotypes, developmental stages etc.) within that group, the flatter the curve because of the differences in sensitivity. If the toxicity of the pesticide for the animals concerned has ended at t_3, the period $t_3 - t_4$ (retention time for recovery) depends on the ecological isolation of the affected habitat. The period $t_4 - t_6$ depends on the reproduction capacity of the populations. The total period $t_3 - t_6$ is also affected by the dispersal capacity of the animals.

6. Selection of Indicator Species

Specific animal indicators can be selected for environmental effects of most insecticides. Some of them are illustrated in Figure 4. Consequently, research concerning side-effects should be done on more than one taxonomic group in order to avoid false-negative observations at the introduction of new chemicals. This requires a considerable taxonomic effort. In some situations a limited number of taxa (<20) from all levels is sufficient to demonstrate an effect by applying multivariate analysis (Green, 1978; Everts *et al.*, 1983). However, the observation of recovery of an affected taxon is of limited biological value when there is no knowledge on its total species composition. On the other hand, information on the species composition does not meet shifts in intraspecific variation and age-structure or changes in behaviour and resistance of particular species.

Many factors play a role with the selection of indicators. Let us consider as an example the ants. This group of animals is of considerable ecological importance. The numbers that are trapped during side-effect studies are high. The individuals are sensitive for most insecticides. However, observations on ant ecology must be directed to the nests which ecologically can be considered similar to plants. The sensitivity of working ants gives very little information on the vulnerability of the nests. The extremely exposed nest of the treedwelling *Oecophylla longinoda*, of which the working ants formed the major part of the casualties that dropped from the vegetation, survived all aerial sprayings. Furthermore, on the Ivory Coast, approximately 1200 species are found, a lesser part of which is described. Thus in this case the ecologically important, abundant and sensitive ants are not good indicators.

7. Geographical Factors

In the area the hydrological cycle is blocked at the end of the annual rainy season. The biological production stops, except in those places where water remains available, namely near rivers and lakes, in marshes or in lower areas. A part of the fauna is adapted to the seasonal harsh conditions. Many animals go into diapause or bury themselves in the ground, eventually in cryptobiosis. Of the species which display activity throughout the year, many are found concentrated around the remaining green areas, which are functioning as refuges. These species are dispersed over a wider area at the beginning of the rainy season. The process of concentration and dispersion is presumably not the result of directional movement, but of a tendency of some species to display more moving activity in unfavorable places than in favorable ones (Baars, 1981).

The crowding and the unfavorable conditions in general in the refuges make the animals more vulnerable for insecticides. Because these populations form the base for a repopulation of the environment, when the growing season begins, disturbance of the refuges will have a consequence for the ecology of a much larger area. These effects are more extreme in dryer zones where at the same time the isolation of the habitats is an important factor in relation to the recovery by reimmigration.

8. Conclusions

Summarizing it can be stated that the effects of insecticide applications against vectors in Africa can be studied by observations on indicator species. Within this group indicators for effect and indicators for recovery can be distinguished. The extent in which the effect disturbs a year-round green area depends on geographical and climatic factors.

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BIO-INDICATORS AND CHEMICAL POLLUTION OF SURFACE WATERS*

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Abstract. Attention is given to two different approaches to determine the water quality in relation to toxic stress.

The first approach is based on direct observations on the state of health of the biota naturally occurring in the environment to be judged. In the original concept of biological indicators of water pollution the existence of differences in stress-susceptibility of different species is assumed. However, toxicity studies indicated that there are no species whose absence or presence gives information on the degree of toxic pollution. When attention is solely directed to health aspects of one species, a higher specificity and response-rate is obtained, but water quality indexing is not possible. Examples of effects of chemical pollution on the health of fish from the river Rhine are presented.

The second approach is based on indirect observations, determining the water quality by examination of the state of health of organisms experimentally exposed to the water under controlled conditions. To save testing time it is useful to concentrate the toxic compounds prior to testing. An example of these methods is given, describing the water quality of the rivers Rhine and Meuse in terms of toxicity and mutagenicity.

As both approaches are complementary with respect to ecological significance and specificity, it is recommended to apply them simultaneously to obtain appropriate information on environmental quality and stress factors.

1. Introduction

The strength of biological methods for environmental judgement is the acquisition of information on the total effect of perturbations in a rather unique and direct way. However, this is also a weakness. Although each stress contributes to a loss of energy (Odum, 1967), the ecosystem response to a stressor depends on the point of attack of the stressor on the system (Lugo, 1978), as well as on the properties of the ecosystem. Therefore a proper quality assessment based on biological characteristics needs a thorough knowledge of the relationships between the type and extension of the stress and the response of the system. As to pertubations by toxic chemicals, this knowledge is insufficient and therefore environmental qualification is seriously hampered. In case of toxic substances biological monitoring should be based on the measurement of (1) deleterious effects specific for toxicity, (2) which are of ecological significance, (3) can be measured accurately, (4) with a high signal to noise ratio, (5) with a high response rate, (6) which are perceptible over a wide range of stress intensity, (7) which are reversible, (8) can be expressed in indices and (9) can be assessed at relativeley moderate costs (UNESCO, 1980). In practice, some of these criteria are not consistent with each other since their fullfilment is directed by different levels of biological integration. In this

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paper examples are given to emphasize the need to use different biological methods to indicate the stress caused by toxic chemicals in the aquatic environment.

2. Stress Quantification Based on Field Observations

2.1. Community studies

The existence of 'keystone' species for chemical stress was already recognized at the turn of this century. Kolkwitz and Marsson (1909) introduced a system, in which species are classified according to their tolerance to biodegradable organics. Although extended by many authors, this so-called saprobian system has not been essentially altered (Sládeček, 1973; Persoone, 1979; Hawkes, 1982).

As for toxicants, it is known that there are large differences in the susceptibility between species (McKee and Wolf, 1963). Differences in the susceptibility of species occupying crucial positions in the food-web may have far-reaching consequences for the structure and functioning of an ecosystem. To indicate whether or not there is some proof for the existence of 'keystone' species relative to toxic compounds, results of some comparitive toxicological studies are evaluated.

The results of a study on the (sub)acute toxicity of 15 chemicals to 22 different species are summarized in Table I and II. (Slooff *et al.*, 1983a) Table I shows that the sensitivity to the toxicants is highly variable amongst the species depending on the chemical tested. This leads to the conclusion that compound-specific indicator species may be recognized. However, when the relative susceptibility of a species based on the individual

TABLE I

Maximum difference in the susceptibility of 22 fresh water species for toxic compounds based on (sub)acute toxicity (Slooff *et al.*, 1983a)

Test compounds	Factorial difference in susceptibility
Allylamine	8970
Aniline	8000
Cadmiumnitrate	2800
Mercury (II)chloride	1000
Pyridine	364
Acetone	278
Pentachlorophenol	185
Ethylpropionate	87
n-Propanol	68
Benzene	58
o-Cresol	46
Trichloroethylene	40
Salicylaldehyde	33
Ethylacetate	32
n-Heptanol	30

TABLE II

Relative susceptibility of 22 fresh water species for 15 chemicals based on (sub)acute toxicity (Slooff *et al.*, 1983a)

Species	Taxonomical group	Relative susceptibility
Pseudomonas putida	Bacteria	4.0
Microcystis aeruginosa		1.2
Chlorella pyrenoidosa		4.2
Scenedesmus pannonicus	Algae	4.2
Selenastrum capricornutum		3.5
Entosiphon sulcatum		2.0
Uronema parduczi	Protozoa	5.3
Chilomonas paramacium		3.2
Daphnia magna		1.4
Daphnia pulex	Crustaceans	1.0
Daphnia cucullata		1.2
Aedes aegypti	Insects	4.6
Culex pipiens		6.3
Lymnaea stagnalis	Molluscs	2.9
Hydra oligactis	Coelenterates	4.6
Leuciscus idus		3.5
Salmo gairdneri		1.7
Poecilia reticulata	Fish	5.3
Oryzias latipes		5.3
Pimephales promelas		1.8
Xenopus laevis	Amphibians	3.7
Ambystoma mexicanum		2.7

toxicity data on all compounds are taken into account (Table II), the differences are much smaller. Therefore the existence of indicator species for gross chemical pollution can be seriously doubted.

In a similar study the acute toxicity of the same 15 chemicals to 13 different macro invertebrate species was determined (Slooff, 1983a). The test organisms used were representatives of 'keystone' groups for the whole range in the saprobian systems. From the results presented in Table III it can be derived that the differences in relative susceptibility of the invertebrate species are rather small. Table IV, showing the toxicity of an organic mixture concentrated from water of the river Rhine, confirms the assumption that 'keystone' species for toxic stress resulting from a variety of chemicals are not likely to be identified. Yet, this conclusion can be criticized for obvious reasons, taking into account the relatively short exposure time and the disregard of sublethal effects like influences on reproduction, development and growth.

However, a study on the long-term effects of toxicants on different fresh water species yielded results similar to those obtained from the (sub)acute tests (Slooff and Canton, 1983).

TABLE III

Relative succeptibility of macro invertebrates for 15 chemicals (see Table I) based on acute toxicity (Slooff, 1983a)

Species	Relative susceptibility
Tubificidae	3.2
Chironomus gr. thummi	2.3
Erpobdella octoculata	3.3
Asellus aquaticus	1.9
Lymnaea stagnalis	2.6
Dugesia cf lugubris	2.8
Hydra oligactis	2.7
Corixa punctata	3.4
Gammarus pulex	1.0
Ischnura elegans	1.5
Nemoura cinera	2.6
Cloëon dipterum	4.9

TABLE IV

The tolerance of benthic invertebrates to mixtures of organic compounds concentrated from water of the river Rhine (Slooff, 1983a)

Species	Concentration factor which results in 50% mortality in 48 h (LCF50)
Oligochaeta	
Tubificidae	159 ×
Diptera	
Chironomus gr. thummi	144 ×
Isopoda	
Asellus aquaticus	158 ×
Amphidopa	
Gammarus pulex	192 ×
Trichoptera	
Athripsodes cinereus	124 ×
Ephemeroptera	
Cloëon dipterum	184 ×
Plecoptera	
Nemoura cinera	214 ×

These examples stress the warning of Sládeček (1973) that traditional biological water classification in which the water quality is expressed in terms of the presence or relative abundance of certain species is not applicable to toxic pollution. Only when a surface water is polluted by a few known toxicants, certain biotic indices may be workable (Winget and Magnum, 1979; Lawrence and Harris, 1979). Loading with a variety of toxic chemicals will result in a non-specific decrease of species richness and population size.

Therefore, the measurement of parameters describing the structure or functioning of ecosystems seems to be of little value in estimating water quality explicitly related to toxicity.

2.2. Single species studies

Laboratory studies on individuals have revealed much about possible toxic effects of all kinds of chemicals. The knowledge gained from this expertise can contribute to the recognition of biochemical, physiological and morphological effects possibly observable in the field related to toxicity. In this way a study on the health aspects of bream (*Abramis brama*) inhabiting surface waters of a different degree of chemical pollution (the rivers Rhine and Meuse, and Lake Braassem as a reference) was performed. The results of this study are summarized in Table V. Bream from the river Rhine areas showed a somewhat higher prevalence of tumors than fish from the river Meuse (hepatocellular carcinoma),

TABLE V

Some parameters on the state of health of bream (*Abramis brama*) from the rivers Rhine and Meuse. The parameters are expressed relative to reference values obtained from Lake Braassem fish.

Biological parameter	Meuse	Rhine	Waal	Lek
Prevalence of tumors	≥ 1	⟶	≥ 1.7	⟵
Prevalence of deformed fins	1.5	3.6	3.8	5.8
Prevalence of pugheadedness	1.7	9.0	8.7	9.7
Relative liver weight	2.0	2.3	2.1	1.7
Hepatic enzyme activity	1.8	2.2	–	–
Fecundity	1.0	1.3	1.0	1.2
Annual mortality (♀♀)	1.5	2.1	1.7	1.4
Annual mortality (♂♂)	1.5	1.9	1.9	1.7

whereas no neoplasms were found in Lake Braassem fish (Slooff, 1983b). This accordates with the observation that bile fluid of Rhine fish is relatively highly mutagenic (Van Kreijl *et al.*, 1982) and that liver homogenates of Rhine fish livers were able to activate pre-mutagens in the Ames-test (Slooff and Van Kreijl, 1982). Besides the livers of Rhine fish were significantly enlarged (hypertrophy; Slooff *et al.*, 1983b). Liver enlargement often results from exposure to xenobiotic compounds and is usually associated with induction or stimulation of hepatic enzyme activities. Based on differences both in time and place of liver mono oxygenase activity and of degree of metabolic activation of pre-mutagens such an association was established (Slooff and Van Kreijl, 1982; Slooff *et al.*, 1983b). Furthermore, several skeletal anomalies were observed such as pugheadedness, deformed fins, absence of fins and girdles, asymmetric crania, shortened operculae, fusions of vertebrae and spinal curvatures (Slooff, 1982). The highest frequency of occurrence was found in the river Rhine areas, the lowest in Lake Braassem. Based on the age-frequency distribution of representative samples of the local populations, the annual mortality proved to be the highest amongst fish from the Rhine areas (Slooff and De Zwart, 1983). This higher mortality rate can not be explained by a higher density of parasites or predators, nor by a more intensive fishing. Rhine fish displayed also a higher fecundity which may be a compensatory response to the enhanced mortality. This hypothesis is strongly supported by (1) the observations on other fish species that showed a significant increase in fecundity when the size of the population was reduced by fishing (e.g. Jensen, 1971), and (2) laboratory observations on neutralization of toxic effects at low pollutant concentrations by antagonistic responses of regulatory mechanisms (e.g. Stebbing, 1981). Besides information on the water quality in terms of toxic stress, the observations also indicated that the load of the river Rhine with toxicants has been reduced during the last years. The first indication is that the frequency of occurrence of the most prevalent skeletal anomalies decreased for succeeding year classes (Slooff, 1982), which corresponds with a decrease of concentrations of possible causative chemicals in the last decade (Rijkswaterstaat, 1980; De Kruijf, 1983). Also the back-calculated length of 5-yr old bream of succeeding spawning years (1966–1976) increased (Slooff and De Zwart, 1983). A third indication of improved water quality is that in the period of 1979–1982 the liver size of Rhine fish decreased to normal proportions, accompanied by diminishing of enzyme activities to levels that do not deviate significantly from those of Lake Braassem fish (Slooff *et al.*, 1983b).

From this study it can be concluded that field observations on one species can be used to indicate temporal and geographic differences in toxic stress in surface waters. Although it can be assumed that, in principle, every species and parameter is suitable for this purpose, this approach has several drawbacks. Leaving aside the rather high research costs and the problems related to whether or not standardization of species and parameters is desirable, most problems are related to the transformation of the obtained data into an acceptable water quality index. Definitely, an indicator is not an index. To reach that state, it has to be compared to a standard (Inhaber, 1976). If reliable reference c.q. standard values are available, this will be no problem for the parameters separately. In the presented studies the data on Lake Braassem fish can be considered as reliable references since both chemical and biological studies revealed that the water quality of Lake Braassem is rather good (Anonymous, 1979; Hovenkamp-Obbema *et al.*, 1982). However, to arrive at a single index for comparison purposes, the indices on the separate parameters should be combined, taken into account the relative ecological significance of the parameters measured. In practice, this process evokes severe problems. For most parameters knowledge is lacking which value is indicative for 'the worst' possible quality. In most cases it is not possible to mark the parameter value within an index range varying from e.g. 0–10. For example, if a frequency of occurrence of skeletal anomalies of 100% is considered to be the maximum, Rhine water should be qualified as rather good as 'only' 20% of the fish showed skeletal anomalies. It is even more complicated when the maximum deviation from normal is not known (e.g. relative liver weights). Also there is insufficient knowledge to express the importance according to the ecological value of the impaired properties and to determine whether or not the properties are mutually independent. Therefore, it can be concluded that observations on the health aspects of one species will never lead to a uniform water quality index; their strength is solely directed to give evidence of toxic stress and the possible causative agents.

3. Stress Qualification Based on Laboratory Observations

Toxic stress can be determined also experimentally. Water quality can be assessed by exposing one group of test organisms to the water concerned and, subsequently, comparing their state of health with that of another group of organisms maintained in unpolluted water under strictly defined conditions (e.g. Van der Gaag *et al.*, 1983). Compared to field studies, this approach has the important advantage of a relatively high signal to noise ratio. However, laboratory experiments are often too time-consuming and too expensive to be performed on a routine base. This disadvantage, which is almost typical for biological methods, has led to the inferior role of biological methods compared to chemical measurements in assessing and controlling environmental quality. The only way to change the attitude towards biological methods is to cast them in the same mould as chemical techniques. Thus, the experimental design has to be modified in such a way that only sum-parameters are studied in simple and standardized tests giving results within a few days. A recently developed feature in this field is to apply a technique to concentrate toxic compounds from the water before testing to speed up the response rate. This also enables the testing of several concentrations in order to determine a concentration-response relationship. This method has been applied to assess the degree of hazardous chemical pollution of surface waters in The Netherlands (Kool *et al.*, 1981; Slooff and Van Kreijl, 1982; Slooff *et al.*, 1983c). Concentrates of the water were examined on mutagenic activity with the Ames *Salmonella*/microsome assay and on toxicity, using an acute (48 h) fish mortality test. Figure 1 shows that both mutagenic

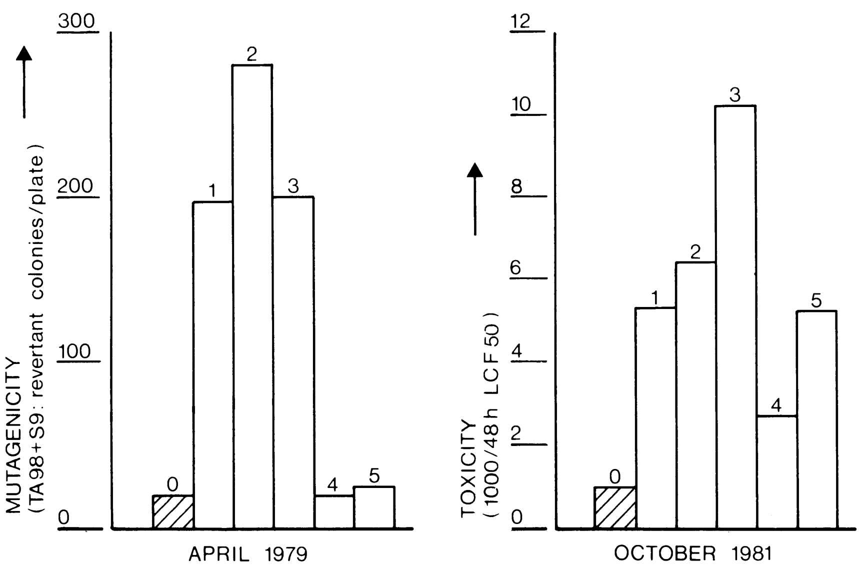

Fig. 1. Mutagenicity and toxicity of concentrates of water of the rivers Rhine and Meuse (0 = control; 1 = Rhine at Lobith; 2 = Waal at Gorinchem; 3 = Lek at Vreeswijk; 4 = Meuse at Eysden; 5 = Meuse at Keizersveer) (After Slooff and Van Kreijl, 1982; Slooff *et al.*, 1983c).

activity and toxicity of water of the river Rhine areas (Rhine, Waal, Lek) are generally higher than those of water of the river Meuse areas. Still the results of such studies have to be interpreted with some caution. Each concentration technique is specific for certain groups of chemicals and its application will result in an alteration of the chemical composition of the concentrate. However, the results give definitely an indication about the presence of hazardous chemicals in the aquatic environment. Therefore it is recommended to incorporate this kind of bioassay as a routine measurement of water quality in monitoring programmes.

TABLE VI

Advantages (+) and disadvantages (–) of the direct and indirect method for determining water quality related to toxic pollution.

Research method		Ecological relevance	Signal to noise ratio	Specificity	Response rate	Response range	Indexibility	Cost
Direct	community studies	+ +	– –	– –	+ +	+ +	+	–
	single species studies	+	±	±	±	±	– –	–
Indirect	longterm studies	±	+	±	±	±	– –	–
	short term studies	– –	+ +	+ +	– –	– –	+ +	+

Conclusions

In the present paper some examples were given of two principally different approaches in assessing water quality in relation to toxic stress: the direct (field studies) and indirect (laboratory studies) method. As summarized in Table VI both have their advantages and limitations. Major disadvantages of the direct method are the low specificity to toxic stress and the low signal to noise ratio, whereas the indirect method usually suffers from a poor ecological significance. Since both methods are complementary, it is recommended to apply them simultaneously to obtain information on the ecological state of surface waters in relation to possible causative factors, such as toxic pollution.

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TOXICOLOGICAL ASSESSMENT OF RIVER WATER QUALITY IN BIOASSAYS WITH FISH*

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Abstract. A series of bioassays with fish was developed in order to evaluate toxicological aspects of polluted rivers in The Netherlands. A long term exposition of trout to riverwater under standardized conditions enables the detection of pathological effects such as growth retardation, liver and kidney enlargement and changes in clinical blood parameters. Bioaccumulation of heavy metals and organochlorine compounds can also be measured. Embryo-larval tests with trout were less suitable, because of yearly variations in egg quality. In the near future, sister chromatid exchange (SCE) assays in vivo with Nothobranchius may become available for the detection of mutagenic effects. It was possible to measure trends in toxicological quality of Rhinewater with these tests. However extrapolation of results to ecosystems and tracing of the causes of changes occurring in waterquality are still problematic.

1. Introduction

In the past decennia, many aquatic ecosystems, and Dutch rivers in particular, have been burdened with various kinds of pollutants. Most of the time such pollution is monitored by chemical measurements. However, chemical monitoring does not allow detection and quantification of adverse effects on aquatic organisms. Only a small part of organic compounds can be isolated from water and identified with present gaschromatographic and mass spectrometric techniques (Van der Gaag *et al.*, 1982; Noordsij *et al.*, 1982). Most compounds identified in river water in The Netherlands occur at concentrations below the 'no toxic effect' levels stated in literature. Also limited data are available on joint toxic action of different substances. Therefore, it seemed worthwhile to investigate whether bioassays with aquatic organisms are needed to obtain more information on effects of pollution on the aquatic environment.

In order to detect and quantify possible adverse effects on fish of polluted river waters in The Netherlands, a number of bioassays has been investigated or developed in our laboratory. The primary aim of this research was to be able to observe toxic effects in raw water sources for drinking water preparation. In this paper the background and a number of results of this research are discussed, with special attention for the possibilities to use these bioassays for the evaluation of aquatic ecosystems.

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2. Experimental Set-Up

In all experiments fish exposed to river water were compared to control fish reared under similar conditions in unchlorinated groundwater of optimal quality. In order to detect effects of water quality on different parameters, test conditions have to be standardized, with respect to continuous water supply, aquarium dimensions, feeding, temperature and oxygen saturation. Most of the bioassays described in this study were carried out at the KIWA-Toxicological laboratory in Nieuwegein, where Rhinewater was continuously available (Poels *et al.*, 1980).

Sublethal influences of environmental factors can be measured at different levels in organisms. Growth, reproduction and teratogenicity can be monitored in whole animals. Measurements of relative organ weight, enzyme activity, clinical parameters in blood and bioaccumulation as well as histological examination can be carried out in different organs. They give information on specific organ activities, stress and fate of non biodegradable compounds. DNA damage or chromosomal aberrations can be measured at cellular level and are an indication for the presence of mutagens. The determination of all these parameters could be possible in one long term experiment. For practical reasons however, the different measurements have been divided into three standardized assays, allowing shorter test durations:

(1) a long term exposition (24 weeks) of yearling trout (*Salmo gairdneri*, Rich.), including measurements of growth, relative liver and kidney weight, blood parameters, identification of accumulated organohalogens and heavy metals. This assay was derived from the long term test described by Poels *et al.* (1980).

(2) an embryo-larval bioassay with trout (6 to 10 weeks) for measurements of mortality, embryonic development, growth and teratogenesis (Van der Gaag unpubl.).

(3) a DNA-damage test with mudminnows (*Umbra pygmaea*) or *Nothobranchius rachowi* by measurement of sister chromatid exchange (SCE) frequency (Alink *et al.*, 1980; Van der Hoeven *et al.*, 1982).

3. Longterm Toxicity Tests

3.1. Longterm toxicity tests on water of the rivers Rhine and Meuse

Compared to control, rainbow trout exposed to water from the Rhine showed retarded growth, increased relative weight of both liver and kidney, and lowered haematocrit (Table I). These effects were observed during experiments in 1975/'76 (Poels, 1978; Poels *et al.*, 1980) as well as in 1981/'82, but their impact was stronger in the first series of tests. Accumulation of organohalogens in adipose tissue was also higher in 1975/'76 than in 1981/'82, while a larger number of different compounds was identified in 1975 (DDT, TDE, PCB's, penta- and hexachlorobenzene and dieldrin) than in 1982 (penta- and hexachlorobenzene, pentachlorothioanisol and γ-HCH) (Table I). Other effects which occurred after longer exposure in 1975 (increased blood glucose levels after 6–8 months, atrophy of hepatocytes, histological changes in the spleen after 15 months) were not observed during the 24 weeks experiment in 1981/'82. Evaluation of effects

TABLE I

Summary of a number of parameters measured in trout exposed to water of the rivers Rhine and Meuse for 24 weeks

	Rhine		Meuse
	1975/76	1981/82	1981/82
Average waterflow (m^3/s) (Lobith)	1600	3800	
Growth			
length	− 22% [a]	− 8% [a]	− 7% [a]
weight	− 36% [a]	− 22% [a]	− 18% [a]
Relative liver weight	+ 54% [a]	+ 21% [a]	ns
Relative kidney weight	+ 30% [a]	+ 20% [a]	ns
Hematocrit	− 28% [a]	− 13% [a]	ns
ΣOCl [b] (mg/kg fat)	9.4	2.4	0.7

[a] $p < 0.01$.
[b] Sum of organochlorine compounds accumulated in adipose tissue.
ns: no significant change.

detected in long term tests over a period of eight years (Poels and Strik, 1975; Poels *et al.*, 1980 and this paper) point to a gradual improvement of Rhinewater quality with respect to chronic toxic effects in trout. Whether this is associated with improved waste water treatment or with increased dilution due to a higher river flow (Table I) is not yet clear.

Next to the evaluation of water quality trends in time in one water body, a comparison of two rivers is also possible. In 1981/'82 the standardized 24 weeks assay was also performed in water of another important river in The Netherlands, the Meuse. The water of this river showed a different effect, resulting only in a significant growth retardation and a slight accumulation of organohalogens (Table I). This indicates that the quality of Meuse water with respect to chronic toxicity to fish was at that time better than that of Rhinewater.

3.2. Growth retardation

Growth retardation is the first chronic toxic effect that can be detected in long term tests with trout exposed to river water. It is the resultant of all small adverse effects that cannot be measured as such. Therefore it is not possible to indicate which (group of) compound(s) is responsible for this effect. However, growth is a very sensitive and accurate parameter under standardized laboratory conditions, and therefore very suitable for quantification of water quality trends over a number of years. One of the adverse effects of growth retardation may be a lowered offspring production, as the egg production of female fish is directly related to their body weight (Weatherley, 1972). However, field studies conducted by Slooff and de Zwart (1983) revealed that a compensation occurred in bream from the Rhine, due to production of a larger number of smaller eggs.

3.3. Liver enlargement

Increased relative liver weight (RLW) in fish has proven to be a specific effect of Rhinewater over a number of years, both in laboratory (Poels and Strik, 1975, Poels *et al.*, 1980) and field studies (Slooff and de Zwart, 1983). Liver enlargement is accompanied most of the time by an increased metabolism of lipophilic xenobiotics or by toxic effects on liver functions (Schulte-Hermann, 1974). In order to obtain more information on the causes of RLW increase, the activity of aminopyrine N-demethylase (APDM) was monitored in livers of trout exposed to Rhine water.

In a first series of experiments, specific APDM activity (maximal capacity) was lowered by 20 to 30% after exposure to Rhinewater for 6 to 18 month (Poels, 1978). Using an improved method, APDM activity was also measured in following tests at low substrate concentrations, more representative of intracellular situations. The enzyme activity was assayed on the day the fish were killed, at the same temperature as that of the water in which the fish were reared (16 °C). This is to be prefered when enzymes of poïkilotherms are assayed (Hochachka and Somero, 1971; Bouck *et al.*, 1975). The APDM activity at low substrate concentration was calculated according to Cornish-Bowden and Eisenthal (1974).

Within two weeks, activity of APDM at low substrate concentrations in trout exposed to Rhine water was 38% higher than in control animals ($p < 0,05$, Figure 1). At the same time, the specific activity was lowered by 12%. These observations would indicate that both toxic effects (lowered specific activity) and adaptation (increased substrate turnover at physiological concentrations) are involved. It is not possible to indicate at this stage whether specific activity inhibition of N-demethylase (this paper) or induction

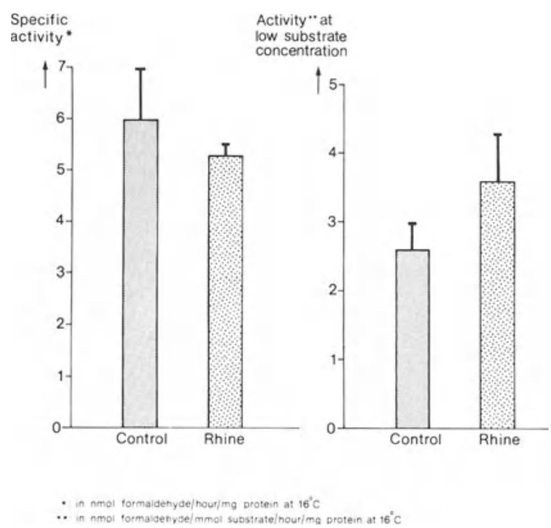

Fig. 1 Specific activity and activity at low substrate concentrations of aminopyrine N-demethylase after a 15 days exposure to Rhine water.

of other enzymes (Slooff and Van Kreijl, 1982) are predominantly responsible for the liver enlargement observed in Rhinewater fish. Such a simultaneous occurrence of enzyme induction and inhibition in fish exposed to complex effluents has also been observed at other sites (Förlin and Hansson, 1982).

Another aspect of liver enlargement is that much knowledge is available about compounds which can induce this effect. One class of such substances consists of organohalogens which are known to be accumulated in adipose tissue. Many of these compounds were detected in adipose tissue of trout exposed to surface waters in the past years. A certain relation seems to exist between the amount of organohalogens accumulated in adipose tissue and the differences in RLW between exposed and control fish (Figure 2). This indicates that bioaccumulating organohalogens contribute to an increase of RLW as observed in river waters in The Netherlands, probably together with many other compounds which can also induce this effect.

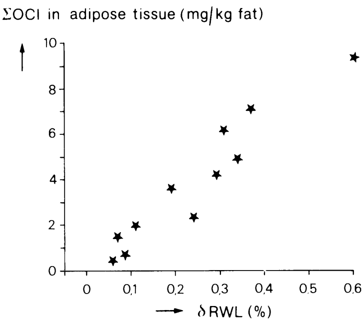

Fig. 2 Relation between the sum of bioaccumulated organohalogens in adipose tissue (ΣOCl) and the difference in relative liverweight as a percentage of body weight (RLW) in fish reared in polluted water and control water.

4. Embryo-larval Test

The embryonic and larval development in fish are known to be more sensitive for toxic compounds than later life stages (McKim, 1977). As a complement of long term tests, short term embryo-larval tests with trout were also carried out in Rhinewater each year in January between 1977 and 1982. Yearly variations in egg quality resulting in differences in control mortality do not allow quantitative comparisons. However, an improvement of Rhine water quality can be demonstrated with this test over the five year period (Figure 3).

In 1977 mortality rates of trout eggs were higher in Rhinewater than in control. This increased mortality mainly happened during the early embryonic development (5–10 days after fertilization) and during the sac-fry stage (28–35 days after fertilization) (Figure 3). In 1978 no differences were found in mortality in the embryonic stage, but larval mortality was still higher (Figure 3). Higher embryonic mortality was only found in following years when eggs were hardened in Rhinewater (Figure 3), a procedure which

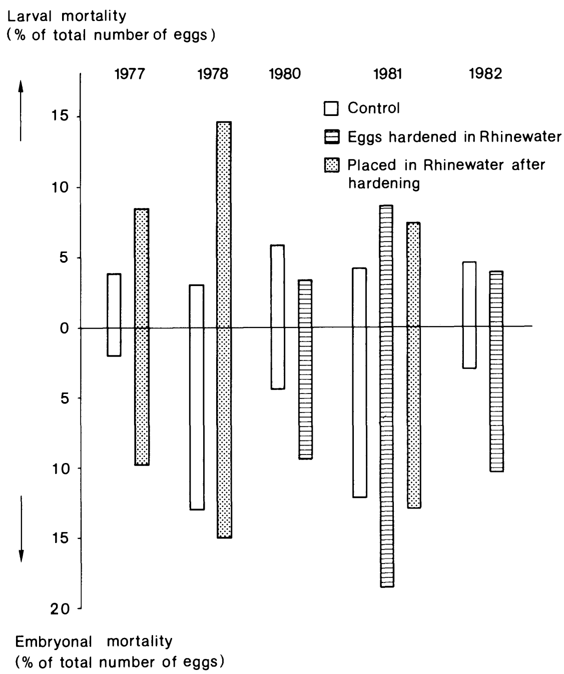

Fig. 3 Mortality of embryo's and larvae of trout in Rhinewater and control from 1977 to 1982.

was not followed in 1977 and 1978. From 1980 onwards, the differences in larval mortality between Rhinewater and control were small and not significant. Similar yearly quality variations of egg batches also interfere with an accurate determination of teratogenic or epigenetic effects. Moreover, no teratogenic effects can be scored in dead eggs. As dead eggs could represent a large part of teratogenic effects, comparisons between groups with different egg mortality are difficult. However, one type of effect, pugheadedness, occurred at a high rate in Rhinewater. The fish concerned had a distinctly shorter upper jaw compared to the lower jaw, while both jaws normally have the same length. In 1981 this effect was observed in 11% of the fish that hatched after incubation in Rhinewater. No such defects occurred in control. Similar effects have been described in bream in the Rhine and in trout and pike exposed to dioxin (2, 3, 7, 8 TCDD) (Slooff, 1982; Helder, 1982). Whether dioxins or related compounds are responsible for the effects found in Rhinewater is not known.

5. Mutagenicity Assays with Fish

The last type of assay involved is aimed at the specific group of genotoxic pollutants, i.e., those compounds which cause DNA damage or mutations. Two techniques are in use to evaluate chromosomal damage in fish in vivo, either monitoring of chromosomal

TABLE II

Induction of sister chromatid exchanges (SCE) in gill tissue of *Umbra* (January 1978) and *Nothobranchius* (November 1981) after exposure to Rhinewater

Test	Group	Number of fish	Number of chromosomes	SCE/frequ. chromosome
1978	control	10	3123	0.050 ± 0.013
	Rhine (3 days)	6	2416	0.128 ± 0.023
	Rhine (11 days)	5	2317	0.155 ± 0.021
1981	control	4	599	0.055 ± 0.026
	Rhine (7 days)	4	1739	0.104 ± 0.018

aberrations (Kligerman *et al.*, 1975; Prein *et al.*, 1978; Hooftman, 1981) or sister chromatid exchange (SCE) frequencies (Kligerman and Bloom, 1976; Alink *et al.*, 1980; Hooftman and Vink, 1981; Van der Hoeven *et al.*, 1982).

The latter technique was chosen for a number of experiments in which either mudminnows (*Umbra pygmaea*) or *Nothobranchius rachowi* were exposed to Rhinewater. Both in 1978 (Alink *et al.*, 1980) and in 1981 (Van der Gaag *et al.*, 1983), a significant increase in SCE frequency was found after a short stay in Rhinewater (Table II). *Umbra* is not very well suited for routine screening because of its poor availability and its relatively low mitotic index (Hooftman, 1981; Van der Hoeven, 1982). *Nothobranchius rachowi* offers better possibilities. But a number of problems associated with suboptimal sister chromatid differentiation staining, are still being investigated in order to obtain a routine test. Accurate evaluation of the possibilities of the Nothobranchius-SCE test will take place when these problems have been solved.

6. Evaluation

Evaluation of the bioassays presented in this paper can be separated in two different parts, depending on the aim of the investigation.

If the aim is to give objective parameters in order to evaluate trends in toxicological aspects of a watertype, these bioassays can be useful monitoring systems. Toxic effects of a specific waterbody with a certain pollution load seem to be rather stable over a number of years, such as was demonstrated for Rhinewater. From 1974 to 1982, a similar pattern of altered parameters was observed. This included embryonic mortality, growth retardation, liver and kidney enlargement, low haematocrit and bioaccumulation of organochlorine compounds in adipose tissue. Over these years the intensity of changes in the different parameters decreased, suggesting a quality improvement of Rhinewater. However the toxic effects of Rhinewater are still more severe than in Meusewater. This suggests that a quantitative routine monitoring of toxic aspects of polluted waters is possible. The long term test with trout is particularily suitable for this purpose, and can possibly be supplemented in the near future by the SCE-test in *Nothobranchius*.

However, a number of difficulties arise when extrapolation of test results is needed, in order to evaluate effects of toxic contaminants on ecosystems. A number of similar effects were found in laboratory and field studies of Rhinewater, such as higher mortality, growth retardation, liver enlargement and even some teratogenic effects (Slooff and de Zwart, 1983). However, it is not excluded that environmental factors could compensate for toxic effects in the ecosystem. Until such aspects have not been subject of further study, it is advisable to remain careful when laboratory results of the present bioassays are used for evaluating the influence of pollutants on ecosystems.

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BIOLOGICAL INDICATORS OF AIR POLLUTION*

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1. Introduction

Man-made air pollution comes from many sources. By far the most important are the stationary and mobile combustion processes, being responsible for most of the sulphur dioxide and nitrous oxides and for the photochemical pollutants in the atmosphere. A great variety of less common pollutants originates in industry and agriculture. Amongst the latter are: fluorides, heavy metals and polychlorbiphenyls (PCB's). Agriculture contributes pesticides, fertilizers, manure and ammonia (bio-industry!) as polluting agents.

Air pollutants may spread over hundreds and even thousands of kilometers, depending on meteorological circumstances, especially wind direction and speed. It is therefore important to establish a monitoring network over large areas, e.g. a whole country, in which the most important air pollutants are measured chemically. Beside chemical measurements biological evaluation of the situation is desirable. For this purpose biological indicators are used. Mostly plants are preferred as several plant species or cultivated varieties as well as mosses and lichens appear to be much more sensitive to most air pollutants than man and animals. Exceptions are hydrogen sulphide (H_2S) and carbon monoxide (CO).

2. Types of Bio-Indicators

Grodzinski and Yorks (1981) distinguish three main categories of bio-indicators:
- True indicators, in which the degree of pollutant-incited damage is related to morphological and/or physiological symptoms in one selected species.
- Scales of indicator species, relating the level of air pollution to the presence or absence of sensitive species.
- Accumulators or collectors, being plant or animal species acting as a quantitative collector and/or accumulator of air pollutants.

3. True Indicators

Some higher plants appear to possess a more or less specific susceptibility to certain air pollutants. Symptoms caused by such components can be distinguished and measured, also under field conditions. If one uses standardized plants, grown in special

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containers, unnecessary variation in the effects to be studied can be prevented. Thus it is possible to monitor, on a local, regional or national scale, the biological effects of certain air pollutants. This has been done e.g. in The Netherlands for the last twenty five years, first only on a local basis, later nationwide. This appeared to be important as a warning for possible damage to natural or cultivated plants and for raising the alarm for possible risks to man, animals and materials by specific air pollutants to which plants are much more sensitive than animals (Posthumus, 1982). It is essential that all fieldwork is supported by careful laboratory work, including fumigation of plants in special fumigation chambers with known concentrations of pollutants during shorter or longer exposures. In fumigation experiments one can also investigate the influence of combinations of pollutants, which may lead to the discovery of synergistic effects. As in the field the presence of more than one pollutant will be the rule rather than the exception, bio-monitoring is an essential addition to chemical monitoring.

Strange reactions of plants have been found as the first symptom of the presence of an (unknown) air pollutant. A classical example of this is the severe damage in Californian spinach fields in the fourties. Haagen Smit *et al.* (1952) could prove that this was due to a new (photochemical) type of air pollution, mainly derived from exhaust gases of automobiles. Later the new pollutant appeared to be ozone. In 1965 the syndrome of another photochemical product, peroxyacetylnitrate (PAN), originally described in California, was found on a local scale in The Netherlands. Under very exceptional weather conditions damage to a number of crop plants by PAN or similar oxidants may still occur, as e.g. in September 1982. For that reason special indicator plants for PAN or related oxidants (e.g. *Urtica urens*) are being used beside those for SO_2, HF, ozone and ethylene, in the national monitoring network of The Netherlands.

Lichens are very susceptible to air pollution, especially SO_2. Here also differences in susceptibility exist among the various species (Skye, 1968; de Wit, 1976). In the papers of Posthumus and de Wit the true indicator plants and to a certain extent the accumulator plants are treated in more detail. A special type of true indicator is common maple (*Acer pseudoplatanus*). The leaves of it are frequently infested by the fungus *Rhytisma acerinum*, causing so-called tar spots. As this and many other fungi are susceptible to sulphur and SO_2, reduction of the number of tar spots is directly related to the annual average SO_2-concentration (Bevan and Greenhalgh, 1976).

Animals are seldom used as true bio-indicators for air pollution (Newman, 1975). Recently André *et al.* (1982) used the bark mite *Humerobatus rostrolamellatus* as indicator for SO_2 in Belgium. After one week the mortality of adult mites in small glass tubes covered by a screen, correlated very well with the average SO_2-concentration in the suburbs of Brussels during that period. Mortality varied from 0 to 49%.

