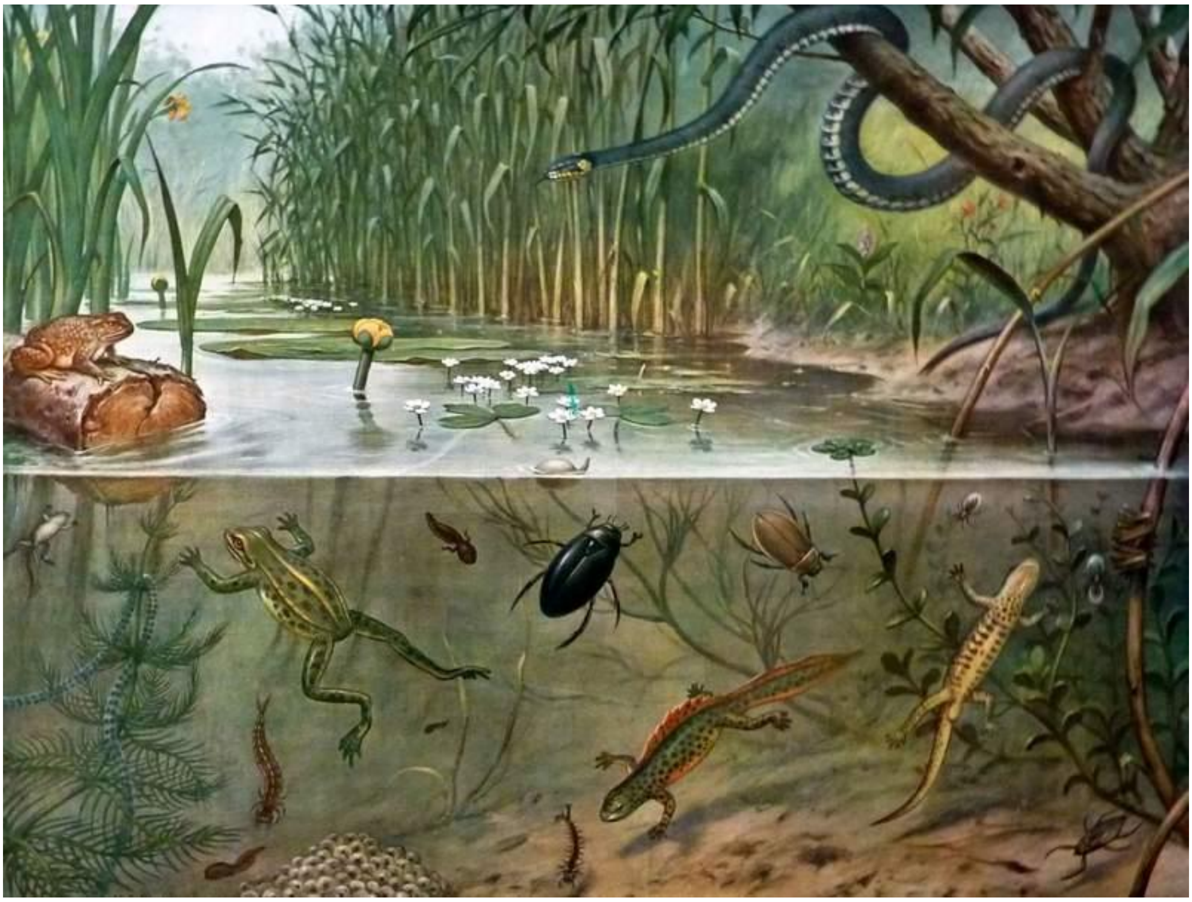
# ‘Habitat Suitability’, an Ecological Key Factor in standing waters



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Dit rapport gaat over ‘Habitatgeschiktheid’, één van de ecologische sleutelfactoren die van belang zijn voor stilstaande wateren. Om een beeld te vormen van de aspecten die van belang zijn voor de uitwerking van de sleutelfactor zijn verschillende deskundigen geïnterviewd en is literatuuronderzoek gedaan. Hierbij is op een rij gezet hoe deze sleutelfactor het best kan worden ingevuld, welke methoden en tools beschikbaar zijn voor diagnose en prognose, en welke aanpak gevolgd kan worden voor een verdere uitwerking.

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# 1 Introduction

STOWA is developing a framework of ecological key factors to assist water managers in their assessment of the current and potential ecological state of water bodies (STOWA 2014). The ecological key factors should cover various impacts and processes acting on the aquatic ecosystem. They describe the thresholds for improving the ecological quality of water bodies, to aid the analysis of the ecological state, and to indicate restoration potential.
In the framework for stagnant water bodies (lakes, canals, ditch and pond complexes) nine Ecological Key Factors (EKF) are recognised:

- EKF1 Water productivity (nutrient availability from external sources)
- EKF2 Light (underwater light climate, turbidity)
- EKF3 Sediment productivity (internal nutrient loading)

When the thresholds for these three EKFs are met within a water body, conditions for recovery of submerged vegetation are met, and they form the basis for further enhancement of the biodiversity of the ecosystem. This may be dependent on other factors:

- EKF4 Factors related to Habitat suitability
- EKF5 Factors related to Connectivity / dispersal
- EKF6 Factors related to Removal of sediment, biomass (e.g. ditch maintenance, grazers)
- EKF7 Organic pollution (oxygen)
- EKF8 Toxicity
- EKF9 Context (uses of water system, e.g. agriculture, recreation)

As a first step in operationalisation of the EKFs, STOWA has published a report on the Ecological Key Factors 1-3, aimed at the restoration of submerged vegetation (Schep et al 2015).

This report is addressing Ecological Key Factor 4 ‘Habitat suitability’ for stagnant water bodies. The aim is to review the existing scientific expertise about the ecological key factor ‘Habitat suitability’ in stagnant water bodies and to present an approach for its further elaboration in the framework of ecological key factors. For this purpose, the scientific literature was reviewed and the opinions of a number of experts in the field were sought.

*Structure of this report*
Different concepts of ‘habitat’ existing in literature are discussed in chapter 2, followed by an overview of existing relevant habitat classifications (chapter 3). Subsequently, some aspects of the influence of water management on habitat structure are shown (chapter 4). In chapter 5, a preliminary outlook for EKF4 ‘Habitat suitability’ is sketched.

# 2 The concept of 'habitat'

When the term 'habitat' was introduced as an ecological concept, it had the simple meaning of "the place where an organism lives" (Odum 1971). Thus, a particular habitat is always species-specific: the environment as it is experienced by an organism. However, the term 'habitat' has subsequently been used in a variety of ways, causing ample confusion (Whitaker et al 1973; Hall et al 1997). Furthermore, the related concepts of 'niche', 'biotope', and 'environment' have sometimes been used in a similar meaning. In common understanding, 'habitat' links the presence of a species to certain attributes of the physical and biological environment (Hall et al 1997).

The habitat has many functions for an organism: it may be the place where it can attach itself, find food or nutrients (resources), shelter, protection against predators or grazers, protection against breaking off or flushing away, where it can reproduce and hatch or germinate, etcetera. Consequently, every species has different habitat requirements depending on its life-form and life-history strategy. Some organisms need complex, partitioned habitats to fulfil all these roles (also referred to as sub-habitats within the habitat), for others the habitat consists of a small patch that fulfills all life-history stages.

In an evaluation of numerous habitat studies, Looijen (2000), concludes that there are at least four conceptual variants in which the term 'habitat' has been used:

1) 'Realised habitat': the environment (or set of environments) in which a species lives;
2) 'Potential habitat': the environment meeting the species' ecological requirements and tolerances (i.e., where a species could live);
3) an environment within which many species may live;
4) the environment of a community.

The term 'biotope' is used interchangeably with the second, third, and fourth meaning of 'habitat'.