Special mention should be made of the work going on in Czechoslovakia, where changes in the physiology of animals are used to indicate the influence of air pollution near factories. The hemoglobin content of the blood of hares was significantly lower in industrial areas and the pH of the urine was higher (8.5) near cement works and lower (3.4) near a SO_2-emitting factory (Novakova, 1968), than those in non-polluted areas.

4. Scales of Indicator Species

As not all plant species possess the same susceptibility to a certain air pollutant and as their reaction to various air pollutants often is different, one can use the composition of plant communities as an indicator to the amount of air pollution. An example may illustrate this. In an area around a HF emitting factory the permanent squares close to the factory had only a small number of (resistant) species (Hajduk and Ruzicka, 1968). In four years time the frequency of two resistant species, *Silene vulgaris* and *Agrostis stolonifera,* which before the pollution was the same, had changed totally: *Agrostis* had developed massively, filling the niches left by the susceptible species, whereas *Silene* was found in the same frequency as before.

The absence of certain species alone cannot be used as indicator for air pollution as it may also be the result of other causes. However, the absence of a whole group of species demanding similar local conditions may be an indication for air pollution, especially if such plants are found in places at a greater distance from the pollution source (Cairns *et al.*, 1979). An abundant presence of otherwise rare but resistant species may sometimes be used as indicator of air pollution as is illustrated with the following example. In Canada *Polygonum cilinote* and *Sambucus pubens* occurred only abundantly in areas with a heavy SO_2 pollution, whereas less resistant species had disappeared (Gordon and Gorham, 1963). Later research indicated that such shifting of species only occurs where pollution is very severe, to a degree no longer acceptable in most countries today (Grodzinski and Yorks, 1981).

5. Accumulators

The third category of bio-indicators consists of the accumulators or collectors. These are either plants or animals which show no physiological or anatomical changes due to air pollution. However, chemical analysis shows that polluting agents can accumulate in living organs such as leaves of plants or body tissues of animals. Experience has shown that some organisms accumulate much more of the pollutant than others, e.g. mosses seem to accumulate heavy metals better than lichens and higher plants (Grodzinska, 1978; Folkeston, 1979).

Others prefer the use of animals as accumulators of air pollution components. Earthworms living in the vicinity of Dutch metallurgical plants showed concentrations of cadmium and zinc which were many times higher than in the surrounding soil (Eijsackers *et al.*, 1982). A large proportion of these heavy metals reach the environment via the atmosphere (Paul *et al.*, 1981). Bromenshenk (1978) suggests to use honeybees as bio-accumulators/indicators for environmental pollution, especially for chemical analysis of fluorides, lead and mercury, occurring in the tissues of bees. Others analyzed honey from bees visiting flowers along roadsides near industries or mines and found traces of lead, zinc and cadmium (Otto and Jekat, 1977). The concentrations were so low, however, that no danger for public health exists.

6. Conclusions

As organisms and ecosystems undergo *all* the influences of the environment, they react on the total pressure being exercised by a (polluted) environment. Moreover if a certain threshold value of chemicals alien to the environment is surpassed, even for a short period, this may have serious effects. As a rule such short peak values of air pollutants will not be registered in chemical monitoring networks. In support to other methods, bio-indicators for air pollution are very useful as early biological warning systems (Manning and Feder, 1980). Whether a certain organism, be it plant or animal, can be used successfully as indicator or accumulator must be investigated carefully in fumigation experiments both in the laboratory and in the field. Especially if it is the intention to establish a regional or country wide monitoring network, such studies are obligatory. So far plants seem more suitable for our purpose than animals for one thing because they ask less attention and react frequently with characteristic symptoms to very low concentrations of specific air pollutants.

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HIGHER PLANTS AS INDICATORS AND ACCUMULATORS OF GASEOUS AIR POLLUTION*

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Abstract. Some higher plant species or varieties are very sensitive to certain gaseous air pollutants, and the resulting effects show sometimes more or less specific, well-visible and measurable symptoms.

On this basis several species and varieties of natural and cultivated plants have been selected to serve as biological indicators for the possible presence of certain air polluting substances. But these indicator plants may also be used for the quantitative determination of the effect intensities of the air pollutants involved.

Besides, some plant species or varieties may accumulate certain components of air pollution, without changing these substances, in such a way that after accumulation in the plants these substances may be analyzed physicochemically (qualitatively and quantitatively).

Definitions are proposed and examples are given of both indicator and accumulator plants. Also information is displayed on the methods for the use of plants as indicators and accumulators of air pollutants (standardized system of plant cultivation and exposure). Some applications of biomonitoring the effects of air pollution with plants are discussed and illustrated with data from The Netherlands.

1. Introduction

Because of the relatively high sensitivity of plants in general to several air pollutants, and the occasional fairly specific symptons accompanying the effects of different air pollutants on certain higher plant species or varieties, these may be used as indicators for the detection, recognition and monitoring of air-pollution effects (Manning and Feder, 1980). When plants accumulate the polluting compounds without changing their chemical nature by metabolism, and the pollutants are easily analyzed in the plant material, such plants may be used as accumulators. If the accumulation of air pollutants by plants is also considered to be an effect of the atmospheric pollution, higher plants are very suitable for detecting, recognizing and monitoring air pollution effects (Posthumus, 1982).

Several types of air-pollution effects are known and these may be divided into acute effects of exposures to high concentrations over short periods and chronic effects of exposures to low concentrations over long periods. Examples of acute effects are clearly visible chlorosis and necrosis of leaf tissue; leaf, flower or fruit abscission; and epinastic curvatures of leaves and leaf stems. Chronic effects may appear as retardation or disturbance of normal growth and development (resulting in reduction of yield or quality of agricultural, horticultural and forestry crop plants), or slow discoloration

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(chlorosis), leaf-tip necrosis, and ultimately total die-back of plant organs may be caused. In some cases the symptoms of acute and chronic effects may be fairly specific for a particular air pollutant or for a combination of different pollutants (Krol *et al.*, 1982).

Many higher plant species and varieties may be useful as indicators and/or accumulators of air pollutants by showing special, well quantifyable symptoms of effects at low concentrations of pollutants. Biological-effect monitoring may be performed by using the natural vegetation and the cultivated plants present in the studied area (passive bio-monitoring), but differences in soil, water and other (for example climatic) conditions may influence the effects and diminish the comparability of results from different sites. It is therefore better to use selected indicator and accumulator plants, cultivated and exposed in conditions of soil and watering that are standardized as far as possible (active bio-monitoring).

Within the complex of air pollution some gaseous components are highly phytotoxic. These components may influence higher plants very drastically, when they occur singly or in combinations, as has been demonstrated by artificial fumigation experiments, for example by Spierings and Wolting (1971), Posthumus (1977), and Mooi (1981).

As most phytotoxic component hydrogen fluoride (HF) is known to have negative effects on several plant species. Specially monocotyledonous ornamental plants as tulips, gladioli, freesia's, and stone fruit species as plums, peaches and apricots, but also crops like maize and natural plants like *Hypericum perforatum* L. and *Picea abies* (L.) Karsten are very sensitive to this HF and other well-soluble fluorides. The F-ion accumulates in the rims and tips of the leaves and causes necrosis of leaf tissue, clearly separated from the living, green tissue by a red-brown boundary zone. Also growth and development of plants may be retarded by HF, specially during chronic exposures, the F-ion accumulating very easily.

A second air pollutant, causing effects on plants in very low concentrations is ethene (C_2H_4), well known as a plant hormone. External ethene may cause the same effects as endogenous, but at an unusual time and in an exaggerated and thereby injuring way. Known symptoms are epinastic curvatures of leaves and leaf stems; leaf, flower and fruit abscission; induction of more, but smaller potato tubers; general growth inhibition (dwarf growth).

Sulphur dioxide (SO_2) is also rather phytotoxic for higher plants. Besides negative influences on growth and (re)production, clearly visible leaf injury (e.g. interveinal or needle chlorisis and necrosis) may be the result. This form of leaf injury is not specific for SO_2 and may be found with many species, for example several coniferous trees, clover species, alfalfa, buckwheat and *Rubus fruticosus* L.

Strongly phytotoxic are also some components of photochemical air pollution, especially peroxyacetyl nitrate (PAN) and ozone (O_3). PAN causes rather specific symptoms of leaf injury at some plant species: for example bronzing discolorations at the abaxial leaf surface, in transverse bands which shift from the base of the older leaves to the top of the younger ones, for *Urtica urens* L. Also *Poa annua* L., petunia and other cultivated plants may be injured. The first symptoms of O_3 effects mostly occur at the adaxial leaf surface in the form of a special speckle necrosis, e.g. with tobacco variety Bel W_3, or a glazing, e.g. with spinach and *Plantago major* L. O_3 may also cause other forms of necrosis and chlorosis, leaf drop and growth reduction.

Some air pollutants cause only effects on plants at a much higher concentration than the preceding ones. For example chlorine (Cl_2), nitrogen dioxide (NO_2), hydrochloric acid (HCl) and ammonia (NH_3). These components do not produce specific symptoms, but all give rise to leaf chlorosis and necrosis, and growth reduction (compare Spierings, 1971, and Van der Eerden, 1982).

2. Materials and Methods

In biological monitoring of air-pollution effects, both the use of indicator and accumulator plants is important for the indication, recognition and quantitative determination of these effects. For a better understanding of this biological-effects monitoring research with plants, the following definitions and descriptions may be useful.

Indicator plants are plants which may show clear symptoms of effects, indicating the possible presence of some pollutant(s). These symptoms may be fairly specific and lead to the qualitative determination of a pollutant, but usually they do not provide a definitive identification, and the presence of a specific pollutant must be proven by other methods. The indicator plants serve to detect and identify the effects of the pollutants, but these effects may also be determined quantitatively to monitor the effect intensities.

Accumulator plants are plants which readily accumulate specific air polluting compounds. These compounds may be analyzed in the plant material after some time by physicochemical methods to identify the pollutants and to obtain a quantitative determination of the pollution load (total amount of pollutants accumulated over a certain period).

Sometimes the same plant species may act as both indicator and accumulator for a special pollutant. But the varieties may be different in their usefulness, a good indicator being not a good accumulator and vice versa.

2.1. Selected Plant Species and Varieties as Bio-Indicators of Certain Gaseous Air Pollutants

Several species and varieties of natural and cultivated plants, which have been shown to be sensitive to one or more air pollutants, are in current use in effect monitoring networks. We have used in The Netherlands a set of indicator and accumulator plants of different degrees of sensitivity, as shown in Table I. This has been based on experiences during several years in our national monitoring network for air-pollution effects on plants, as described by Posthumus (1976).

HF may be easily indicated by tulips and gladioli. Symptoms of fluoride effects are estimated by measuring the areas of necrotic leaf tip and rim necrosis. The total surface of the necrotic areas per leaf is determined relatively by measuring the length of the total necrotic leaf tip (all necrotic tissue is 'transported' to the leaf tip area). The very sensitive tulip variety Blue Parrot and gladiolus variety Snow Princess have been used in spring and summer respectively.

Symptoms of O_3 effects are mostly observed and estimated in the form of the speckle necrosis at the adaxial leaf surface of tobacco plants, variety Bel W_3. Percentages of injured leaf area for all leaves of the exposed plants, cultivated previously in O_3-free air, are determined after one week of exposure. The mean value of these percentages per leaf for a number of four plants is used as a measure for the O_3-effect intensity. These measurements may be made more sensitive by using only the effect intensities of the three most sensitive leaves per plant.

Effects of PAN are indicated rather specifically by the bronzing, band forming discolorations at the abaxial surface of leaves of *Urtica urens* L. Quantitative observation of the effect intensity is performed by estimation of percentages of injured leaf area. Different stages of development of the leaves cause different sensitivity, and this may be used to make the effect measurement more sensitive.

Effects of C_2H_4 on flowering may be indicated with petunia variety White Joy. Dependent on the C_2H_4 concentration in the air smaller, less or no flowers are observed.

SO_2 does not cause effects with specific symptoms, because interveinal chlorosis and necrosis of leaves may also be caused by NO_2, but at much higher concentrations than usually occur in practice. Still there are some indicator plants used for SO_2 effects, the probability for these being greater than for NO_2 effects. Different clover species (red clover and incarnate clover), alfalfa, and buckwheat are sensitive to SO_2 and therefor used as indicator plants.

2.2. Selected plant species and varieties as bio-accumulators of certain gaseous air pollutants

Some plant species and varieties have special morphological and physiological characteristics to make them very suitable to accumulate gaseous components of air pollution, to be analyzed afterwards by physicochemical methods. Of course this relates only to the components which will not be changed spontaneously or by the metabolism of the plants.

Most important are the plants which accumulate F ions, for example in the leaf tips where it may be analyzed easily. This is the case for the tulip variety Preludium and the gladiolus variety Flowersong. But also Italian ryegrass variety Optima has been used to accumulate F and other ions (see Table I).

2.3. Methods for the cultivation and exposure of indicator and accumulator plants

An active monitoring method has been chosen for the study of the presence, intensity and distribution of effects of air pollutants on higher plants in The Netherlands. Indicator and accumulator plants were cultivated and exposed in a standardized way, to eliminate unnecessary variation in the effects studied.

TABLE I

Indicator and accumulator plants used for effect measurements of different air pollutants in The Netherlands.

Plant species and varieties	Air pollutants	Symptoms/effects
Gladiolus, varieties Snow Princess and Flowersong Tulip, varieties Blue Parrot and Preludium	Hydrogen fluoride (HF)	Leaf-tip and marginal necrosis (Snow Princess and Blue Parrot) and fluoride concentrations in dry matter (Flowersong and Preludium)
Tobacco, variety Bel W_3	Ozone (O_3)	Leaf upper-surface speckle necrosis
Urtica urens L.	Peroxyacetyl nitrate (PAN)	Leaf under-surface band forming injury
Petunia, variety White Joy	Ethene (C_2H_4)	Flower-bud abscission, smaller flowers
Red clover Incarnate clover Alfalfa Buckwheat	Sulphur dioxide (SO_2)	Interveinal chlorosis and necrosis
Italian ryegrass, variety Optima	Fluoride and metal ions (F, Cd, Mn, Pb, Zn)	Ion concentrations in dry matter

All plants were cultivated in the same soil mixture with sufficient nutrient value for the cultivation and exposure period. Some plant species were sown and cultivated in greenhouses before they were exposed in the open air (e.g. tobacco variety Bel W_3), others were sown and cultivated in the field.

Because of the uniformity of the plants, selected seeds or other as homogeneous as possible plant material was used. Standardization as far as possible of the soil and water conditions of the plants was achieved by using special plant cultivation sets. This system has been used for the first time in the Federal Republic of Germany by Scholl (1969), and has been developed further in The Netherlands (Floor and Posthumus, 1977). The plants are sown or planted in standard soil in plastic containers with ceramic filter candles in the soil for automatic and regular watering. Three of these containers are placed together in a larger container which serves as a water store. In these standardized cultivation sets all species of indicator and accumulator plants may be cultivated by adapting the number of filter candles to the water requirement of the plants.

3. Results

As an example of results of a biological-effects monitoring network with higher plants, a selection of some results of the national monitoring network for air-pollution effects

Fig. 1. Experimental field at Kolhorn of the National Monitoring Network for Air Pollution in The Netherlands.

in The Netherlands is given. This monitoring network is operated by the Research Institute for Plant Protection as a part of the National Monitoring Network for Air Pollution of the National Institute of Public Health (Anonymous, 1982). In this network the acute and chronic effects of several air pollutants on different indicator and accumulator plants (as shown in Table I) have been monitored at about 40 experimental fields, more or less regularly distributed over The Netherlands, from 1976 onwards (Posthumus, 1982). One of these experimental fields is shown in Figure 1. Results from the years 1979, 1980, and 1981 are compared for both O_3 effects on tobacco variety Bel W_3 and HF effects on tulips and gladioli.

Acute effects of O_3 on tobacco Bel W_3 (as described by Posthumus and Tonneijck, 1982) were determined by estimating for all leaves of four plants per location the percentage of leaf area injured by speckle necrosis, according to the following ratings: 0%, 0–5%, 5–10%, 10–25%, 25–50%, 50–75%, and 75–100%. From these weekly assessments the ultimate mean value for all leaves was calculated for every location. Thus a distribution of the intensity of the O_3 effect in place and time during the vegetation period for each year is obtained. Figure 2 shows the weekly variations of the mean leaf injury for tobacco Bel W_3 at the experimental fields in the northern and southern, and in the eastern and western halves of The Netherlands for the monitoring periods from 1979 to 1981. From these results it appears that the mean intensity of the O_3 effects in 1979 and 1981 was higher in the western than in the eastern half of The Netherlands, and that there were weeks every year when this intensity is maximal (correlated with sunny weather).

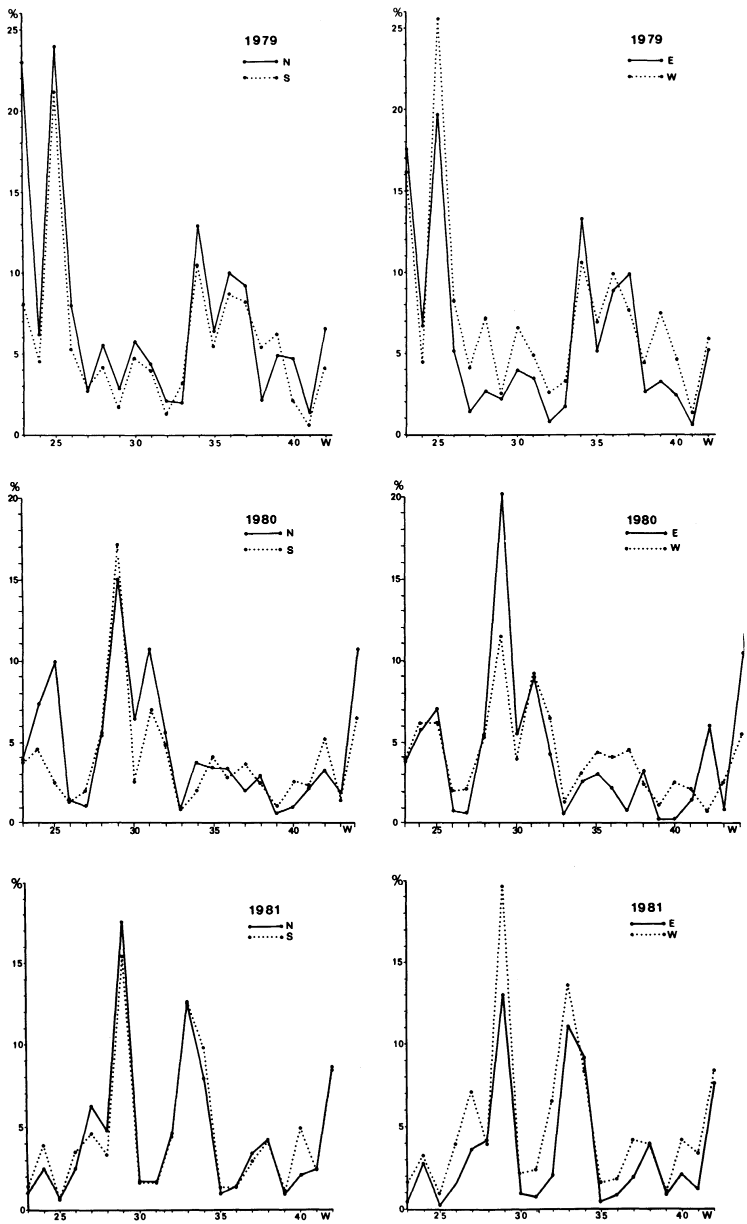

Fig. 2. Variation of the weekly mean ozone-effect intensities on tobacco variety Bel W_3 (percentages of leaf area injured) at the experimental fields of the national monitoring network for air-pollution effects in the northern (N) and southern (S), and in the eastern (E) and western (W) halves of The Netherlands during the vegetation periods of the years from 1979 to 1981 (W is week number from the beginning of each year).

Based on research of Spierings (1967) acute and chronic effects of HF were studied with tulips (varieties Blue Parrot respectively Preludium) in spring and with gladioli (varieties Snow Princess respectively Flowersong) in summer. After exposures for

TABLE II

Lengths (in cm) of the necrotic leaf tips of tulips, variety Blue Parrot (BP), and gladioli, variety Snow Princess (SP), and fluoride contents (in $\mu g\ g^{-1}$ dry matter) of 5.0 cm leaf tips of tulips, variety Preludium (PR), and 7.5 cm leaf tips of gladioli, variety Flowersong (FL), after 17 resp. 22 weeks of exposure at several locations in The Netherlands in 1979, 1980, and 1981.

	1979				1980				1981			
	BP	PR	SP	FL	BP	PR	SP	FL	BP	PR	SP	FL
Afferden	4.8	129	1.4	124	3.2	90	0.7	116	4.8	67	1.1	53
Steeg	5.0	82	0.8	58	2.7	57	0.8	34	4.0	37	1.5	20
Born	4.6	116	1.2	115	3.3	92	1.3	45	4.3	59	1.2	49
Oost-Maarland	3.3	84	1.2	37	2.5	67	1.0	40	3.4	24	1.6	39
Dussen	2.2	73	1.1	47	2.3	54	0.8	34	3.7	31	1.1	20
Heijningen	2.9	64	1.3	63	2.4	36	1.1	35	3.0	34	1.3	13
Best/Welschap	3.7	87	1.0	45	2.4	49	1.2	64	–	–	–	–
Ossendrecht	4.4	144	1.7	50	2.3	52	1.6	54	3.5	47	1.8	53
Zierikzee	2.5	30	0.7	48	2.4	31	1.0	45	3.1	36	1.4	22
Lewedorp	2.8	102	1.8	101	1.8	33	2.4	108	3.1	57	1.8	42
Sas van Gent	5.7	256	2.3	79	4.4	126	1.7	122	5.4	174	5.7	122
Voorschoten	3.0	32	0.5	13	1.7	17	0.9	24	2.9	26	1.2	10
Zevenhuizen	2.3	50	0.8	65	1.7	42	2.4	43	3.1	47	1.2	13
Schipluiden	3.9	85	1.6	101	2.2	133	1.8	208	5.5	64	1.2	86
Delft	4.4	159	0.9	61	2.3	67	1.8	57	4.0	64	1.2	48
Vlaardingen	5.1	308	4.2	356	4.6	480	5.4	565	5.8	310	4.0	120
Rockanje	3.7	24	0.8	27	2.3	47	1.3	–	2.8	34	2.0	11
Spijkenisse	4.4	300	1.0	58	8.4	490	2.1	88	6.7	188	11.2	143
Naaldwijk	3.2	81	1.1	39	2.6	38	1.1	29	4.2	54	1.4	14
Maasland	3.0	74	1.3	97	2.8	43	1.0	56	–	–	–	–
Rhoon	4.4	160	1.8	106	3.5	111	1.2	74	–	–	–	–
Kolhorn	1.5	25	0.5	18	1.3	26	1.0	9	2.2	16	1.4	4
Kwadijk	2.5	36	0.5	41	1.3	25	1.0	21	2.6	10	1.2	9
Lisserbroek	2.7	43	0.9	16	1.5	30	0.9	18	2.9	46	1.6	12
Biddinghuizen	2.0	14	0.4	9	0.7	27	0.4	20	2.1	11	1.0	7
Bilthoven	2.9	92	0.9	43	1.4	28	1.3	16	3.1	27	1.2	12
Cabauw	2.9	67	0.6	57	2.5	37	1.1	15	3.3	58	1.3	19
Wageningen	3.5	78	1.7	176	2.9	71	1.1	92	5.2	41	1.8	42
Barneveld	1.7	57	0.6	27	1.4	20	0.9	30	2.8	16	1.1	20
Doetinchem	4.7	81	1.5	79	1.8	42	0.8	83	3.7	44	1.4	42
Puiflijk	3.1	75	0.4	111	2.9	113	0.9	62	4.2	54	1.4	19
Winterswijk	3.7	70	0.8	44	1.7	33	0.9	40	–	–	–	–
Kuinre	2.0	16	0.4	16	1.2	10	0.7	13	1.8	40	1.4	4
Dalfsen	2.4	17	0.7	6	0.8	10	1.0	16	1.9	10	0.9	11
Delden	3.1	27	0.7	57	1.3	24	0.6	44	2.7	19	1.1	25
Cornjum	2.3	22	0.5	13	0.9	4	0.7	8	2.1	8	1.0	4
Noordwolde	1.5	20	0.5	–	1.3	17	0.1	24	–	–	–	–
Donkerbroek	1.4	12	0.3	10	0.7	9	0.6	15	1.9	10	1.0	3
Sellingen	1.8	18	0.7	23	0.8	13	0.9	12	1.4	10	0.7	14
Nieuw-Balinge	2.6	12	0.5	10	0.8	12	0.6	7	–	–	–	–

several weeks the lengths of the necrotic leaf tips were measured on tulips, variety Blue Parrot, and on gladioli, variety Snow Princess. The results of the years 1979, 1980, and 1981 are collected in Table II. The fluoride contents of the 5.0 cm leaf tips of tulips, variety Preludium, and the 7.5 cm leaf tips of gladioli, variety Flowersong, were analysed after some months. These fluoride contents for 1979, 1980, and 1981 are also shown in Table II. The fluoride content of the leaf tips appeared to be very well correlated with the intensity of leaf necrosis. From the fluoride-effects monitoring network it was possible to show the distribution of fluoride pollution over The Netherlands, the south-western part of the country being most polluted.

4. Discussion and Conclusions

Higher plants may be used as indicators and accumulators of air pollutants for detection, recognition and monitoring purposes. They may serve to raise the alarm for the possible occurrence of air pollution effects on other objects. But the standardized measurement of effect intensities on indicator and accumulator plants may also be used for the comparative determination of the air-pollution effects load in different areas or periods. This form of biological-effects monitoring is relatively cheap and simple to carry out, and it is very close to the problem of the occurrence of air-pollution effects on the vegetation. It is possible to get an impression of the distribution of the effects load in place and time. For some components of air pollution this is still supported by qualitative and quantitative determinations of these components in accumulator plants. However, there is no question of replacing ambient-air monitoring by physicochemical methods with effect monitoring with plants: both should be used jointly (Posthumus, 1980).

A problem is that good indicator plants are not known for all important components of air pollution. The specificity of the indicators used is mostly insufficient, and also the occurrence of combination effects of different air pollutants is a great problem.

When plants are used for the monitoring of air-pollution effects, a high degree of standardization of the plant material and of the environmental conditions is a prerequisite. In more or less extended monitoring networks climatic differences should be taken into account. But it seems to be better to use uniform plant material and to accept an integrated effect of air pollutants and environmental conditions, than to use different and uncomparable plant material adapted to different local conditions. The risk of effects of air pollution on vegetation is largely determined by environmental factors, so these should not be excluded from effects monitoring research.

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LICHENS AS INDICATORS FOR AIR QUALITY*

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Abstract. Indication depends on the existence of a known relationship between the possibilities for existence of the lichens and the quality of their surroundings. These possibilities may be read from the parameters such as: distribution patterns of species, species numbers, physiological and morphological aspects. This is illustrated by examples with emphasis on: choice of parameters, interaction between several factors, comparison of lichens with other organisms and evaluation of the use of lichens as indicators.

1. Introduction

In the 19th century it was already known that in cities with polluted air less lichens occurred than in non polluted areas (Nylander, 1866). Over the last decades, in particular, a lot of research has been carried out in this field. The results indicate that lichens in general, as a taxonomical group, are highly sensitive to air pollution (Ferry *et al.*, 1973, Skye, 1979). The working of direct, operational, and indirect, conditional, factors, as well as unforeseen coincidences however, create complex situations.

In research on relations between organisms and environmental factors two lines can be distinguished: an experimental and a descriptive approach. Experimental research usually is limited to a few factors of which the impact is being studied under laboratory, and therefore non-natural, conditions. Extrapolation to, and interpretation of the findings of such work to natural conditions is difficult. Fumigation experiments on lichens for instance are hard to interpret because of the high, continuous concentrations that are applied and the non-natural microclimate in the glasshouses. Descriptive work whereby observations on lichens, e.g. distribution patterns, are compared with air pollution patterns are complicated by the working of, sometimes unknown, factors such as the simultaneous occurrence of different pollutants. Lichens are not only studied and used as indicators, but also as accumulators, e.g. for radioactive isotopes and heavy metals (Hotzman, 1978; Lawrey and Hale, 1979).

2. Parameters

Considering that the living conditions of lichens are limited by one or more air pollutants and that this limitation can be read from one or another parameter, such parameters may be distinguished at different organizational levels, e.g.

- vegetation level: growth forms, species composition, percentage cover and frequency of species, number of species;

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- species and individual plant level: occurrence, appearance and disappearance, growth, size and vitality, fertility;
- cell level: respiration, chlorophyll content, photosynthesis.

The parameters at vegetation level are natural derivatives from those at species level, similar to those derivative from the parameters related to the physiological functioning of the individual plants. Some selected parameters are briefly illustrated below.

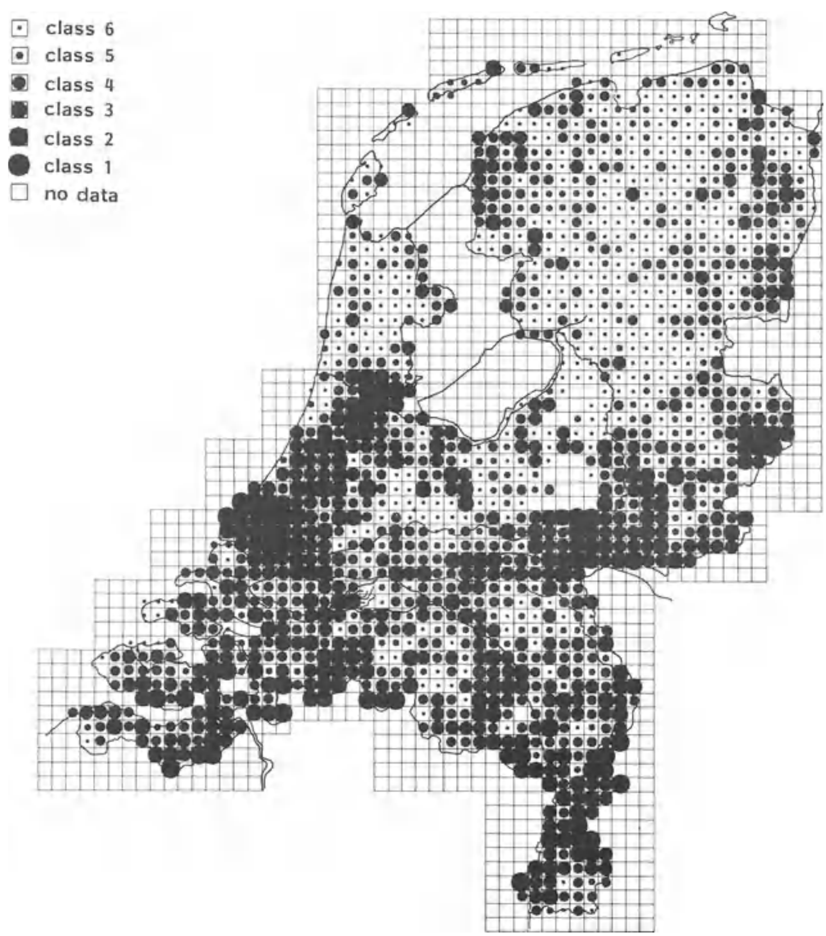

Fig. 1. The richness of epiphytic lichens in The Netherlands around 1972, based on the number of epiphytic lichen species per tree species and per 5 × 5 km grid square. Class 1 = poor, class 6 = rich.

3. Parameters at Vegetation Level

Lichens appear in some clearly recognizable growth forms. The least sensitive species are all crustose. Foliose species are usually more sensitive, and the most sensitive ones are found among the fruticose species. This characteristic has been used in surveys and mapping, e.g. the inventory of Great Britain carried out by schoolchildren, using a simple classification (Gilbert, 1974). The produced map is very similar to the one of Hawksworth and Rose (1970) of England and Wales on which zonations of species and species combinations are shown together with average SO_2-concentrations. In research in The Netherlands the number of epiphytic lichens per unit area (a grid of 5×5 km^2) was used as a parameter (De Wit, 1976). The differences in epiphytic species richness in The Netherlands (Figure 1) appeared to be closely correlated with the SO_2-concentrations.

4. Parameters at Species and Individual Plant Level

The occurrence of one or a few species is also used as a parameter. In particular for very detailed mapping in rather highly polluted areas where few species are found, this technique has given satisfactory results (De Wit, 1976).

Le Blanc and De Sloover (1970) and Trass (1973) used semi-quantitative measures in the format IAP = $\Sigma[Q_{-1} \times f]$ (*I*ndices of *A*ir *P*urity) in which Q represents the sensitivity of the species and f a cover- or frequency measure. In this approach it is implicitly assumed that the presence of one moderately sensitive species has the same meaning as the presence of one highly sensitive and one rather insensitive species. This is entirely different from the approach in which the presence of certain defined species is considered characteristic.

In permanent quadrats in a dune area the performance of the terrestrial lichen *Cladonia foliacea* was monitored. Detailed observations on frequency and dominance in 1 dm^2 quadrats showed that close to a source of pollution, places could be found with a high cover of this species, but that such places were subject to great temporal changes. The degree of change of the vegetation can, therefore, also be used as a parameter.

At present, growth and death of one epiphytic lichen species (*Parmelia sulcata*) is monitored in The Netherlands. A network of permanent plots has been established for this purpose covering lichen-rich as well as lichen-poor areas. The permanent plots are small areas indicated on the bark of trees. Detailed inventories, including stereo-photographs, of the fixed quadrats are made once or twice a year. Growth and death of a thallus can be accurately measured (Figure 2). Radial growth appears to be correlated with the SO_2-concentrations (Figure 3).

The permanent quadrat work has also shown that dying off increases at higher SO_2-concentrations. Dying off and morphological damage is also used in research using fumigation (Türk *et al.*, 1974; De Wit, 1976) and transplant experiments in which lichens are fixed on small boards and placed in areas with different pollution levels (Schönbeck, 1968).

Growth will in general influence the maximum thallus size, a parameter sometimes

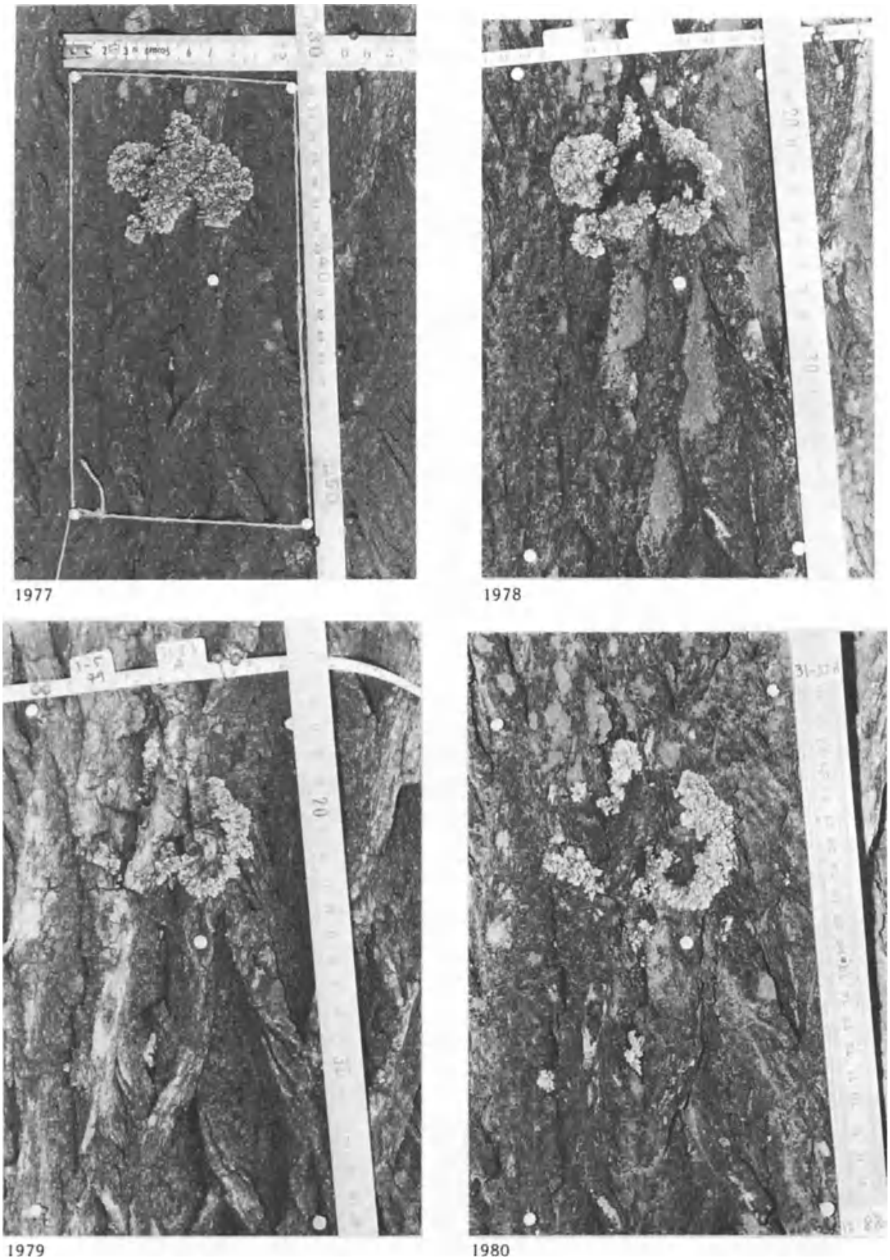

Fig. 2. Permanent plot with *Parmelia sulcata* during four consecutive years (1977 to 1980). The thallus dies off at the center, whereas growth continues at the border.

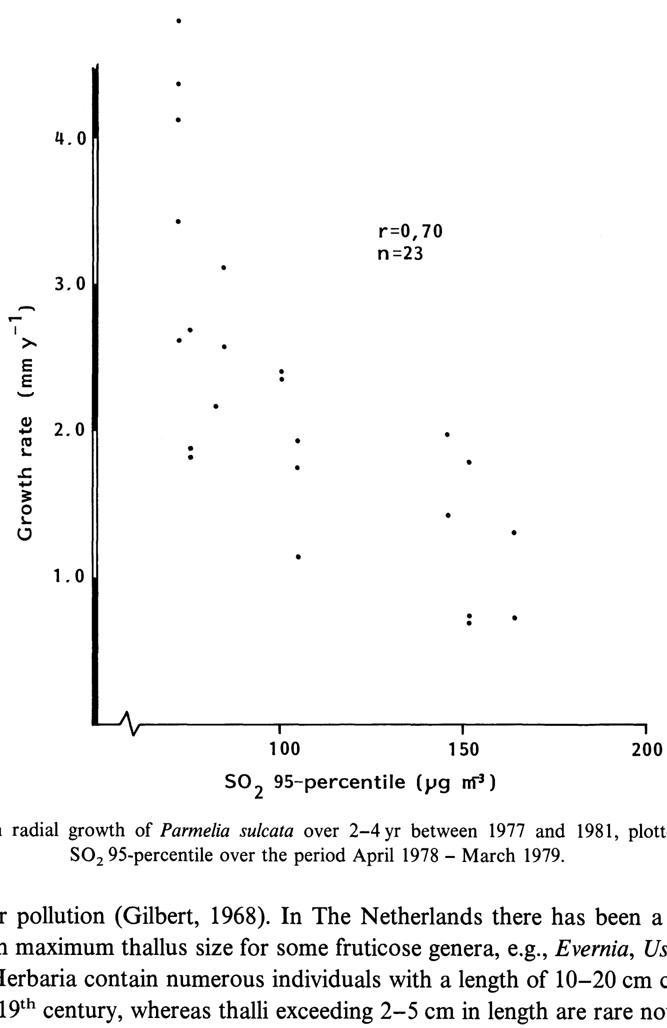

Fig. 3. Mean radial growth of *Parmelia sulcata* over 2–4 yr between 1977 and 1981, plotted versus SO_2 95-percentile over the period April 1978 – March 1979.

used for air pollution (Gilbert, 1968). In The Netherlands there has been a marked reduction in maximum thallus size for some fruticose genera, e.g., *Evernia*, *Usnea* and *Alectoria*. Herbaria contain numerous individuals with a length of 10–20 cm collected during the 19^{th} century, whereas thalli exceeding 2–5 cm in length are rare nowadays. Also, many species show a reduced fertility.

5. Parameters at Cell Level

A number of physiological aspects have been investigated experimentally, especially in relation to air pollution (Farrar, 1973). The intensity of respiration and photosynthesis has often been used in the experimental approach as a parameter to measure the response of lichens. Application of air pollutants generally results in decreased intensities (Richardson and Puckett, 1973).

The time required for photosynthesis to start after a drought period is also longer when the pH of the water used for moistening is lower (Lechowicz, 1982).

At high SO_2-concentrations not only is photosynthesis reduced, but also the chlorophyll content decreases. Concentrations of chlorophyll and phaeofytin are, therefore, also sometimes used as parameters.

6. Sensitivity of Lichens

Lichens appear to be sensitive to a large number of air pollutants, such as SO_2, HF, ethylene and ozone (James, 1973; Nash, 1976; De Wit, 1976). Mapping has yielded good information on the differences in effects under various intensities of air pollution. Fumigation experiments and related research have been useful in providing information on the working mechanisms (Nieboer *et al.*, 1977). Monitoring and historical research has sofar been limited.

In many descriptions of SO_2-effects only the average concentrations are given; information on variability is lacking as well as information on peak concentrations. In a comparison of epiphytic richness with SO_2-concentrations in The Netherlands, a close relation was found, especially between these peak concentrations and the number of lichen species (De Wit, 1976). At lower SO_2-concentration the correlation with the occurrence of lichens is weaker. Other factors are then increasingly important. At very high concentrations, where only few lichen species are found, the relation is most obvious. A fixed concentration over a defined period of time or occurring with a certain frequency over a defined period might be indicated as the limit for a certain species. Concentrations below this limit however may still affect the species. An example was found in *Parmelia sulcata* during the permanent plot observations: in certain areas, where the species is still abundant, growth is reduced to less than half of a maximum found elsewhere.