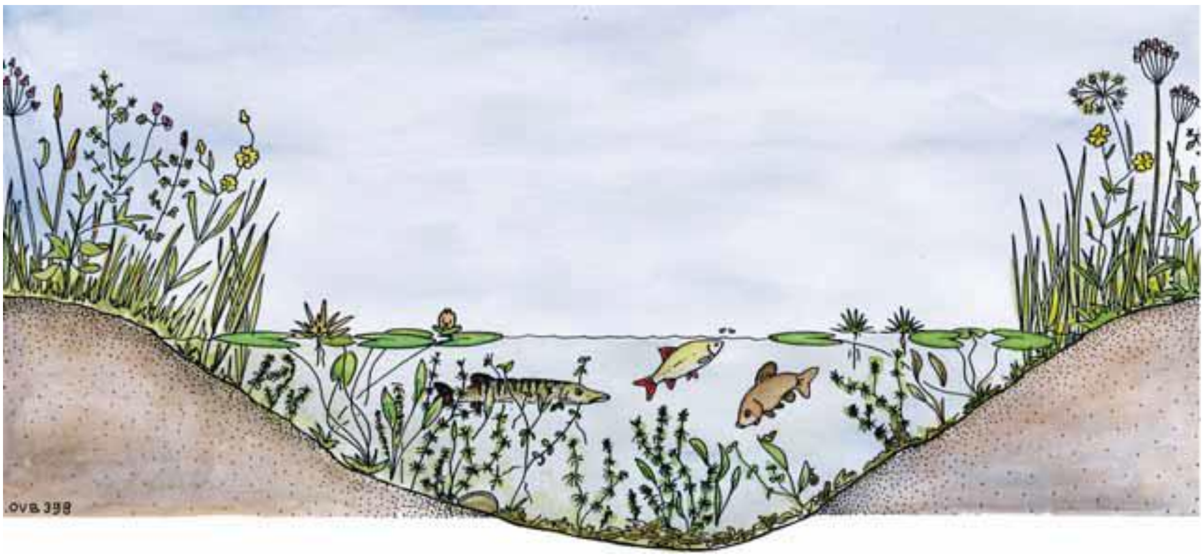


Fig. 2.1. Pike habitat. Source: Handboek Visstandbeheer. Hst 3. Viswatertypering deel 1: ondiepe wateren

As an illustration of these habitat-variants, we may look at the habitat of a predatory fish species (Pike, *Esox lucius*) (Fig. 2.1). According to the first variant, Pike habitat is the part of the lake where Pike actually occurs – i.e. all the parts of the littoral zone where the species may be observed (and will be found when an extensive survey covering the whole lake is conducted). In the second variant, Pike habitat encompasses all areas potentially suitable for different life stages of the species. It should be considered that Pike 'habitat' consists of several sub-habitats for its respective life stages: from shallow inundated, grassy vegetation as the place for egg deposition, to dense emergent vegetation for young stages, and a clear-water submerged vegetation mosaic for adult stages. Pike shares the latter environment (or habitat structure), submerged vegetation-dominated littoral areas, with a number of other fish species such as Rudd (*Scardinius erythrophthalmus*), Bitterling (*Rhodeus amarus*), Crucian carp (*Carassius carassius*), and Tench (*Tinca tinca*) (variant 3). Hence, this type can be regarded as the environment (or 'habitat') of the Pike-community (variant 4) (in angler's terminology: Ruisvoorn-snoekviswatertype).

The term 'habitat' is often used among conservation biologists as equivalent to the physical environment itself (such as in the framework of the EU Habitats Directive, in which habitat types represent different environments). Bell et al (1991) define habitat structure as 'the physical arrangement of objects in space'; and Kent (1981), amongst others, makes no distinction between habitats and sites within agricultural landscapes. Miller & Hobbs (2007) conclude that the notion that habitats refer to areas of similar vegetation or land cover has become more prevalent in recent decades. This notion should preferrably be referred to as 'environmental heterogeneity'.

In the context of the 'ecological key factors', the habitat can be regarded as the particular physical, chemical and biological structure of the environment that makes it suitable for an organism:

- Physical factors: depth (variation), water-level fluctuation, exposure to waves and currents, sediment type and – stability, texture/structure of vegetation, hard surfaces)
- Chemical factors: alkalinity, acidity, salinity, nutrients; affecting vegetation development and hence indirectly shaping the physical factors
- Biological factors: predation, grazing, competition, facilitation, colonisation

Further delimiting the ecological key factor 'habitat suitability', it refers specifically to physical conditions relevant for the flora and fauna inhabiting a lake. The habitat variables of organisms in lakes therefore include hydromorphological- and vegetation structure. Chemical factors (water- and sediment quality) are mostly covered by other ecological key factors (notably EKF1 'Water productivity', EKF2 'Light', EKF3 'Sediment productivity', EKF7 'Organic pollution' and EKF8 'Toxicity'). Biological factors may partly be addressed within EKF5 'Connectivity' and EKF6 'Removal'.

## Hierarchy of ecological factors determining habitat suitability

The different levels at which ecological factors affect ecological communities, and the way they interact, are represented in the 6-S concept (Fig. 3.1, Verdonschot et al 2015). In this concept, the overarching factors are geological and climatic conditions ('Systeemvoorwaarden'), that act on a regional scale. Chemical substances ('Stoffen') and Hydrology ('Stroming'), act on a subsequent more local level. Physical structure ('Structuren") acts at the smallest scale of local sites (fig. 3.1). Water Management ('Sturing') acts on several points in the middle level.

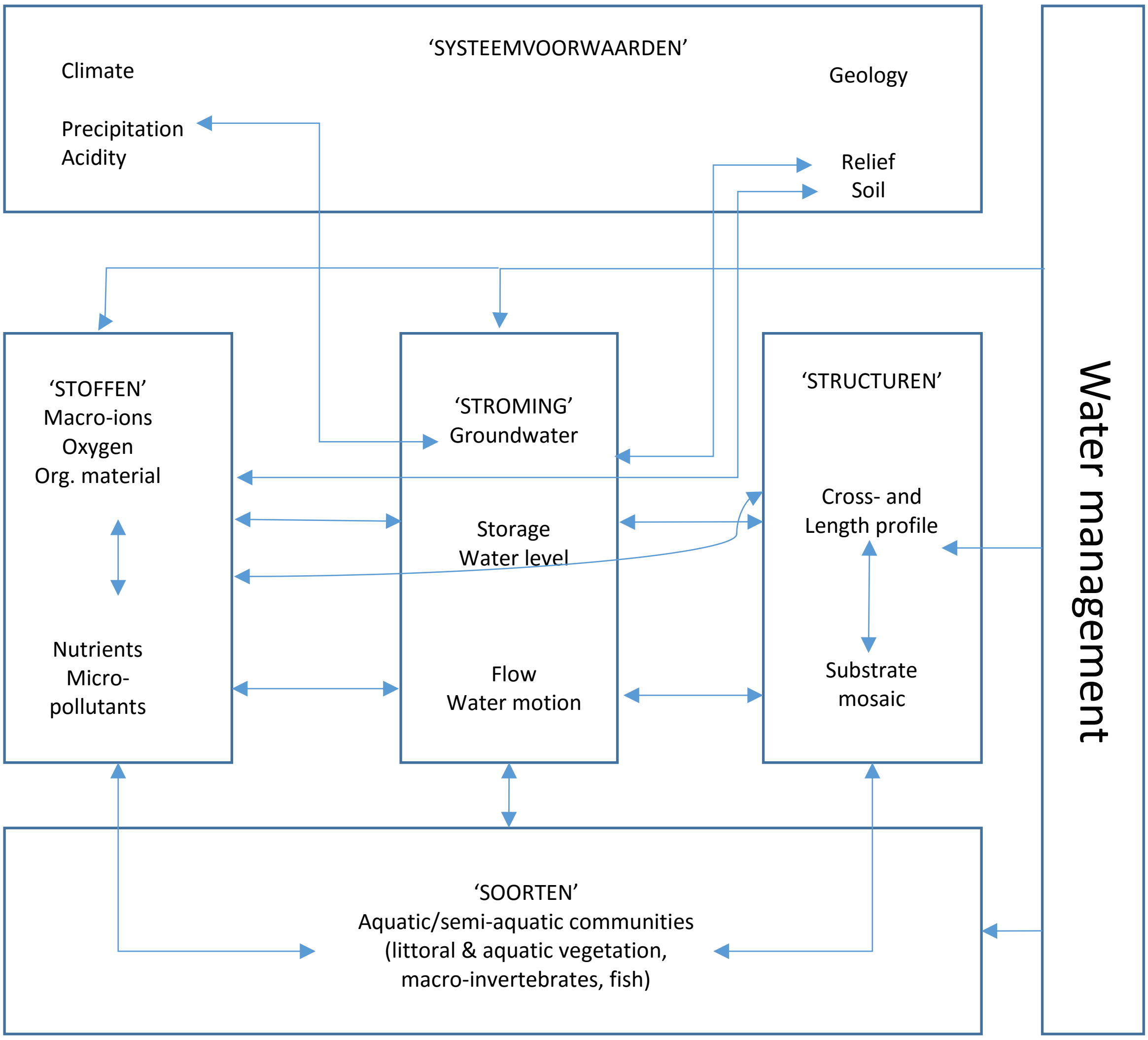


Fig. 3.1. Diagramatic representation of the 6S-model for stagnant water bodies (after Verdonschot et al 2015).

Roni et al 2005 present a hierarchical diagram of the environmental determinants of habitat suitability for aquatic organisms (Fig. 3.2). The diagram, which was originally depicting the habitat determinants for a fish species (salmon), may be generalised to other aquatic species as well. It is roughly similar to the 6S-concept in its hierarchy of System conditions (= Controls), Hydrology (=Processes), and Structures (= Habitat effects); in this case, physical structure and water quality determine habitat availability for organisms.

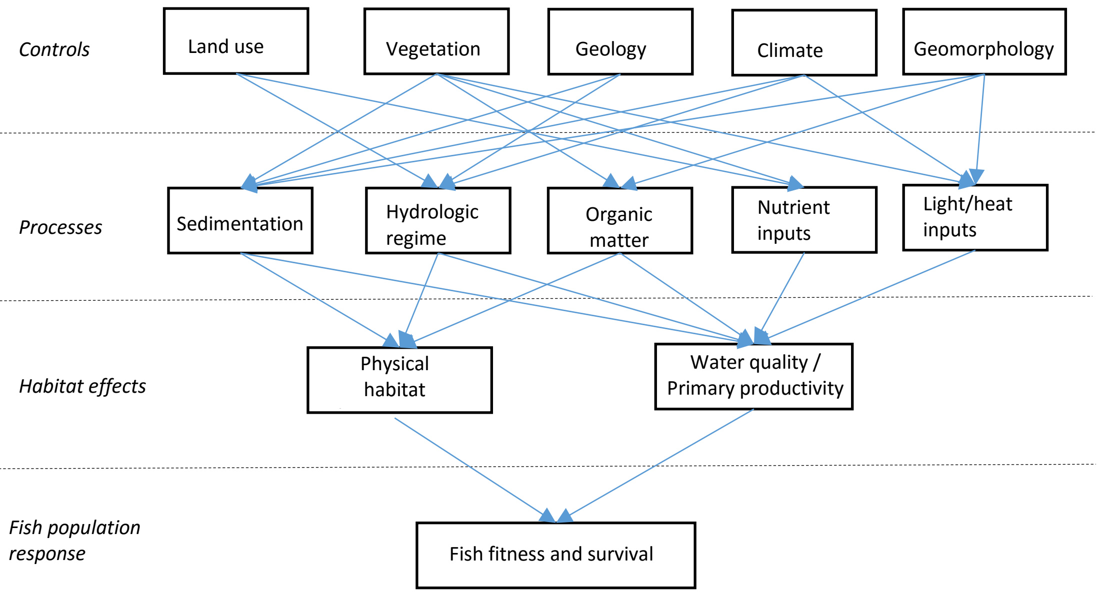


Fig. 3.2. Environmental determinants for fish populations (after Roni et al 2005).

Summarizing, it is recommended within the framework of ecological key factors to delimit the 'habitat' concept to the physical structure of the environment of organisms and/or communities. Physical habitat structure should be viewed at a scale fitting to the organism. In this sense, habitat variables for the relevant groups of organisms in lakes include hydrological and morphological structure, and vegetation structure. Important aspects of the (physical) habitat of an organism in a lake are habitat area, as well as spatial configuration ('habitat complexity'). Apart from the hydromorphological structure, the quality of habitat ('habitat suitability') is also influenced by other ecological key factors, in particular water-and sediment quality.

# 3 Physical habitat structure

Physical habitat structures are spatially recognisable units within a water body, at a scale fitting to the organism. Important aspects of the (physical) habitat of an organism in a lake are habitat area, as well as spatial configuration ('habitat complexity'). For most relevant taxa, mesoscale structure may be the appropriate scale. Apart from the hydromorphological structure, the quality of habitat ('habitat suitability') is also influenced by other ecological key factors, in particular water- and sediment quality (see chapter two).

Various characteristics of physical structure of lakes can be recognised that determine the habitat function for organisms:

- Scale: extent of suitable habitat within a lake, including density, relevant to the scale of the organism;
- Spatial configuration and connectivity, relevant to migration and dispersal capacities; permanence / temporal availability relative to the life-cycle
- Habitat quality: water- and sediment quality factors
- Habitat diversity

Scale

Depending on the organism and/or population studied, the term 'habitat' can apply to hugely different scales, ranging from landscapes/vegetation types, to very detailed descriptions of the range of physical environments used by a species. For avian habitats, Block & Brennan (1993) present a continuum of spatial scale of habitat elements in decreasing order: geographic region > landscape > patch > tree > leaf. The largest scales are referred to as 'macrohabitat' and the smallest scales are called 'microhabitats'.

For aquatic environments, scale may be very different between organism groups as well as between species. Macrohabitat commonly refers to habitats at the landscape-level, such as an entire lake or section of a lake. This is relevant for the tallest (semi-)aquatic organisms, such as water birds (swans, ducks), larger-sized mammals (beaver, otter), and larger fish species. Microhabitats, such as a single plant leaf,  are the living areas of the very small organisms, such as epiphytic flora and fauna. A large group of organisms require habitat structures on an intermediate scale, which is referred to as mesohabitat. Examples of mesohabitat in lakes are, for example, wet grassland in the marginal riparian zone, dense macrophyte patches in the shallow littoral zone, or the deep profundal where there is insufficient light for photosynthesis. The meso-scale is likely the most relevant scale of habitat for assessment of small fishes, macro-invertebrates and macrophytes. However, there are no clear limits to the different scale levels, necessitating a pragmatic choice of scale for habitat studies.

Configuration

Habitat patches can be heterogeneously distributed within a lake, and the size of patches, extent of edges, and spatial configuration, matter. Important aspects of the spatial scale of habitat structure are 'extent' and 'grain' (Lewis et al 1995). Extent is the total available area of a particular habitat; grain is the density and distribution of patches. The spatial configuration of habitat structures is a key determinant of an organisms' distribution, since for a population to subsist, a particular habitat structure should either sustain a population, or allow sufficient influx from outside populations. This means that the extent of the habitat should be regarded as the sum of all patches of that habitat if individuals can move between them. Consequently, habitat connectivity is as relevant an aspect as the total size of a habitat within the water body, or within the wider landscape network.

Also, habitat patches that are mobile in time, are habitat for those organisms that are able to move around with the patches, and that find suitable refugia when the habitat is temporarily unavailable. For example, vegetation patches may occur in different places in the lake littoral or in ditches from year to year. In spring, after the end of hibernation, small macro-invertebrates migrate to the (seasonally available) vegetation patches that form their habitat in the growth season of the plants. There are large differences between organism groups in capacity of reaching suitable habitat patches: for example, for Trichoptera species the maximum distance between habitat patches is no larger than a few m, whereas Simuliidae can move to patches throughout a water body (Verdonschot, Appendix 1).

Habitat quality

While the presence of suitable physical habitat is essential for organisms, the organisms' ability organism to survive, grow and propagate depends also on water quality (e.g., salinity, acidity, nutrients, toxic substances). In lake restoration, creating physical structures as a means to supply habitat for organisms only makes sense when water quality has been restored to the needs of the target organisms/communities. Also, interactions with other organisms (e.g., predation, grazing, competition, allelopathy) play an important role.

## 3.2 Species-habitat relationships

Species - habitat relationships can be highly complex and variable, however in many cases it seems possible to describe tolerances/optima of habitat factors ('habitat suitability') for specific taxa. Different habitat factors are relevant for different species or species groups. An attempt to identify the relevant habitat factors for different biotic groups and for various water systems in the Netherlands has been made by experts in a special workshop (Verdonschot 2015). Such a descriptive approach depends the availability of data that includes relevant structural parameters. However, it should always be kept in mind that whereas an organism may occur within a certain bandwidth of environmental variables, environmental conditions within the same bandwidth do not guarantee the organism will occur there.

Macrophytes

The habitat of macrophyte species consists of the physico-chemical environment in which the plants grow (light, carbon, sediment stability, water flow, etc.), while on the other hand the presence of macrophyte vegetation forms an important habitat factor for organisms such as macro-invertebrates and fishes.

Macrophyte species have different tolerances for hydromorphological conditions; the growth forms of the species in vegetation reflect water depth, slope, wave exposure, water level (drawdown and inundation – frequency, timing, duration), and substrate.

Determinants for macrophyte presence are variables of water and sediment quality, as well as morphological characteristics. Generally, the abundance of different macrophyte growth forms and species can be strongly related to light, water depth, dominant carbon form, and other biogeochemical factors. For species, characteristic optima and tolerances for many variables have been measured (e.g. Bloemendaal & Roelofs 1988).

Extensive data are available for occurrence of aquatic macrophyte species according to local water- and sediment quality (e.g. Bloemendaal & Roelofs 1988, as well as various other data sets). However, for emergent vegetation, hydrology may be the most important structuring variable, for which, however, less data are available.

<u>Macro-invertebrates</u>

Although some species of macro-invertebrates have highly specific habitat requirements, the general view is that there are in general a limited number of habitat structural types with distinct species composition. A main subdivision in ‘soft’ (organic mud sediment) and ‘hard’ (mineral sand, clay) sediments, (submerged) plant beds, and hard substrates (stone, wood, etc.) would probably be sufficient for the purpose of EKF “Habitat” (Irvine, Appendix 1).