The fact that effects of concentrations that occurred three years earlier are still reflected in the distribution pattern of *Lecanora expallens* indicates, at least for this species, a low ability to recover. When air quality deteriorates, lichens probably react rather quickly. The choice of the parameter, however, determines to a great extent how well this can be observed. Changes in the rate of photosynthesis will give considerably faster results than parameters such as species composition and cover.

Possibilities to study changes in lichen vegetation over longer periods of time are limited by the availability of data from earlier times. Such data are rarely found in the desired quantity and format. Incidentally, possibilities arise e.g. through analysis of herbarium collections including accidentally collected species. An example is the work of Van Dobben (in press) on an area of appr. 20 × 20 km around 's-Hertogenbosch in The Netherlands. In 1971 only 46 species could be found of the 115 species, collected around 1900. In this study a shift was found in habitat preference: species formerly occurring on both acid and neutral bark now have a strong preference to neutral bark. The acidity of the bark in interaction with air pollution apparently influences the possibilities for survival.

Lichens depend upon stemflow water for their nutrient supply. Chemical composition of this water is governed by both air pollution and bark characteristics, such as acidity and buffer capacity (Grodzinska, 1977). Some other factors may however play a role here. In The Netherlands it was shown that some species are least sensitive on a substate considered optimal for that species, e.g. *Ulmus* for *Physcia tenella* or *Quercus* for *Evernia prunastri* (De Wit, 1976). It was also shown that species with a narrow ecological amplitude are generally more sensitive to air pollution than species with a wide amplitude (Van Dobben, in press). For species with a very wide amplitude, the distribution is only limited by SO_2. These are usually very common species, lacking only in areas with high pollution levels. More sensitive species have a less wide amplitude and their distribution is therefore limited by other factors as well as SO_2 (see Figure 4).

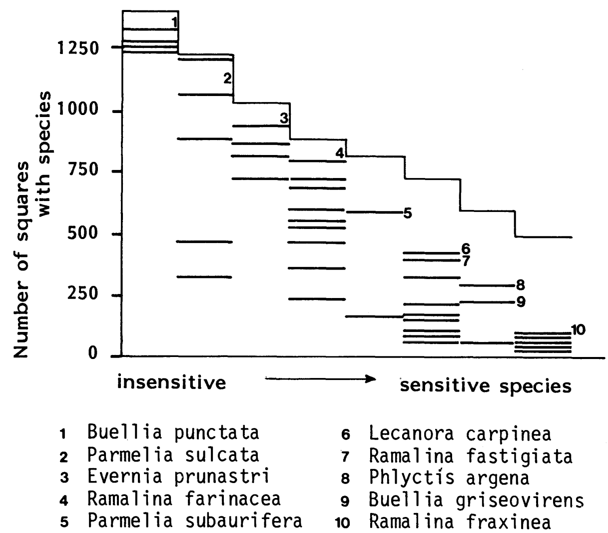

Fig. 4. Relation between theoretical and actual number of squares with some epiphytic species. The broken line gives the theoretical number of squares in which a species can be expected on the basis of its sensitivity; the short lines give the number of squares in with the species have actually been found.

Ideal indicator species are those for which the distribution is limited by only one factor, but in practice it will be impossible to find such species. Nearly-ideal indicators for air pollution are: *Buellia punctata*, *Parmelia sulcata*, *Evernia prunastri* and *Ramalina farinacea* (Figure 4).

It is usually assumed that lichens are much more sensitive to air pollution than other organisms, e.g. higher plants. However, the main reason for this might be that the disappearance of lichens is very obvious and cannot be easily ascribed to habitat destruction such as is the case with higher plants. In The Netherlands, an attempt was made to correlate changes in the distribution pattern of some phanerogamic species during this century with air pollution (Van Dam, 1983). For some species there proved to be a significant positive correlation between disappearance in 5 × 5 km grid squares and SO_2 level, even if habitat destruction was taken into account. This is the case with

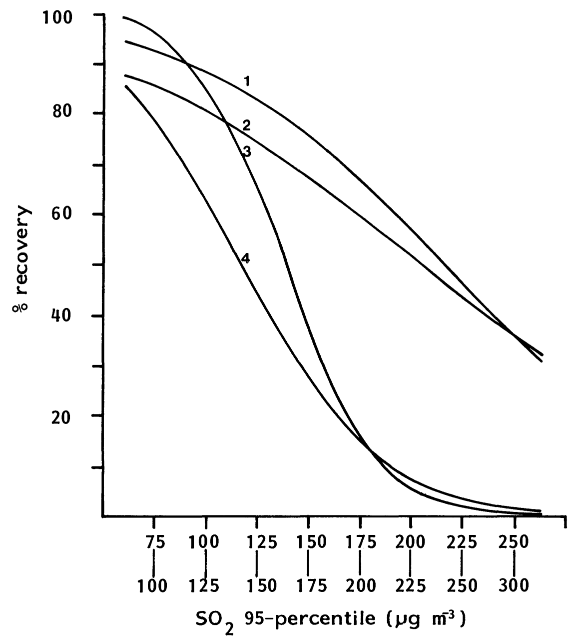

Fig. 5. Percentage of recovery in 5 × 5 km grid squares after 1950 for some higher plant species, plotted versus SO_2 95-percentile over the period April 1978 – March 1979. Values have been corrected for the effect of habitat destruction. 1 = *Nardus stricta*, 2 = *Viola canina*, 3 = *Arnica montana*, 4 = *Antennaria dioica*.

Arnica montana and *Viola canina* (Figure 5). Some other cryptogamic species also showed positive correlations, e.g. fruiting *Dicranum scoparium* and *Cantharellus cibarius*. Obviously causal relationships cannot be shown by this type of descriptive study. There are indications that acid rain plays a role, especially on dry, oligotrophic soil (Van Breemen *et al.*, 1982). The observations cannot be readily explained as direct effects of SO_2 or NO_x as ambient concentrations are usually below threshold levels for these effects (e.g., leaf necrosis, Posthumus 1983).

Very little is known about the effect of air pollution on animals. There are indications that for some insects and mites, lethal concentrations are in the same order of magnitude as those for lichens (André *et al.*, 1982).

7. Conclusions

It appears that lichens are sensitive to air pollution. Most detailed knowledge exists on the relation between epiphytic species and SO_2, such as the model given by De Wit (1976). However, there is not a single parameter which will give an accurate measure for air pollution; in nearly all cases, interactions with other factors such as habitat, climate, etc. were shown. It should be kept in mind that the observed effects must be considered as the sum of the effects of various pollutants and cannot be used as a measure for a single pollutant. Lichens therefore can never replace technical equipment for the measurement of air pollution. They should rather be used as an alarm signal indicating air pollution levels that can affect various organisms. In this respect, epiphytic lichens, for which the influence of other factors can easily be minimized, are most suitable (De Wit, 1976). A drawback might be that they do not lend themselves easily for experimental work.

The conclusions can be summarized as follows:

- for measurement of abiotic parameters, technical equipment should usually be preferred over indicator organisms;
- indicator organisms can give alarm signals indicating deterioration of ecosystems, which can be caused by changes in abiotic conditions;
- some effects of changes in abiotic conditions can be predicted if sufficient knowledge is available on the response of indicator organisms;
- restrictions applicable to indicators in general also apply to lichens, but epiphytic lichens as indicators for air quality have the advantage that their habitat may be regarded relatively well 'standardized', thus minimizing the effect of other factors.

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SOIL PROPERTIES INDICATIVE FOR QUALITY*

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1. Soil Types and Properties

Even within the small territory of The Netherlands, soil properties show a considerable diversity. A number of soil types, such as clay soil, peat soil, and sandy soil can be distinguished with several transitions and mixtures in between. All these soil types can be characterized by their physical and chemical properties. As such features as structure, particle size, pore volume, organic matter content, cation exchange capacity, pH and mineral content are used. Most of these features within each soil type may change with soil water table and land use.

With very few exceptions all our soils are man-made or at least highly influenced by human activities. This holds not only for the area in use in agriculture but also for the grounds around agricultural settlements and the more or less natural reserves. Yet we may enjoy what we have since the great variation in character of the soil is coupled with the same variation in vegetation and landscape.

2. Evaluation of Quality

It is self evident that the scenery of to-day is quite different from what it used to be in the past. Together with the development of human activities and requirements the natural environment has changed with concomittant changes in flora and fauna. But so far only one situation worthwhile to live in was replaced by another still worthwhile environment.

It is very likely that in the past people have regretted the loss of some familiar scenery since they did not get used to the new one at once. Yet development proceeded and will do so in the future. We may wonder why we are beating the alarm so violently to-day. Could it be that we have more time for nostalgic musing or do we see the consequences a bit better than our ancestors, or do we realize that the present situation is much more risky than ever before. Indeed, all kinds of information in professional papers as well as in the newspapers are urging people to get worried.

To demonstrate this we have to consider which changes in soil quality are occurring and where this can lead. Since the definition of soil quality is rather arbitrary, as it largely depends on the soil function we have in mind, within the framework of this

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symposium most attention will be paid to the soil as a substrate for organisms living in and upon it.

3. Processes in the Soil

Soils of high quality are characterized by intensive activities of micro-organisms like moulds and bacteria but also of a variegation of animals belonging to various systematic groups. They all have in common that they are dependent on organic matter fixed by green plant parts. Their primary requirements are supplied by plant roots and plant residues which are present in the soil, dead or alive. On the other hand an adequate supply is only guaranteed by continuing photosynthetic activities which in turn depend on the water and minerals absorbed from the soil by plant roots. Thus biological activity in the soil depends largely on organic matter supplied by the vegetation and vegetation prospers from biological activity. Both are strongly dependent on each other. The threat therefore comes from two sides:

- selective suppression or poisoning of the flora and fauna in the soil from which natural equilibria are disturbed,
- changes in the content of organic matter as a substrate for biological activity.

The first mentioned aspect is particularly sensitive for all kinds of soil contamination and will always have consequences for the second aspect. Disturbance of the ratio between breakdown and deposition of organic matter (low in natural peat soil and heath, high in litter of climax vegetation) means disturbance of natural equilibria. As a consequence of the increasing population and our present way of life, soil quality is under constant stress. The allied problems will be discussed in other papers in this special issue (heavy metals, Ernst; organic components, Eysackers). The important question is whether we have sufficient facts and insight at our disposal to make the soil protection regulations work in a satisfactory manner (Vonk). It seems very important for the future to know as to how far effects of contaminations are reversible.

4. Effects of Nutrients on Soil and Vegetation

The increased production in agriculture through the past hundred years is strongly correlated with the increased fertilizer use. Since the percentage absorbed by the harvested product does not depend much on the level of fertilization at higher rates more nutrients are accumulated in plant products left at the land. Part of it is washed out by the winter rains to surface waters and transported in the ground water.

Concomitant with higher fertilization rates in many areas, soil water tables have been lowered. This measure adds to the enhanced fertility level by an enhanced breakdown of organic matter (penetration of O_2 to deeper soil layers). The consequences of the increased fertility for the flora and fauna are reason for serious concern.

Eutrophication leads in higher plants to an increased above ground production relative to and often at the cost of below ground growth (Brouwer, 1968). Strong effects

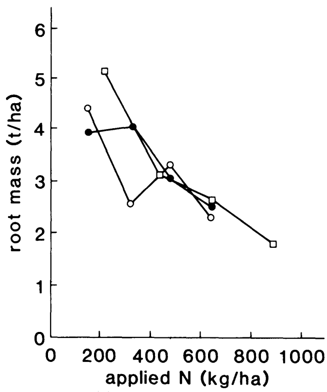

Fig. 1. Effect of N-fertilization rate on the amount of roots of perennial ryegrass at three clipping frequences (every 2, 4, or 6 weeks). Growth period March–October (Ennik, 1980).

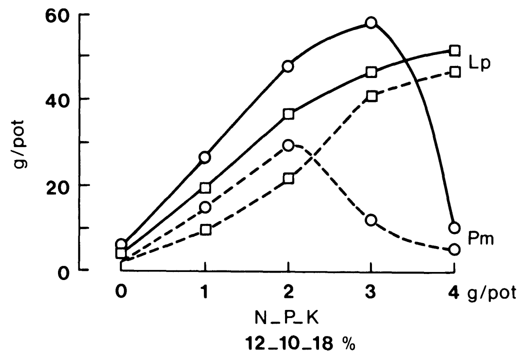

Fig. 2. Effect of N-supply on production of shoot fresh weight of *Plantago major* and *Lolium perenne* grown in monoculture (full drawn lines) or in mixture (dotted lines) (Brouwer, 1983).

have been observed (Figure 1). The plant residues get additionally a lower C/N-ratio and are broken down more easily which again favours leakage to other areas.

Although in principle all plant species respond favourably to an enhanced fertilization level, quantitatively considerable differences have been found (Rorison, 1968). As a consequence plants which are stimulated most and to the highest levels are gaining at the cost of less responsive species (Figure 2). As shown by research of Van den Bergh (1979) and Willems (1980) species diversity in grassland is gradually decreasing (Figure 3) concomitant with the increase in biomass production. These results fit in a more general picture that indicates that at a gradient of an environmental factor from unfavourable to favourable total biomass production per unit area increases and that species diversity passes through an optimum (Grime, 1979).

In the unfavourable range only few species are able to tolerate the adverse condition.

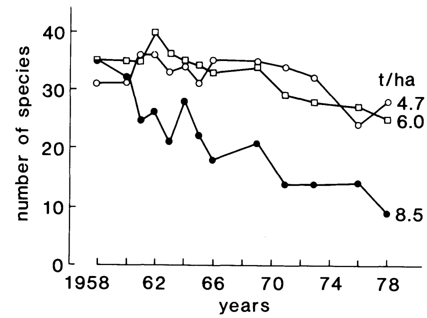

Fig. 3. Changes in species diversity resulting from differences in fertilization in hayland parcels at Wageningen (Van den Bergh, 1979) (no fertilizer; PK; NPK). Figures indicate dry matter production in tons per hectare per year, average of the last three years.

With decreasing stress more species complete their life cycle since each of them does not reach a size which would suppress one of the others. In the most favourable range species with a high relative growth rate are gaining the competition with the slowly growing species (Figure 4).

Although the effect of fertilization on species diversity seems to be, explained in this way, the yearly fluctuations observed (Van den Bergh, 1979) show that there are still large gaps in our insight which can only be filled by further research.

In the framework of this issue, however, the indication loss of species diversity in grassland upon contamination of the soil with nutrients is only part of the total effect of eutrophication. The enhanced biomass production urges the farmer to harvest more frequently and earlier in the spring. This in turn has important consequences for the chances that birds have to raise their chicks.

We conclude that even a relatively innocent change in one factor may have a great number of unexpected consequences, which may be reversible or not. Hence we are not exaggerating when we are asking for more research funds.

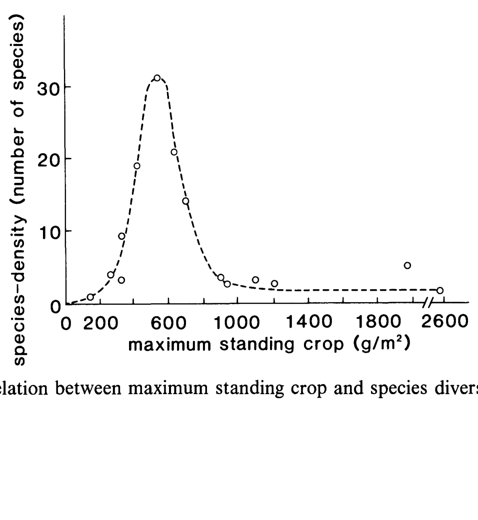

Fig. 4. The relation between maximum standing crop and species diversity (Grime, 1979).

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PROBLEMS IN CHARACTERIZING THE ECOLOGICAL QUALITY OF SOIL IN RELATION TO HUMAN ACTIVITIES*

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Abstract. The soil ecosystem is composed of various groups of organisms which have complex relations. The physical structure and chemical characteristics of the soil provide the boundary conditions. In view of various deteriorating human activities, it is important to find soil quality characteristics with respect to its most important function: the ecological function. An enumeration has been given of chemical, physical and biological soil parameters which are more or less important for soil quality. Several of these parameters are discussed. For use as indicators of deterioration, for a given site, the optimum values of the soil parameters have to be established, as well as acceptable deviations from the optimum, taking into account natural fluctuation. It is concluded that, due to lack of data, such an approach is not possible at this moment. However, it might be possible to identify those soil parameters which should be taken into consideration when evaluating human activities.

1. Introduction

Man has protected the soil for centuries already, but only for special functions, such as agriculture and drinking water production. Only recently a more broad, ecological concept of soil protection has arisen, whereas this concept for air and water protection had already firmly been established since some time. This may be explained by the following facts:

– The impact, soil especially of pollution, is initially of a local nature only. Its dispersion takes place much more slowly in the soil than in water or in air. Soil pollution therefore may be a rather sneaky phenomenon. After many years the pollution may demonstrate itself at quite unexpected and undesirable places, in surface waters, drinkingwaterresources or by upward seapage in upper soil layers.

– The soil as a medium is not transparent, literally as well as figuratively. Many processes in the soil cannot be observed. Soil structure is a complex thing and so are the processes occurring in it. Certainly our knowledge of ecological soil processes is anything but perfect. We know very little indeed about the consequences of soil affection and pollution caused by human activities to soil ecology.

Figure 1 shows the relations between various groups of organisms in the soil ecosystem and their relation to the abiotic environment. Physical structure and chemical characteristics are relatively more important boundary conditions to the functioning of the soil ecosystem than they are in the aquatic environment. Also there is a continuous influence by physical and chemical soil parameters on the soil ecosystem. In the present

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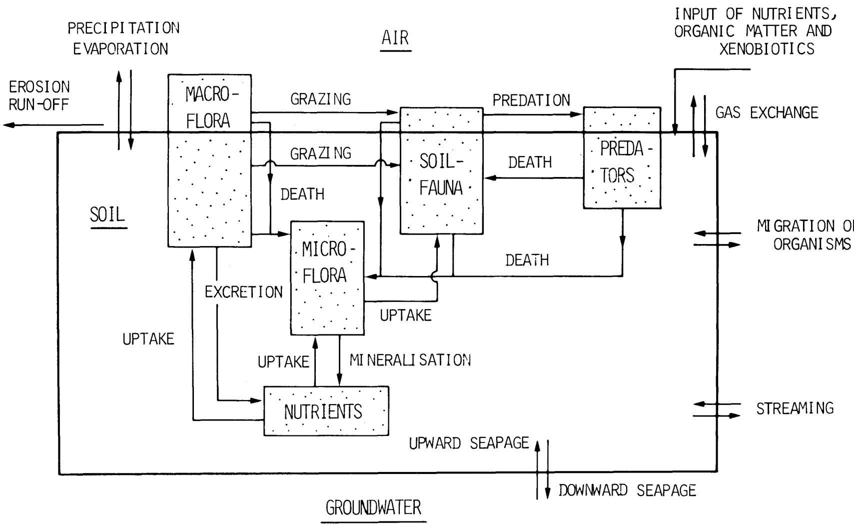

Fig. 1. Relations between the different organisms in the soil ecosystem.

contribution an attempt will be made to identify those soil characteristics which are important for describing the ecological quality.

2. Soil Quality and Soil Functions

Based on the Dutch Soil Protection Bill (in preparation) all kinds of activities in or on the soil will be submitted to restrictions.

According to the Explanatory Memorandum to the Bill this means as far as the soil is concerned: 'A total of measures for the prevention, restriction or undoing of detrimental effects to the soil quality as a result of human activities at the same time aimed at the preservation of the desired soil quality'. Thus the Bill centralises on soil quality. Now an important question arises: What determines soil quality, what are the criteria, in other words what are the quality characteristics. These questions cannot be separated from the different soil functions, since they all have their distinguished quality characteristics. The Explanatory Memorandum mentions the following functions:

- bearer function for human activities
- user functions for agriculture,
  supply of drinking- and industrial water,
  production of minerals
- aesthetical functions
- ecological functions.

These functions all have a different meaning. The ecological function is the only one not man-bound. The other ones are user-functions to man or reflect his appreciation for his surroundings, like the aesthetical function. The ecological function is the soil's most important basic function, both from man's point of view as well as nature and scenery are concerned. If we bear this in mind, it is very important to find soil quality characteristics for its ecological functioning.

3. Quality Characteristics

Soil quality both for the living as well as for the non-living part is determined by a great number of factors or features hereafter called 'soil parameters'. This implies an objective, quantitative description. We attach an ample significance to the expression 'soil parameter'. A soil parameter is a biological, physical or chemical soil factor or feature, either simple or complex, which is relevant for the description of the quality of the soil. Processes, activities and symptoms are included as well.

For some purposes certain soil parameters have already been used as characteristics for the quality of the soil. They judge the feasibility of the soil for a certain function, such as agriculture, architectural engineering, hydrological and civil-technical works.

In Tables I and II a review is given of chemical, physical and biological (ecological) soil parameters which are more or less important for characterizing the soil quality. For practical reasons the parameters of Table II have been classified into soil fauna, terrestrial vegetation and soil microflora, although of course these three groups are

TABLE I

Physical and chemical parameters of importance for the soil quality

Physical parameters	Chemical parameters
General	Organic matter
Distribution of particle sizes, soil type	Humus
Soil profile	Organic compounds with small molecules
Soil colour	Minerals
Bulk density	Calcium carbonate
Density of the solid phase	Oxides and hydroxides
Soil moisture economy	Clay minerals
Level of groundwater	Anions
Porosity	Cations (including heavy metals)
Moisture tension	pH
Hydraulic conductivity	Adsorption-desorption processes
Soil atmosphere, Gas diffusion	Precipitation-solution processes
Thermal conductivity and heat capacity	Redox potential
Mechanical soil density	
Groundwater	
Resistance of semi-permeable layers	
Hydraulic head	
Transmissibility	
Penetration depth	

TABLE II

Biological soil parameters of importance for the soil quality

Structural characteristics	Functional characteristics
1. Soil fauna	Dispersion of organic matter
Density	Formation of soil profile
Reproduction and growth	Bioturbation
Immigration and emigration	Homogenization
Predation	Litter fragmentation and humus formation
Diversity	
Aggregation	
Association	
Distribution of micro-, meso-, macro-fauna	
2. Terrestrial vegetation	
Subsoil parts, rooting, rhizosphere	
Biomass and production	
Rhizosphere activity	
Mycorrhiza	
Seed germination	
Superterrestrial parts	
Biomass and production	
Absorption and accumulation	
Description and analysis of vegetation	
3. Soil microflora	Degradation of xenobiotics
Composition of population	Cycles:
Biomass	Carbon cycle
	Sulphur cycle
	Nitrogen cycle
	Phosphate cycle

interrelated in many ecological processes. Within these groups structural characteristics and functional characteristics were separated from one another.

It should be noticed that on the earth the values of soil parameters may vary between wide boundaries. Nearly every single factor can run into extremity in natural occurring contrasting habitats, which are still well functioning ecological systems. It is therefore impossible to use limiting values of these factors for general ecological soil evaluation.

Instead of this it should be established what the optimum conditions with regard to soil parameters are for a chosen site, and how much a deviation from the optimum is tolerable. The problem is that many chemical/physical as well as biological soil parameters are subject to considerable natural fluctuations. For instance, for important ecological structure characteristics such as population size (density, reproduction and growth, *etc.*), as well as diversity, large fluctuations are considered normal.

Thus, the use of these indexes for measuring soil deterioration is limited. In addition there is an important lack of knowledge of the natural soil ecosystem as well as of the influence of human activities on these ecosystems. This holds also for the function indexes. In general these are easily accessible for measuring, though we lack a lot of knowledge also in this field. Recently considerable progress has been made in determining effects on the soil fauna, especially earthworms.

4. Important Physical and Chemical Soil Parameters

The soil parameters mentioned in Table I are often subject to change by human activities. Such changes mostly result in disturbances of the soil ecosystem. In this short outline there is no opportunity for extensive discussion of these soil parameters. Consequently, I will confine myself to the most important ones (Swift *et al.*, 1979).

4.1. Soil profile

Geogenesis (deposition of the original material) and pedogenesis (the alterations after deposition influenced by climate, vegetation and human activities) resulted in most countries into a stratification of the soil. Layers with different texture and composition interchange, resulting into a soil profile. Influence of human activity may disturb the soil profile, e.g. removal of upper layers, deepplowing and alteration of the groundwater level. The upper layers are of great importance with a view to supply and decomposition of organic matter.

4.2. Organic matter

Organic matter in the soil is partly found as not or partially decomposed remains of vegetable and animal matter. By humification processes this is partly converted into a more or less stable final product: the humus. In practice it is not possible to differentiate precisely between organic matter and humus.

The organic matter in the soil plays in important part in the various cycles, in particular in the carbon cycle. Input of organic matter takes place a.o. in the litter, originating from the conversion of vegetable and animal remains by soil fauna and by mechanical processes. Hereafter decomposition takes place by microbiological activities to low-molecular products on the one side and to stable humus on the other side.

4.3. Humus

From a chemical point of view humus is a hardly definable, heterogeneous polymeric compound. A hypothetical structure is given in Figure 2. The ion-exchange properties of humus are large; therefore this substance is of considerable importance for binding cations.

Changing the organic matter and humus content of soil may have serious detrimental effects on the soil ecosystem. The presence of organic matter not only contributes to the maintenance of an essential soil structure, but also functions as a buffer for pH fluctuations and as a supply for nutrients. The soil moisture economy is highly dependent on the presence of organic matter. This moisture economy is as important for the soil ecosystem as the forementioned factors are.

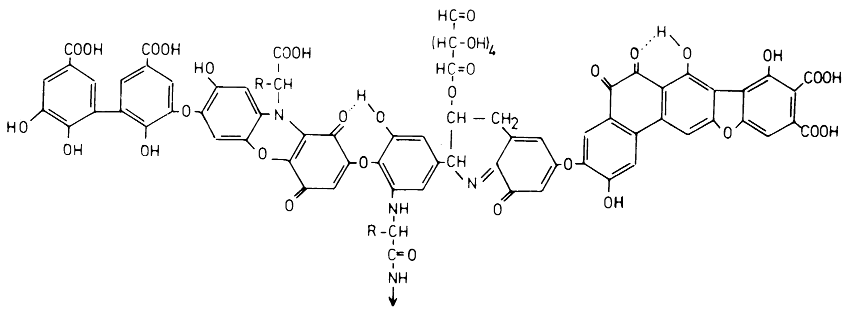

Fig. 2. Hypothetical structure of a humic acid molecule (after De Haan and Van Riemsdijk, 1978).

4.4. Soil temperature

Soil temperature is another important physical parameter from the ecological point of view. The temperature regulates the activity of most soil organisms, which are not able to regulate their own body temperature. Changing the soil temperature therefore may change the soil ecosystem.

Daily and annual temperature fluctuations occur in the upper soil layer. Human activities may disturb the natural fluctuations of the deep ground temperature. Examples are: construction of pipelines for conducting warm water, draining of cooling water into the subsoil, construction of heat emitting underground high voltage lines.

4.5. Soil pH

Soil pH should certainly be mentioned as one of the most important parameters, since many biological and chemical processes are influenced by the pH. Every organism shows an optimal activity within certain pH limits, so that a pH shift will result into a shift in population composition. In this way most bacteria may tolerate comparatively narrow pH limits in the neutral area, contrary to fungi showing a wide pH optimum, and which are generally more active at a lower pH.

The pH may be of importance as a determinating factor for distribution as well as for the activities of the meso- and macrofauna in the soil. In this way some species of the earthworm family Lumbricidae may be grouped according to the pH limits tolerated by them (Swift *et al.*, 1979).

Lowering the soil pH may result in certain cases in mobilisation of ions toxic to plants, e.g. Al^{3+}. This is the case when acid deposition occurs on acid soil with low buffering capacity.

5. Relation between Biotic and Abiotic Parts of the Soil

From the above it will be clear that physical, chemical and biological terrestrial parameters are closely related and tied together. In order to illustrate this I would like to consider briefly the effects and fate of toxic chemicals in the soil environment. The following aspects are of importance:

– In general the toxicity of a certain chemical may vary for different species of soil organisms. If a certain compound is toxic to a certain species, but less toxic to another, shifts in population and composition of the ecosystem will occur.

– The availability of the chemical, hence the concentration with which the organism may come into contact, plays an important role, in its toxicity as well as in the possible accumulation in the body of the bigger animals.

– The duration of the exposure is important. The latter two aspects are shown in Figure 3. The duration of exposure is determined by the rate of decomposition of the chemical. This again is influenced by the nature of the soil environment, type of soil, temperature, moisture content, oxygen, nutrients, *etc.* The available concentration depends on the dispersion in the soil and the distribution between the various soil components, including the organism in question.

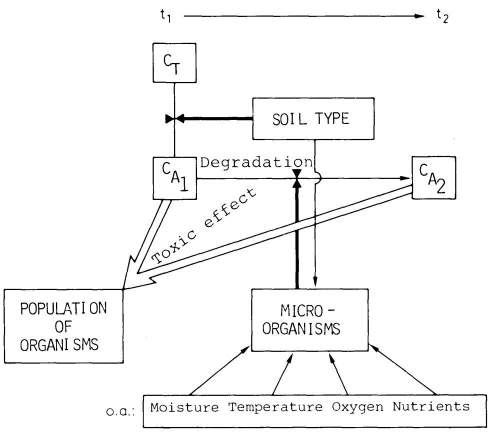

Fig. 3. Some factors determining the toxic effects of chemicals in the soil. t_1, t_2: time base; C_T: total concentration; C_A: available concentration.

Consequently we are facing an extremely complex system. Moreover, all kinds of parameters are changing regularly by natural stress situations so that it will be difficult to compare laboratory findings with a field situation.

6. The Use of Relevant Soil Parameters

In my opinion all the biological parameters mentioned in Table II are characteristics for soil quality and indicators for the influence of human activities, but yet their usefulness is still limited at present.

Of late some important microbial processes such as soil respiration, ammonification and nitrification are put forward as tools for judging the effects of pesticides on soil microorganisms. The use of soil enzymes for measuring the effects of toxic chemicals is still controversial (Greaves *et al.*, 1980).

On evaluating the above mentioned physical and chemical soil parameters (Table I) an important number of them appeared to be of interest for the functioning of the soil ecosystem, or for the behaviour of pollution in the soil. The question arises whether these can be used to evaluate potential harmful effects of human activities to soil.

The following types of human activities may be distinguished. They are taken from the Explanatory Memorandum of the Dutch Bill on Soil Protection.

- actions of depositing matter on or into the soil for permanent location
- actions of adding matter to the soil in order to influence its structure or quality
- works on or in the soil with mechanical interferences or applying matter that may pollute or affect the soil
- activities for the transport of chemicals or substances on or in the soil
- operations with the side effect of soil pollution or soil affection
- activities causing erosion, condensation or salination of the soil.

It will be clear that a certain activity does not have an influence on all soil parameters. It might be possible to indicate for activities belonging to each category which soil parameters are important for judging the effects of the activity in question. For instance, the use of herbicides, nematicides and soil fumigants is an activity which potentially jeopardizes the ecological soil quality, since these chemicals are intentionally used to kill certain soil organisms. Primarily, in this respect all biological quality characteristics are important. Moreover, the degradation of the chemicals is mainly dependent on the type of soil, humus contents, organic matter, pH, redox potential, moisture tension. Possible transport to and dispersion by groundwater is determined by groundwater level, adsorption/desorption processes and behaviour in deep groundwater. Thus, a number of soil parameters have been identified which should be taken into consideration when evaluating effects to the soil. A similar approach may be followed for other human activities.

Finally we would observe that the actual place of action is of considerable importance. To determine as quickly as possible the type of the local soil ecosystem, it may be useful to investigate whether it is possible to classify the ecosystem of the Dutch soil and to study the relation of the type of ecosystem with the characteristics of the physical and chemical environment.

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BIOINDICATION OF A SURPLUS OF HEAVY METALS IN TERRESTRIAL ECOSYSTEMS*

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Abstract. A survey of the methods of bioindication of heavy metals in terrestrial ecosystems and their effectiveness for predicting the consequences of environmental stress on organisms is presented. Two main inputs of heavy metals for terrestrial ecosystems have been considered: airborne and soil-borne.

Airborne metals can be monitored due to physical adsorption on plant surfaces or due to chemical exchange processes in cell walls. Active biomonitoring widely uses both aspects, however, without predictive values.

Meaningful bioindication of soilborne heavy metals can only be achieved by passive monitoring. Due to the different functions of heavy metals in organisms – micronutrients and trace elements – the knowledge of natural background values is important, considering the qualitative aspects of metals in the soil. In exceptional situations morphological and anatomical changes of plant organs will facilitate bioindication; in every case chemical analysis of the concentration of heavy metals is an essential part of the monitoring program.

A long-term exposure of organisms to heavy metals will influence the genetic structure of populations. Therefore measurement of heavy metal tolerance of plants has to be a standard procedure in monitoring programs.

1. Introduction

Bioindication of heavy metals has a more than two thousand years' old tradition, already used by Greek and Roman ore prospectors (Ernst, 1974). Nowadays the meaning of bioindication is mostly restricted to the indication of emission sources and pollution hazard (Steubing and Jäger, 1982). Input of heavy metals to the environment by human activities can occur via air, soil and water: local dustfall around smelter complexes (Ernst, 1972; Joosse and Van Vliet, 1981) and power stations (Folkeson, 1981), regional use of sewage sludge, copper-rich pig manure (de Haan, 1975; Lexmond *et al.*, 1982), metal based pesticides (Hirst *et al.*, 1961) and the global dissemination of heavy metals by traffic (Nriagu, 1978).

Heavy metals have different functions in biological systems: Fe, Mn, Cu, and Zn as micronutrients in all organisms, Mo, Ni, V, and Co in some groups of organisms. Besides some uncertainties for Cd and As, all other heavy metals occur as trace elements in every organism without any functional necessity.

Due to the different functions of heavy metals in biota it is not useful to discriminate between biomonitoring as a quantitative method and bioindication as a qualitative method (Posthumus and Tonneijck, 1982). The only realistic contrast is that of sensitive and resistant organisms.

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The aim of this contribution is to elaborate the evidence of effectiveness of biological indication of a surplus of heavy metals.

2. Material and Methods

For the aspect of biomonitoring atmospheric metal fallout, plant material has been collected and digested without washing. For monitoring of soil pollution by plants, fresh plant material has been washed twice with demineralized water, dried at 80 °C and digested with strong inorganic acids ($HNO_3/HClO_4$ 7:1). All analyses of heavy metals were carried out by atomic absorption spectrometry. The sampling localities and data as well as the number of analyzed samples are given in the relevant figures and tables. For measuring the metal tolerance of grasses the rooting technique has been applied in a modified form (Ernst, 1982a).

3. Results and Discussion

3.1. Background values of heavy metals in plants

Due to the different functions of heavy metals in organisms and to the different metal contents in various geological formations the natural background and/or threshold has to be considered in every bioindication. Plant species with a high metal demand, i.e. that

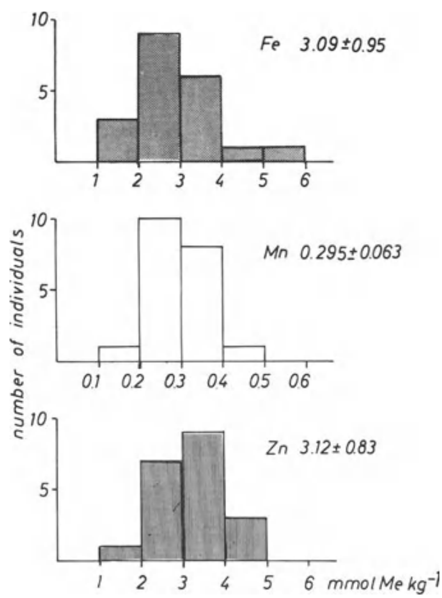

Fig. 1. The variation in the concentration of Fe, Mn, and Zn in the leaves of *Populus balsamifera L.*, growing on a sandy sea clay in North Holland. The leaves have been collected in October 1982.

of Zn by birch, willow and poplar will indicate less precisely a metal pollution (Denaeyer-De Smet, 1970) than those species with a low demand. Despite this drawback *Populus nigra* has been proposed for national monitoring programs of heavy metals (Knabe, 1982).

Due to the tremendous variation between individuals of one population (Figure 1), sampling of very small numbers of individuals will not give a realistic picture of the effects of pollutants on populations. There is also a time dependent effect. In the case of a smelter pollution the difference between a short (14 days) exposure of standardized *Lolium multiflorum* (MAGS, 1977) and a long-term exposure of wild plants has been quite obvious (Figure 2). It demonstrates the drawback of active biomonitoring of heavy metal pollution.

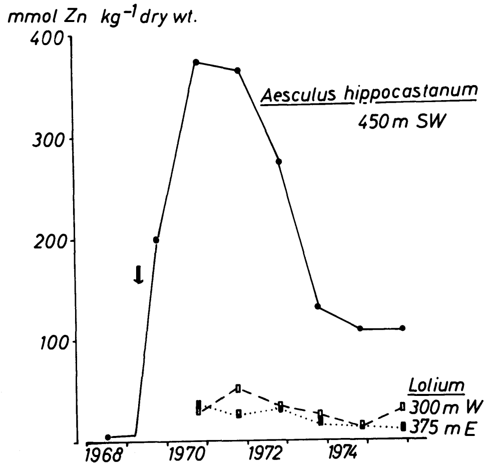

Fig. 2. Effects of Zn fallout from a Zn smelter on the Zn concentration of the leaves of *Aesculus hippocastanum L.* in the autumn of every year and Zn concentration of *Lolium multiflorum Lamk.*, as the mean of 14 days exposure during the vegetation period (after Ernst, 1980).

In monitoring soil-borne heavy metal pollution a further complication is the interaction of heavy metals with other nutrients and especially with the soil organic matter. The speciation of a heavy metal influences the uptake by plants and its translocation from root to shoot (Figure 3). Generally, heavy metals are less taken up if they are complexed in comparison to those in ionic status (Marquenie-van der Werff *et al.*, 1981).

3.2. Bioindication by Physical Processes at the Plant Surfaces

Wet and dry deposition of heavy metals via rain or dustfall, which can increase to 6.7 kg Zn, 4.5 kg Fe, and 0.4 kg Cu per ha per year in The Netherlands (CBS, 1981), can be fixed by plant organs with sufficient rough and/or hairy surfaces (Ernst, 1982b). The same holds for the bark of trees with a slow turnover rate (Ernst, 1983a). Bioindication by analysing the dry and wet deposition can help to detect emission sources but it will not allow a prediction of biological consequences of such pollution.

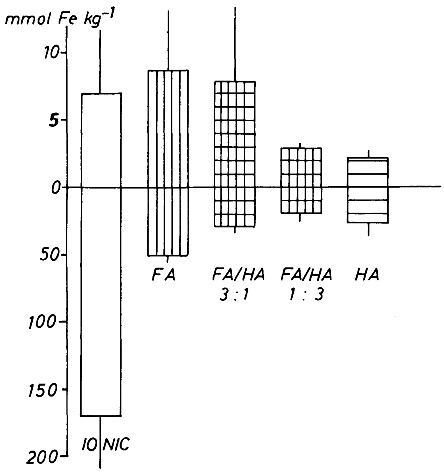

Fig. 3. The uptake and translocation of iron by *Holcus lanatus*. The Fe has been supplied in different chemical forms: ionic and complexed by humic and fulvic acids in various ratios (after I. Riphagen, unpubl.).

3.3. Bioindication by Chemical Exchange Processes in the Cell Wall

Often bryophytes and lichens have been used as bioindicators of heavy metals (Folkeson, 1981). Due to the high cation exchange capacity of the cryptogamic cell walls H^+-ions and other monovalent ions can be exchanged by heavy metal ions. Species specific affinities to heavy metals demands an interspecific calibration (Folkeson, 1979). Passive biomonitoring as well as active biomonitoring by exposition of *Sphagnum* bags (Goodman and Roberts, 1971) or *Hypogymnia physodes* transplants (Schönbeck, 1969) will help in localizing emission sources, but not in predicting biological effects. A replacement of these systems by the exposition of bags with ion exchange resins may be considered.

3.4. Bioindication by Physiological Processes on Short-Term

The first reaction of sessile organism to environmental stress will be a change in physiological processes in such a way that the metabolism tries to regain the physiological equilibrium. Changes in enzymatic activities can be used in connection with heavy metal analysis for biomonitoring, if many conditioning factors will appropriately be taken into account (Ernst, 1980).

If this compensating reaction to stress remains insufficient, then more serious changes in the physiology of an organism will facilitate biomonitoring. In such situations physiological changes can cause visual symptoms, such as chlorosis, necrosis, dwarfism and other teratogenic aspects. These symptoms alone, however, are not typical for heavy metal stress.

Generally, metal-stressed plants with chlorotic leaves have higher metal concentrations than those with green leaves, as demonstrated for *Agrostis tenuis* in various

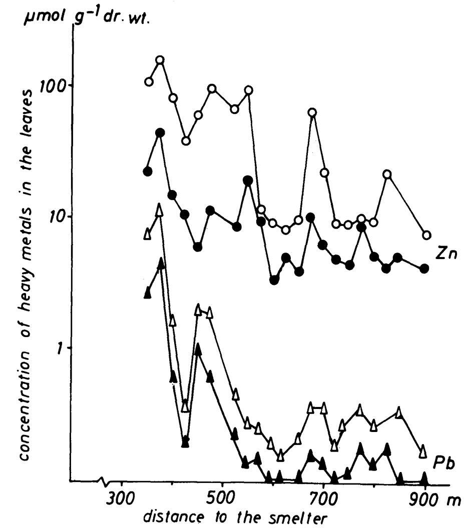

Fig. 4. The concentration of Zn and Pb in green (filled dots) and chlorotic (open dots) leaves of *Agrostis tenuis* Sibth in relation to the distance from a Zn smelter in Brabant/The Netherlands (after J. Faber, unpublished).

distances to a Zn smelter in The Netherlands (Figure 4). Owing to a disturbed photosynthesis a reduced production of propagules will affect the stability of the population and can contribute to changes in the vegetation pattern as long-term effect.