Particular groups of species can be linked to these different structural habitats, and may be used for assessment of the habitat quality of each. Benthic groups (oligochaetes, chironomids, bivalves) are associated with the open sediment, whereas several other taxonomic groups (odonata, heteroptera, coleoptera, gastropods) generally associate with vegetation.

Organisms usually use more than one habitat; the habitat configuration within a lake therefore is highly relevant, as is the distance between patches. Some groups of organisms are able to overcome only short distances between habitat patches (e.g. Trichoptera), whereas others (such as Simuliidae) can easily mover throughout the whole water body (Verdonschot, Appendix 1).

Many macro-invertebrates shift between habitats for different life stages. For example, many insects inhabit submerged vegetation-dominated patches during the larval stages, whereas the adult stage lives in terrestrial environments. Another example is Dreissena, whose larval stages attach to plants or other underwater structures, whereas the adult mussels form dense mussel beds on the sediment.

Data on habitat preferences of freshwater macro-invertebrates is relatively scarce, often based on expert information or anecdotal. Verdonschot (2011) and Verberk et al (2012) have listed habitat information of freshwater macro-invertebrate species in the Netherlands, based on information obtained from existing datasets, experts and grey literature. Habitat variables described include incidence of drawdown, substrate type, and dimensions of the water body (Table 3.1). Associations with specific vegetation types, or wave exposure, are not or only indirectly included.

Table 3.1. Habitat variables for which species preferences are scored in Verberk et al (2012).

| | | |
|---|---|---|
| ‘STOFFEN’ | Acidity | pH <5, pH 4.5 - 6.5, pH 6 - 7.5, pH >7 |
| | Salinity | Fresh (<300 mg Cl/l), 300-1000 mg Cl/l, 1000-3000 mg Cl/l, 3-10 g Cl/l, >10 g Cl/l) |
| | Trophic class | Oligotrophic, meso-oligotrophic, mesotrophic, meso-eutrophic, eutrophic |
| | Saprobic class | Oligosaprobic, β-mesosaprobic, α-mesosaprobic, polysaprobic |
| ‘STROMING’ | Flow velocity | stagnant (< 5 cm/s), very slow (5-9 cm/s), slow (10-15 cm/s), moderately fast (16-25 cm/s), fast (>25 cm/s) |
| ‘STRUCTUUR’ | Permanence | Temporary (> 5 months), (3-5 months), (6 weeks – 3 months), Semipermanent (< 6 weeks), permanent |
| | Substrate | Clay/loam, sand, gravel, stone, silt, fine detritus, coarse detritus, wood, water plants, other |
| | Dimension & Connectivity | Very small, small, moderately large, large<br>Connected, isolated |

Fishes

Fish habitats are generally described on a ‘landscape’-scale, because most fish species use a combination of ecotopes and depend on multiple habitats for different life stages and for different activities (foraging, sheltering, etc.). The example of pike, which is present in different habitats during their development from egg to adult, has been shown in Chapter 2.

Relevant determinants of habitat quality for fishes are: presence of a loose mud-layer, presence of submerged vegetation patches, underwater structures suitable for shelter (such as tree branches hanging in the water, open rip-rap), and inundated shore zone (accessible for fishes).

The typology of water types for fish (‘Viswatertypering’; see Handboek Visstandbeheer) may be a useful approach for fish habitat description.

# 4 Classification and measurement of habitats

## 4.1 Typology of stagnant water bodies

Hydromorphological surveys are the basis of physical description of lakes; a review of methods of hydromorphological classification has been made by Bragg et al (2003). In a review of habitat studies (mostly terrestrial), it was concluded that habitat structure is commonly equated with vegetation structure (McCoy & Bell). Concordantly, habitat assessment for the EU Habitats Directive is also based on vegetation types (Janssen & Schaminée 2003).

The Dutch lake typology compliant with the requirements of the EU Water Framework Directive (WFD) includes categories of lakes that can be considered habitat for the type-specific organisms (species) derived by experts (Van der Molen et al 2012).

The Dutch WFD-typology recognises 42 natural water types and 13 artificial types (Van der Molen et al 2012), of which 9 are M-types (lakes). Descriptors for these types are:

- Size (lakes): < 0,5 $km^2$, 0,5 – 100 $km^2$, > 100 $km^2$
- Width (linear water bodies): < 8, 8 - 15 m, > 15 m
- Average depth: < 3 m, > 3 m
- Salinity: < 0,3 gCl/L, 0,3 – 3 gCl/L, 3-10 gCl/L, > 10 gCl/L
- River influence: connected to river or not
- Buffer capacity: acidic, weakly buffered, well-buffered

For all these types, species lists have been assembled of communities that are characteristic for the natural reference. The lake types to which species were assigned by experts can be regarded as macro-habitats.

However, for most aquatic species the mesoscale habitat may be more applicable, because species/communities use only a particular space within a water body. Certain measures to improve conditions for species/communities over the whole water body, e.g. reduction of nutrients, but for many species the availability of physical structure may remain a bottleneck. It is, therefore, essential to understand what restoration/creation of physical habitat contributes to recovery of natural communities (i.c. the Good Ecological State).

## 4.1 Meso-scale habitat classification

Several classification methods have been proposed for quantifying habitats. Three approaches may be followed to describe habitat (Kent 1981): 1) evaluation approach; 2) indicator species approach; 3) inventory approach.

The evaluation approach comprises of quantifying potential habitat by measuring or mapping structural elements. Most methodologies have been developed for rivers, such as the Gewässerstrukturgütekartierung in Germany (Zumbroich et al 1999), the QBR-index for floodplain geomorphology (Munné et al 2003), and the River Habitat Survey in the U.K. (Raven et al 1998). For lakes, the Lake Habitat Survey methodology (Bragg et al 2003, Miler et al 2015, Rowan et al 2006) has been developed in the U.K. and applied in different countries in Europe, loosely based on the EMAP/USEPA-methods developed in the U.S. (Kaufmann et al 2014). For large water bodies in the Netherlands, the Rijkswateren-Ecotopen Stelsel (RWES) has been developed (Van der Molen et al

2000). Geomorphological maps and vegetation maps may also be useful for mapping habitat structure.

Evaluation methods measure the effects of environmental change, e.g. hydromorphological alteration. Examples of such exercises are the Lake Modification Index (LMI, Peterlin & Urbancic 2013) and the Hydromorphology of Lakes (HML) protocol (Ostendorp 2015). The key issue for this approach is how much the physical structures that can be recognised are a meaningful representation of habitat quality for organisms (Diaz et al 2004).

The Indicator species and Inventory approaches focus on the species or species groups reflecting the condition of habitats. The Indicator species approach looks at the presence of specific taxa indicative of certain habitats, whereas the Inventory approach looks at the species composition in its entirety. As a consequence, these approaches measure the 'realized habitat' (sensu Looijen et al., 2000, see page 4). However, using species as state variables has several disadvantages, because there are too many species and in a particular case many potential species are lacking (Feld, Appendix 1). Sampling issues (scale, timing, intensity of sampling) are often complicating the use of species-oriented approaches (White & Irvine 2003). Therefore the use of relatively common indicator species, or of well-defined species groups, is recommendable (Irvine, Appendix 1).

Additionally, habitat models may be valuable tools for gaining insight in species-habitat relationships (Guisan & Zimmermann 2000, Rosenfeld 2003).

## Ecotopes and vegetation maps

On a generic level habitat complexity of lakes may be represented in spatial patterns of physical structure and/or vegetation structure. Maps of geomorphological features and vegetation types may be useful as a basic description of the habitat structure of lakes.

An ecotope classification and mapping routine for large water bodies has been developed by Rijkswaterstaat (Van der Molen et al 2000). Ecotopes are generically distinguished based on hydromorphological dynamics, water depth, sediment type, and biotic structures (so-called 'eco-elements'). For lakes and canals, a lake-ecotope system ('Meren-Ecotopen-Stelsel', or MES) can be applied. Updates of the ecotope maps are produced every 6 years.

Vegetation maps may also indicate the presence and spatial extent of (vegetated) habitats in the littoral and riparian zones. E.g. for Natura 2000 'habitat maps' have to be produced for designated N2000 areas;  the N2000 habitat maps consist of mapped vegetation types on the plant community level.