Necrosis can also indicate a surplus of heavy metals. As in the case of chlorosis, the concentrations of heavy metal(s) in the necrotic leaves is higher than in green ones (Table I). The long-term effects are the same as those mentioned for chlorosis. Even

TABLE I

Zn concentrations (mmol kg^{-1} dry weight) in leaves and roots of sugar beet, ***Beta vulgaris L. var. altissima Döll***, on fields which have partially been flooded in spring by heavy metal rich sediments from river Innerste at Langelsheim F.R.G. The heavy metals in the river bed are remnants of mining activities in the Hartz mountains during the last centuries (Ernst, 1974, Ernst, unpubl.)

	Green plants	Chlorotic plants
contaminated plants		
leaves	573 ± 58	1450 ± 72
roots	2290 ± 107	3050 ± 205
uncontaminated plants		
leaves	120 ± 17	–
roots	150 ± 12	–

without chlorosis and necrosis metabolic disturbances diminish growth. Dwarfism is a well-known reaction of plants to a lot of environmental stress such as SO_2, phosphorus deficiency, and also metal toxicity (Ernst, 1982b). Further evidence of diminished growth by metal stress has been demonstrated in the vicinity of a Zn smelter, where the needles of coniferous trees were not only small (Figure 5), but their length was asymmetrically distributed. This dwarfism was clearly related to increased amounts of Zn in the needles (Ernst, 1982b). Using physiological parameters, biomonitoring can make valuable predictions for risk assessment (Ernst and Joosse-van Damme, 1983).

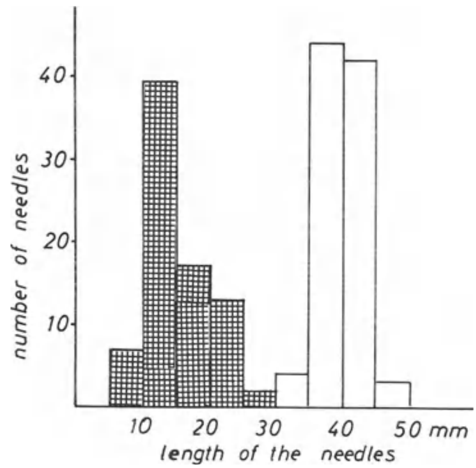

Fig. 5. The length of second year old needles of *Pinus sylvestris* L. from the vicinity of a Zn smelter in Brabant (The Netherlands) in comparison to needles of non-polluted pine trees. The open columns represent healthy needles, the cross-hatched columns needles from trees in the vicinity of a Zn smelter.

3.5. Bioindication via Physiological and Genetical Reaction on the Long-Term

The innate different sensitivity to high concentrations of heavy metals can vary within species and within populations. Due to the slow migration of heavy metals through the soil profile (Ernst *et al.*, 1974) a more or less constant or increasing emission rate gives rise to an accumulation of heavy metals in the topsoil.

On the long term a high metal stress causes genetic changes within populations. They are the most dramatic effects of environmental pollution (Bradshaw, 1976). However, only a small group of plant species is capable to evolve heavy metal tolerance. Important grassland species such as *Lolium perenne L.*, *Dactylis glomerata L.*, and *Trifolium repens L.* are very sensitive to a surplus of heavy metals, as already indicated by their absence on geological metal anomalies (Ernst, 1974). Plant species which are not promising for agricultural purposes such as *Agrostic species*, *Festuca ovina L.*, *Anthoxanthum odoratum L.* and *Deschampsia cespitosa (L.) P.B.* can evolve resistance against many heavy metals.

Genetic changes in the metal tolerance of grasses and sedges can be monitored by measuring the relative root growth in control and metal containing solutions, the so-called rooting technique (Wilkins, 1978 for a re-evaluation of the technique). Due to the pattern of aerial fallout around smelters bioindication with the aid of the rooting technique can demonstrate that in the immediate vicinity of the smelter the genetic changes are the most severe ones (Figure 6).

The rapidity of selection may be demonstrated in the vicinity of a Zn and Cd smelter in Northern Germany (Ernst, 1972, 1976). After coming into operation of the smelter in 1969, populations of *Agrostis tenuis* and *A. canina* (Figure 7) became within three

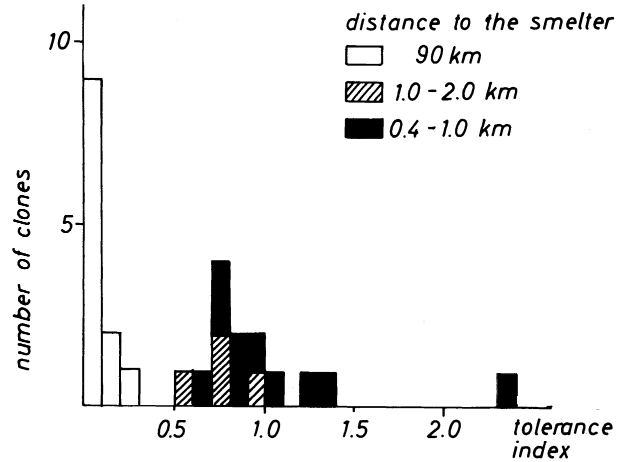

Fig. 6. The Zn tolerance index of the roots of *Agrostis tenuis* from clones in the vicinity (0–2 km) of a Zn smelter and from clones in a control area (90 km from the smelter).

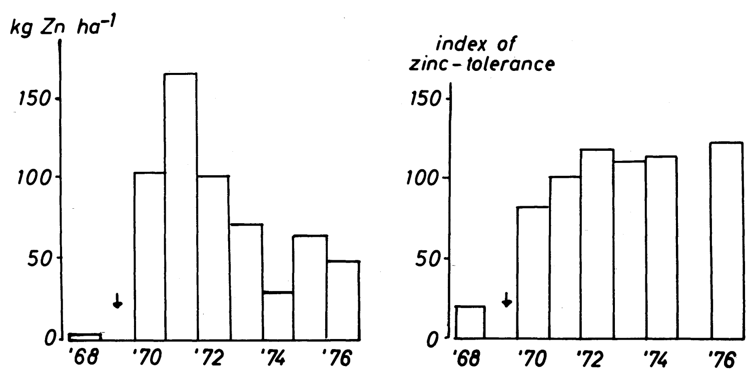

Fig. 7. The rapid evolution of Zn tolerance in *Agrostis canina* in 400 m distance from a Zn-Cd smelter in Datteln/FRG. The smelter started operation in 1969, first legislative restrictions of emission were given in 1972. For comparison the amounts of the fall-out is presented according to MAGS (1977).

years fully tolerant to Zn. The first year's emission was about 100 kg Zn ha^{-1}; governmental regulations had only resulted in a reduction of the emission to 50 kg Zn ha^{-1} (MAGS, 1977) so that the genetic changes will be present for a long time. Animals, which are less able to evolve metal tolerance (Ireland, 1975) will suffer extremely by metal toxicity, if they are consuming metal-tolerant plants in metal-contaminated areas. Due to the dangerous aspects of resistant plant populations to the non-resistant populations of cattle and other animals the modern biomonitoring system has to look at genetic changes in plants and animals.

4. Concluding Remarks

(1) Bioindication of a contamination by heavy metals is possible.

(2) Bioindication by analyzing the metal concentration on plant surfaces (wet and dry deposition) and in plants is only useful for localizing unknown emission sources.

(3) Bioindication with a predictive value has to be accompanied by analyzing heavy metal concentrations of plants and metal speciation in soil, because the chemical status of heavy metals severely influences their toxicity and their long-term effects.

(4) Bioindication has to regard the genetical changes in populations of plants and, as far as possible, those of animals.

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SOIL FAUNA AND SOIL MICROFLORA AS POSSIBLE INDICATORS OF SOIL POLLUTION*

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Abstract. Research on biological indicators of soil pollution is hampered by soil variability and temporal and spatial fluctuations of numbers of soil animals. These characters on the other hand promote a high biological diversity in the soil. A high diversity combined with persistent soil pollutants increases the chance to select good indicators. However research on these topics is still limited. Examples of specific indicators are the changed arthropod species patterns due to pesticide influence and the changed soil enzyme activity under the influence of specific heavy metals. Another approach is to look for organisms that give a general indication of soil pollution. In this respect the earthworm species *Allolobophora caliginosa* proved to be sensitive for different types of manure especially pig manure with copper, for sewage sludge, for municipal waste compost and for fly ash. A third way of indication is by organisms accumulating pollutants. For some heavy metals (Cd, Zn), earthworms are very efficient accumulators. More research is needed especially on the specific relation between biological responses and abiotic soil characteristics.

1. Introduction

In all discussion on soil pollution little attention has been paid to the biological effects of soil pollution (i.e. negative affection of soil quality) and to indicators of biological soil quality. Soil quality can be defined as the system of abiotic and biotic characteristics which secure the functioning of the soil ecosystem. These characteristics therefore must have certain minimum levels; above these levels soil quality will vary according to the succession phase and type of soil ecosystem.

Soil ecosystem functions are:

- breakdown of organic matter and mineralization to plant nutrients,
- creation and maintenance of a good soil structure,
- purification of groundwater.

Especially mineralization is essential for continuation of nutrient cycles. Therefore a deterioration of soil quality should have prime attention regardless the level of single soil quality parameters.

The soil is characterized by large local variations and usually slow and restricted temporal fluctuations of the abiotic conditions. These conditions promote the development of a diverse life in the soil. Populations of soil organisms show a large local variation too. This is related to the soil type (see Anderson, 1975; Ghilarov, 1977), main differences are summarized in Table I.

So far most research on biological effects of soil pollution has been carried out in field trials. More insight is needed in the undisturbed (background) situation. In The

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TABLE I

Sequence of humus types and related phenomena (Wallwork, 1970)

Bacteria increasing / Fungi decreasing →

pH acid → pH nearly neutral or slightly alkaline

Decreasing importance ↓	MOR →	MODER →	MULL-LIKE MODER →	MULL
	(a) Mites and Collembola	(a) Mites, Collembola and Insect larvae	(a) Myriapoda and Isopoda	(a) Annelida and Termites
	(b) Insect larvae and Myriapoda	(b) Myriapoda	(b) Insect larvae and Annelida	(b) Myriapoda and Insect laervae
	(c) Annelida	(c) Annelida and Isopoda	(c) Mites and Collembola	(c) Mites and Collembola
	(d) Isopoda			

Crumb-formation (Organo-mineral complexes) increasing →

Netherlands Edelman (1983) has made a start by measuring the levels of 30 chemical elements in the soils of 40 natural areas; extension to soil organisms and their uptake of chemical elements is in progress.

2. Soil Quality Indicators

Indicators can be defined as organisms which respond to an impact by their presence or absence, by a change of defined characteristics or activities, or by an increased content of a pollutant. Indicators are expected to be easy in handling, sensitive, fast and cheap, which resulted in large numbers of criteria (Luepke, 1979). In practice two types of indicators can be distinghuished:

- groups of indicator species with specific changes in species composition due to individual or a few clearly defined toxicants,
- individual indicator species which give a broad indication that soil quality is negatively affected requiring furter investigation by specially designed sampling programs or dose-effects studies.

It is important to verify the sensitivity or uniqueness of the response of an indicator. If a decrease in number of an indicator can be ascribed to another agent too, the indicative value will be limited. Moreover, indicators are primarily important because they reflect (negative) effects on basic biological systems or processes. Impairment of the indicators themselves is of secondary importance.

3. Shifts in Species Composition or Microbial Activities

A classical example of a shift in species composition by pesticides is the effect of DDT on decrease of predatory mites and resulting increase of springtails. Moreover certain species showed a specific reaction to the amount of occurring DDT; the absence or presence of *Tullbergia krausbaueri* (Börner), *Isotomina bipunctata* (Axelson) and *Isotomodes productus* (Axelson) coincided with large or small amounts of DDT (van de Bund, 1965).

These shifts are more pronounced at comparison of the groups at the species-level than at the level of ordo or super-family. Hoy (1980) showed that the influence of lindane is measured faster (a shorter interval after application), more sensitive (distinct effects with lower amounts of lindane) and more clearly (lower levels of significance) by comparing cryptostigmatid species than by comparing the summed numbers of all Cryptostigmata (ordo) (Table II).

TABLE II

Effect of lindane on Cryptostigmata expressed as percentage reduction in number (+ indicates percentage increase) at two spray treatment rates (after Hoy, 1980)

	$1.13\ g\ m^{-2}$			$11.3\ g\ m^{-2}$		
Days	45	141	381	45	141	381
Cryptostigmata	52	34	62	67	79	83
Aphelacarus acarinus	79	97	99	22	97	99
Eremaeus sp.	64	75	89	84	99	100
Eobrachythonius sp.	96	–	95	97	–	100
Eremaeus stiktos	58	–	51	91	–	94
Zachvatkinibates sp.	92	81	–	98	100	–
Epidamaeus sp.	+ 117	38	65	60	93	98
Autogneta sp.	56	54	52	38	87	98
Sphaerochtonius sp.	6	25	73	12	71	85
Opiella nova	+ 200	9	9	66	53	78
Scheloribates sp.	36	+ 108	+ 172	49	45	+ 160

Single underlining indicates $p < 0.05$.
Double underlining indicates $p < 0.01$.
Counted number transformed to log(N + 1).

Use of these higher taxonomic levels even can lead to misinterpretation of results as demonstrated by Edwards and Brown (1982). After yearly application of benomyl onto grassland earthworm populations showed a characteristic pattern of recovery (Figure 1). Further analysis however proved that the formerly dominant species *Lumbricus terrestris* Linnaeus had disappeared after the first application and had not recovered at all which was compensated for by increased numbers of *Lumbricus festivus* Savigny.

An example of the use of species patterns to indicate specific pesticide effects is given by Smith *et al.* (1980). From their data a selection is made so that the combined effects are specific for each pesticide (Table III).

A major dilemma in this approach is whether to select dominant species with an ubiquitous distribution, or sub-dominant species with a sparse distribution. From

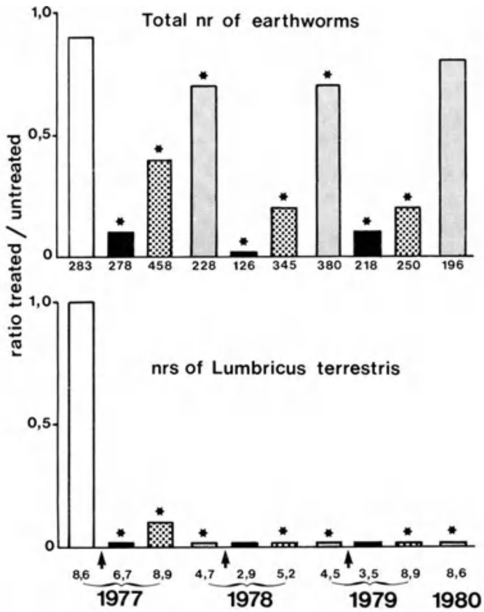

Fig. 1. Total number of earthworms (upper graph) and of *Lumbricus terrestris* (lower graph) 1 month (■), 6 months (▨), and 12 months (□) after annual application of 5 kg a i ha^{-1} benomyl for 3 yr (↑). Numbers expressed as ratio benomyl treated/untreated (□), on the abcissa the average control number m^{-2} (after Edwards and Brown, 1982).

TABLE III

Significant in- or decrease in number of arthropods after treatment with six pesticides (after Smith *et al.*, 1980)

	dia-zinon	fenitro-thion	mala-thion	methoxy-chlor	car-baryl	mexa-carbate
Astigmata						
Tyrophagus dimidiatus	–	+	+	+	–	0
Rhizoglyphus rotundatus	–	–	0	+	+	–
Prostigmata						
Tarsonemus randsi	+	+	0	0	+	+
Stigmaeus sphagneti	–	0	0	–	0	–
Nanorchestes collinus	0	0	–	0	+	+
Scutacarus lapponicus	+	+	0	–	0	+

– = Decreased numbers; + = Increased numbers; 0 = No change in numbers observed.

Zyromska-Rudzka (1977) and Freckman *et al.* (1980) it can be deduced that less abundant species or populations with a higher species diversity are more sensitive to adverse influences. On the other hand a common distribution enables a statistically justified sampling procedure.

As soil functioning is one of the main objectives of soil quality protection, it is worthwhile to study metabolic activities of soil biota as indicators. Doelman and Haanstra (1983) have investigated the effects of Cd, Cr, Cu, Pb, Ni, and Zn onto β-glucosidase, arylsulphatase, urease, phosphatase, and protease activity in five different soil types. These enzymes catalyze specific steps in respectively the carbon, sulfur, nitrogen, phosphate, and carbon cycle. For each soil type and each heavy metal different enzymes were sensitive as indicated by the ED 10 (Effective Dose for a 10% inhibition) (Table IV). In general arylsulphatase, urease, and phosphatase are the most sensitive. Besides, in sandy soils effects are more pronounced that in clay or peat soils, although specific abiotic characteristics like Mn- or Fe-content can interfere with these heavy metal effects too.

TABLE IV

Soil enzymes which showed the most sensitive reaction 1.5 yr after application of 6 heavy metals in 5 different soil types and the dose needed for 10% reduction of enzyme activity ED_{10} (after Doelman and Haanstra, 1983) (A = arylsulphatase, F = phosphatase, U = urease)

	humus-poor sandy soil		humus-rich silty-sand soil		humus-rich sandy-loam		heavy clay soil		sandy peat soil	
	enzyme	ED_{10}	enzyme	ED_{10}	enzyme	ED_{10}	enzyme	ED_{10}	enzyme	ED_{10}
Cadmium	A & U	4	U	0.5	A	7	U	2	–	
Chromium	A	4	A	1	A	85	U	270	–	
Copper	F	6	A	350	A & F	290 & 170	U	520	F	45
Nickel	A	1	A	330	A	2	U	10	–	
Lead	U	120	U	2400	A	1630	U	80	–	
Zinc	F	4	U	0.2	U	75	U	8	U	4

4. Earthworms (Especially *Allolobophora caliginosa*) as Indicators

Earthworms may be important as indicator because they:
- are a very important part of the soil fauna,
- influence significantly litter breakdown and soil structure,
- take up large amounts of litter or soil (because of their inefficient metabolism) and thus come into contact with large amounts of substances present in the soil,
- bury through the upper soil layers (20–100 cm) thus 'integrating' the toxic impact of these profile layers.

The significance of earthworms as indicators is investigated in our laboratory by Dr Wei-chun Ma, the author and a number of co-workers in field and laboratory experiments with different manures, fly ash and sewage sludge of which some examples are given next.

4.1. Effects of Manure

In general manure has a positive influence on earthworm numbers. Food additives (antibiotics, copper, etc.) however could give adverse effects. In a trial field, applicated

TABLE V

Relative distribution in percentages of the three most common earthworm species after manuring grassland plots for ca. 10 yr

Species	pig slurry ($ton\ ha^{-1}\ yr$)			poultry slurry ($ton\ ha^{-1}\ yr$)			calf slurry ($ton\ ha^{-1}\ yr$)		
	10	30	50	12	36	60	10	30	50
A. caliginosa	69%	75%	25%	53%	66%	39%	60%	74%	83%
A. rosea	22%	23%	54%	44%	24%	35%	37%	20%	10%
L. rubellus	9%	2%	21%	3%	10%	26%	3%	6%	7%

	poultry manure ($ton\ ha^{-1}\ yr$)			NPK ($kg\ N\ ha^{-1}\ yr$)			Nitro-chalk ($kg\ N\ ha^{-1}\ yr$)		
	10	30	50	0	200	400	0	100	400
A. caliginosa	63%	66%	79%	100%	72%	79%	71%	47%	60%
A. rosea	32%	17%	16%	0%	11%	15%	28%	35%	20%
L. rubellus	5%	17%	5%	0%	17%	6%	0%	18%	20%

for 10 yr with pig slurry, poultry slurry, calf slurry, poultry manure, NPK, and nitro-chalk earthworms were sampled (Table V).

Pig slurry coincided with an absolute decrease of *Allolobophora caliginosa* (Savigny). With poultry slurry we found a relative decrease of *A. caliginosa* due to an increase of *Allolobophora rosea* (Savigny) and *Lumbricus rubellus* Hoffmeister, whereas with calf slurry and poultry manure decrease in *A. rosea* was observed.

Further experimentation with pig slurry concerned the copper compounds especially toxic for earthworms, the most sensitive earthworm species for copper compounds and the occurrence of these phenomena observed in practice.

Laboratory experiments with pig slurry containing 94 ppm copper and a similar amount of $CuSO_4$, revealed that copper in slurry is far more toxic. In the slurry copper is conjugated with organic protein complexes which presumably are consumed by the earthworms.

In order to test the sensitivity of earthworm species juvenile specimens of *A. caliginosa* and *L. rubellus* showed no differences in a water-immersion test with $CuCl_2$. In a soil test with $CuCl_2$ six species (*A. caliginosa*, *Allolobophora chlorotica* (Savigny), *Allolobophora longa* (Ude), *Eisenia foetida* (Savigny), *L. rubellus* and *L. terrestris*) did not differ with respect to mortality, cocoon production, litter consumption, and change in weight.

To investigate effects in practice an inventory was set up in an area with a high density of pig fattening farms. Although it was not possible to sort out the effects of other management practices, in all cases *A. caliginosa* was the most sensitive species; it was almost absent in all fields where high amounts of pig slurry had been used (soil Cu-content $> 50\ mg\ kg^{-1}$).

4.2. Effects of Fly Ash and Sewage Sludge

In a fly ash deposit the natural colonization by soil animals and survival of inoculated earthworms was investigated. *A. caliginosa* was scarcely found and only in old fly ash (15–20 yr), whereas *L. rubellus* colonized better and survived well (Table VI). Recently deposited fly ash (1–4 yr ago) was first colonized by *Dendrobaena rubida* (Savigny) and next by *L. rubellus*. In more weathered fly ash (deposited 5–20 yr ago) also *Eiseniella tetraeda* (Savigny), *Lumbricus castaneus* Savigny and *Allolobophora chlorotica* were present.

TABLE VI

Percentage survival of earthworms (*A. caliginosa* and *L. rubellus*) 14 weeks after inoculation in a fly ash deposit with ash of different ages

age ash (yr)	1–2	3–4	4–5	15–18
pH	11.1	10.1	8.2	7.9
survival (%)				
A. caliginosa	0	5	10	5
L. rubellus	0	42.5	32.5	92.5

Sewage sludge that had been applied in amounts of 6, 12, or 18 tons $ha^{-1} yr^{-1}$ for 4 yr had a detrimental influence on earthworm populations. Moreover the number of *A. caliginosa* decreased in favour of *L. rubellus* (in control plots the ratio was 52 : 48% versus 27 : 73% in the plots with 18 tons $ha^{-1} yr^{-1}$ sewage sludge). Further analysis of heavy metal effects still has to be done.

5. Accumulation of Heavy Metals

Earthworms can also be used as indicators of the presence of heavy metals. For this purpose, they should accumulate heavy metals preferentially. In laboratory experiments Pb and Ni accumulated negligibly, Cu accumulated when the copper contents of the soil surpass a certain level above which the Cu-regulating mechanism of the worm seemed to become insufficient, whereas Cd and Zn accumulated strongly (Ma, 1982) (Fig. 2). With earthworms sampled in the vicinity of a former zinc smelter the accumulation or uptake rate of the earthworms, expressed as the bioconcentration factor CF, increased for Cd, Zn, and Pb with a decreasing pH of the soil. For Cd and Zn was $CF > 1$, indicating higher contents in the earthworms than in the soil. Moreover, the CF for Cd and Zn decreased with the amounts in the soil (Ma *et al.*, 1983).

A second series of samplings was carried out in trial fields with six soils (marine clay loam, sandy loam, riverine clay loam, peaty sand, reclaimed sandy podzol, plaggen soil) treated with municipal waste compost for 10 yr. Earthworms were sampled and analysed for Cu, Cd, Zn, Pb, Ni, and Cr content (Table VII). Significant negative correlations were found between CF and pH for Cd, Zn, and Pb, whereas for Ni it was

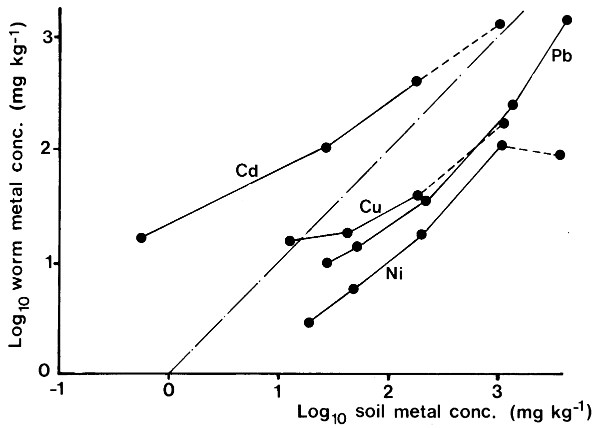

Fig. 2. Accumulation of various heavy metals in *Lumbricus rubellus* exposed to sandy loam soil after 12 weeks (——) or 6 weeks (- - -). The straight broken line indicates a hypothetical 1 : 1 relationship (Ma, 1982).

almost significant ($0.05 < p < 0.1$). All elements except Cr, had a negative correlation with CEC. Only Cu correlated negatively with organic matter content of the soil (Ma, 1982).

With these data it can be evaluated to what extent heavy metals are accumulated from the soil into earthworms and so transferred into terrestrial food chains. Moreover it could give some indication of heavy metal availability in relation to changes of the pH of the soil by acid rain.

TABLE VII

Correlation coefficients between the concentration factor of a metal and either cation exchange capacity (CEC), soil pH or soil organic matter content (Ma, 1982)

Metal	CEC	pH	Organic matter content
Cadmium	- 0.63 [b]	- 0.75 [c]	- 0.01
Chromium	- 0.30	0.15	- 0.01
Copper	- 0.72 [c]	- 0.27	- 0.58 [a]
Nickel	- 0.78 [c]	- 0.46 [a]	- 0.22
Lead	- 0.66 [b]	- 0.60 [b]	- 0.02
Zinc	- 0.70 [c]	- 0.68 [c]	- 0.23

[a] $p = 0.05$;
[b] $p = 0.01$;
[c] $p = 0.001$.

7. Discussion

The high invertebrate species diversity in soil provides the potentialities for a fruitful use of indicators, although much further research has to be done.

Because of the variable soil types, at least in The Netherlands, it wil not be possible to use indicators for the soil without further distinction. The different soil types themselves have to be characterized, or the effects have to be related to the abiotic characteristics of the different soil types (i.e. pH, CEC, organic matter content). Relating biological effects and abiotic soil characteristics would gain insight in the biologically active fraction of a given component.

For the research on indication s.s. it seems worthwhile to discriminate between specific indicators for one or a limited number of precisely characterized substances, and general indicators which just indicate that something is wrong. As specific indicators soil micro-arthropods and soil enzymes look promising. From our research on earthworms it can be concluded that *Allolobophora caliginosa* is negatively affected by pig slurry, sewage sludge, municipal waste compost and fly ash, all substances with heavy metals notably Cu. Therefore reduction in the number of *A. caliginosa* could possibly be used as an indicator of some polluting agents. However it is still uncertain whether this indicator value is exclusive for pollution and not related to natural stress factors too. Further research has to elucidate this obscurity.

When using the term indicator in a more general way also accumulation of pollutants may be included. Earthworms proved to be efficient accumulators of organochlorine compounds and specific heavy metals. Using earthworms in this way may surpass the problem of the interference of the total amounts of heavy metals present with the abiotic soil characteristics. The heavy metal contents of an earthworm give an indication of the biologically active fraction of the heavy metal and of the amount of heavy metal entering the food chain.

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GENERAL REMARKS WITH REGARD TO BIOLOGICAL INDICATORS USED IN WATER POLLUTION STUDIES*

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The quality of larger bodies of water such as lakes and rivers is of special importance. These aquatic biotopes differ greatly from the terrestrial ones. Accordingly, also the biological characteristics of the inhabitants differ from those of terrestrial organisms. The same holds for the functioning of plankton as compared to that of terrestrial communities. The pelagic zone is much more homogeneous than the mosaic of the various parts on land. Spatial differentiation to habitats is hardly possible in the aquatic environment. Consequently, the phytoplankton and also the zooplankton species have more or less similar needs and an extensive niche overlap may be expected. These properties seem to be the ideal setting for a classical experiment to demonstrate competitive exclusion. Since nothing of the kind occurs in nature, but, on the contrary, a reasonable number of algae and zooplankton species live together, Hutchinson (1961) felt justified to speak of the Paradox of the Plankton. The solution to this paradox is a set of abiotic factors always slightly varying with time in combination with specifically adapted species with a high potential to increase populations as soon as these factors have the right values. Of course, a stability of the kind observed on land is never equalled. This ever changing composition of the community renders these tiny organisms less suitable as living detectors for occasionally occurring pollutants. Their position at the beginning of the food chain and a high turnover rate render an accumulation of toxicants such as it is known for toppredators unlikely as well. At low concentrations of toxicants no lethal dose level will be reached in due time. This aspect of bio-indicators is dealt with in the paper of de Wolf (1983).

As a consequence of the spatial homogeneity of the pelagic environment this biotope may be characterized more easily as a whole by a macroscopic property than terrestrial ones. Accordingly, such macroscopic parameters of the system can be used to detect the presence of factors detrimental to the system. An example is the diel oxygen regime which is dealt with in the paper of Veeningen (1983).

Generally it may be said that water quality is poor everywhere in densely populated areas. For instance, water works companies complain of too high contents of salt and of substances affecting taste and smell, recreation is hampered by masses of blue green algae washed into the littoral zones and the decreasing number of plants and animals are a problem to be tackled by nature conservancy. It must be concluded that water quality does not have the same meaning to everyone concerned, but depends on the use

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that is made of the water. Therefore, it is advisable not to look for bio-indicators that can be applied in all cases.

As long as the use that is made of water is of economical importance, no difficulty is encountered in defining which quality is appropriate. For instance, if large sums of money have to be spent on the manufacturing of drinking water, the raw material is apparently of poor quality. The factors that make it so can be detected by chemical or biological means. However, if an aquatic ecosystem must be credited with an independent ecological value, difficulties are bound to arise. In such a case no well-defined human profit may be brought out to provide the criteria by which the system may be judged. These have to be found in the ecological properties of the ecosystem itself, its composition and functioning. Since the understanding of ecosystem functioning is still in its infancy, few ways are open to deal with this problem. It is hardly possible to imagine that single species may be used to characterize ecosystem functioning. One may think of macroscopic properties, for instance oxygen metabolism or species diversity. The number of these system parameters is not large and it is not always clear in what way they can be used. The contribution of biological processes to the oxygen regime (mean value, amplitude of oscillations, extreme values) can be small compared to physical and chemical influences. Since photosynthesis and metabolism do not differ much from one species to another qualitatively, the oxygen regime as such contains little ecologically relevant information. Consequently, its usefulness as an indicator of the ecological value of an ecosystem is questionable. Compared to the oxygen regime, species diversity has great ecological significance. However, the absolute value of a calculated diversity index tells us even less than the unmanageable species abundance list on which it is based. Such a value is only important in relation to the probability distribution to which it belongs. If, however, it is known in what way diversity index values calculated for a wide range of comparable ecosystems are distributed, a particular value has much to tell about the quality of the ecosystem it stands for. These diversity indices have to be hall-marked, which has never been done.

At the present moment our knowledge of ecosystem functioning is such that no simple, easily manageable parameters are available with which to compare the value of one ecosystem to another. It is still necessary that thorough research by well-trained ecologists should be done. Our knowledge about ecosystems as functioning entities has to be increased. This is fundamental research but it would be wise to ask with every new aspect that is worked out, how it may be used to meet the demands of ecosystem management. There is a tendency to prefer doing research in polluted waters. However, since many of the valued properties have been lost, a disturbed ecosystem can hardly be expected to reveal these properties. It would be the same thing as studying someone who is ill in order to gather knowledge about his normal functioning. Of course, this does not mean that hypertrophic aquatic ecosystems must be ignored. This unbalanced situation should be described as well but will only be fully valued in comparison with a situation more normal, that is oligotrophic to moderate eutrophic.

Several advantages may be attached to the use of bio-indicators. Such an indicator works like an accumulator of past effects of a deleterious factor. It is a dose-effect measuring unit rather than a concentration-effect measuring device. If different agents work synergistically, this effect can only be found by the use of biological indicators. Therefore, these indicators may be expected to be more sensitive than most easily applicable chemical analyses. On the other hand, the same properties render the biological indicator less specific. It is, therefore, not surprising that most efforts to calibrate a bio-indicator system to a set of different concentrations of a chemical factor are not successful. A simple causal relationship cannot be expected and this is in the nature of these indicators. Nevertheless, in some cases the presence of a particular chemical factor can very well be estimated. For instance, a long duration of low concentration stress of heavy metals may be detected if these metals accumulate in body fats, as is the case in mussels. Since small inputs of phosphorus are immediately absorbed by algae, no concentration increase in the water can be detected. However, the increase in biomass can be found rapidly.

More details about the possible use of various biological indicators in the aquatic environment will be discussed in this issue.

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THE DYNAMICS OF DISSOLVED OXYGEN CONCENTRATION FOR WATER QUALITY MONITORING AND ASSESSMENT IN POLDER DITCHES*

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Abstract. This study deals with the use of the dynamics of dissolved oxygen concentration for water quality assessment in polder ditches. The dynamics of the dissolved oxygen concentration, i.e. the temporal and spatial variations in a few polder ditches under a range of natural, pollution and management conditions is presented.

Five requisites formulated for the water quality indicator are discussed: (1) its relation with water quality goals, (2) nature and amount of information it provides, (3) if it could be standardized, (4) if it could be manipulated and (5) its measurability.

1. Introduction

Important requisites for adequate indicators for water quality assessment and monitoring are:

(1) relationship between the nature of the information provided by the indicator and the water quality goals connected with socio-economic and ecological functions of the surface water;

(2) provision of information to characterize the aquatic ecosystem under a range of natural circumstances;

(3) high sensitivity to the effects of both pollution and management control measures directed to maintain the aquatic ecosystem in a certain condition;

(4) that it can be controlled either directly or via other factors related to it;

(5) that it can be measured with relative ease in terms of technology, money, time and space.

For water quality indicators, structural and functional characteristics of the aquatic ecosystem can be used (Matthews *et al.*, 1982). A polder ditch served as the aquatic ecosystem, and the dynamics of dissolved oxygen (DO) was used as indicator. The above mentioned requisites were investigated in a research project financed by the Ministery of Housing, Physical Planning and Environment.

2. Description of the Study Site

In the Netherlands, ditches are the most common water type and therefore a characteristic element of the landscape. The ditches form networks of which the pattern and

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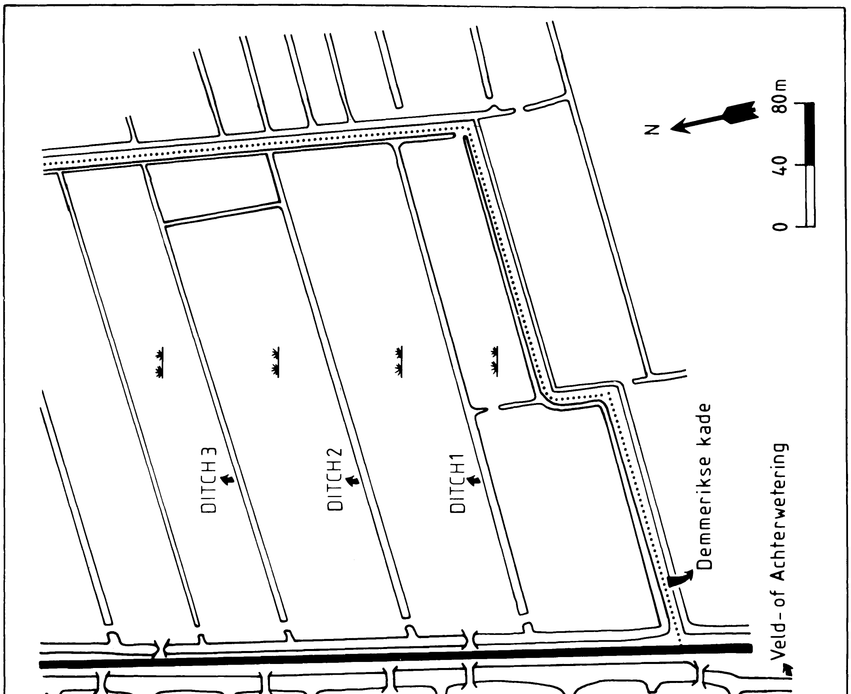

Fig. 1. The study site in The Netherlands (A), the topography of the direct surroundings (B) and of the study site itself (C).

hydrology differ regionally. The three ditches (Figure 1) and their surroundings were described in detail elsewhere (Veeningen, 1982). The main morphometric data are: length, 320 m; width, 4–7 m; and mean depth, 0.5 m (range, 0.3–0.7 m). To ensure a free discharge of water, the macrophytes and the top layers of the bottom sediments were removed periodically.

3. Methods

The dissolved oxygen (DO) concentration and temperature were measured *in situ* with an oxygenmeter (YSI model 57) equipped with a submersible stirrer. Concentrations were converted to % saturation following Mortimer (1981). The oxygen was measured *in situ* up to five times a day from sunrise to sunset (half way the water column) the measuring depth varied temporally and spatially from 0.15 to 0.35 m. In the thermal stratification study, the DO was measured just below the water surface and above the sediment.

4. Results

4.1. Annual variations

The diurnal and spatial variations of DO throughout the year show a distinct pattern (Figure 2A, B, C, D). The variations are small in winter when the DO saturation is around 100% (Figure 2A). In spring the diurnal variations increase and there is distinct spatial variation of DO longitudinally across the ditch (Figure 2B). The variations reach their annual maximum in summer (Figure 2C). The oxygen fluctuations are extreme at locations with filamentous algae at the west end of the ditch. In autumn the variations are smaller (Figure 2D).

4.2. Vertical gradients

Vertical variations of temperature and DO were observed when wind was absent and temperatures are high (Figure 2E, F, G). At most locations the diurnal variations at the bottom were less than those just below the water surface. There were, however, locations in all three ditches where the maximum at the bottom was equal or even higher than that in the top layer. There was a spatial variation along the length of the ditch, and there were distinct differences between the three ditches.

4.3. Ice cover

The ditches being shallow and the water temperature following closely the pattern of air temperature, ice cover is a normal phenomenon. Under ice cover with snow the DO decreased and no diurnal variation was observed (Figure 2H). When the ice was clear and snow absent, the western part of the ditch was continuously supersaturated, but the eastern part was undersaturated (Figure 2I). During the third period with a clear ice cover in February, the water was permanently supersaturated (Figure 2J). The spatial

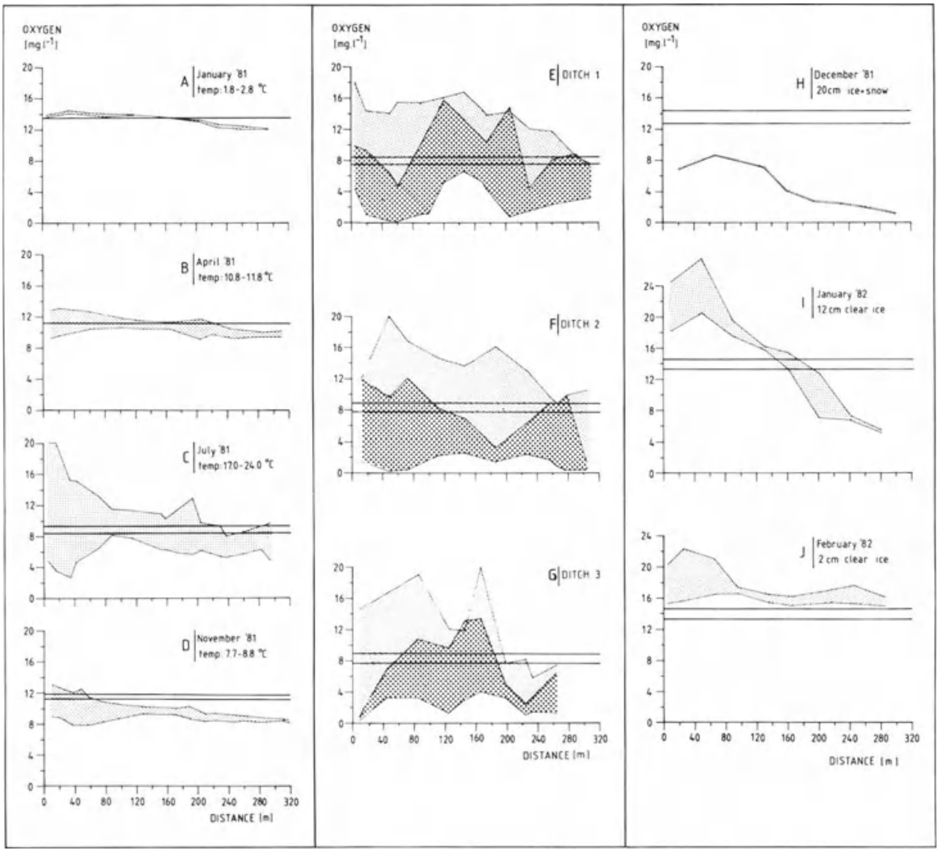

Fig. 2. The diurnal and spatial variations in DO concentration in ditch 1 in four different seasons in 1981 (A, B, C, D), in ditch 1, 2, and 3 during thermal stratification in summer 1982 (water temperature, 21–29 °C) (E, F, G) and in ditch 1 under ice cover during winter 1981–1982 (H, I, J). The lower line of the dotted area reflects the minimum DO concentration during the day, the upper line its maximum. Areas with two different dots indicate vertical gradients: the upper lines of the areas either with heavy or light dots give the maximum DO concentrations, respectively just above the sediment and just below the water surface during thermal stratification. (Vertical gradiënts were absent when the minima were reached). These lines connect the DO observations at about 15 locations along the ditch. The horizontal lines indicate the DO concentrations at 100% saturation at the minimum and maximum temperature at that time.

variation was far less than that found in January. In February there was a bloom of fytoplankton with a chlorophyll-a concentration of up to 200 $\mu g\, l^{-1}$, the normal value in the rest of the year being below 10 $\mu g\, l^{-1}$.