Table 4.1. Classification criteria RWES-Meren (Van der Molen et al 2000).

| criteria | classes | characteristics |
|---|---|---|
| Mechanical dynamics | Highly dynamic (z)<br>Strongly dynamic (s)<br><br>Dynamic (d)<br><br>Low dynamic (l) | (not in lakes and canals)<br>highly exposed to waves; sandy sediments, or artificially strengthened<br>exposed to waves, potential growth of macrophytes and benthic fauna<br>very little to no wave impact, usually silty sediment |
| Water depth | Very deep (z)<br>Deep (d)<br>Moderately deep (m)<br>Shallow (o) | more than 5 m; long stratification<br>3-5 m; less stratification; low macrophyte cover<br>1-3 m, high macrophyte cover<br>0,3-1 m, rarely exposed, helophytes |
| Sediment type | Clay (k)<br>Silt (s)<br>Sand (z)<br>Hard substrate (h): | -<br>-<br>-<br>e.g. gravel |
| Eco-elements | Potamid vegetation<br>Charid vegetation<br>Nymphaeid vegetation<br>Helophyte vegetation<br>Dreissena-beds | |

## Field Operations Manual for Lakes and Lake Habitat Survey

The Environmental Monitoring and Assessment Program – Surface Waters, has described methods for lake surveys in the US in a Field Operations Manual (FOML) (Baker et al 1997). The FOML provides protocols and sampling strategies, and was developed by the USEPA to provide a standard for monitoring of surface waters in the USA (both running and standing waters).

The Lake Habitat Survey method (LHS) has been developed in the U.K. and was building on the FOML as well as the already existing River Habitat Survey (RHS). The LHS partly uses the methodology described in the FOML. It has been anticipated to become the standard method for assessment of hydromorphological characteristics of standing waters in the U.K. (Rowan 2004).

The LHS methods include collection of a range of biological, water quality and hydromorphological data. The hydromorphological data should ensure the evaluation of habitat condition. According to the requirements of the EU Water Framework Directive, habitat information (whether or not expressed in a metric) is required for establishing what the pristine state of a lake would look like, it is required to produce a quantitative, reproducible estimate of habitat condition, and it is required for analysis (‘diagnosis’) of the ecological state. Physical structure of the riparian, shore and littoral zones is measured at 10 predetermined points around the perimeter of the lake. Furthermore, riparian and littoral habitats are mapped for the whole lake. The method has been extensively described and evaluated by Kaufmann et al (2014a,c).

The LHS method consists of the investigation of a number of habitat observation plots (Hab-Plots) per lake. In each Hab-Plot, observations are made of the structure of the littoral, shore and riparian zones. Additionally, data is acquired on developments and pressures in the whole lake, such as hydrological information and visible features including indications for bank modification, riparian and shore use, erosion, and extent of particular habitats (Table 4.2).

Table 4.2. Information collected in standard Lake Habitat Survey (Rowan 2008)

| Section | |
|---|---|
| 1 | LAKE INFORMATION AND SURVEY DETAILS<br>1.1. Background information: maximum depth (m); mean depth (m); lake perimeter (km), lake altitude (m); lake surface area (km2); catchment area (km2); intensive land use (%) in upstream catchment; geological lake type (WFD lake typology); mode of lake formation; water-level control, catchment geology; dominant catchment land cover; designation status.<br>1.2. Survey details<br>1.3. Hab-plot locations<br>1.4. Photographs |
| 2 | HAB-PLOT ATTRIBUTES<br>2.1. Riparian zone: areal cover of vegetation height categories, standing water, bare ground, artificial cover; dominant land cover; presence of alien plant species; bank top features; presence of streams/flushes; fetch length.<br>2.2 Exposed shore zone: Bank face (height, angle) and predominant bank material; bank face modifications; bank face vegetation cover; bank face vegetation structure; evidence of bank face erosion; beach (width, slope); predominant beach forming material; beach substrate texture; beach modifications; beach vegetation cover; beach vegetation structure; signs of erosion or deposition; height from waterline to upper trash-line.<br>2.3 Littoral zone: Distance of offshore station from waterline; depth at offshore station; Littoral substrate (predominant type, components (particle size distribution), signs of sedimentation; Littoral habitat features (tree roots, woody debris, overhanging vegetation, rocks); Vegetation structure; Total macrophyte PVI; Lakewards extension of vegetation; Non-native plant species.<br>2.4. Human pressures: Commercial activities; Residential areas; Roads, tracks and footpaths; Parks and gardens; Hard- or soft bank engineering, flow control structures, piled structures, floodwalls; Dumping, sediment extraction; Macrophyte management; Moorings; Recreational pressures. |
| 3 | WHOLE LAKE ASSESSMENT<br>3.1. Lake perimeter characteristics; Riparian land use pressures; Wetland habitats; Other habitats<br>3.2. Lake site activities / pressures<br>3.3. Landform features: islands, deltaic deposits.<br>3.4. Outlet geometry |
| 4 | HYDROLOGY |
| 5 | LAKE PROFILE INFORMATION AT INDEX SITE<br>5.1. Index site: location, depth.<br>5.2. Water conditions: Secchi disc transparency.<br>5.3. Dissolved oxygen and temperature profile.<br>5.4. Index site sediment: predominant substrate texture, presence of macrophytes |
| 6 | FIELD SURVEY QUALITY CONTROL |
| 7 | FURTHER COMMENTS<br>E.g. animal sightings. |

Similar classification methods specifically developed to describe shoreline alteration have been developed for lakes in Germany (Hydromorphologische Übersichtserfassung, Ostendorp et al 2008) and Italy (Lakeshore Functionality Index, Siligardi et al 2010).

## 4.2 Assessment of habitat change

Many studies focussed on one type of habitat attempt to quantify changes in the dimension (e.g. area) of a specific habitat within a water body (such as areal cover of a specific ecotope, macrophyte-covered area, length of fringing reedbed, or density of freshwater-mussel beds). Also, local or regional changes of species composition and/or abundances, as linked to environmental changes, have been studied extensively. However, fewer studies have attempted to relate changes in whole-lake habitat structure to species diversity (Table 4.3). One example of this is a recent study showing that increased lakeshore development (i.e. loss of natural vegetation) results in homogenisation, and hence lower diversity, of littoral macroinvertebrates (McGoff et al 2013b). These studies show general correlations between habitat structural diversity and species diversity and don't allow specific conclusions on species richness of specific habitat elements. Also, the effectiveness of the habitat classifications that were used has not been evaluated in these studies.

Table 4.3 Selection of studies of the relationship between physical habitat structure and species diversity.

| Publication | Organism group | Location | Findings |
|---|---|---|---|
| Brauns et al 2007 | Macro-invertebrates | Shorelines 7 lakes, Germany | Whole-lake species richness pos. correlated with number of habitat types. All groups except chironomids decrease with increasing shoreline development. |
| Della Bella et al 2005 | Macro-invertebrates | 21 ponds, Italy | Number of species related to hydromorphology (depth, hydroperiod, surface area) and macrophyte beds. |
| Eadie & Keast 1984 | Fishes | Lakes, Ontario USA | species diversity positively correlated with shoreline length and shoreline development, not with within-lake vegetation structure |
| Jurca et al 2012 | Macro-invertebrates | 6 lakes, Ireland | Community composition related to littoral habitat features |
| Kaufmann et al 2014b | Fishes | Lakes, northeast USA | Species richness declined with increased shoreline development and decreasing riparian vegetation complexity |
| Lorenz et al 2015 | Macro-invertebrates | Lakeshore, Germany | Presence of woody debris pos. affects communities/eco. status |
| Mastrantuono et al 2015 | Macro-invertebrates | Lakeshore, Italy | Several taxa neg. related to shoreline alterations |
| McGoff & Irvine 2009 | Macro-invertebrates | Lake littoral, Ireland | Species richness pos. correlated with habitat quality index score |
| McGoff & Sandin 2012 | Macro-invertebrates | Lakes, Sweden | Substrate variables most important determinant of littoral community structure, followed by riparian variables |
| McGoff et al 2013a | Macro-invertebrates | 42 lakes, Europe | See text |
| McGoff et al 2013b | Macro-invertebrates | 46 lakes, Europe | Beta diversity decreases with lakeshore development |
| Miler et al 2013 | Macro-invertebrates | 51 lakes, Europe | Densities related to morphological pressure. |
| Pätzig et al 2015 | Macro-invertebrates | Lake, Germany | Effects of lakeshore modifications on species diversity strongest in upper littoral |
| Verdonschot et al 2012 | Macro-invertebrates | Exp. Habitats in ditches, Netherlands | Structural complexity of microhabitat affects colonizing species assemblage |
| Whatley et al 2014 | Macro-invertebrates | Peat ditches, Netherlands | Emergent vegetation structure important for insect diversity in eutrophic conditions |

The Lake Habitat Quality Assessment method (LHQA, Rowan et al 2004) provides a measure of the habitat diversity of a lake, based on Lake Habitat Survey data. Features included in LHQA are: 1) Naturalness and structural complexity of the riparian zone; 2) Naturalness and structural complexity of the shore zone; 3) Hypsographic variation and littoral substrate diversity; 4) Macrophyte cover and structural diversity; 5) Structural diversity of littoral habitat features; 6) Presence/diversity of special habitat features; 7) In-lake landform complexity. In an adapted form the metric has been used to assess the quality of individual sites within a lake (HabQA, McGoff & Irvine 2009). McGoff & Irvine (2009) found an overall correlation between HabQA and macro-invertebrate taxon richness within Lough Carra, a large shallow lake in Ireland. However, specific natural habitats with low numbers of species are underestimated by the HabQA approach; the presence of macrophytes had a strong influence on the assessment result. In a study of macroinvertebrates by McGoff et al (2013a), including 42 lakes throughout Europe (north: Sweden, Finland; mid: Germany, Denmark; western: Ireland, UK; south: Italy), relationships were found of macroinvertebrate community composition with certain LHQA descriptors, but significant relationships with overall LHQA were found only in the north- and south-European lakes. In the mid-European lakes, there was a match between macroinvertebrates and LHQA only for hard substrates; in southern and western lakes there were particular relationships with macrophyte vegetation descriptors, whereas in northern lakes certain riparian characteristics matched with macroinvertebrate composition.  This indicates that species-habitat relationships are extremely complex and dependent on many interrelated factors.

Metrics that express or valuate the change of habitat structure in an entire water body are scarce, due to inherent difficulties. In the EU-WISER project, a clear distinction has been between habitats and lake alteration; natural lakes throughout Europe showing a much higher habitat diversity and macro-invertebrate richness that lakes classified as high- or medium alteration (Miler et al 2012).

The Lake Habitat Modification Score (Rowan et al 2004) is a summary metric generated from LHS data. It includes various features: 1) % shoreline construction/reinforcement; 2) % shore zone subject to intensive use; 3) Severity of in-lake pressures and uses; 4) Degree of hydrological alteration; 5) Extent of unnatural sedimentation; 6) Presence of invasive species.

In the cross-European study by McGoff et al (2013a) no relationship between LHMS and littoral macroinvertebrate composition was found.

## 4.3 Habitat diversity

'Habitat diversity' applies to the variation and distribution of physical habitat types within a landscape (e.g., a lake). The term 'habitat diversity' is also referred to as 'environmental heterogeneity' which is actually more correct terminology. In the simplest way of definition, habitat diversity is the number of habitats present in a water system (Feld, Appendix 1). However, the term is very much dependent on the scale of measurement.

Three hierarchical levels of diversity are generally recognised:

1) α – diversity: refers to the species (or habitat) assemblage at site-level
2) β – diversity: refers to the heterogeneity of assemblages among sampling sites ('turnover')
3) γ – diversity: refers to the species (or habitat) assemblage at landscape level (e.g. lake).

Environmental heterogeneity within a lake, i.e. the diversity of habitat structures, may be correlated with species γ-diversity, i.e. total species richness of a lake.

Analysis of species diversity may give indications about the diversity and quality of habitats in a lake. Particularly interesting is the β-diversity, which is the heterogeneity of species assemblages among sampling sites. A high β-diversity indicates more variation within a particular habitat type, and hence a higher quality of that habitat type, whereas a low  β-diversity indicates homogenisation ('everywhere is the same').

The development of tools for the ecological key factor 'habitat', the results of the NIOO/NWO-project 'Biodiversity works' may be useful. The project aims to statistically explore the distinction between habitat diversity (the number of physical habitats) and water quality in lake biotic data.

## 4.4 Habitat models

Many ecological models are habitat models, as they are used in the analysis of species-habitat relationships. However, most of those models focus on specific habitat characteristics, without considering how species are distributed between spatial units.

Species' habitat models have been developed to conduct Habitat Evaluation Procedure (HEP) (Schamberger & Krohn 1982). These models establish a Habitat Suitability Index (HSI) based on the relative performance of a species over one or more environmental gradients, or depending on the presence of certain habitat features. The US Geological Survey (USGS) provides online information of Habitat Suitability for a large number of marine and freshwater species occurring in North America (http://www.nwrc.usgs.gov/wdb/pub/hsi/hsiindex.htm).

An example of a HSI-model is a model for Great crested newt (*Triturus cristatus*)-habitat in the UK (Oldham et al 2000) considers seven separate habitat features determining the overall habitat suitability. For the range of values for each feature, an index value between 0 (unsuitable) and 1 (maximally suitable) is assigned. In this case, the suitability of square grid cells can be assessed by combining the joint suitability indices of all seven habitat features.

Several HSI-models have been constructed or adapted for (semi-)aquatic species in the Netherlands (Van der Lee et al 2000). A major constraint for applying HEP-models is that sufficient knowledge and data is available for only a limited number of species. Moreover, the complexity, lack of data, and the inevitable simplification of specific habitat relations may have serious consequences for the validity of the output of these models (Brooks 1997).

A HEP-instrument was developed in the framework of the water systems analysis for the national water policy in the Netherlands, to assess the habitat suitability of water management scenarios for certain target organisms (so-called AMOEBE-species). A set of ecotope- and network models has been included in the analysis, notably: MORRES (species-ecotope relations) (Baptist et al 1999); EKOS (a 'library' of HSI-models of species) (Duel et al 1996); and LARCH (landscape ecological model with rules for habitat configuration) (Pouwels 2000).

Although highly elaborate and sophisticated habitat models can be built (Guisan & Zimmermann 2000), usually the necessary data are lacking, and models have limited applicability beyond the region they were originally developed for.

# 5 Habitat restoration

The ultimate purpose of lake restoration measures is to achieve a good ecological state. This state is defined in terms of communities (species) as closely resembling the natural state as feasible. This applies to water quality as well as habitat structure. Usually, the natural state, or reference state, is not achievable because water bodies have been modified to meet the interests of various functions; or, as in many cases in The Netherlands, are artificial. In such cases the question which habitats should be restored is a complex one. Restoring communities / species assemblages belonging in the (near-) natural state, requires identification of the essential habitat structure and natural processes (Fig. 5.1).

The species diversity of a water body reflects the diversity of habitat structures, under the current water and sediment quality. Compared to the good ecological state, missing species may represent the habitat structure that has been lost relative to the good ecological state. With sufficient data on species and habitat structure, the relationships between habitat structure and species diversity depicted in the diagram of Fig. 5.1 may be clarified.