4.4. Pollution

In the second half of 1981 the hydrological regime in the polder changed drastically, leading to an increased phosphorous loading via the inlet water. The ortho-phosphate

(PO_4-P) concentrations increased from about 15 to 500 $\mu g\, l^{-1}$ at the inlet. In three successive summers (1980–1982) especially sharp increases in the diurnal variation were found (Figure 3A, B, C). In the same period (1980–1982) the area covered by filamentous algae increased sharply. However, the fytoplankton biomass did not change.

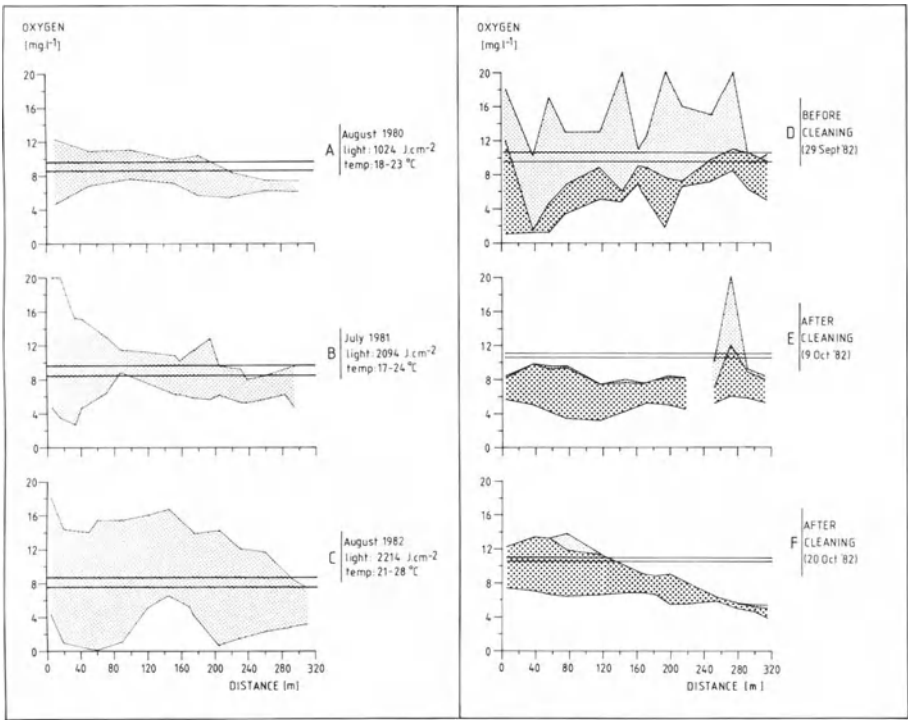

Fig. 3. The diurnal and spatial variations in DO concentration in ditch 1 in summer in three successive years (A, B, C) and just before (D), one day after cleaning upto 220 m (E) and twelve days after cleaning (F). The daily amount of light in the summer periods is indicated. See further in Figure 2.

4.5. Cleaning operation

As expected, the diurnal and spatial variation of DO dynamics was greatly influenced by the cleaning operation in the ditch (Figure 3D, E, F). Before cleaning there were enormous variations of DO, both vertically and horizontally (Figure 3D), but the following day especially, the spatial variation was smaller in the cleaned section (Figure 3E). The oxygen dynamics in the uncleaned section did not differ essentially from that of ten days earlier. This reduction in variation and maxima continued in the next twelve days (Figure 3F). The diurnal variation in the western section might be due to patches of filamentous algae left behind.

5. Discussion

5.1. Water quality goals

In the so-called Water Action Programme 1980–1984 (Ministry of Roads and Waterworks, 1981), the Government has recommended to base water quality management on the ecology of the aquatic ecosystems, and to derive the criteria and standards from the functioning of these systems. The dynamics of DO may be considered as an integral measure for the functioning of the whole aquatic ecosystem. In fact this characteristic enhances the value of DO as an indicator, as it is suggested in the ecological approach for management of water quality as outlined by the Government.

5.2. Ecological characterization

The second requisite is that the indicator provides adequate information about the aquatic ecosystem. The dynamics of DO is the functional aspect of the ecosystem that received most attention during the present study. The production and respiration processes cause a diurnal variation of DO concentration. The temporal variations of DO depend mainly on water temperature, light climate, biocoenosis, etc. Assuming that the factors determining the exchange of oxygen between the water-air interface except for the actual DO concentration itself, are the same along the entire length of the ditch, the temporal and spatial variation of DO reflect the activity of the biocoenosis in relation to both structural and functional aspects of the ditch ecosystem nuanced in space and time.

As the ditch was cleaned at the end of 1980, flora and fauna were limited in January 1981 to the free water and to benthic communities. Low fytoplankton concentration (7 μg chlorophyll-a l^{-1}), low levels of light intensity, daily irradiation and water temperature resulted in decreased metabolic activity and insignificant diurnal and spatial variations in DO.

In spring (March–April) growth of macrophytes and fytoplankton started; the chlorophyll-a levels of fytoplankton increased and ranged between 17 and 46 $\mu g\, l^{-1}$. This autotrophic growth resulted in a rise in the diurnal variation of DO. The macrovegetation occurred mainly in the western part of the ditch, whereas the eastern part was characterized by patches of germinating *Nymphaea alba* but more common complete absence of macrophytes. This spatial heterogeneity caused the variation of DO along the longitudinal axis.

In summer when the light and temperature were optimal, the macrophytes and filamentous algae attained their cover and biomass maxima, causing strong diurnal and spatial variations. The extreme variations at the western side (10–17 $mg\, l^{-1}$) were ascribed to the local dominance of filamentous algae over the whole vertical axis of the ditch. The DO concentration in most of the eastern section reflected the activity of the *Nympha* vegetation or the mere absence of macrophytes.

In autumn the macrophytes decayed gradually, leading to small diurnal and spatial variations of DO. In autumn a greater part of the ditch was continuously undersaturated, in contrast with the spring situation apparently caused by negative oxygen balance. The filamentous algae in the western part of the ditch, however, still photosynthesized causing pronounced, local diurnal variations.

The metabolic activity in the different compartments and its contribution to oxygen production and consumption were examined (Veeningen, 1982). The free water community consisting of phytoplankton and bacteria, contributed substantially only during the phytoplankton bloom in spring when net production and respiration ranged from 0.2 to 0.3 and 0.05 to 0.10 mg $O_2\,l^{-1}\,h^{-1}$, respectively, and the chlorophyll-a concentration was 80 $\mu g\,l^{-1}$. During the rest of the year the fytoplankton mass as expressed by chlorophyll-a was much lower, 10 $\mu g\,l^{-1}$. The oxygen consumption of the benthic community was regulated largely by water temperature. The regression relation between the so-called Sediment Oxygen Demand (SOD) and temperature (T) was $\ln \mathrm{SOD} = -0.99 + 0.04T$ ($r = 0.69$, $n = 35$; $P < 0.001$; SOD in g $O_2\,m^{-2}\,day^{-1}$, T in °C). The maximum net oxygen production by the benthic community, measured in the field using transparent bell jars, was 150 mg $O_2\,m^{-2}\,h^{-1}$. The maximum net production during the light period was 800 mg $O_2\,m^{-2}\,day^{-1}$. Oxygen evolution by the benthic community was not surprising as the amount of intact chlorophyll-a on areal basis of sediments was about 20–50 times that of the watercolumn. The highest production rates were measured on sunny days at very shallow locations (ca 0.3 m). The eastern end of ditch 1 was representative for locations where the DO dynamics are controlled by the benthic community. Oxygen evolution by the benthic community is always lower than the oxygen uptake, as the DO values indicated continuous undersaturation.

The vertical gradients of DO (Figure 2E, F, G) accentuated the spatial heterogeneity of the biocoenosis along this axis. Oxygen production in the upper water layers was mostly higher than in the bottom layers. However, at a few locations the production by the benthic community exceeded the production by the community above. The extremely high values were ascribed to mats of filamentous algae on the sediment surface and the slightly lower ones to the so-called 'bare' sediment. Usually the thermal gradient disappeared at night due to mixing. It is, therefore, difficult to quantify separately the dark respiration in the upper layers and the sediments.

As the changes in water temperature in the ditch follow closely those in air temperature, an ice-cover is readily formed after short spells of freezing. The DO dynamics during the three periods of ice-cover in the winter 1981-1982 differed. Snow covering the ice strongly reduced the light transmission, resulting in low DO values along the length of the ditch. This as well as low water temperature caused low metabolic activity, reducing the diurnal variations. Comparison of the DO dynamics in the western part under a clear ice cover, as present in January 1982, with those in November 1981 (Figure 2D and I), revealed that in January supersaturation by filamentous algae occurred. The eastern part, however, did exhibit a diurnal DO variation, although it was continuously undersaturated just as in November 1981. In February 1982, when a thin ice layer covered the ditches, the DO dynamics changed completely over the whole length of the ditch. Fytoplankton bloom caused DO concentrations to reach ca 25 mg $O_2\,l^{-1}$ but spatial variations were small.

In the preceding paragraph we showed that the temporal and spatial variations in DO were directly related to changes in the metabolic activity of the organisms under a range of natural circumstances. The information provided by the DO dynamics was obscured by the exchange of oxygen with the atmosphere to a certain extent but accentuated by thermal stratification and ice cover.

5.3. Pollution and management

The indicator should reflect the effect of pollution and of control measures aimed to improve or maintain a certain water quality. If this condition is met, the DO dynamics may be used for establishing water quality classes.

Increased loading of inorganic nutrients in the ditch was assumed to be typical of pollution in polder areas. In the present case the phosphorus concentration increased substantially due to changes in hydrology within the area. The latter caused changes in the pattern of water movement and in the source of the inlet water during water shortage (May to November). The impact of the increase in nutrients becomes clear by comparing the DO dynamics in three successive years. The spatial variation increased slightly from 1980 to 1981, but it reduced from 1981 to 1982, when the change in hydrology had occurred. The diurnal variation increased from 1980 to 1982, and the section with large variations expanded. The DO dynamics was related to considerable changes in biomass. The area with extreme diurnal variations was dominated by filamentous algae. Changes in the DO dynamics could not be due to changes in fytoplankton mass, as this remained the same during the successive years.

Cleaning is a normal management procedure to prevent clogging of the ditches and consequent obstruction of water flow. The DO dynamics is likely to change significantly after cleaning. This applied particularly to the spatial variations which were much reduced and the extremely low minimum DO concentrations disappeared.

5.4. Controlling the DO dynamics

The indicator must be either controllable or related to another controllable factor. Steerability of the indicator is an important prerequisite to employ it in water management. The DO dynamics was investigated and tested as a possible indicator for water quality assessment (Figure 4). The DO dynamics in a ditch can be manipulated by artificial aeration or by stirring. Only the factors which contribute the most to the DO variations must be taken into consideration for the purpose of DO control. In this respect the macrophytic community is important; both biomass and species composition, but also temperature and light, both of which can be controlled hardly in the field, determine the activity of the community. The nutrient supply which also affects these vegetation characteristics is, however, more or less governable in the ditch system. The water quality in these ditches may be restored by manipulations in the hydrology, either by changes in the source of inlet water or by lowering the nutrient concentration of the inlet water.

A manipulation of the indicator variable was attempted in a few polder ditches. The success with which it can be achieved depends upon supplementary information on

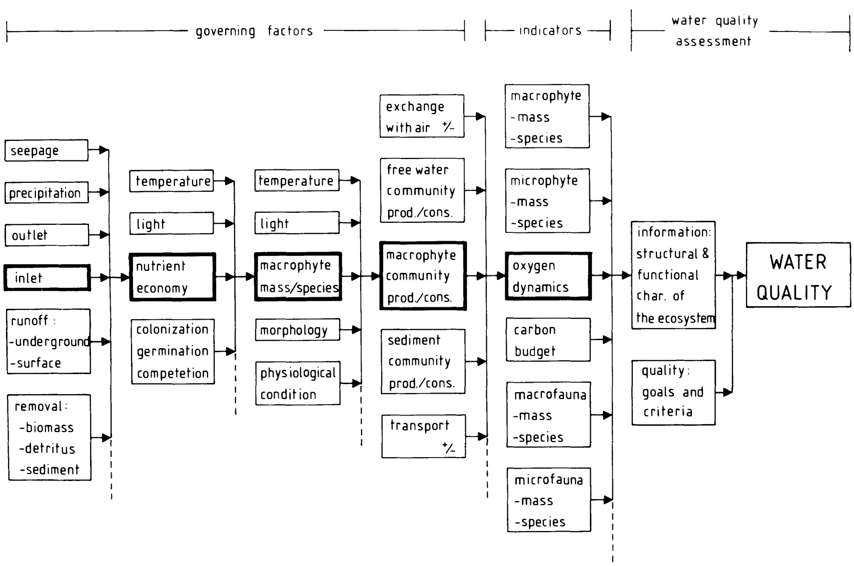

Fig. 4. An outline of the factors affecting the DO dynamics as indicator for the assessment of the water quality. For explanation see text.

other environmental factors. That the dynamics of DO as an indicator is governable (Figure 4) is not generally valid. It needs to be tested for each water type or body. Also care needs to be taken that the management measures are not in conflict with other water quality goals and criteria.

5.5. Measurability

An important requisite for the indicator concerns practical aspects, namely, measurability in terms of technology, money, time and space. The results suggest that water quality assessment and monitoring in ditches by means of DO dynamics require intensive field studies. Technology for continuous monitoring, storage and data processing, if available, will minimize the present restraints (Kersting, 1983). Although the costs of this technology will decrease in the near future, the financial aspect will always be one of the decisive factors in selecting indicators for water quality.

Guidelines for the intensity of the monitoring programme are the objectives for application of the data generated. Continuous registration of DO during 24 hours once a month may provide insight into the diurnal variations of DO and the causal factors, namely the biocoenosis and climatic factors like light and temperature. It is far more difficult to discern a general tendency in the spatial variation of DO than in its temporal variation. This is caused by the strong spatial heterogeneity of the biocoenosis within a ditch and even more so between different ditches. A few monitoring sites in a certain area, e.g. one in each ditch, give information limited to the location concerned which is not adequate to assess the water quality in a whole area; the DO dynamics is a better measure for water quality in a limited area with a distinct water quality gradient.

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HYDROPSYCHIDAE AS BIO-INDICATORS*

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Abstract. The applicability of single species as bio-indicators for the characterization of running waters is investigated. For this, species of the family of Hydropsychidae (Trichoptera) are chosen. Ten species have been recorded for the Dutch fauna, but some of them have disappeared and others are restricted in their distribution nowadays. Several authors have established a distribution pattern of Hydropsychidae according to a zonation from source to large river. In The Netherlands we could use this scheme only in small, fast running streams. For the characterization of lowland streams more data on the fauna are required. In the large rivers only one species is occurring (*Hydropsyche contubernalis*), increasing in numbers during the last decade. Probably a certain improvement of the water quality of the river Rhine is responsible for this.

1. Introduction

The presence or absence of organisms is related to biotic and abiotic factors. The repeatability of these relationships can be used for making water typologies and water quality assessments. Organisms and biocommunities function in this way as bio-indicators. Combinations of species are indicatory for the different types of running waters in The Netherlands. Moreover, human activities have their impact on streams, causing changes in the original circumstances. Under the new conditions alterations in the composition of the biocommunity are observed, and here again organisms can act as bio-indicators of the new situation or maybe even of the alterations.

Most waterbodies in The Netherlands are rich in nutrients, not very acid and the streams seldom have high current velocities. For this reason, many invertebrate species can be found in waters of different character; so a large number of water types cannot be characterized with only one or even a few species. The more deviating from this 'average' the environmental conditions are, the better are the possibilities to find more characteristic species with a higher indicatory value. In the present paper the applicability of single species as bio-indicators is investigated. For this, species of the family Hydropsychidae, and especially of the genus *Hydropsyche* are chosen.

2. The Genus Hydropsyche

Caddis fly larvae of the family Hydropsychidae are found in all types of running waters and sometimes in lakes. Former investigations have shown that representatives of the

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family generally occur in restricted parts of the stream system. A stream can be divided in stretches from source to mouth by characteristic species and their combinations (Badcock, 1976; Edington and Hildrew, 1973; Gordon and Wallace, 1975; Verneaux and Faessel, 1976). A similar zonation, based on the genus *Rhyacophila* (Marinković-Gospodnetić, 1966) could not be applied because of the restricted distribution in The Netherlands of only three species. Ten species of the family Hydropsychidae have been reported for The Netherlands, so we decided to investigate a possible zonation in our country (bio-indicators for water types) and the significance of possible deviations from this zonation as reactions to changed conditions (bio-indicators for changes in the environment).

In order to answer these questions, it is necessary to know the distribution of the ten Dutch species under relatively undisturbed conditions (the past); then to compare this distribution with the actual one, and finally to find relations between the probable discrepancies in the distribution patterns and changes in the environment. In doing this, one should be prepared to meet obstacles of various kinds. First of all few data are known from those glorious days when streams and large rivers were unpolluted, not regulated or affected in one way or another. Next there are taxonomic problems. Larvae and a number of adults as well can only be identified since the mid seventies. In some cases sufficient knowledge on a certain stream before and after radical changes is available, but this seldom provides a causal explanation for the disappearance of a species. The only conclusion is that differences exist and with a thorough autecological knowledge and study of comparable situations one can try to find relations that justify the use of organisms as bio-indicators.

Cheumatopsyche lepida (Pictet 1834) is found in the middle and lower stretches of large rivers over 40 m of width and with a stony bottom (Badcock, 1976; Hildrew and Morgan, 1974; Dowling *et al.*, 1981; Tobias and Tobias, 1981). According to Nielsen (1976) the species can occur in polluted rivers. It is found in all surrounding countries. These data give an indication of the habitat as can be found in certain stretches of the river Meuse. There are not more than four reports from The Netherlands, all from the nineteenth century. Three of these concern the southernmost part of The Netherlands (river Meuse), one is from Arnhem (centre-east), probably along the river Rhine. The author (Albarda, 1889) states, that the species is common along the borders of the large rivers. The larvae must have been numerous in riffles and artificial breakwaters. As no later reports are known, the disappearance of this species could be a result from the construction of weirs causing periodic falls in current velocity, accompanied by low oxygen contents and silt sedimentation. Silt cloggs up the fine meshes of the nets constructed by the larvae of Hydropsychidae.

Three more species of Hydropsychidae belong to the large river fauna, of which two have disappeared from our country (*H. exocellata* Dufour 1841 and *H. ornatula* McLachlan 1878). The identifications of this material are to be checked, because the older keys are not sufficient. *H. contuberbalis* McLachlan 1865 shows a very interesting distribution. The larvae are to be found on firm substrates in the middle and lower reaches of large rivers. It is the only species of the family found in high numbers in the rivers Meuse and Rhine. However, it has been absent in the river Rhine for some decades in The Netherlands as well as in the lower reaches in Germany. In 1976 the first specimens were captured in Nordrhein-Westfalen and in 1978 the first ones were found in the river IJssel (a branch of the river Rhine) (van Urk, 1981). In subsequent years the numbers rapidly increased. In the same period a change in the chemical composition of the water occurred resulting in better oxygen conditions, lower values for BOD, lower concentrations for ammonia-nitrogen, oil components, cadmium, mercury and chromium; nitrate-nitrogen concentration increased (RIZA, 1982). It is evident that the organic load diminished and so did some of the heavy metals. Less organic load surely means less silt, but it is not possible to conclude whether this, or the better oxygen conditions, the decrease in ammonia, heavy metals or a combination of some of these factors has made the environment suitable again for *H. contubernalis*. The least we can say is that the reappearance and flourishment of the species form a significant bio-indication for a certain improvement of the water quality in the river Rhine.

The remaining six Dutch species of the genus *Hydropsyche* are found in small and larger streams. Four of these only occur in the southern part of the country which is hilly and rich in limestone. *H. fulvipes* Curtis 1834 and *H. saxonica* McLachlan 1884 are restricted to small, fast running mountain streams of the first order (Badcock, 1976; Hildrew and Morgan, 1974; Tobias and Tobias, 1981; Verneaux and Faessel, 1976; Wiberg-Larsen, 1980). Sometimes these species occur together, but their life cycles differ greatly (Marinković-Gospodnetić, 1961). We found *H. saxonica* in a number of tributaries of the river Geul, sometimes as the only *Hydropsyche* species, sometimes with *H. instabilis* and once with *H. fulvipes*. It has been found once outside southern Limburg in a fast running part of a small stream in eastern Gelderland (pers. comm. J. van Tol), but is met with regularly in larger streams as well (Geul a.o.). *H. fulvipes* has more precise requirements for its environment than *H. saxonica* but both species are said to occur only in non-polluted, small streams.

H. instabilis Curtis 1834 belongs to the fauna of fast running mountain streams as well but it occurs also in larger streams (Badcock, 1976; Hildrew and Morgan, 1974; Verneaux and Faessel, 1976). We found this species in the streams Gulp and Geul and some of their tributaries. It is a southern species, that reaches its northernmost distribution of the European mainland in southern Limburg.

H. siltalai Döhler 1963 was recognized as species only 20 yr ago. In most European countries it appears to be very common in larger streams and small rivers with fast running water, predominantly in hilly regions (Badcock, 1976; Edington, 1968; Hildrew and Morgan, 1974; Malicky, 1981). The species is rather tolerant for organic pollution (Tobias and Tobias, 1981; Verneaux, 1974). Recent localities are small rivers and some of their tributaries in southern Limburg. Old records, attributed to *H. instabilis*, show a somewhat wider distribution. The distribution of the last four species is in accordance with data from literature. A rough indication of the type of stream can certainly be given with the help of these species. Before looking in detail to the zonation in the streams we shall deal with the two remaining Dutch species.

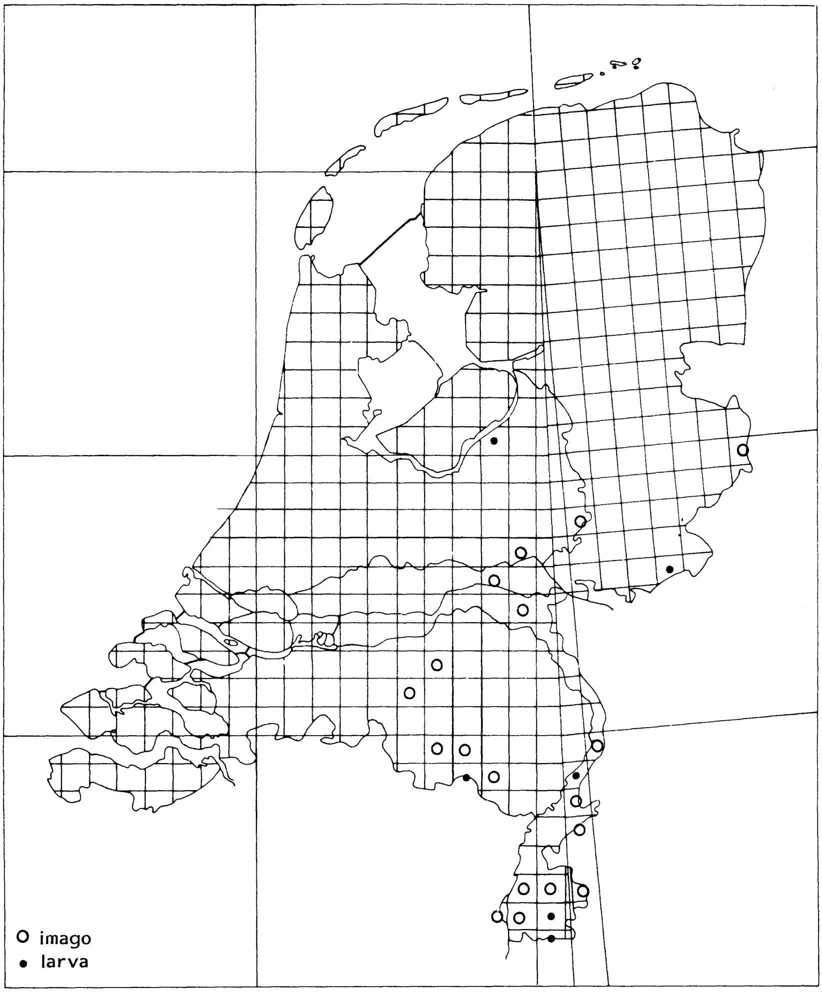


Fig. 1. The distribution of *Hydropsyche pellucidula* in The Netherlands.

H. pellucidula Curtis 1834 is found in large rivers and small streams as well. It often occurs together with *H. siltalai*, but it goes further downstream and can tolerate slower current (Badcock, 1976; Boon, 1979; Hildrew and Morgan, 1974; Malicky, 1981; Philipson, 1957; Wiberg-Larsen, 1980). In Poland it is the commonest species in mountain and hill streams, but it is also found in lowland streams (Szczesny, 1974). Sometimes high numbers are found in places with organic pollution (Verneaux, 1974). Based on these data it should be a common species in The Netherlands; however the number of localities is restricted (Figure 1), probably due to a too low current velocity in most running waters. We shall consider this matter later.

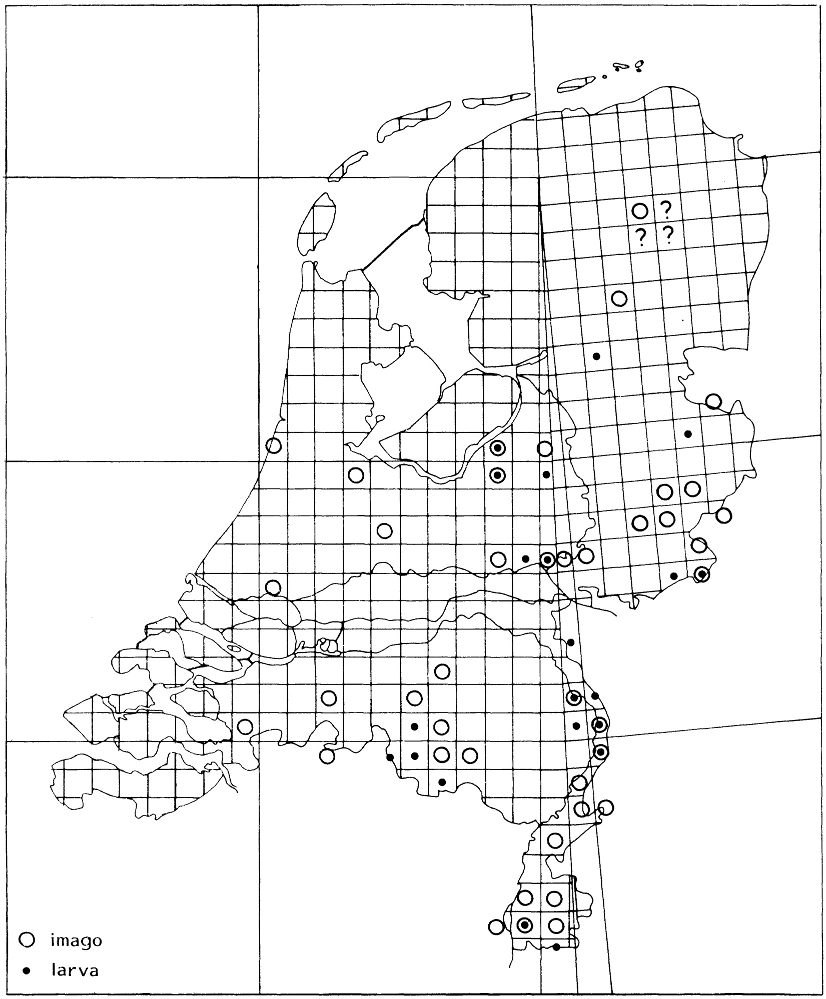


Fig. 2. The distribution of *Hydropsyche angustipennis* in The Netherlands.

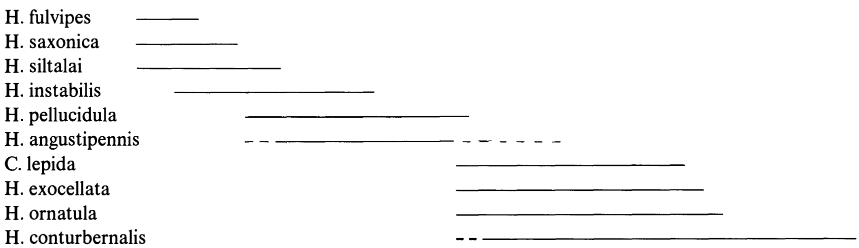
H. angustipennis Curtis 1834 is the most common species in The Netherlands (Figure 2). Most authors point to the occurrence in small and larger streams with higher temperatures and to the resistance against pollution and low oxygen values (Ambühl, 1959; Badcock, 1976; Hildrew and Morgan, 1974; Szczesny, 1974; Verneaux and Faessel, 1976; Wiberg-Larsen, 1980). It is the only species that is found regularly in stagnant waters, although in this habitat water movement caused by stream inlets and stony shores is preferred (Wichard and Unkelbach, 1974). It is a typical species of lowland streams and small lowland rivers, that is accompanied sometimes by *H. pellucidula* and *H. siltalai* (Badcock, 1976; Statzner, 1979; Szczesny, 1974). With this habitat description the bio-indicatory value is rather limited; streams, small rivers and the surf margin of lakes. Just as with the previous species there is a better indication for changes in the natural environment.

3. The Zonation

From the preceding remarks it can be concluded that the Dutch *Hydropsyche* species can be arranged according to the distribution in streams. The range extends from small, fast flowing mountain streams via larger, fast running streams and small rivers to the large rivers Meuse and Rhine. In most European countries the range starts with a Hydropsychidae species, not yet mentioned, *Diplectrona felix*. As this species does not occur in The Netherlands, we can construct the range as depicted in Table I.

TABLE I

Range of Hydropsychidae species from small streams to large rivers, according to literature



The upper three species are restricted to southern Limburg since especially there small, fast running mountain streams are present. The other species may have a wider distribution. Firstly the possible range in southern Limburg was investigated and we choose for this the discharge area and stream system of the river Geul. The river Geul and its important tributary the small river Gulp cross the Belgian border as small hill rivers or hill streams. We have restricted our investigation to the Dutch part and to the small tributaries on Dutch territory because of the current sampling programme and the pollution in most of the Belgian streams. In the following we indicate the stream order as described in Hynes (1970) in which a first order stream has no tributaries, a second order stream is formed by the confluence of two first order streams and so on. In Table I the range goes from first order to higher orders. In streams of the first order the dominant species is *H. saxonica* (our own observations, confirmed by Wolters, 1980). Once *H. fulvipes* was found to be the accompanying species, more frequently *H. instabilis* and sometimes *H. angustipennis*. In second order streams *H. saxonica* predominates, covering 70 to 80% of total numbers accompanied by *H. pellucidula*, *H. instabilis* and *H. angustipennis*. In Figure 3 the relative distribution of these species in the small river Gulp is depicted. It is remarkable that *H. instabilis* increases in numbers with regard to *H. pellucidula* in downstream direction. This is not in agreement with the data of Table I.

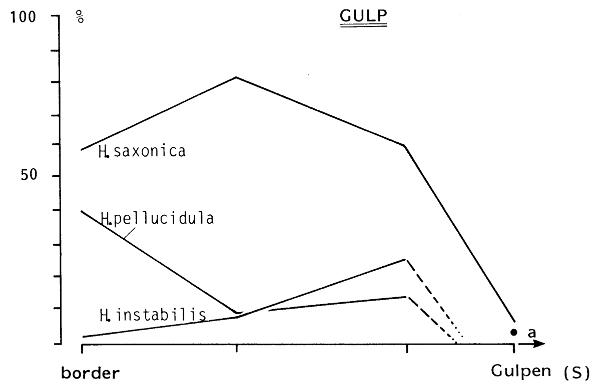


Fig. 3. The distribution of *Hydropsyche* species in the small river Gulp. At the town of Gulpen only a few specimens were found, so here no percentual distribution has been applied. At the other stations hundreds of specimens have been collected. (a) = *Hydropsyche angustipennis*; (S) = sampling stations.

The river Gulp is a second/third order stream with only a few *Hydropsyche* specimens downstream because of the heavy pollution from the town of Gulpen.

In the river Geul (third/fourth order) we find a more complicated situation with six *Hydropsyche* species (Figure 4). Some of these show a beautiful distribution pattern, but others do not occur conform to the expected pattern. *H. saxonica* and *H. instabilis* for example are found downstream of *H. siltalai* and *H. pellucidula* where the contrary is expected. Starting with sampling station 5 *H. angustipennis* is dominant, however near the town of Valkenburg (10) some more demanding species suddenly reappear. The presence of a few specimens of *H. contubernalis* at station 8 also does not conform to expectations. There seem to be some important factors that prevent the distribution in

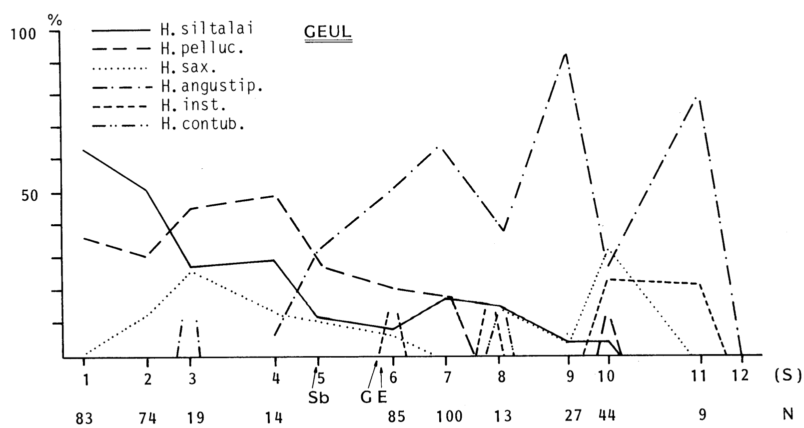


Fig. 4. The distribution of *Hydropsyche* species in the river Geul from the Belgian border (1) to the town of Meerssen (12). (S) = sampling stations; (N) = number of specimens; (Sb, G, E) = important tributaries.

accordance to the zonation. One of these must doubtlessly be water pollution. At the stations 5 and 6 three important and heavily polluted tributaries enter the stream and more downstream there are more sources of pollution. Obviously *H. angustipennis* is the only species prospering under such conditions, although downstream from station 11 even this species cannot survive. Probably it is impossible to attribute a bio-indicatory value in the sense of zonation to the species in a small river like the river Geul that is influenced by man to a large extent. Unfortunately there are too few available data, especially from the original situation in the past, for testing the theoretically constructed zonation. Although relations can be found between the occurrence of *H. saxonica* and *H. instabilis* and the environmental conditions at station 10 (if many more observations are known), an investigation of all macro invertebrates gives more indication and the autecological data of the *Hydropsyche* species only give complementary information.

4. Hydropsyche in Lowland Streams

Most streams in The Netherlands are lowland streams, where only two species can be expected. *H. angustipennis* is the commoner of the two and it is always found in those plases where *H. pellucidula* also occurs. Both species have a good indicatory value as will be shown with two examples.

In a certain stream, the Tongelreep, a well developed population of *H. pellucidula* occurs at stations with a high current speed over stones (80–100 cm s^{-1}). The depth and width of the stream are similar to the middle stretches in the river Geul (stations 3–6). Here also *H. angustipennis* is present in much lower numbers (rate 3 : 1). In a tributary only *H. angustipennis* occurs and at the place of confluence 80% *H. angustipennis* goes with 20% *H. pellucidula*. A hundred metres downstream a 50/50 distribution is found. The stations where *H. pellucidula* predominates are characterized by the presence of high current speed over stones. *H. angustipennis* can tolerate lower current velocities and takes tree branches and other hard substrates for granted. The temperature in the tributary is higher in summer, which is a disadvantage to *H. pellucidula*.

In another stream (Hierden stream) where both species occur, *H. pellucidula* is restricted to a few short stretches, where the current velocity is higher than elsewhere in the stream and the bottom is composed of gravel, stones or cemented boulders of an artificial cascade. *H. angustipennis* is occurring everywhere in the stream on hard substrates. A characteristic of the finding places of *H. pellucidula* is a high minimum current speed. In most of our lowland streams the current speed in summer is too low. In this special stream, both species are threatened by abundant mud transports and periodic pollution by liquid manure of fattening farms (Higler and Repko, 1981).

The tolerance for organic pollution is rather high, especially in *H. angustipennis*. Still both species are disappearing from most of the Dutch lowland streams. The most important causes are changes in the hydrological regime leading to a decrease (temporary or permanent) in the current velocity, lower oxygen concentrations and sedimentation of fine mud particles. A decline in the oxygen concentration occurs particularly concomitant with pollution, forming indirectly a side cause. Pollution with toxic substances and canalization lead directly to the disappearance of *Hydropsyche* species.

In lowland streams *Hydropsyche* species can certainly be used as bio-indicators, but a remaining problem is the necessity of a thorough knowledge of the potential distribution in the country. It is useless to expect *H. saxonica* in the northern provinces, since the streams concerned were never suitable for this species. Therefore criteria must be used for a classification of streams, which are independent from recent changes in water quality and hydrological regime.

5. Classification of Running Waters

Classification of running waters with characteristic biocenoses must take the climatological and geomorphological possibilities into account. A hierarchical system can be constructed in a region for watershed areas, and within these for the separate streams (Figure 5). A certain stream can be considered a suitable environment for aquatic fauna based on measurable variables. If there is sufficient knowledge about the ecology of the organisms considered, one can indicate the impossibility for the establishment of species in this way. This is an important factor in considering typical running water species, because in lowland streams they often cannot fulfill certain minimum requirements. Most *Hydropsyche* species have to deal with such difficulties. Changes in the hydrology or water chemistry can be processed in the scheme of Figure 5. In this way a comparison can be made between the former and the recent situation using the same kind of parameters.

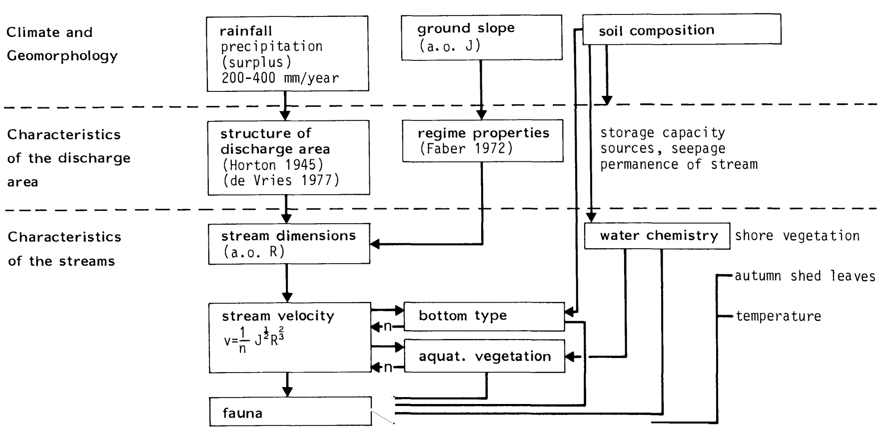


Fig. 5. Scheme of factors controlling the conditions for the aquatic fauna in running waters. (J) = measure for the slope of a stream (effectively that of the water surface); (R) = hydraulic radius; (n) = measure of the roughness (in streams from 0.025 to 0.050); (v) = mean velocity.

6. Conclusion

In the introduction the concept of bio-indicator as a living measure for a situation was defined. The possibility was questioned to use the species of the genus *Hydropsyche* as bio-indicators in the first instance for the natural conditions of the Dutch streams, and in the second instance for changes in natural conditions. The natural conditions were analysed with the help of the scheme of Figure 5. It was demonstrated that the single species usually cannot be used for a clear characterization of stream types. Exceptions are the small, fast running mountain streams in southern Limburg and perhaps roughly the lowland streams. Since there are well-defined differences between lowland streams, they have to be classified in several types. In these cases the use of single species is not allowed, but combinations of species from different groups can be used. Changes in the stream conditions, like hydrological regime and chemical composition of the water, can only be indicated if the natural conditions are known. This means that the species can be used as bio-indicator in small, fast running streams and for a rough indication in lowland streams. Here the use of the biocommunity is a better tool as well and *Hydropsyche* species can serve as part of the communities.

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ZOOPLANKTON AND ITS GRAZING AS INDICATORS OF TROPHIC STATUS IN DUTCH LAKES*

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Abstract. The existing data on the species composition of zooplankton and grazing intensities of crustacean plankton are discussed in the light of trophic status, particularly in the Dutch lakes of varying trophy. Several species of rotifers in northern Europe and North America are considered to indicate eutrophic environments. However, unanimity is less regarding crustacean zooplankton, since several species are encountered in lakes varying widely in trophic degree.

The zooplankton to seston (33 μm) biomass ratio may provide information about the ecological transfer efficiency and trophic status. In the Dutch lakes the ratio decreases sharply with increase in food concentration during eutrophication, namely from ca 0.4 in oligotrophic lakes to about 0.05 in the hypertrophic ones.