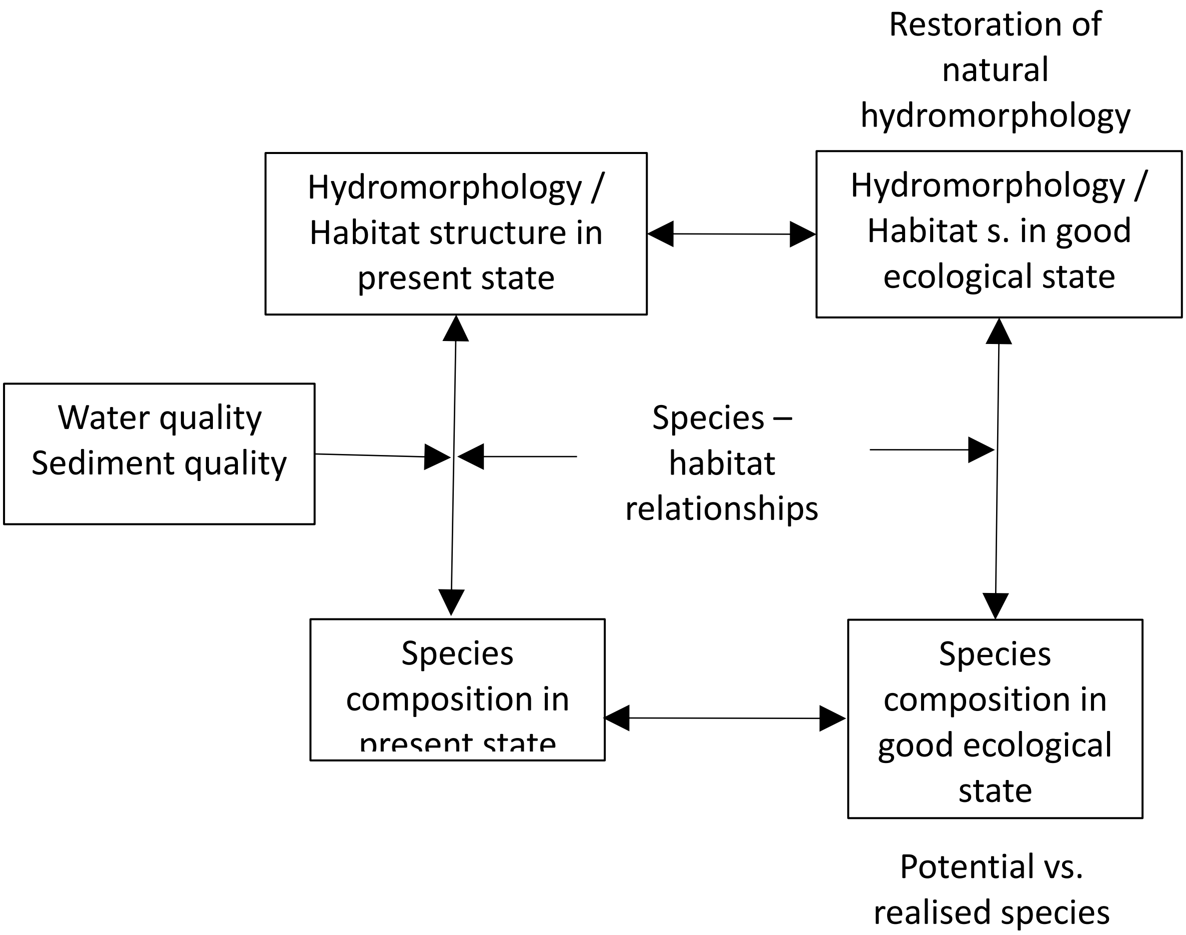


Fig. 5.1 Schematic guidance for analysis of habitat restoration goals. Data is needed of habitat structure and species diversity in the present state. The relationship between physical habitats and species composition is influenced by water and sediment quality, and can be predicted by species-habitat relationships. To establish the goals for restoration (in terms of restored habitat types) the species-habitat relationships are applied to to good ecological (or reference) state.

Habitat restoration means the recovery of physical structures necessary to fill the "gap" between the habitat structure in the present state and the habitat structure in the good ecological state. This requires good knowledge of species' habitat requirements. Miller & Hobbs (2007) summarise the questions to be considered before attempting restoration of target habitats (Fig. 5.2).

A similar decision tool is provided by the 'Standplaatsbenadering' ('plant habitat approach') for shoreline vegetation (Sollie et al 2011). This tool consists of several keys that weigh different options for creating and managing environmentally-friendly shorelines depending on habitat conditions for vegetation.

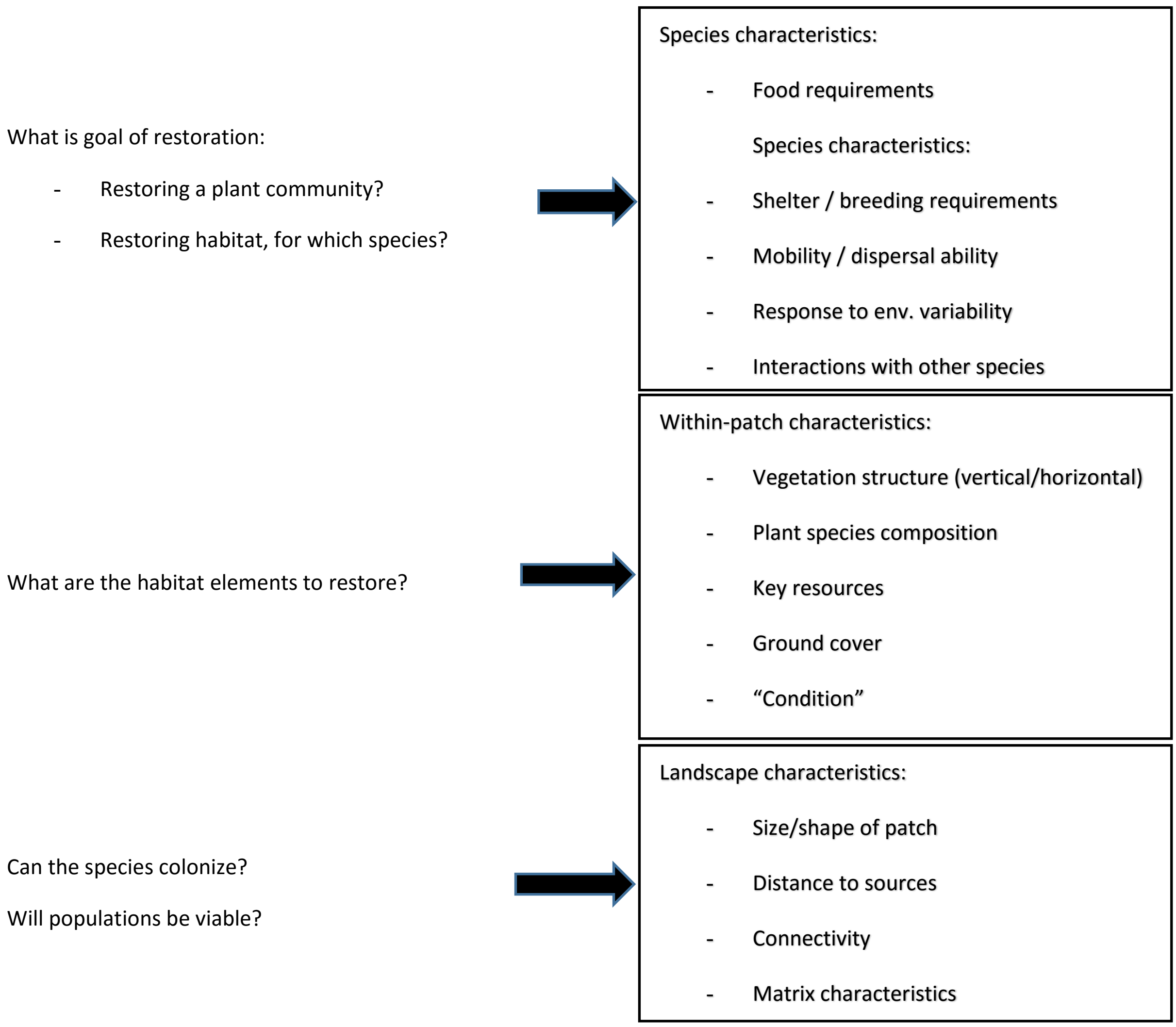


Fig. 5.2. Key considerations for setting goals for habitat restoration projects (Miller & Hobbs 2007).

In summary, physical habitat analysis should be based on specified targets, i.e. the good ecological state (or good ecological potential). Since the good ecological state is defined in terms of biotic structure, habitat tools such as species-habitat relationships are necessary to design and create the suitable conditions for the target species.

# 6 Approach for Ecological Key Factor ‘Habitat suitability’

The analysis of the ecological key factor ‘Habitat suitability’ in a lake involves the hydromorphological structure that provides habitats for target organisms. Habitat analysis includes an inventory of physical habitat types present, and the assessment of species diversity within the habitat types. The diagnosis should address the following questions:

- What are the characteristic habitat types in reference areas or ‘best site’ conditions? (including definition of scale, spatial configuration, connectivity, quality, diversity)
- What are the target organisms (species, functional or taxonomical groups, or community)? The target is related to the reference community, i.c. the biotic community in the good ecological state.  However, in many cases it might be more feasible to assess the species or communities associated with critical hydromorphological elements (see next question).
- What are the physical habitat requirements for target organisms?
  As a prerequisite for the inclusion of habitat assessment in the analysis of aquatic ecosystems, information on relationships between species (or species groups) and physical habitats (as well as other habitat requirements such as water quality) should be available. As a general conclusion, however, it can be stated that sufficiently detailed data is often lacking. Both qualitive and quantitative species-habitat relationships are sparse; even more so for regionally specific data.
- What is the hydromorphological structure in the present situation and what elements are missing/not functional? Is the extent (area) and configuration limiting the development of biotic communities?
- What are the limitations when other ecological key factors are not (yet) in a good state? When water and sediment quality are not sufficiently restored (ESF1-2), enhancing physical structure in a lake may have not the desired outcome. Likewise, when connectivity problems reduce dispersal and migration of organisms (ESF5), creating physical structures may not have the desired results. Hence, the analysis cannot be done in isolation from other ecological key factors.
- What measures are needed to create these physical habitats?
  This involves also which measures are feasible (considering other ecological key factors, in particular the socio-economical context (EKF9)).

Habitat assessments of water bodies involve the following aspects:

1. Scope: which habitats to include
2. Field protocol for quantification of habitat types
3. Determination of habitat preferences of species (groups)
4. Establishing reference (GET, GEP, best site) communities/species and habitat distribution
5. Diagnosis: confronting current state with ‘reference’ conditions
6. Prognosis (habitat modelling)

Concrete steps for an approach of Ecological Key Factor ‘Habitat Suitability’ are further elaborated in Appendix 2.