The zooplankton community grazing is high and variable in lakes of low trophy but low and relatively constant in lakes of high trophy. The fluctuations in the filtering rates of *Daphnia* sp. (e.g. *D. magna*) may provide information both on trophic degree as well as dissolved substances in lake waters. The dominance of small cladocerans in lakes may be due to quality of food and trophic level, besides fish predation. The recurrent clear-water phase in lakes would indicate oligo-mesotrophic situations in which the zooplankton plays an important role in the phytoplankton wax and wane.

1. Introduction

Man's activities which introduce excess nutrients as industrial wastes, run off from fertilized agricultural fields and domestic sewage are resulting in significant changes in the quality of water in our aquatic ecosystems. These changes in rivers, lakes and other waterbodies are called eutrophication or pollution, the distinction between the terms being essentially of degree. Eutrophication is a natural process which if accelerated may lead to undesirable effects, i.e. pollution. Both, eutrophication and pollution can be monitored using indicators of water quality. The indicators concern both structural and functional properties of the ecosystems.

The present contribution is a review of the data on zooplankton structure and grazing activity as indicator of water quality. There have been few attempts to correlate the changes in zooplankton structure and feeding rates with water quality in natural waters. The zooplankton, because of its central position between the autotrophs (algae, phytoplankton) and other heterotrophs (fish and other carnivores), forms an important link in the food web of aquatic ecosystems (Tevlin and Burgis, 1979; Gulati *et al.*, 1982). Its strategic position both in terms of feeding and energy flow in the ecosystem as well as its sensitivity to both man-made and natural changes make zooplankton quite suitable for biological monitoring of water quality. This incorporates both structural and

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functional aspects of monitoring. By measuring grazing rates of the zooplankton community in the field, it has been demonstrated (Haney, 1971; Gulati, 1975; Gulati *et al.*, 1982) that zooplankton can recycle suspended particulate material (dead organic matter, algae and bacteria) in one to three days, but during its peak activity the zooplankton can consume all the available food in four to twelve hours.

Recent studies show that high growth and reproduction rates of zooplankton indicate quality food (Allen, 1976). The replacement of one taxonomic group by another is related to food abundance (Bogdan and McNaught, 1975), and perhaps also food quality. Thus zooplankton species, especialy *Daphnia* spp, can be used as 'trackers' of environment (Porter *et al.*, 1982). The zooplankton offers a wide array of possibilities to be used as biological indicators of trophic status as discussed further.

The terms oligotrophic, mesotrophic and eutrophic, employed in this paper refer to the trophic status rather than to water quality which for each of the three categories may be 'bad' or 'good' depending on the use of water. For example, a waterbody may be oligotrophic and adjudged good from the viewpoint of nature conservation but bad for sport fishing.

2. Indicators Based on Zooplankton Structure

The indicator value of a species is apparently a complicated outcome of its interaction with the environment. The following section deals with the changes in zooplankton species composition and densities in relation to trophic level.

2.1. Species composition and densities

Recent studies demonstrate that zooplankton is a more useful indicator of trophic conditions than has been generally realized (Gannon and Stemberger, 1978). Compared with phytoplankton, the zooplankton has lower densities, larger size and lesser number of species. These features can be used to great advantage in order to employ zooplankton as indicator of trophic status. Because of its intermediate position between phytoplankton and fish, the zooplankton responds to changes in both food and predation. Nevertheless, in certain situations appearance or disappearance of the macrophytes and their growth rates, and intensity of algal blooms may be superior indicators of trophy, providing information without a detailed scientific study.

Important abiotic factors causing changes in zooplankton community composition are nutrient loading, water temperature, dissolved oxygen, and salinity. Predation by fish or other planktivores would usually determine changes in the relative abundance of large and small-sized species (see e.g. van Densen and Vijverberg, 1982; Hall *et al.*, 1976). The zooplankton structure and dynamics may also reflect at changes caused by biotic factors such as fish mortality. Bernardi and Giussani (1978) related the increase in *Daphnia* maximum size to fish mortality due to gill disease. Hrbáček and Hrbáčkova-Esslova (1966) stressed the importance of *Daphnia* sp. as ecological indicators.

The changes in species composition under natural situations may be slow and difficult to trace even after decades of monitoring. However, in cases of accelerated eutrophication, the sensitive species may disappear, the hardy ones persist and some new species may appear. Only in a few lakes are there continuous records of changes. Comparative data on lakes in similar geographical regions, or in the same area but varying in trophy are owing mainly to Beeton (1969), Patalas (1972), and Pejler (1965).

2.2. Crustacean zooplankton

Gannon and Stemberger (1978) found the calanoid copepods *Limnocalanus macrurus* and *Senecella calanoides* as excellent indicators of oligotrophy. These species are cold stenothermal forms occurring in well oxygenated bottom waters. The near-disappearance in the late 1950's of *L. macrurus* from Lake Erie is attributed to eutrophication. This species, however, inhabits oligotrophic waters in Sweden (Pejler, 1965). Similarly, *Diaptomus sicilis* indicates oligotrophy in the Great Lakes region (Patalas, 1972). Its usefulness and of *Holopedium gibberum*, also reported to indicate oligotrophy (Pejler, 1965), is, however, limited because they both occur in a wide range of habitats (Gannon and Stemberger, 1978). *Eudiaptomus gracilis*, a common calanoid in European freshwater lakes, prefers oligotrophic and mesotrophic waters. It is nearly absent from distinctly eutrophic water bodies in The Netherlands (author's unpublished data). However, both *E. gracilis* and *E. graciloides* are limited in their present distribution by their dispersal capacity.

Among the cladocerans, *Daphnia cristata* and *D. galeata* are encountered in more or less oligotrophic waters and *D. cucullata* in more eutrophic ones, although in The Netherlands this last-named species is present in lakes varying widely in trophy. In using species of *Bosmina* as indicators one faces taxonomical problems. In the Dutch lakes, Gulati (1972) found no evidence of replacement of *B. coregoni* by *B. longirostris* during eutrophication as suggested by Frey (1969). In contrast, both the species are concurrent in highly eutrophic lakes (Beattie *et al.*, 1978) in The Netherlands. *Chydorus sphaericus*, although a littoral form, often moves off-shore into the open water of lakes especially when blooms of blue-green algae develop. Its use as indicator of eutrophic waters is also supported by palaeolimnological evidence (Frey, 1969).

2.3. Rotifers

The rotifers have received poor attention as indicators of trophic status, mainly because of identification problems in preserved samples. Secondly, most of the rotifers are not captured by using coarse nets (mesh-width ca 100 μm). This underestimates their importance in the species composition as well as in abundance, both of which features may reflect the trophic situation.

Based on European literature (see references in Pejler, 1965) several species may serve as indicators. Summarizing the European and North American works, Gannon and Stemberger (1978, Table I) listed 19 species among which 11 species were considered by three or more authors as indicators of eutrophy. Data from a eutrophic lake in the tropics (Duncan and Gulati, 1981), some lakes varying in their trophic degree in The Netherlands (author's unpublished data; pers comm. B. Z. Salomé) and from Lake Trummen before restoration (Andersson *et al.*, 1973) support the earlier works.

The species that appear typical of eutrophic waters are: *Anuraeopsis fissa*; *Pompholyx sulcata*; *Polyarthra euryptera*; *Trichocerca cylindrica*; *T. pusilla*; *Brachionus angularis*; *Filinia longiseta*; and *Keratella cochlearis f. tecta*.

Andersson *et al.* (1973) cite interesting cases of disappearance of *A. fissa* and dramatic decline of *B. angularis*, *T. pusilla*, and *K. quadrata* in the year after the restoration of Lake Trummen.

The number of rotifer species that indicate oligotrophy is limited. Those from Europe (Pejler, 1965) were with some exceptions found also in America in northern Michigan (Gannon and Stemberger, 1978). Since species named are generally distributed widely, their indicator value is limited. *Kellicottia longispina*, reported to occur in the oligo-mesotrophic lakes of Michigan, avoids eutrophic environments (Pejler, 1965). I found this species abundant in the colder, deeper layers of the meso-eutrophic Lake Vechten and also sporadically even in eutrophic lakes in The Netherlands.

Indicator value of some of the rotifer species mentioned is clear. The rotifer composition and abundance may be influenced also by intensity of fish predation on the larger crustacean zooplankton.

2.4. Community structure

The occurrence of certain species in lakes may be related to pH, specific conductivity, humus content and degree of pollution (Pejler, 1965). Diversity and similarity indices have been used by some workers to compare water types. Sprules (1975) applied the species diversity concept to a number of lakes in Ontario in relation to abiotic factors, but with little success. However, Gannon and Stemberger (1978) found the principal component and cluster techniques useful new lines of approach.

Alterations in the community structure may indicate (1) the changes in nutrient loading and (2) in intensity of fish predation. The first one provides information about food quality and production and affects the abundance of zooplankton, and the second results in selective mortality of zooplankton thus affecting its composition and size. In Lake Ontario, McNaught and Buzzard (1973) reported a marked decrease in copepod densities in the period from 1939 to 1969–1972. McNaught (1975) attributed this to increased eutrophication and the accompanying changes in the size of food particles and ingestion rates. Similarly, Bradshaw (1964) related the increase in the cladoceran densities in Lake Erie partly to a large increase in phytoplankton. Patalas (1972) reported a general trend in zooplankton changes from the oligotrophic L. Superior to increase in trophy via L. Huron, L. Ontario to the more eutrophic L. Erie. The calanoids *Diaptomus sicilis* and *D. ashlandi* became less significant with the increasing predominance of cyclopoids and cladocerans. Patalas ascribed these changes to phosphorus loading and increase in chlorophyll concentration. Similar trends were observed in L. Michigan by Gannon (see in Gannon and Stemberger, 1978). In the straits region of L. Michigan and in L. Huron the density ratio of calanoid copepods: cyclopoid copepods plus cladocerans was much lower in the nutrient-rich shore water than in the off-shore water. This was confirmed by principal component analysis that helped resolve even slight limnological differences. This ratio appears to be a good index for assessing trophic conditions. It may be applied to the Dutch lakes with ease since calanoids are either absent or sparse in most of the eutrophic and hypertrophic lakes examined. In contrast, in mesotrophic lakes like Vechten (Gulati *et al.*, 1982) and Maarsseveen and in less eutrophic ones like Wijde Blik, *Eudiaptomus* sp. is an important zooplankton. Similarly, in an area under the hydrological influence of the grossly-polluted river Vecht, in the central part of The Netherlands, a decrease in trophic degree, from the river via the Hilversum Canal to Lake Wijde Blik, was generally accompanied by a decrease in the number of rotifers but an increase in that of the cladocerans. Thus, inter-community comparisons may provide a useful insight into the trophic changes.

3. Zooplankton Grazing and Related Aspects as Indicators

The growth patterns and dynamics of zooplankton are related to changes in the available algal and detrital matter which depend on nutrient supply. However, the biomass relations between the zooplankton and its food are not strictly linear but broadly follow the Michaelis-Menten relationship. Thus, increased eutrophication or pollution does not necessarily result in a proportional increase in zooplankton biomass. The biomass relations are not as simple as may appear but involve functional response of the zooplankton. The latter is reflected in the zooplankton grazing activities which may be measured as rate either of community filtering or of individual filtering, or both (Gulati *et al.*, 1982).

3.1. Zooplankton to phytoplankton biomass ratios

The quality and quantity of available food (phytoplankton, dead material and bacteria) will determine the zooplankton fecundity and abundance. The zooplankton to phytoplankton biomass ratio may therefore provide information about ecological efficiency of energy transfer in relation to the trophic status of a water body as discussed by McCauley and Kalff (1981). There is evidence of decrease in the biomass ratio with an increase in trophy. In the Dutch lakes of varying trophy, the ratio decreased by an order of magnitude, whereas the seston concentration (Figure 1) increased by a similar order. The mean ratio decreases from ca 0.4 in oligo-mesotrophic lakes to about 0.05 in hypertrophic lakes. Interestingly, the ratio decreases sharply as food increases from ca 0.5 to 1 mg seston C l^{-1}. The eutrophic and hypertrophic lakes have a constant ratio, ca 0.05, although the seston increases from about 5 to 11 mg C l^{-1}. Most eutrophic lakes are shallow, highly turbid and productive, with dominance in summer of blue-greens which compared with nanoplankton, would be poorly utilized by zooplankton (Gliwicz, 1977). Lastly, these biomass relations may lead to faulty interpretations of trophic status when examined in isolation. This is because fish can modify zooplankton biomass and thus also phytoplankton concentration due to changes in the intensity of zooplankton grazing.

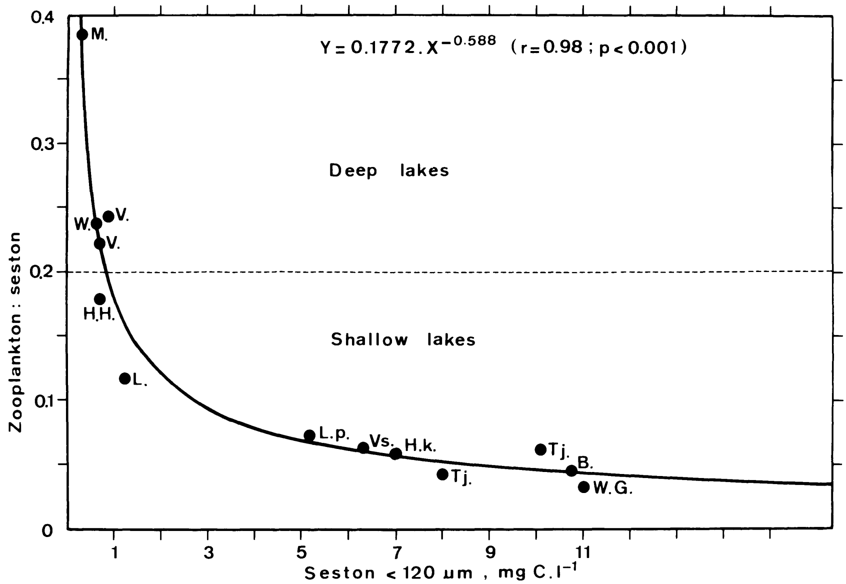

Fig. 1. Regression relation between seston concentration (x), and zooplankton: seston biomass ratio (y) in Dutch lakes varying in trophy. Each point represents 6 replicate measurements or more in the period May–October. The abbreviations: (M.) Maarsseveen; (V.) Vechten, (W.) Wijde Blik; (H. H.) Het Hol; (L.) Loenderveen; (L. p.) Loosdrecht lakes; (Vs.) Vuntus; (H. k.) Hilversum Canal; (Tj.) Tjeukemeer; (B.) Breukeleveen; and (W. G.) Wijde Gat.

3.2. Zooplankton grazing

The filtering (F) and feeding (f) rates of zooplankton depend chiefly on food concentration and temperature. The animals filter maximally up to a certain food concentration, the so-called incipient limiting level (ILL), above which the decrease in F is at first sharp but gradual thereafter. Feeding rate at first increases linearly with food concentration up to the ILL but then becomes more or less constant. Comparing the F either of the entire crustacean community or of species common to the lakes, may provide information about the food concentration and its availability and utilization and about the trophic status of the lakes. Several techniques are now available to measure F. However, for the comparison of lakes an intercalibration of the existing methodologies or a use of the same technique in different lakes is desired. Here, about a dozen lakes in The Netherlands varying in trophy are compared on the basis of F expressed as specific filtering rates (SFR) (Figure 2) of the community. Also compared is the F of *Daphnia magna* acclimatized to waters from lakes varying in food concentration (Figure 3).

Both in case of zooplankton community and *D. magna*, the decrease in F was related significantly to increase in food concentration as well as to trophic degree based on other indicators. The SFR varied by more than an order of magnitude comparing the oligo- to mesotrophic lakes, Maarsseveen and Vechten, with the eutrophic lakes Loosdrecht

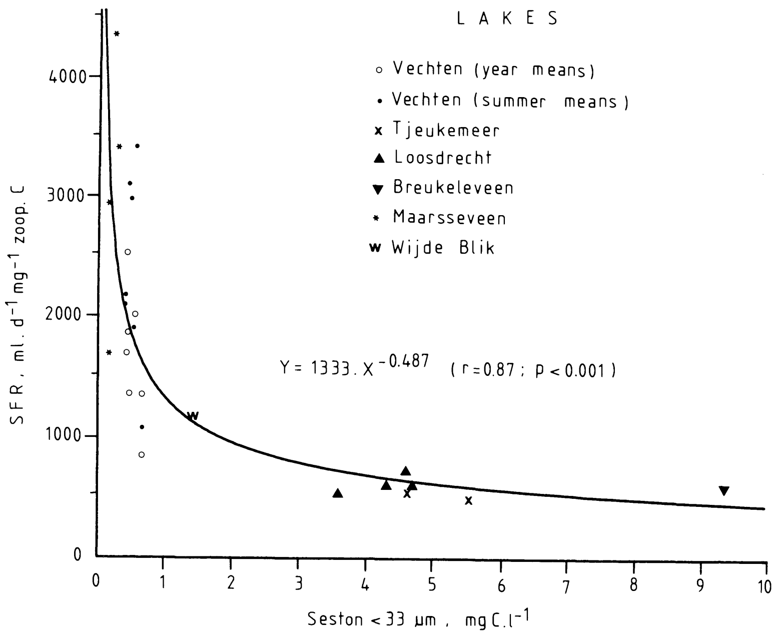

Fig. 2. Regression relations between seston concentrations and community filtering rates (SFR) in lakes of different trophy.

Lakes and Tjeukemeer and with the hypertrophic lake Breukeleveen (Figure 2). A similar but sharper decrease in F was noted in case of *D. magna* (Figure 3). Interestingly, in *Daphnia* even using *Chlorella* as food to extend the range of food concentrations beyond those in the lakes Wijde Gat (WG) and Vuntus (Vs), did not adversely affect the correlation between food concentration and F. Because *D. magna* can filter food particles varying widely in size (Geller and Müller, 1981), as is normally the case in lakes, it can serve as a good indicator of food availability and trophic degree.

The curves in Figures 2 and 3 despite the difference in the slopes, look alike. A sharp fall in SFR is coincident with mean food concentration of ca 1 mg C l^{-1} as prevalent in the less-polluted waters. This is true for the deep, stratifying lakes, Maarsseveen, Vechten and Wijde Blik, which have also the highest zooplankton to seston biomass ratio (> 0.2; Figure 1). In these deep lakes both sinking of material during summer stratification and zooplankton grazing, probably contribute to reduce the algal mass. The SFR in the lakes with food concentration of ca 3 mg C l^{-1} and more is minimal and more or less constant. However, a significant portion of algae in these lakes is filamentous blue-green and coarse algae that the filter feeders may reject. The energy lost in rejection of food may be high so that the larger crustacean forms cannot thrive and are replaced by small-sized crustaceans and by rotifers. In eutrophic lakes the grazers feed on smaller particles, including bacteria, more efficiently (Peterson *et al.*, 1978). Indeed, the eutrophic lakes in The Netherlands abound in finefeeders, e.g.

Chydorus sp. and small-sized *Daphnia*. However, selective and size dependent fish predation (Van Densen and Vijverberg, 1982) in these eutrophic, shallow lakes may be higher than in the less eutrophic, deep lakes. This may contribute to changes in species composition similar to those caused by food. The changes in size structure of zooplankton, therefore, provide information about the food quantity and composition, but also about the trophic status and predatory fish.

The fluctuations in F not only provide information on the food quality or concentration but also on the dissolved inorganic and organic substances. In the grazing studies (Figure 2 and 3) even though the role of food is evident, it was difficult to discriminate between the effects relating to food and to dissolved materials. This was examined in the lakes Vechten and Tjeukemeer using the food budget parameters of *D. magna* as indicators. The two lakes differ significantly in their trophic status, morphometry, and hydrological regimes (Figure 4; Gulati, 1975; several papers in Gulati and Parma, 1982). The natural food in water from both the lakes was removed using a membrane filter (0.45 μm Ø). In two different experiments (Figure 4) *D. magna* was acclimatized to the lake waters, with *Chlorella* as the food added. Despite identical food quality and concentration the F, assimilation efficiences and daily ration, i.e. weight specific consumption, were considerably higher for animals in Vechten water than for those in Tjeukemeer water. Tjeukemeer is a eutrophic lake with a high concentration of humic acids and of copper (De Haan, 1982) both of which may inhibit the grazing activities. This may explain poor growth conditions for *D. hyalina* in this lake, besides food availability (Vijverberg, 1976).

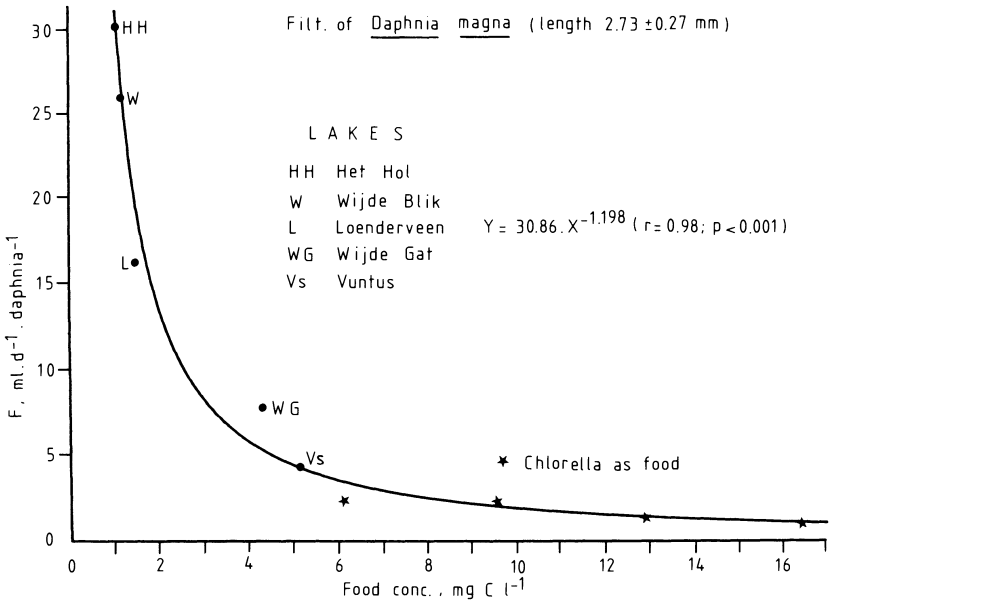

Fig. 3. Filtering rates versus food concentration of *Daphnia magna* in lakes of different trophy. The range of food concentration in the lakes was extended using cultured *Chlorella vulgaris*.

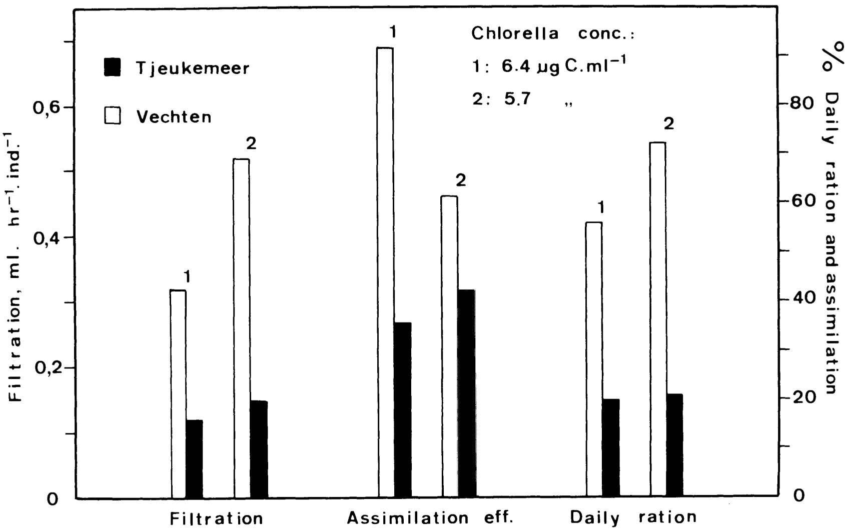

Fig. 4. Food budget parameters of *Daphnia magna* in two experiments using cultured *Chlorella vulgaris* in filtered water from lake Vechten and Tjeukemeer.

3.3. Grazer type and trophic status

The food niche of filter-feeding crustacea depends upon the morphology of the filtering apparatus and the size of food particles consumed (Geller and Müller, 1981). The grazers can consume a wide spectrum of food particles, namely from 0.1 to 50 μm or more, depending on mesh dimensions of the filtering apparatus.

The dominance of small cladoceran species, namely, *Chydorus*, *Diaphanosoma*, some *Daphnia* spp. and *Ceriodaphnia* would generally indicate availability of nanoseston. This often is the case in most eutrophic lakes having a rich bacterial flora, fine detritus and ultra-nanoplankton. The common *Daphnia* species, e.g. *D. hyalina* and *D. pulicaria*, and *Bosmina* owe their success in lakes to the wide range of particles, 1–30 μm, they can filter. The presence or absence of these species indicates only roughly defined meso-trophic to eutrophic conditions, but may be governed also by intensity of fish predation. The calanoids, e.g. *Eudiaptomus gracilis*, a quite common macro-filter-feeder in the oligo-mesotrophic waters, feeds upon coarse particles (4–29 μm). Their near-absence in the hypertrophic water may be due to their inability to feed on bacterial and other fine food particles abundant in these waters.

The seasonal succession of grazers in temperate lakes, (a) macro filter-feeders in winter; (b) low efficiency filter-feeders in spring and early summer; and (c) high efficiency bacteria-feeders in late summer and early autumn may provide information on the production potential and seasonal changes in food quality in these lakes. The role of zooplankton appears to be less clear in hypertrophic lakes with their almost predominant and perennial blue-green algal flora. In oligotrophic and mesotrophic lakes, on the other hand, the amount of food consumed by grazers in spring and early summer may far exceed that produced by phytoplankton. Thus the seston mass may decrease noticeably so that water transparency increases significantly. In Lake Vechten it is a recurrent phenomenon in May and June when the Secchi depth increases to 4–5 m compared with 2–3 m normally. The occurrence of this 'clear water phase' in many temperate lakes (Gulati *et al.*, 1982) is not only of academic interest but also important for management of water quality in drinking water reservoirs. Also, the zooplankton grazing activities in sewage lagoons and hyper-fertilized ponds, at high temperatures, may suppress phytoplankton growth so that the vast supply of nutrients remains unused by autotrophs (Uhlmann, 1971). Thus, related to zooplankton grazing, low level of phytoplankton in water bodies permits increased light penetration which may stimulate growth of macrophytes and thus also of epiphyton and epipelon.

Summarizing, the grazers prevent both outburst and nutrient limitation of nanoplankton and improve light climate, thus preventing massive growth of blue-green algae. Therefore, an important measure to restore lakes and improve water quality would be, besides decreasing the external load of nutrient, to resort to biological manipulation (see Nilssen, 1978), namely by decreasing predation pressure on large filter-feeders. Intensive fish predation and lack of fishery management may lead to a virtual wiping out of larger zooplankton forms but increase of rotifers and dominance of blue-greens. This was observed by Duncan and Gulati (1981) in a eutrophic reservoir in Sri Lanka. Such waters are unattractive in the long run for commercial fisheries; their recreative and aesthetic value is low, too.

4. Other Possibilities and Concluding Remarks

This paper is confined mainly to characterize trophic status of natural waters employing changes in zooplankton composition and grazing activities as indicators. Several other minor but useful aspects of zooplankton may also provide information on the trophic conditions.

Some evidence for the trophic status of lakes may be obtained from knowledge of the rotifer diet (see several cases cited by Pejler, 1965). For example, Nauwerck (1963), observed *K. longispina* to feed on small chrysomonads. Indeed, such algae are abundant in oligo-mesotrophic water bodies giving extra weight to the indicator value. This approach opens up new possibilities for future research, like the ones concerning the changes in grazing pressure, food quality and quantity and selective predation, in relation to lake types.

A study of the gut contents of zooplankton, compared with seston composition in the milieu, may provide broad but basic information on availability of food and its utilization in the food chain (see Nadin-Hurley and Duncan, 1976). Similarly, staining the guts of animals may quickly reveal the gut-filling time, a comparison of which for a known species may provide information about the food quantity and availability.

A cursory look at swimming *Daphnia* in small ponds and ditches may provide information on conditions relating to the trophic situation. For example, haemoglobin formation and red colour in *Daphnia* (Fox *et al.*, 1949) as often found in shallow Dutch waters, particularly ditches, would invariably indicate low oxygen content of water.

Lastly, the present attempt to employ zooplankton as indicator, especially in relation to grazing, was confined to crustacean species. The rotifers but especially Protozoa have been examined poorly so far by different workers but may be useful indicators. This indicator value should be generally connected with conservation, socio-economic and aesthetic aspects, among which domestic water supply and public health, cost of water treatment, recreation amenity and effect on fish life, and commercial fishing need consideration before making a choice of indicator.

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BIO-INDICATORS AND THE QUALITY OF THE WADDEN SEA*

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Abstract. The definitions of the notions 'bio-indicator' and 'water quality' are critically reviewed; it is shown that both have been used ambiguously.

The quality of the Wadden Sea is discussed using a number of indicators for pollution effects; the Wadden Sea is now an unsuitable environment for a number of marine mammals, and, to a lesser extent, for some bird species. It cannot be shown whether or not this pollution has any effect on r-selective species.

1. Introduction

'Ecology is not the science of pollution, nor is it environmental science. Still less it is a science of doom. There is, however, an overwhelming mass of writings claiming that ecology is all of these things.' These opening lines of a small book by Colinvaux (1980) are the incentive for challenging the credibility of certain 'bio-indicators' and the concept of water 'quality'. First, let us consider bio-indicators. Odum (1971) remarked (although the notion is much older) that the environment of organisms can be judged on the basis of the species that are present: the indicator species. Related to this idea is the concept of bioassay, which is applied when physical or chemical factors in the environment are difficult to detect, or during the survey of new, unknown, conditions or of large areas.

The use of indicator species was originally limited to land plants, and was used to assess climatic factors only; later it was extended to the indication of metals in the soil (e.g. zinc in the province of Limburg, The Netherlands). A few things must be considered when using indicator species: it is preferable to use 'steno' species (with a narrow amplitude) rather than 'eury' species, but true stenoceous species are not always numerous, or even present in sufficient number to be used as indicators. An indicator, therefore, is in any case a compromise between presence in reasonable number and an ecological amplitude as narrow as possible. Furthermore, for a species to be a good indicator, one must be clear that the ecological niches of the species are occupied by individuals of that species. Large, easily observed species can better be used as indicators than small species, and long-living species are in general more useful than species with a short life-span; however, both these conditions depend on what we intend to do with the indicator.

In this paper the results of studies on several animal species and the inferences that can be drawn from these studies to identify long-term and place-dependent changes in the Wadden Sea are discussed; these changes would have gone unnoticed had their effects on the species not been noticed. Some of these changes were recognized because

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of the reactions or changes in individuals (e.g. deformities) or populations (e.g. changes in fecundity) of these species; it is questionable whether the species are, on that basis, indicator species.

Colinvaux's warning of the danger that ecology will be considered to be a science of pollution, etc., is apposite: unless 'indicators' are used with care the inferences drawn from them can be trite.

1.1. Water quality

The word 'quality' has at least two different meanings (Kruyskamp, 1961):

(a) the properties of matter or materials, in relation to their use; in other words: the merits and demerits of the object being considered. Our – subjective – judgement is therefore dependent upon how we use the matter or materials. Difficulties arise from the fact that the sailor and seal assess the properties of the water in the Wadden Sea differently.

(b) The sum of properties of matter or material (without any judgment of merit or demerit). Reports on water quality usually follow this definition; it has however, a disadvantage: the properties of water have little or no value unless an evaluation (subjective or otherwise) of these properties is given. Each evaluation of water quality is subject to the function that is attributed to the water body. These functions are attributed in the Tentative long-term Plans for Water, and Key Planning Decisions that are published by the State government of The Netherlands.

1.2. The Wadden Sea

The Wadden Sea is a shallow coastal sea behind a line of barrier islands, with connections with the water from the North Sea; the water in the Wadden Sea is frequently exchanged with the North Sea. Tidal influence is large, and hence the environment for marine organisms is very variable and largely unpredictable. As a result of the shallowness there are large ranges in temperature and salinity; the tide induces high current velocities with accompanying sediment transport and changing sedimentation and resuspension of sediment. The organisms in the Wadden Sea are therefore exposed to a great physical stress. It must be assumed that the organisms that are present are adapted to that stress: selection and survival of the fittest have taken care of that. Nevertheless this process has left a large number of organisms (approximately 1300 species of benthic and 260 species of pelagic invertebrates, and approximately 50 species of fish (Dankers *et al.*, 1981).

It has been customary to describe the Wadden Sea as a vulnerable ecosystem; I do not think, however, that it is vulnerable to naturally occurring environmental conditions. The extent to which it is vulnerable to man-made conditions will be shown in this paper; it is my contention that it is no less vulnerable to these conditions than any other ecosystem.

1.3. Biological organization

In this issue Zonneveld (1983) and others have given examples of levels of biological organization and of the changes that occur at these levels of organization as a result of man-made influences.

In general, small effects on a certain level of organization have repercussions at higher levels. It should be noted that the scientific evidence for effects at higher levels is usually sought at lower levels; the reverse, the study of the consequences at higher levels of an effect at a lower level, is seldom carried out.

The examples of bio-indicators of the quality of the Wadden Sea in this paper are all taken from higher levels of organization; most of the examples are well known.

Following Gray (1982) bio-indicators can be classified into K-selective species and r-selective species; K-selective species have a low reproduction rate, slow growth, and a selective advantage in a crowded environment. K-selective species can be studied in the field at the population level, they are usually species at the top of the food pyramid. The r-selective species are opportunists, with a selective advantage in an uncrowded environment; they grow fast and rapid. Field studies of pollution effects at the population level are hampered by the high natural mortality, and are generally impossible.

2. K-selective Species

2.1. Common porpoise (Phocaena phocaena L.)

Before 1960 the common porpoise was numerous in the Wadden Sea and in the coastal zone of the North Sea; nowadays the species is rarely seen and only a few dead animals are washed ashore. Verwey (1975) and Verwey and Wolff (1982a) presented records of the number of common porpoises observed in the Wadden Sea in the period from 1946 to 1977. A reasonably reliable record of the number of dead common porpoises washed ashore on the coasts of The Netherlands is given in Figure 1. The decline in numbers since 1960 is ascribed to poisoning (Verwey, 1975); very high contents of mercury, DDT and PCB's have been recorded in dead animals (Koeman *et al.*, 1972; Duinker and Hillebrand, 1979). The latter authors have also observed that organochlorine compounds are transmitted via the placenta from the body of the mother porpoise to the foetus. The common porpoise, which once was very common indeed, is now so rare that each observation (one or two per year) is mentioned in the local newspapers.

2.2. The bottlenose dolphin (Tursiops truncatus Mont.)

Before 1940 the bottlenose dolphin used to enter the Wadden Sea from the North Sea in early spring, as a follower of and predator on the Zuiderzee-herring stock. After the Zuiderzee was enclosed this herring race died out; Verwey (1975) has shown that there is a connection between the diminishing numbers of Zuiderzee herring landed by the fishermen and the numbers of bottlenose dolphins observed. After 1965 the bottlenose dolphin also disappeared from large parts of the North Sea; this is reflected in the greatly decreased number of animals washed ashore on the Dutch coast (Figure 2). It is reasonable to assume that the same factors that caused the decline of the common porpoise are operative here too (Verwey and Wolff, 1982b).

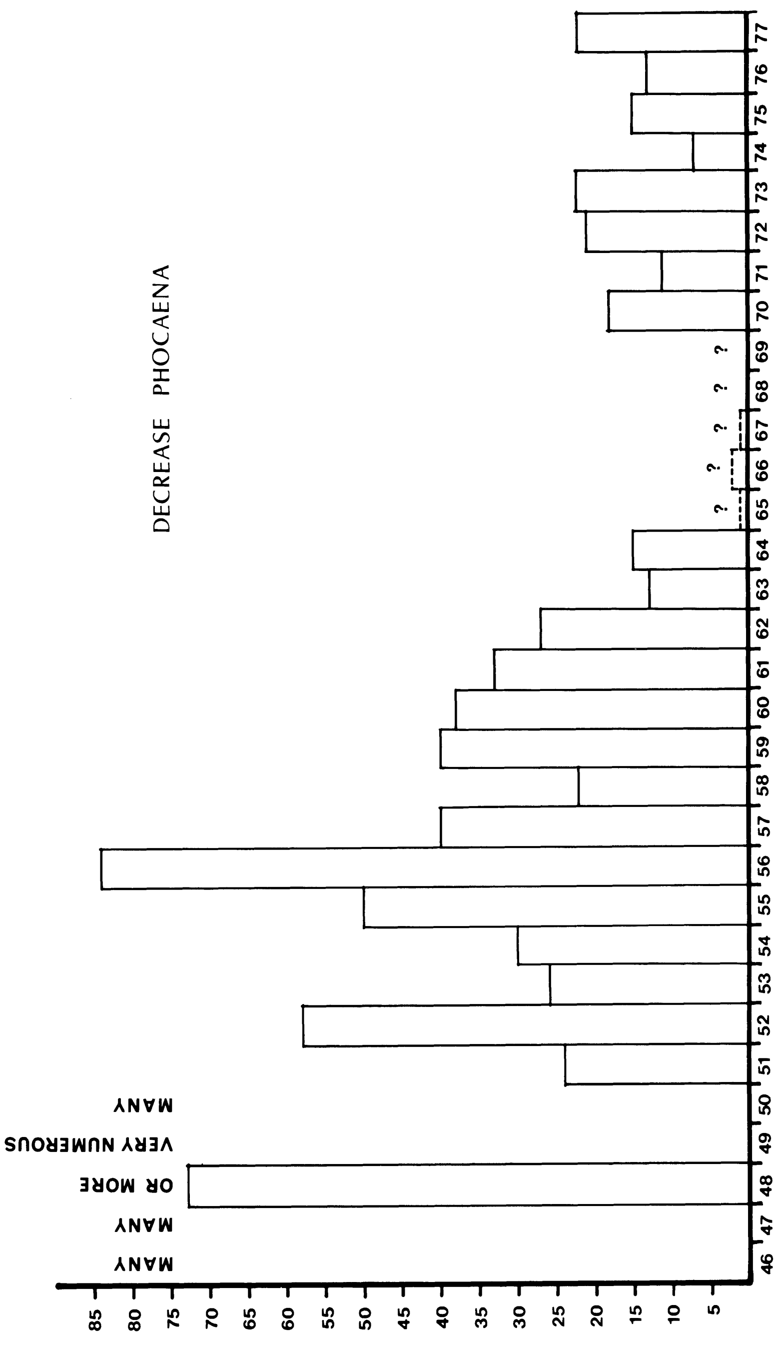

Fig. 1. Numbers of common porpoise as washed ashore or accidentally caught on The Netherlands coast. (Verwey and Wolff, 1982a).

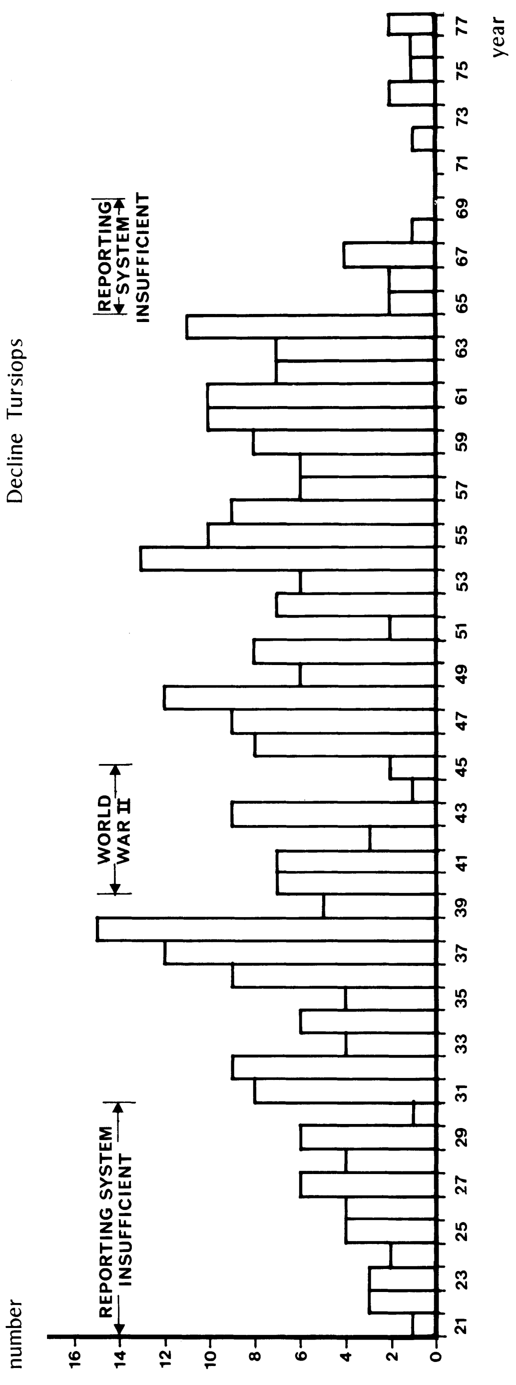

Fig. 2. Numbers of bottlenose dolphin stranded on The Netherlands coast (Verwey and Wolff, 1982b).

2.3. Harbour seal (Phoca vitulina L.)

The story of the harbour seal in the Dutch Wadden Sea is now generally known; before 1954 the numbers decreased slowly. After the hunting of seals was stopped, the population increased slowly.

After 1965 the population declined rapidly until 1975 (Figure 3) and then stabilized

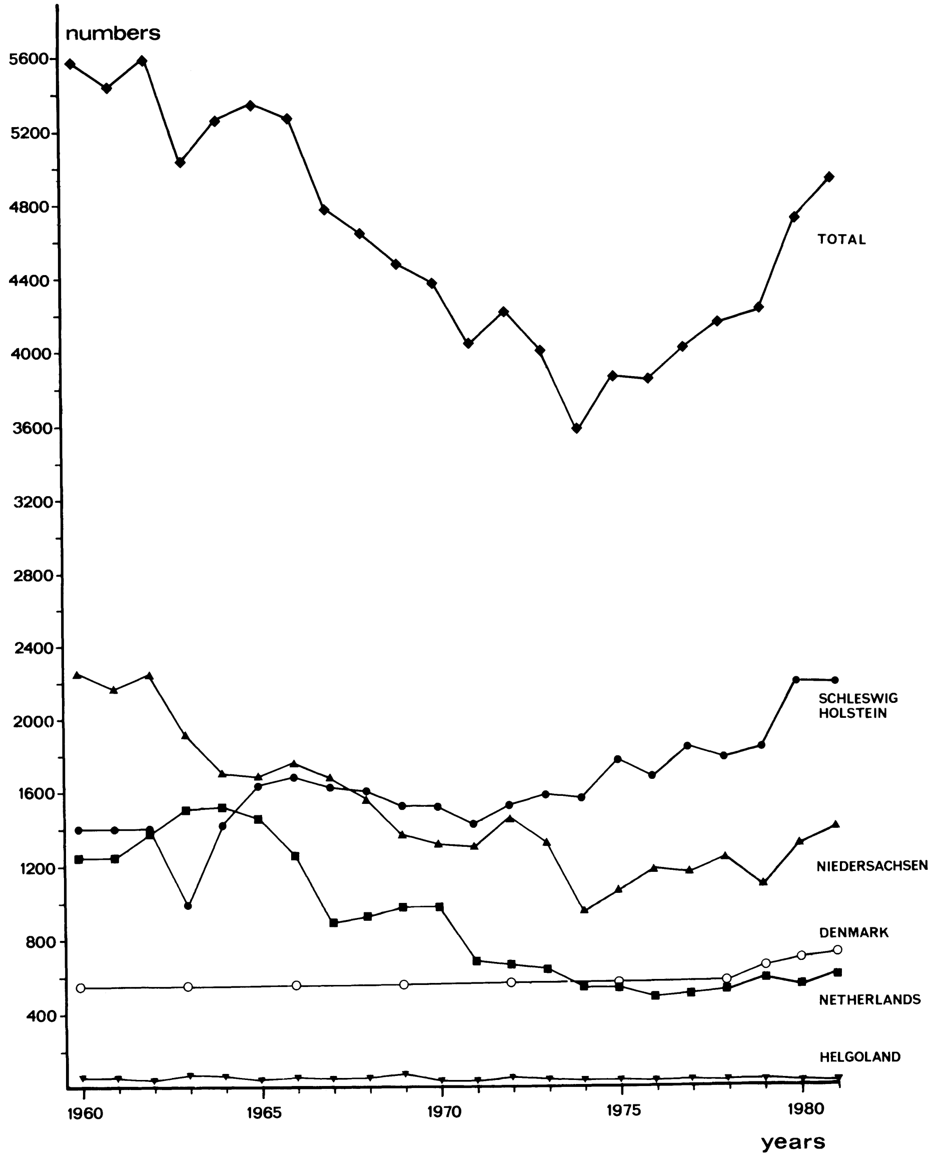

Fig. 3. Maximum number of seals in parts of the Wadden Sea. (Reijnders *et al.*, 1982).

at about 450 individuals. From the work of Reijnders *et al.* (1982) it is known that the reproduction of the seal is low in the Dutch Wadden Sea (Figure 4); there are reasons to believe that there is a causal relation between this and high contents of PCB's; research on this relation is in progress. The present population of seals in the Dutch Wadden Sea is mainly maintained by the immigration of animals from the German and Danish parts of the Wadden Sea; in the German part, however, reproduction is also clearly lower than in the Danish part (Figure 4).

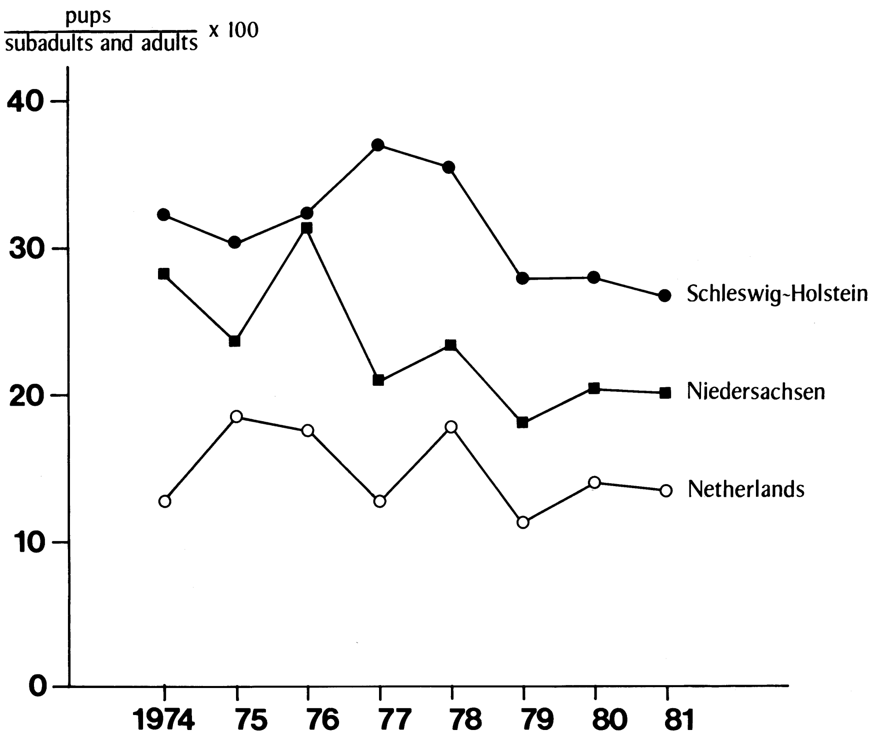

Fig. 4. Production of pups in the harbour seal. (Reijnders *et al.*, 1982).

2.4. Sandwich tern (Sterna sandvicensis) and Common tern (Sterna hirundo)

Figure 5 gives the numbers of breeding pairs of the sandwich tern on the Dutch Wadden Sea islands for the period 1953–1979. From 1953 untill 1957 the number of pairs fluctuated between 12 000 and 26 000; it is remarkable that at this high level large fluctuations do occur from year to year. Before 1953 even larger numbers of breeding pairs were present: 25 000–40 000 (Rooth and Mörzer Bruyns, 1959; Rooth, 1980).

In 1954 the production of pesticides of the -drin group commenced in the Rotterdam area; transport of part of the waste by the residual current to the Wadden Sea, and through a short food-chain, caused the number of breeding pairs of the sandwich tern to decline to 650 in 1965.

After the telodrin factory had been closed and the waste purification plant of the dieldrin factory had been improved, the number of breeding pairs slowly increased to 3000. The paper by Koeman (1971) on the influence of the -drins on the sandwich tern is an excellent example of scientific evidence of the accumulation of the -drins in the food chain. However, several questions remain open: although the populations fluctuated greatly from year to year before 1954, since 1972 the fluctuations have been less extreme (Figure 5). Also, it is remarkable that the population is recovering very slowly. The population only recently reached 8000 breeding pairs (1982) (Rooth, private communication).

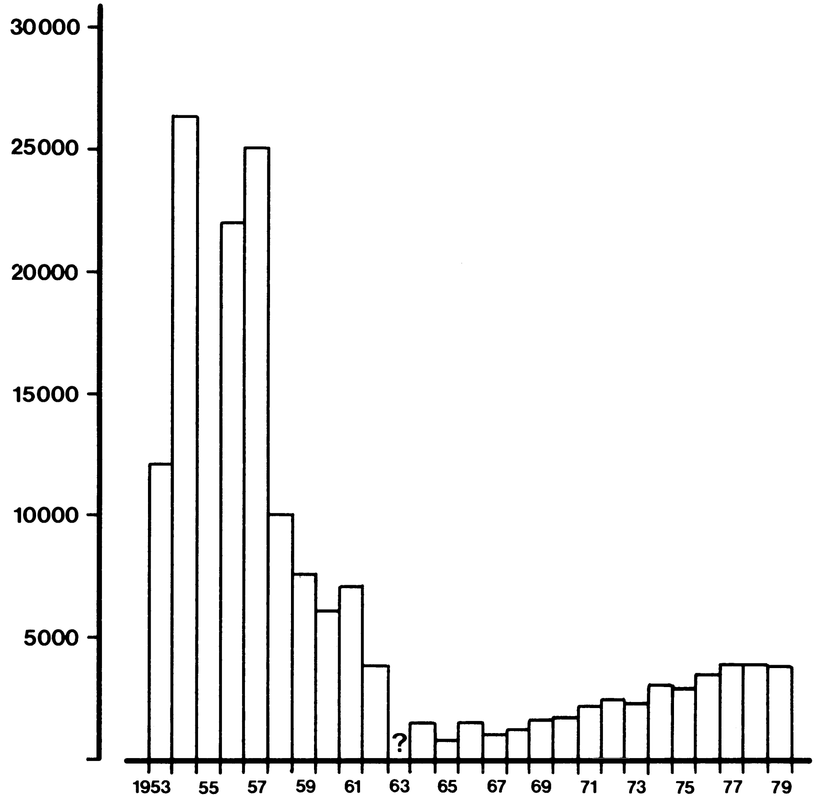

Fig. 5. Breeding pairs of the sandwich tern on The Netherlands Wadden Islands. (Rooth, 1980).

The population of the common tern showed the same trend in the same period (Dijksen and Dijksen, 1977).

2.5. Eelpout (Zoarces viviparus L.)

The eelpout is a resident fish in the Wadden Sea, and it is assumed that individuals remain within a small area all their life. Eelpout is a viviparous fish, and thus has a limited reproduction capacity. Although the species is a bio-accumulator of mercury this has nothing to do with Odum's concept of bio-indicator: eelpout cannot be used as an indicator (see introduction) of mercury in the environment.

A. Stam and W. Chr. de Kock (pers. comm.) have found high concentrations of mercury in eelpout from the Ems Dollard estuary (see also Mussel, section 3.1 below).

Eelpout is mentioned here because of the very elegant use of this fish K. Essink made (pers. comm.), when comparing the mercury pollution of the western part of the Wadden Sea with that in the Ems Dollard estuary. Reasoning from a suggestion (de Wolf, 1975) that mussels remove part of their body burden of mercury with the gametes at spawning, and the observation by Duinker and Hillebrand (1979) that in the common porpoise organochlorine compounds are transmitted via the placenta from mother to unborn young, Essink used the survival period of young eelpout in an aquarium as a measure of the body burden of the adult. The experiment indicated that the survival period for young animals from the western Wadden Sea was significantly longer than the survival period for young from the Ems Dollard estuary, as would be expected from the known distribution of mercury pollution. However, experiments are seldom as beautiful as they look at first sight: the mercury contents of young eelpouts with varying survival periods were not significantly different.

3. r-Selective Species

In contrast to K-selective species, r-selective species cannot always be used as indicators in the field at high levels of organization, except perhaps in extreme situations.

3.1. Mussel (Mytilus edulis L.)

In the Ems Dollard estuary the mussels had, in 1973, a relatively high mercury content which coincided with the discharges from a well-known industrial waste water outfall (de Wolf, 1975).

Work of the same nature in the Wadden Sea has been published by de Kock and Kuiper (1981) (Figure 6). From these data the effects on the mussel populations cannot be inferred; the reproduction capacity of the mussel is large, and the natural mortality probably exceeds 99.9%. In terms of research, an extra mortality resulting from toxicity effects should cause a mortality of 99.9% and these mortality values are hard to discriminate. Therefore laboratory experiments are needed to assess the effects.

3.2. Nematodes

The use of sedentary organisms as indicators in the sea and in estuaries is attractive from the point of view of describing a location; non-sedentary species may have moved recently, either actively or passively by water currents. Interstitial nematodes are not

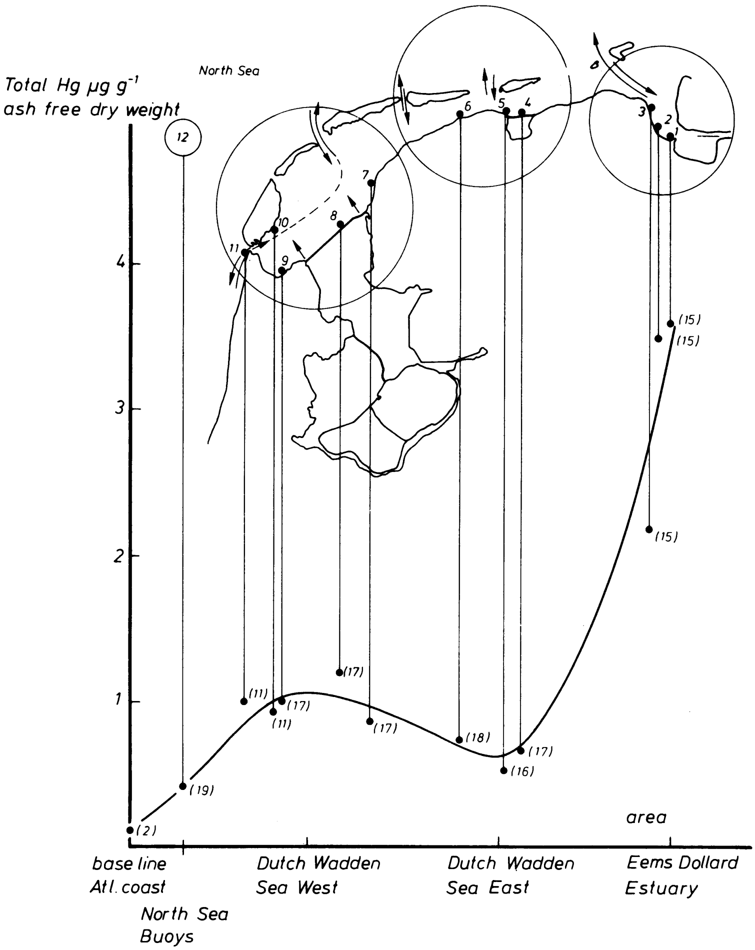

Fig. 6. Mercury content of mussels in The Netherlands Wadden Sea, 1971–1973. In brackets: numbers of samples per location; every sample contained 60–100 mussels of 3–3.5 cm long. (De Kock and Kuiper, 1981).

strictly sedentary, but they can be considered to be so. They are used as indicators of the level of biocenosis and the diversity of the biocenosis is the measure of indication. Unfortunately there are many species, and few specialists are able to identify them. Bouwman (1981) calculates diversity indices for the nematode population (Figure 7) along the length axis of the Ems Dollard in relation to the waste water outfall of a large amount of organic waste from the potato-flour industry in Nieuwe Statenzijl; there approximately 30×10^6 kg organic carbon is sluiced out in a few months each year (van Es, 1982).

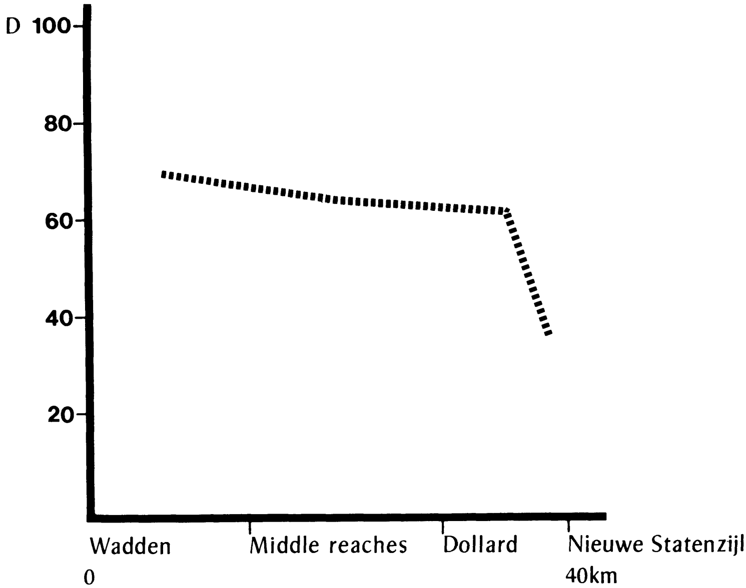

Fig. 7. A diversity index for the Nematode biocenosis in the sediment of the Ems Dollard estuary. (Bouwman, 1981).

A difficulty in interpreting Figure 7 is that all estuarine gradients, in oxygen content, salinity, concentration of nutrients, etc. follow a similar course, and it is not clear which factor is responsible for what.

Raffaelli and Mason (1981); Warwick (1981); Coull *et al.* (1981); and Raffaelli (1981) took part in a heated discussion on the use of a nematode/copepod ratio, which proved mainly that this ratio is in any case not universally suitable as an indicator of pollution.

3.3. Capitella capitata

Capitella is a small polychaete worm. Worldwide the species is known to occur in marine waters with severe organic pollution; Pearson and Rosenberg (1978) give no less than 39 literature references. The classic answer to the question why *Capitella* is abundant in such places is that the species is very tolerant of low concentrations of oxygen. Reish (1970) however, showed experimentally that *Capitella* is certainly not the species most tolerant of low oxygen concentrations! It appears that *Capitella* reacts to each disturbance in the environment that kills the fauna, (e.g. an oil spill accident, the laying of a marine pipeline, a red tide) by rapidly colonizing the resulting 'vacuum' (Gray, 1982).

Capitella is a real r-selective species, with a rapid reproduction; a reproduction which, moreover, takes place during most of the year. Nevertheless, *Capitella capitata* does not colonize the almost lifeless south-eastern corner of the Dollard, where each autumn the fauna is killed by the anaerobic waste from the potato-flour industry. The explanation is simple: the south eastern corner of the Dollard has a low salinity, and *Capitella* does not live in water with a salinity below 10‰.

4. Closing Remarks

The preceding paragraphs deal with indicator organisms, quality and Wadden Sea.

It appears that, since the first use of the term 'indicator organism', in Odum's sense, the use of the term has degenerated, to include organisms used for bioassay, and for organisms that accumulate substances (compounds), although in the last two cases the organisms do not indicate the accumulation. In this paper I have tried to show a series of increasingly trivial uses of 'bio-indicators'.

The separation of indicator organisms into r-selective and K-selective species leads to the conclusion that at high levels of biological organization only K-selective species can be used as indicators for an 'early warning system' (Cairns and van der Schalie, 1980) (although even then the 'warning' is far from early). That was already known, as K-selective species are also top-predators.

The use of r-selective species, at high levels of biological organization can show results only in extreme situations; at lower levels of organization these species (mostly invertebrates) can be used as bioassay organisms, or as accumulators, together with usually elaborate methods of analysis.

The ambiguous use of the word 'quality' leads to frustration; either the word implies a judgement of the quality or it does not. The authors of water quality reports are usually very proud of their elaborate lists of figures, while users of the reports feel frustrated as the judgement of the quality is lacking, and vice versa.

The quality of the Wadden Sea is well below that advocated by the government. This is shown by the following:

(a) Common porpoise and bottlenose dolphin have disappeared.
(b) The seal population persists only because of the immigration of partly toxified animals.
(c) The populations of sandwich terns and common tern have been decimated in the last 25 years.

Many other examples could be given.

To quote the last lines of the book by Colinvaux:

> As long as the finding of new ways in which to live was left to natural selection there was always a tenuous peaceful coexistence of the living things on earth. But eventually one kind of animal found it possible to occupy new niches at will, escaping the ancient constraint of a fixed niche that is imposed on all others by natural selection ..... The activities of this new form of animal are inevitably hostile to the interest of almost all the other kinds. It has been carrying on this new way of life for only nine thousand years.

I have one criticism of Colinvaux's book: I do not understand why it is called 'Why Big Fierce Animals are Rare'. Man is probably the most common of all the large animals, and is certainly the fiercest!

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INDICATORS IN COMPLEX SYSTEMS*

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1. Introduction

Previous contributions have already shown many interactions between air, water, soil, chemicals and biotic factors. When these interactions occur at one specific site they are called vertical relationships. Besides, there are the horizontal relationships between areas that are geographically apart, which have not been dealt with extensively in this issue. Horizontal relations usually cross the country borders and thus are international, e.g. man-induced climate changes, oceanic pollution and European-African bird migration. Several international organizations keep themselves busy with environmental matters and assess whether mankind as a whole or as a group of countries is gaining or losing in environmental quality. From time to time the environmental thermometer is read and a so-called State of the Environment presented. Since the US-Council of Environmental Quality started to do so in 1970 this has become customary in the European Communities, the Council of Europe, the OECD (Organisation for Economic Cooperation and Development), the ECE (the UN – Economic Commission for Europe) and UNEP (the UN – Environment Programme).

For such statements environmental indicators are needed, and one can wonder how these relate to the ecological indicators discussed here. However, hardly any connection exists, as is illustrated by the following (UN-ECE, 1981).

Three East and three West European countries agreed in a harmonisation test of what should be understood with environmental indicators. The Eastern countries mentioned statistics on housing, sanitation, social and medical care and public utilities, the Western countries emphasised land use and emissions of pollutants, but none of them used ecological quality parameters.

2. Indication as a General Term

An indication should simply make aware of something that is happening or going on. It then becomes important to find features or symptoms that can be analysed: the variables or parameters. When ecological features are being measured at regular intervals and over large areas it may be called biological or ecological monitoring. An example is the monitoring of bird migration (Kwak and Stortelder 1981).

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Bird migration is so complex that no straight-foreward relation with one single factor can be concluded. Temperature, light intensivity, daylength, food and the hormonal internal clock are sensorially and physiologically integrated into migratory behaviour. Migration is just a general indicator of a complex happening; more specific indications of environmental change can only be obtained by many years of observation (monitoring), revealing changes in numbers of migrants or wintervisitors and in migration time and direction. Thus, parametrisation is needed for an ecological monitoring system whose aim it is to alert and assess.

3. Factors and Trends

Changes (= effects) are rarely simultaneously monofactorial (e.g. nutrient dependent) and on a micro-scale (one or a few individuals) as in the case of Taraxum (Oosterveld, 1983).

The extinction of birds of prey in the eastern part of The Netherlands during the sixties (Van Os, 1981) could be monofactorially correlated with the use of pesticide-dressing of seeds. But the rapid decrease of seals in the Waddensea can surely not be monofactorially attributed to PCB's (Reijnders, 1980); too much emphasis on PCB's might even obscure attention for possible other causes. (de Wolf, 1983). The decrease in the population of the great tern in the late sixties could be explained satisfactorily by an incidental large release of pesticides, and was thus well to parametrisize, but widespread strong increase in populations of the black-headed and herring-gulls can only be very generally correlated with overall pollution, in particular by wasting around food surplusses of our affluent society, and therefore is hard to parametrisize, let alone to be monitored. The absence as well as the presence of something can be regarded as an indicator (negative or positive). If lampreys and millers thumbs disappear from our rivulets, in spite of strict protection enforced under the Nature Protection Law, is it a negative indication, but it is not clear for what: manure-emissions or biotope destruction, which land development engineers try to sell us euphemistically as 'normalization'. Conversely, the encroachment of The Netherlands' dune valleys with ruderal vegetation is a positive indication of both eutrophication and desiccation and well to parametrisize (van Dijk, 1982).

In general, in The Netherlands, a decrease is observed in the frequency of plant species of oligotrophic biotopes and an increase of species of eutrophic ones.

The averaging broader bill and longer intestine of city blackbirds compared with those from more natural areas, is a well parametrisized indicator for their urbanization and altered consumption pattern (Maréchal, 1982). Previously we used terms like culture-eschew and culture-loving animals; now we call them negative and positive indicators, with as a general tendency for the former to get rare and for the latter to get abundant, and the overall trend being a levelling of differences in ecosystems and landscape due to the land developmental 'normalization'.

4. Ecosystem Parameters Used as Indicators

Even complex variables such as population dynamics, diversity, rarity, trophic structure and stability can serve as indicators.

Regarding population dynamics some relevant parameters are clutch size, breeding success, predation pressure, carrying capacity of the environment and other density-dependent factors which can be used to establish the vitality index of species.

Sometimes, however, all this neat ecological research is rendered useless. When in May in the middle of the breeding season hundreds of godwits (supreme indicator of moist meadows; see Beintema, 1983) on first sight healthy but aimlessly stroll around the shores of the Oostvaardersplassen in higher densities than anywhere else, then only one supposition seems at hand: this is an indication that the godwits population dynamics is once again heavily disturbed by circle-mowers that mashed nests and chickens and expelled the parents. Thus, if ecosystem-indicators are to be used one should be sure that no artifacts like mowing-regimes or artificial feeding and nestboxes disturbs the functioning of the ecosystem processes. Even then the purity of the biological information can be doubted, as this may be derived from geographically separate populations. For instance before taking the population dynamics of the black grouse as an indicator, geographical differences should be first established (in Norway much more a forest bird than in The Netherlands) as well as other factors which make that in different areas only certain trajects of a much wider amplitude of habitats is being realized (Maréchal, 1983).

There may be sampling problems, simply because the area is too small for a reliable sample to be taken. The decision to use a species as an indicator is often only possible after a longitudinal research as e.g. in the case of the bird census of the Province Drenthe (van Os, 1981) or the work on soil and earthworms by the State Institute for Nature Management (Eijsackers, 1983).

5. Diversity and Stability

Ecosystems function as if being one super organism in which feedback mechanisms regulate stability between trophic levels (primary producers, herbivores, carnivores, decomposers) and between species of the same level. Differences in species diversity can be indicators of complex phenomena such as agricultural management. A Swiss study (Luder, 1982) mentions for orchards and other wooded areas 50 bird species against 31 for open agricultural land. The diversity is 10–29 species for wooded areas and 1–11 for cropfields and pastures with average densities of 1.9 against 0.5 bird per ha. De Boer (1983) and Beintema (1983) make it clear that the spectacular decrease in diversity in grasland vegetation and in populations of meadow-birds, respectively, are indicators for such complex changes as manure application, drainage and grazing. On the ecosystem-level changes in the interactions between plants, animals and micro-organisms, such as in pollination, litter decomposition and predator-prey-relationships can be considered. The disfunctioning of an ecosystem features in what we call plagues or pests. Much agricultural research is focussed on controlling this disfunctioning and has therefore contributed much to the knowledge of ecological principles, making clear, among others, that there is no straightforeward relationship between diversity and stability.

6. Flows of Matter, Energy and Information

All ecosystems function on the basis of matter, energy and information. Their flows in space and time are interwoven. Thanks to pioneers like the Odum's (Eugene and Howard), R. Margalef, A. Macfadyan, D. Pimentel and others progress in the parametrization of matter flows in open and closed systems, of energetic efficiencies of trophic conversions in the foodweb and of genetic information has come to a point that it can be applied to rational management of ecosystems, provided that the political will and power for such a management is present. Flow of genetic information still seems to be the most difficult of the three to be managed. Taking the political will and executive power to implement available know-how for granted, Tinbergen (1982) mentions two crucial areas where extension of fundamental knowledge is still needed for humankind and the preservation of the biosphere as a whole:

- the role of the biosphere in the climate (i.e. the relationship between climate and the bio-geo-chemical cycles of carbon and the impact of climate on the biosphere) and
- the long-term impact on the stability of separate ecosystems and the biosphere as a whole of the gradually increasing rate of genetic erosion (the loss (for ever) of genetic diversity that was built up over millions of years).

The climate-biosphere interactions are studied at an international symposium in Osnabrück under the European Communities Climate Programme (Lieth, 1983).

About the long-term impact of genetic erosion one can only guess. Extinction of species no doubt causes an impoverishment of ecosystems but it has not yet resulted in catastrophic situations. For instance it bothers only a very small part of the population that more than 50 plant species in The Netherlands have disappeared and that another few hundreds have become rare since the beginning of this century. Almost no ecosystem will escape from anthropogenization, i.e. subjugation to human utilization and impact. That also means that no ecological indicator escapes from 'noise' by artifacts and that it will become increasingly difficult to distinguish signal from noise. De Boer (1983) makes a point with regard to information flow, in emphasizing the importance of vegetation-relicts as nuclei for policies aiming at restoration of the environment. Such policies, of course, do not redress the anthropogenization but it is a means of regulation and management within a longer term perspective (i.e. a survival strategy for the biosphere).

7. Lines of Research

To come to grips with ecological complexity, multi- and interdisciplinary research is needed, in particular in Biosphere-Reserves. The idea of BR's was developed since 1973 under the UNESCO programme-Man and the Biosphere. A Biosphere Reserve implies monitoring of physical, chemical, biotic and anthropogenic parameters.

In their study on the meaning of biological monitoring Meijers and Van Selm (1982) and Meijers *et al.* (1982) come to the conclusion that only an approach such as for Biospere Reserves makes sense, because of the feed-back on management measures and for (optimal) discovery of worldwide trends. It is hoped that for The Netherlands the Council for Research on Environment and Nature will focus new attention on the usefulness of participation in an international cooperative programme like Man and the Biosphere and that at some time the Waddensea-area becomes the first transboundary Biosphere Reserve.

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VEGETATION AS AN INDICATOR OF ENVIRONMENTAL CHANGES*

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Abstract. Composition of the vegetation and the properties of its environment are related, as was shown by research. In these, mostly statistical-correlative studies, both the vegetation and some growth factors, such as plant nutrients and moisture supply were analyzed and studied on interdependence.

At present the environmental conditions can be estimated in the field from the floristic composition with regard to differences both in the combination of plant species and in their relative biomass production.

With a vegetation survey the spatial pattern of the different environmental conditions can be indicated. For instance, the places where moisture supply gradients occur can be detected, also a better understanding is obtained of the environmental equalization and the decreasing number of plant species and spatial diversity.

Conclusions can be drawn about changes in the vegetation to be expected, from the combined occurrence of, a terrestrial vegetation indicating an eutrofied environment and a water vegetation indicating a relatively oligotrophic environment.

By comparing vegetation recordings of the past and present, environmental changes that have occurred in the same place can be indicated.

By vegetations situated in different places in relation with soil profile properties the consequences of environmental changes can be predicted. For instance, lowering of the ground water table and intensifying the agricultural use.

On the other hand, measures can be suggested to increase the biological value of land and water, for instance, indication of seepage areas and floristically rich areas in the field.

1. Introduction

The term vegetation is used in different ways. Often it is used in a general sense of plant cover. Then, the term includes all the places where plants grow, for instance, woods, agricultural and horticultural crops, grassland, etc.

In vegetation science the term vegetation simply means a composition of plants including one or more species of which the combination, the proportion and the spatial order depend on the growth conditions and the competitive ability and adaptation. Field experience has shown that vegetation types or plant associations can be distinguished. Analyses of the floristic composition both according to a method of selection of the sample area and according to select method of sampling via lines or transects have demonstrated this.

In several studies the habitat was analyzed for a number of abiotic factors. This analysis showed a relation between the floristic composition and the abiotic factors analyzed (Kruijne *et al.*, 1967). In the reverse, with this knowledge the abiotic growth factors or environmental conditions can be estimated from the floristic composition of

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the vegetation. When the defined vegetation types are mapped, the spatial pattern of one or more factors of the abiotic environment can be derived (de Boer, 1956).

Since the vegetation and sometimes the plant cover is important to the fauna, partly as food and partly as habitat, a vegetation map also shows the possibilities for animal species. Of course, this implies knowledge of the relations between vegetation and fauna.

From the preceding it may be concluded that the vegetation map may be an important contribution to the landscape ecology of an area (de Boer, 1965). Moreover the vegetation map can be helpful in formulating the 'aesthetic' value of the landscape.

2. Development of the Dutch Grasslands

When the abiotic factors from place to place vary widely, in general the differences in the composition of the vegetation will be greater than when the variations are smaller. Great differences in vegetation type may also be caused by biotic factors: differences in the use by man and animals, or by differences in management.

The terrestrial vegetation types, which vary most in structure and floristic composition are formed by these differences in use. For instance, the forests, which have partly been planted, but in which the herbaceous layer still closely resembles that of the natural forests. The formerly wooded areas which have been transformed to grassland by burning, grazing and cutting show a completely different vegetation type consisting only of a herb and a moss layer, whereas the forests consist in general of three (four) vegetation layers, namely herbs (mosses), bushes and trees. Differences in the abiotic factors, such as soil moisture and acidity of the soil, natural differences in plant nutrients and, to a less extent, in soil texture and structure cause distinct differences in the floristic composition of these grasslands. In addition the use as pasture or hayfield greatly affects the floristic composition.

Since the use of the grassland in many areas in The Netherlands has been practically the same for centuries, relatively stable vegetation types were formed. The hay harvested from the fields situated far from the farm buildings was used in indoor feeding. The greater part of the plant nutrients are passed in the droppings. This dung was used to manure the pastures near the farm buildings and on the mixed farms on the arable land. Thus an influx of minerals started to move from the far-off parcels of grassland to those situated nearby. The hayfields were more and more exhausted by this and so the 'blue-grasslands', in vegetation science called Molinietum, were formed. In this type of grassland numerous plant species occurred (sometimes even 120 species). The dominant species were *Molinia caerulea* and *Carex panicea*. The bluish coloured leaves of the latter species together with some purple and blue flowering species, led to the name 'blue-grassland'. Near the farm buildings a completely different grassland vegetation was formed by the accumulation of plant nutrients and the management of continuous grazing. *Lolium perenne* and *Poa*-species were dominant here. The colour of these grasslands was bright green. Between these two types many transitions existed. This caused the well-known phenomenon of zonation of vegetation types in various grassland districts of The Netherlands, which could be observed on a large scale in a somewhat moderate form towards the end of the forties of this century.

Man had increased the diversity of the abiotic environment, because the use of certain areas had to be adapted to natural variations, for example, elevation above the soil moisture level: the arable fields were on the more elevated soils and the grasslands on the lower ones. The differences increased even more.

In the present landscape the differences are fading. The differences in the content of plant nutrients, originating from the differences in use, have almost disappeared everywhere because of the imported nutrients: the whole abiotic environment was brought at a higher nutrient level. Moreover, with grassland the use of all fields is more uniform, involving alternately grazing and cutting. The same applies, to a less extent, to changes in the vegetation types of roadsides and ditches.

3. Vegetation Typology in the Present Cultivated Landscape

If in the present cultivated areas a vegetation survey is made, which more or less indicates the environmental differences, it is not sufficient to use only the variations in the combination of plant species. Only those plant species, which converted the available supply of plant nutrients into a greater growth rate persist, whereas the other ones disappeared mostly by deficiency of light in the dense plant cover (Kruijne, 1964).

However, the plant species at present still occurring show a relation of their proportion in the vegetation with the greater or smaller effect of a growth factor on the environment. Two methods were applied to establish this. In one method a study was made of the extent to which a plant species occurs more than co-incidentally in a vegetation, dependent on growth conditions, competition and adaptation. This method is also known as the cluster analysis, because mathematically clusters of plant species are obtained. Because the place of the cluster in the multi-dimensional diagram is determined by the growth conditions, ecological data on a few plant species will allow an assessment of the growth conditions belonging to a certain cluster (de Vries *et al.*, 1954; de Lange, 1972).

Another method is to make vegetation analyses in a great number of sites, determining at the same time various growth conditions, such as soil moisture supply, phosphate and potassium status, pH value, for grassland use, etc. In Kruijne *et al.* (1967) a summary is given based on data of 1577 grasslands in which 453 plant species occurred. Botanical samples were taken and analyzed and in this way the frequency percentages per species were assessed in the experimental fields. The growth factors observed were divided into classes, such as phosphate classes, grassland use classes, etc.

Next, the relative frequency percentage was calculated, based on the average occurrence per environmental factor, so that less frequently occurring species also had comparable values. Thus a comparable outline of all the species was obtained, of the height of the relative frequency percentage per class of the various factors, indicating the chance of a species occurring more or less frequently in, for instance wet, moist, moderately dry or dry environments. An arithmetic method was used to calculate an indication number per plant species and per environmental factor. Hence, the indicator values for the different environmental factors can be calculated for a vegetation by multiplying the percentage share per plant species with its indicator values (Kruijne *et al.*, 1967).

Another method of assigning an indicator value to plant species for environmental factors is to collect from all kind of observations, data on the occurrence of plant species in all kind of habitats and to assign with these data an indicator value per environmental factor (Ellenberg, 1979). However, because many of these data are not comparable, this method is less clear than the former method restricted to grasslands.

This knowledge together with vegetation analyses of the currently occurring vegetation types were used to form groups of indicator species, which say something about a complex or about one growth factor. A higher percentage of such a group indicates more influence of the concerning growth factor at that place.

4. Moisture Supply Classes

Groups of indicator plants for the soil moisture status are determined on the basis of the above mentioned research and my own studies on moisture and drought indicators. Occurrence of such indicator groups is expressed in classes of basal plant cover percentages. The soil moisture indicated by the vegetation is not only related to phreatic water levels in the soil, but also to the texture and the organic matter content of the soil (de Vries and de Boer, 1959; de Boer and Ferrari, 1961).

The above mentioned percentage classes of moisture supply indicator groups are estimated during the field survey. The areas belonging to the same class are mentioned in the legend with terms as wet, moist, somewhat dry, etc.

Studies on the relation between the moisture supply map based on the vegetation and a phreatic soil water map based on oxidation and reduction phenomena in the soil profile showed a reasonable similarity per soil type. Yet there are always deviations, both to the wetter side and to the drier side. A more detailed study showed that this might be due to different reasons. One being possibly the methodological difference between a vegetation and a soil survey in adjusting the border between the mapping units. In a soil survey the determination of the border between two mapped areas, belonging to different soil types depends to a large extent on the distance between the auger holes. Of course, the final scale of the soil map is also taken into account. In addition, however, small differences in height in the area are also used. In a vegetation survey the borders between the areas belonging to different types can be directly observed in the field. However, in the field there often are no sharp limits between differences in the floristic composition and therefore neither between the vegetation units, which are based on these differences. This is distinctly so for a vegetation indicating the moisture supply. Only if the field boundary coincides with vegetation moisture classes, due to differences in trenching, additional drainage, etc., there is a distinct border (Kop, 1965).

Besides other causes for the differences between the soil moisture classes and the vegetation moisture classes were established in the field afterwards. One of these may be poor permeability of the upper layer in the soil profile, or thin layers of good, moisture retaining soil. The floristic composition always responds distinctly to these differences, this in contrast to the soil moisture classes.

A mixture of moisture and drought indicators can also be observed, for instance, on a soil profile where boulder clay and tertiary clay occur rather high in the profile. In rainy periods the soil is very wet in these places and in periods of drought the soil is dry. This applies to rather horizontal soil surfaces and also to the situation of a slope, but only if the surface of the soil and of the boulder clay layer are parallel. If the slope of the boulder clay layer is less steep than the slope of the soil surface, but in the same direction, we get stow water in the profile, even by deeper laying boulder clay. An undulating boulder clay surface also gives differences in the water supply situation at the soil surface demonstrated by differences in the number and species composition of the indicators.

5. Eutrophication Classes

The moisture supply classes were treated in some more detail to explain the principle of a vegetation as an indicator of an environmental factor. The same principle is used in a classification of eutrophication by the vegetation. For grassland this is usually expressed in agricultural pressure classes, because the intensity of grazing and the frequency of cutting increases with the amount of fertilizer applied. Fertilizer applications cause the eutrophication. With increasing eutrophication of roadsides, ditch sides, and water in the ditches and with raising the agricultural pressure on grassland, other indicator plants will occur or the coverage of these indicator plants will vary, but in addition the number of plant species will decrease.

6. Other Environmental Indications

Other factors affecting the growth site, which are indicated by the vegetation are not treated in this paper. They are phenomena, like the frequent opening of roadsides to lay down cables and pipelines, regular removal of water vegetation, damage of the sward by cutting too deep or scorching by urine, etc. When the soil is eutrophied this is accompanied with the invasion of species like couch grass (*Elytrigia repens* (L.) Desv.), common dock (*Rumex obtusifolius* L.) and curled dock (*Rumex crispus* L.). In vegetation surveys derived maps are also made, which indicate this disturbance of the vegetation.

7. Vegetation as an Indicator of Environmental Changes

By mapping the vegetation types distinguished in this way, the pattern of the moisture gradients and the extent of eutrophication can be better understood. The plant species occurring in addition to the indicator species often indicate to some extent the composition of the former local vegetation. The vegetation map also gives information about the natural vegetation types along fields and ditches and roadsides, because it covers an area completely. In this way some idea can be obtained about vegetation types which were present in the past. A map of the actual vegetation can therefore give some indication of the environmental changes that have occurred.

Vegetation surveys of 30 to 50 yrs ago, available for some places, also give a rough idea of the vegetation units and their spatial distribution at that time.

At present vegetation maps are made in relation to land development planning in many areas. With the help of both types of information, the vegetation along ditches, etc. and the old maps it is possible to give a rough indication of the environmental changes that have been taking place as compared with 30 to 50 yrs ago.

Via the spatial pattern on the vegetation map it is also possible to indicate which environmental changes will take place in the area without changing the management. Simultaneously with the vegetation survey throughout the area, the growth sites of the rarer plants are indicated, which provides extra information on the environmental changes that have occurred. Often these species are relicts of former vegetations. Since these have no relation to the current vegetation types, they have to be mapped separately. The vegetation map also gives information on the sites in an area, where it is likely that the plant association of the past can be restored (regenerated) with a purposeful management. Studies in experimental plots showed that this will take a shorter or longer time, depending on the growth site.

Restoration of the vegetation will occur more rapidly on dry lime or acid soils than on wet soils, particularly if plant associations are desired under oligotrophic conditions. It may be concluded that it is possible to indicate environmental changes by means of vegetation surveys. One survey will enable this, but repeated surveys will be much the better.

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TARAXACUM SPECIES AS ENVIRONMENTAL INDICATORS FOR GRASSLAND MANAGEMENT*

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Abstract. A classification of the microspecies of the genus *Taraxacum* was made in a range from low to highly dynamic habitats based on qualitative inventories of grasslands under different management conditions. After several years of constant management, a characteristic species composition occurs. Under mowing (hayfield) conditions, dandelions disappear over a period of about twenty years in a sequence where the low-dynamic species *T. adamii* and *T. nordstedtii* are the last to vanish. Different microspecies in the section *Vulgaria* in one field can show small differences in response to environmental conditions, even where no other directly visible indication exists. New appearance of highly dynamic species can indicate disturbance of some kind or other within a relatively short period.

The classification adopted seems to be correlated with the phosphate content of the soil. Differences in two easily perceptible morphological characteristics, namely position of the outer bracts and colour of the leaf-stem, fit into the established sequence. Small changes in these characteristics indicate conditions in the field that are improving or worsening from a nature-conservation point of view. A system is introduced in which merely these two morphological characters, without further taxonomical knowledge, can be used for an evaluation of grasslands and the impact of management practice.

1. Introduction

In The Netherlands, the preservation of grasslands, rich in plant and animal species, which developed as a result of old farming practices, is a main objective now for nature conservation. Within the framework of land reallotment schemes, already improved grasslands were also set apart for nature-conservation purposes. Under mowing or grazing management and little or no manuring and, if possible, restoration of the former abiotic conditions like groundwater levels, attempts are being made to restore conditions for species-rich communities.

Natural establishment, development and disappearance of plant species are our measuring-instruments for ecological and technical indication with respect to conservation objectives (Table I). Ecological indication is related to environmental factors, while technical indication allows us to judge the efficiency of the applied management practice according to standards such as 'species diversity' and 'rarity'. Species occurrence in itself can never explain improving or worsening conditions: the appearance of *Cardamine pratensis* and *Lychnis flos-cuculi* in the top of Table I is to be considered as negative, whereas judgment must be positive if the same species appear in the low category of grasslands (Londo, 1983). The technical judgment, therefore, depends on the starting point and reference level.

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TABLE I

Ecological and technical indication for grassland management

Technical indication		N	P	K	Ecological indication
worsening conditions / improving conditions	Carex panicea	3	− 83	− 66	more nutrients available (manuring) / less nutrients available
	Carex hostiana	2	− 100	− 65	
	Orchis maculata	?	?	?	
	Molinia caerulea	2	− 88	− 73	
	↓ ↑				
	Lychnis flos-cuculi	×	− 24	− 42	
	Cardamine pratensis	×	− 5	− 6	
	Rumex acetosa	5	− 14	− 21	
	Holcus lanatus	4	− 4	− 10	
	↓ ↑				
	Lolium perenne	7	+ 22	+ 29	
	Taraxacum officinale	7	+ 17	+ 8	
	Rumex obtusifolius	9	+ 18	− 10	
	Poa trivialis	7	+ 17	+ 14	

N = Nitrogen according to Ellenberg (1974): scale 1 (poor in nitrogen) to 9 (rich in nitrogen).
P = Phosphate according to Kruyne *et al.* (1977): scale − 100 (poor in phosphate) to + 100 (rich in phosphate).
K = Potassium according to Kruyne *et al.* (1977): scale − 100 to + 100 as for phosphate.
× = Indifferent behaviour.
? = Unknown or insufficiently known.
———— = A possible rapid and easy development.
= A not always possible, slow, and laborious development.

After Londo (1983)

Species-rich communities always occur at places which are relatively low in nutrients, especially when differences in available nutrients from low to higher levels appear in gradual transitions (Zonneveld, 1983). Development of a full transition is only possible when the most oligotrophic category is dominating. For this reason, improving conditions for nature management can be summarized as the reduction of available nutrients. Worsening conditions are indicated by the vegetation relatively soon, but it takes as a rule a considerable period of time before new plant species appear under improving conditions. As part of the botanical research for nature management purposes in The Netherlands, an attempt is made to arrange species in series according to the available nutrients in the soil. Such series have been published for the gramineae and the genera *Ranunculus* and *Rumex* (RIN, 1979). Especially the establishment of similar series of ecologically closely related species of one genus can highly refine indication. Such a series for some *Carex* species has been worked out by Dirkse (1979).

When a technical indication is required for grassland management, some characteristics related to the occurrence of dandelions are striking during the month of May. Most important is that differences in densities of the yellow colour in the meadow landscape coincide with border-lines of the agricultural plots. The supposition that the occurrence of dandelions has something to do with the agricultural management is obvious. A comparison between agricultural grasslands still in modern use and neighbouring fields where farming stopped about a year earlier, already showed quite different dandelion aspects. Similar observations strengthened the idea that the genus *Taraxacum* might be a quite useful indicator of improving or worsening conditions in rather short terms.

2. General Ecology of the Genus Taraxacum

The common feature for all dandelion growth is the regular supply with new available nutrients. The form in which this happens is, however, different for the various sections of the genus. Inventories of 115 grassland plots with a known management history have made clear that species of the section *Palustria* are only found in plots which are periodically flooded with an accompanying effect of new available nutrients from the sediment. Species of the sections *Obliqua* and *Erythrosperma* are growing at places where new minerals in the form of drifting sand are accumulated regularly. Where both phenomena take place at the same time, microspecies with characteristics of the *Palustria* as well as of the *Erythrosperma* have been found (Nordenstam and van Soest, 1974; Hagendijk *et al.*, 1978). In The Netherlands species of the section *Spectabilia* can be found in plots under relatively low organic manuring, but they disappear gradually when fertilizers are used. The *Vulgaria* species increase in numbers and microspecies when more intensive farming is practized, especially manuring of the fields. An ecological diagram for the occurrence of the sections of *Taraxacum* in The Netherlands related to nutrients and moisture is given by Oosterveld (1978).

3. Aspects of Dandelion Indication

3.1. Genus level

The inventories have provided evidence that the total number of dandelions decreases rapidly under constant management. The more yellow a meadow is in springtime, the more manure has been applied. Flowering time beyond the April-May period indicates a high frequency of management activities or disturbances (Sterk, 1982).

3.2. Section level

Every section of *Taraxacum* is found under a specific set of environmental conditions. The occurrence of the section *Spectabilia* in grasslands indicates a potentially better situation for the development of communities rich in plant species than the occurrence of *Vulgaria* species only. The *Erythrosperma* indicate dry, most sandy, habitats and the

Palustria periodically flooded habitats. When *Vulgaria* species appear in grasslands where they were not found before, something undesired from a conservation point of view must be taking place. The occurrence of *Vulgaria* plants in a species-rich hayfield nature reserve which was already for decades under haymaking management, could be attributed to the gradually drying-out of the reserve due to the activities of muskrats; drying-out means mineralization of the topsoil layer and better availability of nutrients.

3.3. Species level

When fields have a longer period of constant management of some kind, not only the total number of dandelions but also the number of species decrease. At the same time more identical species-compositions occur according to the period of management constancy. Dandelions can disappear fully under haymaking conditions without additional manuring and they always disappear in the same sequence. The disappearing series ends up with *T. adamii* in about 15 yr and *T. nordstedtii* in about 20 yr (Oosterveld, 1978; Table II).

TABLE II

Taraxacum species a) in hayfields without manuring in relation to management constancy

Number of fields	10	7	4	3	6
Management constancy in years	5	8	12	15	20
T. species					
nordstedtii	+	+	+	+	(+)
adamii	+	+	+	(+)	
bracteatum	+	+	+		
infestum	+	+	(+)		
fulgidum	+	+			
hamatum	+	+			
lucidum	+	(+)			
quadrans	+	(+)			
copidophyllum	+				
hamatiforme	+				
hamatulum	+				
pannucium	+				

a) Only species with a frequency of 60% or higher are recorded

The same disappearing sequence is found when inventories in the same fields are repeated after three or more years. Evidence of establishment of new *Taraxacum* species under a non-manuring management is scarce.

After grouping of all plots in classes according to the intensity of use from no-manuring to highly fertilized plots, a classification of *Taraxacum* species can be made in a range from low to high availability of nutrients (Table III).

TABLE III

Classification of Taraxacum species a) in a sequence from low to highly dynamic habitats

more nutrients available ↓	nordstedtii
	adamii
	bracteatum
	prionum
	infestum
	hamatum
	lucidum
	hamatiforme
	hamatulum
	quadrans
	eudontum
	sellandii
	ancistrolobum
	croceiflorum

a) Only species with a relatively high frequency of occurrence are incorporated. With the exception of *T. nordstedtii* (s. Spectabilia), all recorded species belong to the section *Vulgaria*

The low frequency of occurrence of most of the *Taraxacum* species, especially those with a geographically restricted distribution, has so far prevented placing of all microspecies in one series in a statistically justified manner. Both ends of the series are clear, but, especially in the lower middle part, numerous species seem closely related in their response to effects of manuring.

From each of the three types of grasslands of Table I, more or less corresponding with the upper, middle and lower part of the series presented in Table III, one species was taken for a closer analysis of the underlying environment factors. Sampling was carried out in one field where these species were occurring at relatively short distances. The mineral content of the plants as well as the soil directly surrounding the root was determined (Table IV).

The sequence of dandelion occurrence from low to highly dynamic habitats seems to be related to the phosphate content of the soil. The increasing availability of phosphate in the environment may be the main factor responsible for the increasing numbers of dandelions in the fields. In this direction points also the fact that 50 yr ago they were only found in high numbers along roadsides.

TABLE IV

Relative percentages of some minerals in plants and directly surrounding soil for three species of *Taraxacum*

	Plant/soil ratio (%)			Soil		
				Humus content (%)	Phosphate (mg P205/100 g dry m)	
T. species	N	P	K		P(H20)	P(CH3CH(OH)COONH4)
nordstedtii (n = 10)	4.6	4.0	22.0	16.5	4	4
hamatum (n = 10)	2.2	2.4	13.6	21.8	8	9
ancistrolobum (n = 10)	7.5	4.0	14.8	8.0	27	25

The figures in Table IV show that the different microspecies of *Taraxacum*, even when growing close together, respond to different environmental conditions. Differences which are levelled off by modern agricultural use, may still be indicated by a high diversity of *Taraxacum* species. In cases where nature conservation has to choose which fields have the best capacities for a development to species-rich communities, *Taraxacum* diversity may be the only directly visible indication to base the decision upon.

4. Taraxacum Indication for Practical Use

A *Taraxacum* indication system based on the microspecies can only be useful for few specialists in taxonomy. However, when the morphology of dandelions of a species is studied, two characteristics show a distinct variation in relation to the environmental factors of the place where they are growing. For instance, in a grassland reserve at one side bordered by heath vegetation, poor in nutrients, and at the other side by agricultural grasslands, only *T. nordstedtii* occurs in low densities. The specimens of the agricultural side are robust with almost green leaf-stems and somewhat spread outer bracts. The closer the plants grow to the opposite side of the reserve, the more they decrease in size, while their leaf-stems become gradually more red and the outer bracts are closed.

This phenomenon appears to be a general one for all *Taraxacum* species with the restriction, however, that the entire possible range of variation is rarely covered. Microspecies adapted to habitats poor in nutrients become gradually green with a more reversed to retroflexed collar when such places are manured. Species of heavily disturbed habitats react in the opposite way when manuring and disturbing activities cease, resulting in a decrease of available nutrients.

The species on the bottom of the list (given in Table III) have green leaf-stems and reversed outer bracts, in the middle part pink leaf-stems and spread bracts and in the upper part red to purple leaf-stems and closed outer bracts. Some observations on one microspecies on gradients of soil compaction seem to confirm the assumption that phosphate availability may be responsible for the described variation in the two characteristics. The plants are losing colour and show a more reversed collar with the increase in soil density. A more dense soil has a lower oxygen content, which promotes a higher availability of phosphate.

The variation in the two characteristics mentioned, which are easily recognized in every dandelion, enables the presentation of an indication system for general use. With a point-score for the two characteristics, in which the outer bracts are weighing somewhat heavier than the leaf-stem colour, nine classes of dandelions arise, from two points for the 'bad' ones to ten points for the 'good' ones (Figure 1). This system does not exclude the possibility that the same microspecies can get different markings, while the appearance of the two characteristics can differ.

The summed markings of thirty dandelions, randomly sampled, give a relative evaluation of the grasslands covered. Repeated scores over a number of years can show improving or worsening conditions in relation to the applied management for nature conservation purposes, as visualized in Figure 2.

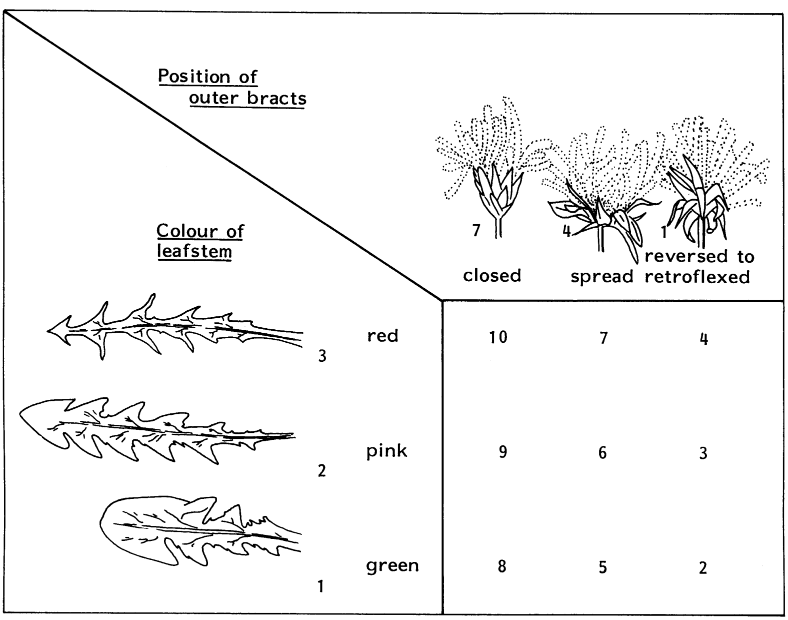

Fig. 1. Marking of *Taraxacum* species based on two morphological characteristics.

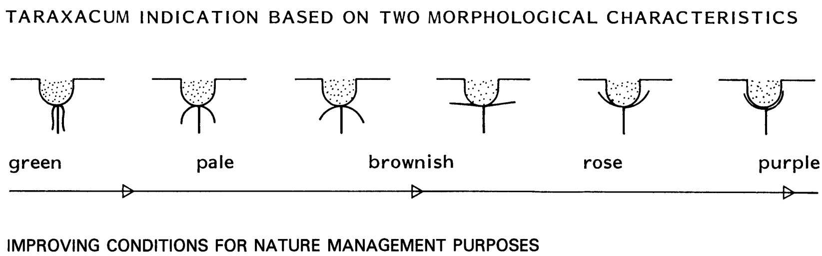

Fig. 2.

5. Discussion

Work on the indicator value of *Taraxacum* and the present research on the species genetics and ecophysiology (Sterk, 1982) is based on the taxonomical work started in The Netherlands by J. L. van Soest. The present study shows far more variation for the important diagnostical characteristics than for taxonomical purposes can be tolerated. Further taxonomical information is essential, however, at first for recognizing micro-species and in a later stage to assess their ecology and morphological characteristics as a possible response to a change in environmental factors. So far, new morphological forms have always been found in areas with changing environmental conditions. In the course of the present research programme, some forms were encountered which did not fit in the present taxonomical system. These specimens had developed under 'new' environmental conditions such as man-made water regimes nowhere found before.

It is not unlikely that the relatively young and vital genus *Taraxacum* can develop species or specific characteristics in relation to many types of environmental stresses and pollution, especially when phosphate availability is involved. For nature conservation purposes it is important to recognize such developments in an early stage. Whether the gradually increasing amount of phosphate in environments is also the key agent of species diversification within *Taraxacum* needs closer investigation.

Dandelions appear to be rapid indicators under worsening conditions and under improving conditions as well. Indication in historical sense is restricted to the lifetime of the individual plant. To what extent the present situation, measured with respect to dandelion occurrence, is a prediction for development under certain management regimes, has to be investigated more extensively. The first results are promising.

Under very favourable developments, from a nature conservation point of view, this can however hardly be deduced anymore from dandelions, while these must have largely disappeared by that time.

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MEADOW BIRDS AS INDICATORS*

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Abstract. The use of birds as indicators for 'biological qualities' is not without risks, and should always be based on a sound knowledge of population dynamics and ecological requirements of the species involved. Meadow birds form a comparatively well-studied group of waders, which breed in Dutch grasslands, heavily influenced by agricultural management. The individual species show different tolerances to intensity levels of management, and can therefore be used as indicators for these levels.

1. Introduction

The term 'meadow bird' is a translation of the Dutch word 'weidevogel', which has no true equivalent in any other language, simply because the 'weidevogel' phenomenon is only very locally known outside The Netherlands. Meadow birds do not only inhabit meadows, but grazed pastures as well (in modern dairy farming, the distinction between true meadows and pastures is becoming less clearly defined). The typical Dutch polderland, with wide open spaces of moist grasslands, holds a great variety of meadow birds, in high densities. These birds originated from natural open habitats, and established themselves secondarily in agricultural habitats. The six major species, on which this paper is mainly based, are the Lapwing *Vanellus vanellus*, the Oystercatcher *Haematopus ostralegus*, the Black-tailed Godwit *Limosa limosa*, the Redshank *Tringa totanus*, the Common Snipe *Gallinago gallinago*, and the Ruff *Philomachus pugnax*.

The use of indicators in describing biological systems is more common practice than often is realised. For instance, it is possible to give a description of a polder, which still has high water tables, and consequently, old-fashioned farming. This means low cattle densities, late mowing, etc. As a result, the air is filled with the cries of meadow birds, the pastures are rich in flowers, and the meadows even hold orchids.

Instead, I could simply state that this polder looks suitable for breeding Ruff. The insider knows that such a statement includes the properties described above. This is indicator use. In fact, the description given in the example already includes cases of indicator use. Mentioning an orchid indicates a complex set of properties of the area. However, this has only value if the relationships between indicator and the indicated phenomenon are known. To a botanist the presence of an orchid means more than the presence of just that orchid. Similarly, some knowledge is needed to understand the meaning of breeding Ruff.

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The more intricate these relationships are, the greater the risk that lack of knowledge leads to false conclusions. An example is the Golden Plover *Pluvialis apricaria*, which has been considered as an indicator for the best part of moorland peat. With the disappearance of this habitat, it disappeared as a breeding bird from The Netherlands some 50 yr ago. In Western Germany a similar development took place, but recently the plovers changed their habits, which resulted in an unexpected increase over the last decade. In large-scale peat exploitations, vast areas are drained, after which the top layer, including all vegetation, is removed. In the year after this dramatic change, the soil turns slightly green, as a result of the emergence of *Rumex acetosella*. It seems that this situation is favoured by the plovers, which thereby lose their value as indicators for living peat. This parallels the case of the Dotterel *Charadrius morinellus* (allegedly an indicator of undisturbed tundras and highlands), which started to nest below sea level in newly reclaimed polders, in freshly emerging crops of flax, beetroot and green peas.

The basic problem is that, in principle, the bird indicates itself and its ecological niche. Of course, there will be a strong correlation with a certain type of landscape or management, but there is always a possibility that niche requirements can be met with in other ways than one could ever think of.

2. History of Indicator Use in Meadow Birds

In a crowded country, like The Netherlands, there is always a conflict between different interests in land use. Therefore, planological decisions are difficult, take much time, and often include comparisons of different forms of land use, which cannot be compared by the same standards. In the late sixties and early seventies, systems were designed to describe nature and its values more quantitatively, in order to measure these against economic values. Due to basic drawbacks, which could never be satisfactorily solved (Meelis and Ter Keurs, 1976), most of this practice has been abandoned by now.

Meadow birds did not escape numerical evaluation. They form a characteristic element in the Dutch avifauna, and are considered as an important item in nature conservation. In order to choose areas to buy for refuges, or in which arrangements with farmers should be promoted, governmental nature conservancy agencies developed a method to assign numerical values to such areas. The least vulnerable species, Lapwing and Oystercatcher, were given 1 point per pair, the Black-tailed Godwit 2, the Redshank 3, the vulnerable Ruff 5, and the comparatively rare Curlew *Numenius arquata* 10. The total of the points per hectare is then a measure for the quality as meadow-bird area.

For its purpose – selection of the best 100 000 ha – this method served well (Ministry of Culture, Recreation and Social Affairs, 1979). However, points, scale, and standard started to live their own life, which gave rise to problems, especially when the scale was applied locally, or under changing conditions (Beintema, 1979). There are three problems:

- the difference between actual and potential value of an area;
- regional differences in species composition;

– the criteria used to set up the scale.

If an area has lost value due to intensified farming, it may no longer meet the 'standard'. Adversaries of nature conservation may then try to get it removed from the selected list, while it is well known that adequate management will restore the area. Nature conservationists may then, in response, urge to lower the standard, in order to get the area back on the list. Thus we may end up in reversed reasoning, in which selection of areas is no longer based on a desired standard, but selection of the standard is based on desired areas. Also, any change in the standard will affect other areas, in which changes occur less, or more quickly.

The second problem (regional differences) is best illustrated in the Curlew. Its high 'value' finds little appreciation in regions which have no Curlews, and therefore need higher densities of other species to collect enough points. Local people want to compensate for that by assigning high values to regionally characteristic species, which are not represented in the scale. Obviously, such a change leads to a chain reaction of problems, each shifted to the neighbour. Again, there is the danger of reversed thinking.

The third problem (criteria), can also be illustrated in the Curlew. The main criterium used was rarity, combined with vulnerability towards changes in habitat. In The Netherlands, the Curlew is an uncommon bird of heathlands, moorlands, and dunes, which has considerably decreased as a result of cultivation of its habitats. In recently cultivated areas it remains in small, dwindling numbers in marginal grasslands. Apart from this, Curlews tend to develop into 'new style' meadow birds in modern, intensively used pastures, which have already lost their significance for most other species. I will return

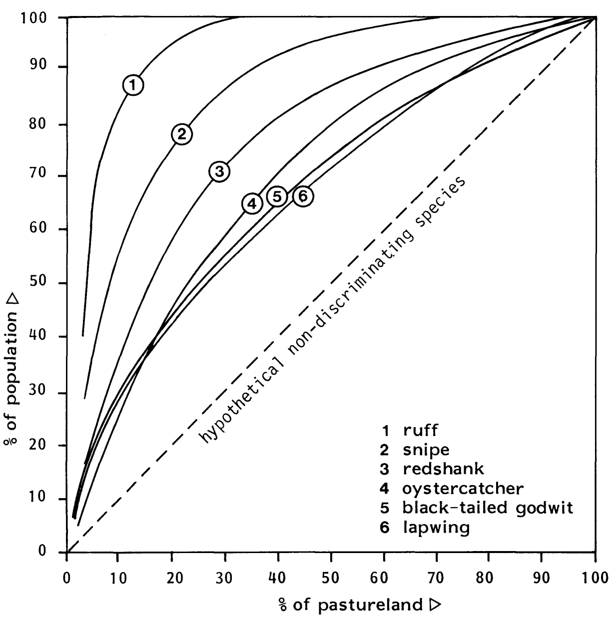

Fig. 1. Selectiveness of meadow birds; explanation in text.

to this later, and leave this point with the remark that rarity may be caused by other factors than those for which the indicator is thought to be used.

As an alternative criterium I have introduced un-evenness in spatial distribution. A non-discriminating species is thought to show an even distribution, while a species with specific preferences will occur more patchily (Figure 1, Beintema, 1975). To illustrate this, regional counts within one large area were used. For each species, regions were arranged, ranked according to densities from high to low. In the same order, the accumulated total of pairs (as percentage of the grand total) was plotted against the accumulated percentage of the total area of pasture within those regions. A species with an even distribution will then follow the diagonal (dotted) line in Figure 1. The more uneven the distribution of a species is, the more it will deviate from this. If this deviation is used as a criterium for selectiveness (quality), the Ruff gets the highest value, the Lapwing the lowest. The order resembles the numerical scale, only the Oystercatcher falls into the wrong place, as it is generally believed to be the least selective, and least vulnerable of the meadow birds.

In the same data, the indicator value (for good meadow-bird areas) for each species was analyzed, by judging the densities of other species occurring in the best areas for that particular species. The same order appears: the Ruff is the best, the Lapwing the worst. For each of the six species, Table I gives the percentage of the total populations of all species, found in the best 10% of the area, for that species. For example, the best 10% of the area for the Ruff (case a in Table I), not only holds 85% of the total Ruff population, but also more than half the Snipe population, one third of the Redshanks, and 15–20% of the remaining species. In sharp contrast the best 10% for the Lapwing (case f), only the Lapwing itself and the Black-tailed Godwit exceed the 'hypothetical non-discriminating' 10%. Snipe and Redshank even score below 10%, and the Ruff is totally lacking.

For planological purposes, this way of indicator-use is a good and easy alternative for assigning numerical values (Beintema, 1979). If a certain amount of habitat has to be 'placed on a list', one can simply start with areas which still have breeding Ruff, and

TABLE I

Values of meadow birds (a-f) as indicators for meadowbirds areas. Figures indicate percentages of populations in the best 10% of the area, for different species; explanation in text. Figures above 10 rounded to nearest 5.

	Ruff (a)	Snipe (b)	Redshank (c)	Oystercatcher (d)	B.t. Godwit (e)	Lapwing (f)
Ruff	85	85	75	75	30	0
Snipe	55	55	35	30	35	7
Redshank	35	35	35	25	30	6
Oystercatcher	15	15	20	25	20	10
Bl.t. Godwit	20	20	20	25	30	15
Lapwing	15	15	10	15	20	25
Sum (= not total)	225	225	195	195	165	65

if there are no more places which hold Ruff, add areas with the highest densities of Snipes, followed by Redshank areas, etc.

3. Background of Vulnerability

The value as an indicator is only applicable to factors for which the indicator was meant. In the case of meadow birds, indicator value is obviously related to factors which threaten their existence (the impact of further intensifying of agriculture). One should realize that a non-discriminating, not vulnerable bird (as meadow bird) may be extremely vulnerable to factors which we do not investigate, or maybe even not recognise.

Vulnerability towards agricultural pressure is based on population dynamics. If the six species are arranged according to increasing annual mortality rates, the following order appears: Oystercatcher – Lapwing – Godwit – Ruff – Redshank – Snipe. Two things can be noted:

- in the same order, body size (weight) decreases (a general rule, throughout the animal kingdom);
- the order resembles both numerical-value order, and indicator-value order. Only this time the Ruff falls into the wrong place, as it is considered to be the most vulnerable.

A population should have an annual recruitment, sufficiently high to compensate for annual mortality. In the above order, recruitment should increase from left to right. These differences in 'obligations' can be expected to be reflected in reproduction strategies. Generally, birds with high obligations (small birds) produce larger clutches and/or more broods, than those with low obligations (large birds). Neither of this is true for our meadow birds. Instead, we see that in the order from Oystercatcher to Snipe, nests are increasingly better concealed, which reduces egg loss through predation. Thus, Oysterchatcher and Lapwing can afford higher nest losses than Redshank and Snipe. This explains vulnerability towards agriculture: hiding helps against predators, but not against cattle and machines!

The situation is more complex. Not only the 'obligatory recruitment' counts, but also the timing in relation to agricultural activities. As the amount of destruction increases with the progress of the season, late nesters suffer more losses than early nesters. This comes on top of the previous effect, because better hiders tend to start later – they need more vegetation. The effect of late nesting is particularly severe in the case of the Ruff.

Finally, it is not only nest loss which determines the chances to reproduce, but also the possibilities to make replacement clutches. Thus, it is possible to make a Lapwing re-lay up to eight times. Re-laying capacity differs between species, and is strongly influenced by the length of the season. The longer the season, the more opportunities. In combination with the other factors, it is its low re-laying capacity which makes the Ruff the most vulnerable meadow bird.

A combination of all properties yields the final vulnerability order: Oystercatcher – Lapwing – Godwit – Redshank – Ruff. The Snipe is omitted, this time, because of insufficient knowledge of some of its parameters. I have tried to combine all these properties in a simple model (Beintema and Müskens, 1981), which predicts for any given management scenario, whether the species can produce sufficient offspring or not (Snipe again not included).

With this model the hypothetical chance of reproduction for each species was estimated for several management schemes, which were recorded in the field. Estimates were made for each management unit (parcel) separately, and the average over all units was calculated. In all cases, the model predicted decreasing probabilities for sufficient reproduction in the order: Oystercatcher – Lapwing – Godwit – Redshank – Ruff (true reproduction success was not known).

When calculating the average probability for a whole area, one can weigh this average, according to the actual differences in densities of the birds (counted in the field). An interesting experiment is to estimate the probability of reproduction for the Ruff, assuming that it had the density distribution of the Oystercatcher. The same was done for all combinations of species. This led to some observations:

Ruff are only found where the model predicts the highest probabilities for reproduction. The weighed average for a whole area, for the Ruff, is highest if the spatial distribution of the Ruff itself is used. The result is minimal if the distribution of the Oystercatcher is used. This means that Ruff choose places with the least intensive management (alternatively: they may be wiped out elsewhere). Thus, the Ruff is the best indicator for non-intensive management. The Oystercatcher chooses more in favour of intensive management.

All other species give the best results in the model, if the average outcome is weighed according to the distribution of the Ruff. Why do they then adopt another, less successful distribution pattern? In the first place, the model does not take specific habitat choices, such as the striking preference of the Redshank for coastal saltings, into account. Of course, this is a shortcoming, and the model cannot be used to explain densities. It was purely designed to test, given a certain density, whether management permits sufficient reproduction. Still, within this limitation, species can be compared with respect to their tolerance. From a management point of view, only very few small spots are still suitable for Ruff. If other species would adopt this distribution pattern, they simply would have to abandon most of the area they inhabit at present. Their higher tolerance enables them, at the cost of more nest losses, to occupy more land. In the order from Oystercatcher to Ruff, the birds become better indicators for non-intensive management.

4. Discussion

Properties which give meadow birds indicator values are now better understood. This is also interesting from a historical point of view. All meadow-bird species need a minimum of agricultural intensity, otherwise the whole phenomenon could never have developed. The system flourishes, until the maximum limit of intensity which the species can tolerate is reached. After that, the system collapses. Levels of management, at which minimum, optimum, and maximum occur, differ between species. In the Dutch agricultural system, where the aim is an ever continuing increase of intensity, the maximum limit has been passed a long time ago in the case of the Ruff. The Redshank has gone over the edge more recently, and the Lapwing and the Godwit are in a critical stage. The Oystercatcher has only recently passed its minimum level of intensity needed, and it still spreading and increasing as a meadow bird.

The model gives a good clue for relative intensity levels for the maximum limits to be tolerated. The minimum level which is needed is a different case. Hypothetically, this may be purely a matter of body weight. The heavier a bird is, the heavier also its eggs are. Still, all species produce a full clutch in five days, so the heavier birds need more extra protein food. Thus, going from Snipe to Oystercatcher, the birds may need a higher density of food organisms, and this is correlated with the level of fertilization. Thus, intensifying has two opposite effects: potentially, the birds can settle in higher densities, but the chances to achieve sufficient reproduction are lowered. A rich meadow-bird system can only develop within the limits discussed above.

Assuming that minimum levels are strictly related to body weight, and following the model for the maximum levels, then not only different tolerance levels are found, but also different ranges of tolerance for the different species (Figure 2). Although highly speculative, Figure 2 might give a clue to the 'wrong' position of the Oystercatcher in Figure 1. According to Figure 2, the Ruff is not the only good indicator for management levels (because of its narrow range of tolerance), but the same is true for the Oystercatcher, albeit that the latter indicates high intensities of management instead of low ones. Obviously, the Lapwing is the worst indicator.

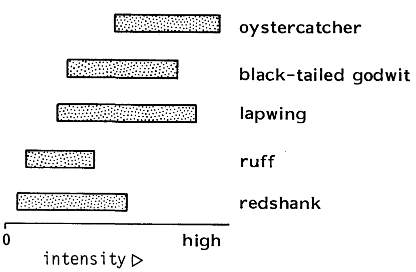

Fig. 2. Preference and tolerance of meadow birds for intensity levels (arbitrary) of agricultural management. Alternatively, the intensity scale can be seen as an arbitrary time scale.

With these new ideas, I return to the Curlew in the Dutch meadows, trying to fit it into the scheme. It appears that a Curlew is heavier than an Oystercatcher, it has a lower mortality rate, it starts relatively early in the season, and has a good re-laying capacity. Summarizing: the Curlew has excellent properties to become a new, tolerant, and successful meadow bird in the future, following the example of the Oystercatcher.

This is already happening locally. In areas, which never had breeding Curlews, they move into places which lost their significance for other species a long time ago. In some areas, where Ruff have disappeared twenty years ago, Redshanks and Godwits have become scarce, and only Lapwings can maintain themselves, Curlew populations are steadily increasing, apparently doing well.

Of course, many questions remain, but it becomes clear that defining criteria can hardly be done carefully enough, when complex creatures like birds are going to be used as indicators. Two vital restrictions should be borne in mind:

- indicator value can only be applied locally. Obviously, the occurrence of Ruff in Siberia gives us little information about the activities of Siberian farmers;
- an indicated relationship cannot be reversed. The Ruff (in The Netherlands, that is) indicates a certain type of agricultural management. On the other hand, this type of management will never guarantee the occurrence of Ruff.

As a conclusion, it must be stated that a bird only indicates its own occurrence, and that any further conclusions need a lot of supporting evidence.

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ECOLOGICAL INDICATOR ORGANISMS FOR ENVIRONMENTAL PROTECTION POLICY*

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Abstract. Environmental protection policy strives to maintain an environment favourable to human health, agriculture, and the preservation of natural heritage. Infringements upon the environment have been either by sudden deliberate action of man (construction, land reclamation, dams, etc.) or by gradual, insipid stress of chemical and physical agents (chemical substances, heat, noise, radiation, etc.). Indeliberate unwanted stress upon the environment may be measured either by observing biological effects on indicator organisms or by chemically analyzing contaminants in these organisms. In this respect the author pleads for modest, cost-efficient monitoring programmes of limited duration and providing policy related information in a direct way. Biological effect monitoring programmes show limited prospects at this moment.

1. Introduction

The other papers of this issue gave a scientific approach of the relation between environmental parameters and organisms, respectively ecosystems. One may wonder how this knowledge can be used to develop a policy for environmental protection. In answer I shall make some remarks to define the term policy, to illustrate the relation between science and policy and environmental protection policy in particular. Finally I shall try to indicate how biological indicator organisms may be used to construct policy.

2. Policy

The term policy appears frequently in contemporary discussions without a proper definition. A possible definition of the term policy for our purpose would be: policy is to influence development or processes, so that these developments or processes change their course. Tools for policy must thus influence, that is to say, change or disturb existing situations, or create unrest. Ecologically important to note in this respect: the time-scale for policy decisions is often small.

The objects of policy are developments or processes which need to be influenced. Therefore at first it has to be determined which developments or processes need to be influenced, and subsequently how they are to be influenced and to which end. The most suitable policy usually remains after less suitable alternatives have been eliminated.

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3. Science and Policy

Alert scientists may identify developments which need to be influenced provided that they are supported through social acceptance of their ideas. This identification may require considerable expertise. A description of the undesirable effects, as well as an analysis of the possible causes of these effects are indispensable. Policy may be designed either to change or to delete these causes. To support policy, science must provide the following information:

- a qualitative, and possibly a quantitative, description of socially significant effects;
- terms of reference to classify described effects as permissible/not permissible or desired/not desired;
- identification of parameters that cause or influence the described effects.

This implies a certain amount of basic research. In the limelight of publicity and in view of the short time-scale for policy decisions there is little patience for this basic research.

4. Environmental Protection Policy

Environmental protection policy, directed towards management of the environment, distinguishes in its choices and, in the elimination of less favourable alternatives, the following environmental parameters:

- human health: to ensure man as a consumer of air, water, food, and space of sufficient quality;
- agriculture: to ensure sufficient crop of sufficient quality (lack of contaminants, good taste, etc.);
- preservation: derived from ethical and aesthetic concerns but also to ensure sufficient genetic diversity and sufficient biological markers to show deterioration of human health and agricultural parameters at an early moment.

The promotion of the different parameters mentioned requires policy measures which are not always compatible. Therefore it has to be noted that environmental protection policy is developed simultaneously in different government departments and that these departments together provide a carefully balanced policy.

5. Infringements upon the Environment

In analyzing the effects and the concomitant deterioration of the environment, it is useful to distinguish deliberate and indeliberate infringements upon the environment. Deliberate infringements upon the environment usually aim at a different use of available space. They change the environment usually quite suddenly: for instance, creation of industrial zones, construction of houses, roads, etc., but also of agricultural activities like land reclamation, cultivation, fertilization, irrigation and the use of pesticides to combat unwanted organisms. These changes have considerable biological consequences in that sometimes the existence of numerous species and ecosystems are threatened, locally or globally.

On the contrary, the indeliberate and unconscious infringements are more sneaky. They are caused through stress by introduction of chemical or physical agents into the environment, and proceed gradually, causing pronounced biological effects only after considerable time of stress.

6. Ecological Indicator Organisms

For deliberate infringements upon the environment, the accompanying appearance and disappearance of species is of no significance. It is useless, for instance, to try and prove that a natural parc has been changed into an industrial area. Yet it is significant to relate men's activities to their biological impact upon the environment. Some figures may illustrate how some biological heritage was lost in the last decades as a result of the activities of society. In 1900 about 1400 plant species occurred in The Netherlands; at this moment 90 of these species have disappeared and 400 have become rare and yet another 260 are threatened in their existence. Several animal species have suffered too, with respect to mammals, especially bats and carnivores. For many bird species the number of breeding couples decreases year after year. The occurrence of reptiles and amphibians has decreased significantly. Since 1920, one third of the freshwater fish species in The Netherlands have either disappeared or become rare (de Molenaar, 1980). This decrease in number of species indicates a general trend in the quality of the environment.

Environmental impact assessment has been developed in many countries as a means to weigh environmental protection against social and economic benefits, in corporate as well as in the government's decision-making process. A Dutch bill, proposed to amend the Environmental Protection (General Provisions) Act, envisages procedures for environmental impact assessment; this bill was put before parliament on May 21, 1981 but not yet enacted. Environmental impact assessment may motivate the public at large and the government to carefully weigh cost and benefits, before infringing upon the environment. The objective of the afore mentioned bill is to give environmental considerations their rightful place in the decision-making process concerning activities that could have serious environmental effects. Environmental impact assessment strongly depends on scientific research.

For indeliberate, gradual infringements upon the environment, ecological indicator organisms may help detect problem areas and causes. Alert observation of biological effects, combined with analysis of causes of these effects, may help formulate effective environmental protection measures. For example, massive fish mortalities in the late sixties forced the development of emission standards and discharge controls. The Netherlands Pollution of Surface Waters Act entered into force in 1970; its main instruments include a licensing system for discharge of waste into surface waters, a system of levies, and a water quality control plan. A Multi-year Water Programme of which the last issue concerns the period 1980–1984 contains guidelines and principles for our national policy on water quality control. The Netherlands Pollution of the Sea Act, which entered into force in 1977, similarly prohibits dumping of pollutants by ships or airplanes unless exemption is granted. Yet, despite all contemporary legislation, in The Netherlands Northern Wadden Sea the seal population has declined considerably – a clear ecological indication which needs to be translated into the quality of Rhine Water (Reijnders, 1980).

A final example to be mentioned on ecological indicators in the past is massive bird-mortalities some 20 years ago, which set off a more responsible application of pesticides. The Netherlands Pesticides Act, which dates from 1962, was amended in 1975 in view of protecting the environment. A Soil Protection Bill, put before parliament at the end of 1980, envisages to provide the protection for soil and groundwater against all forms of pollution. At this moment a research programme is being conducted to draft standards for soil protection.

Apart from observing casualties one could think of a monitoring programme using ecological indicator organisms to provide continuous information on the quality of the environment in time and space. Such monitoring programmes may, for instance, be designed to measure the occurrence of certain environmental contaminants in biological material. It is not always possible to predict which contaminants in the future may need to be measured in samples collected at this moment. Therefore several countries, especially the United States and the Federal Republic of Germany have set up specimen banks to store biological material over a long time (Luepke, 1979). These samples, stored at low temperature, may then be analyzed at some later moment.

Monitoring programmes may also be designed to measure biological effects. For instance, The Netherlands Monitoring Network for Air Pollution uses plants sensitive to certain substances in the air (Coordinating Committee for the Monitoring of Radioactive and Xenobiotic Substances, 1982). Monitoring programmes conducted over longer periods of time may reveal trends and generate data to support our environmental protection policy. However, biological monitoring programs have so far provided few scientifically founded results which can support policy. Biological monitoring programmes – even though they may be feasible – are not easily set up. Experience with chemical monitoring programmes helps define criteria which biological monitoring programmes should also meet (Wessels Boer, 1982), namely:

- the monitoring programme should be maintained relatively easily;
- the use of the results of the monitoring programmes should not excessively depend on irrelevant environmental changes, like local changes of the weather;
- the cost of the measurements and of the monitoring programme as a whole should correspond to the importance of the results;
- the sensitivity of the measurements should correspond to the accuracy required to support policy decisions;
- the results of the monitoring programme should relate to established norms *i.e.* the results should be evaluated to allow a classification into categories permissible/not permissible or desired/not desired. It is important that monitoring programmes are maintained only to measure existing problems and that they are not developed for their own sake: monitoring programmes should be discontinued, if they cease to provide policy-related information.

The future shall tell if biological monitoring programmes can be constructed to fit the above-mentioned requirements.

7. Conclusions

– Ecology and ecotoxicology are sciences important to interpret observed effects in the environment, important to retain diverse species of plants and animals in the environment, and important to signal environmental stress caused by physical or chemical agents.

– Flexible modest programmes of limited duration to measure either biological effects on indicator organisms in the environment or the occurrence of contaminants in biological materials, may be important to assess the risks of environmental stress to various other species and ecosystems.

– Utilization of biological effect monitoring programmes to measure environmental stress is not common at this moment, and it is doubtful whether it will be in the near future.

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