## 1. Scope

> For the further development of the Ecological Key Factor 'Habitat Suitability', the primary focus should be on the habitat types in the shoreline zone, where physical structure / hydromorphology are the dominant factors in shaping the organisms' habitats. The questions to be addressed particularly is to what extent shoreline habitat types should be created / restored to achieve system-wide effects on biotic diversity.

Considering the relevant habitats in a lake, the main focus should be on the littoral parts of a lake with a special focus on the shoreline zone, including the adjoining semi-terrestrial zone (Irvine, Appendix 1). In the deeper water parts and the shallow littoral of lakes, habitat improvement is usually achieved by improving water quality and transparency (EKF 1-3). Hence, probably the most significant zone for physical habitat restoration and creation is in the shoreline zone. Improvement (restoration) of habitats of organisms in the shore zone is usually achieved by hydromorphological measures: adapting water-level regime, altering inundation/drawdown zones, wave-reducing constructions, etc. These measures have an impact on the type and extent of habitat available for various organisms.

Almost all lakes in the Netherlands have a modified hydrology and morphology. On the one hand, natural shorelines may be absent or altered, on the other hand seasonally inundated riparian zones are of very limited extent. Restoration of natural communities in the shore zone depends on available space and the potential to restore hydrological and morphological processes.

## 2. Field protocol for quantification of habitats

> There is a need for the development of a mesoscale habitat classification method that can be coupled to the range of relevant organisms end/or communities. Additionally, higher spatial scales are highly relevant to include. Sufficient flexibility should be kept to ensure that regionally different approaches can be dealt with.

For the diagnosis of the EKF "Habitat", the habitats that are present in the current situation need to be mapped and quantified. Several methods are available, e.g. the Lake Habitat Survey (LHS), and the 'ecotope' method (see chapter 4.1). Germany has a Lake Habitat Protocol, as a non-official assessment system, which is developed by IGB (Martin Pusch, WISER); The German Fauna Index also includes a habitat structure index.

Existing aquatic habitat classifications combine hydromorphological characteristics and vegetation patterns as the basic spatial units. For analysing the ecological key factor 'habitat' a combination of an 'ecotope'- and LHS-like approach seems suitable. Ecotope maps can be produced in a relatively straightforward way and information concerning the size and/or edge length of the habitat units can be measured.

For the development of a protocol for mapping and quantification of habitats, the following prerequisites should be fulfilled:

- The quantification of habitat types requires the establishment of a habitat classification at the appropriate scale and detail for all relevant organisms groups (viz. macrophytes, macro-invertebrates, fish, birds?, mammals?).
- It is important is to include fringing habitats into the protocol. This means not only the (emergent) helophyte zone, but also the vegetation structure and land use of the adjacent terrestrial zone.
- The method should be relatively simple, and make use of available information at the water boards as much as possible;
- The method should be flexible, because of:
    - large knowledge gaps in the habitat requirements for the species (groups), especially at larger spatial and temporal scales. Hence, it should be easy to update the method with new (scientific) knowledge;
    - large differences in availability and quality of data between water boards;
    - wide variety of water body characteristics

Several experts (Irvine, Verdonschot) noted that the Lake Habitat Survey method was not designed by ecologists, but by hydromorphologists, mostly for the purpose of hydromorphological monitoring by the WFD. Clear recommendations about the addition of other variables (both from experts and literature) are absent however, probably because there are still large knowledge gaps for EKF 'Habitat' with regard to the question what and how to measure. Especially for questions like the optimal spatial configuration of habitats, the methods still need to be developed. The optimal configuration of habitats may possibly be derived from water bodies with a high ecological quality.

**3. Determination of habitat preferences of species (groups)**

Datasets of habitat preferences for organisms and organism groups should include variables for physical habitat structure (hydromorphological and vegetation characteristics). Simple parameters of community diversity may be more useful in evaluations than individual species presence/absence.

For the development of EKF "Habitat" in stagnant water bodies, it is important to have information on the habitat preferences of species (groups). These preferences should be linked to the delineated habitat types. In addition, diagnosis can be carried out by assessing what species are missing of these groups and which are dominating.

For species – habitat relationships, it is important to distinguish a hierarchy of spatial scales in the data. For each species (group), the appropriate scale and detail of habitats should be determined. As a first step, a distinction can be made in:

- Macro-scale (whole lake or segments of large lakes): dimensions (surface area, depth profile), residence time of water, amplitude and seasonality of water-level fluctuations, percentage cover of growth forms of macrophytes);
- Meso-scale: (patch, depth zone, eco-element): water depth, duration of inundation or drawdown, cover of macrophyte growth form, sediment type, wave exposure)
- Micro-scale: (object, plant): substrate type, macrophyte species/growth form/cover, specific depth.

For EKF “Habitat”, it is recommended to develop a habitat typology at the spatial level of meso-scale. From this scale, data can be upscaled to macro-level. For the choice and the appropriate scale and habitat types for different organism groups, the variables included in Table 4.1 (RWES ecotope method) and Table 4.2 (Lake Habitat Survey) may be applicable. Already existing datasets on species - habitat relationships need to be expanded, in particular to include relevant hydromorphological variables and larger spatial scales. It is essential that these data can be linked to the hydromorphological units recognised in the classification of habitat types. The purpose is to develop a database in which the following variables are included:

1. Structural requirements of habitats (vegetation growth form, height, density), sediment type and –thickness, presence of wood and stone, and hydrology (water-level fluctuations, inundation, drawdown); .
2. Spatial requirements (distance between habitat-patches, length of habitat edges relative to surface area, fetch, obstacles for migration)
3. Habitat quality, viz. e.g. water and sediment chemistry, toxic substances, etcetera). With habitat quality, there is a clear link with other ecological key factors (especially with regard to EKF 1 -3, which is a prerequisite for ecological recovery of the whole water body.

*Taxonomic level*

With regard to the choice for the taxonomic level (viz. separate species *versus* indicative functional or species groups), several experts recommended the use of species groups (instead of separate species). Feld indicated that using species themselves as metrics has several disadvantages: often there is a long list of potential species, many lacking species, and species with identical (habitat) requirements. Moreover, the state – organism response relationships are often not clear. As an alternative the use of trait groups may be possible (“traits” such as feeding types, e.g. shredders). Using community metrics or functional groups also averages out seasonal bias. Nevertheless, in some cases however, indicator species might be useful as biotic state variables. Irvine made similar comments, and suggested macro-invertebrate groups indicating for habitat types (as an example):

- loose mud: tubificids
- solid substrates: oligochaetes, chironomids
- tall growth forms vegetation: snails, beetles, mayflies
- low growth forms (charophytes): particular indicator species for charophyte communities
- reedbed: copepods (also dragonflies and birds)

Different macrophyte growth forms (e.g. magnopotamids, parvopotamids, charids, eloids, etc) have been proposed as important habitat variables instead of individual macrophyte species, as there is little difference between macrophyte species of the same growth form in macro-invertebrate community composition. Verdonschot indicated that the difference between dense and open aquatic vegetation type matters more for macro-invertebrates rather than differences in vegetation types.

Verdonschot also indicated that the softness of the structure is of importance for macro-invertebrates, e.g. rootable versus non-rootable (e.g. very fluid or rock) sediments, macrophytes versus wood/stone.

For fish, making a distinction between life stages may be relevant, because habitat requirements for spawning, 0+ fish and adults may be very different within the same species. Additionally, habitat requirements could be summarized at the level of fish guilds (limnophylic, eurytopic, rheophylic, etcetera) or a fish community typology (e.g. habitat requirements of “Ruisvoorn-Snoek”, or “Snoekbaars-Brasem”-gemeenschap.

**4. Establishing habitat structure and –distribution in reference conditions (GET, GEP, best site)**

To make a diagnosis of habitat suitability, one has to refer to the habitat conditions associated with a ‘good’ state of the ecosystem. In practice, habitat conditions in the ‘good state’ may be defined using species-habitat relationships, as well as expert opinion. They should include the scale and configuration of habitat types, or descriptions and measurements of ‘best sites’.

Irvine strongly advocated the inclusion of local knowledge about a particular lake, while not constructing a generalised reference for habitats to be restored. Whether certain “reference” habitats should be “restored” seems to be a philosophical question, and in practice water managers could pick their choice of restoration from a “sweetshop” depending on what they want to restore. Verdonschot stated that establishing a target image (or reference) involves the question: what is a well-functioning ecosystem. To address this, one has to look at food-web relationships and environmental heterogeneity. It may also be desirable to include non-quantifiable criteria in the formulation of ecological targets, such as aesthetic value.
However, it should be kept in mind that there are pitfalls in the use of local knowledge as the basis for ‘reference conditions’. For instance, the use of data of ‘best sites’ from the past decade may not reflect the full recovery potential of the water bodies, because even ‘best sites’ may already represent (moderately) degraded ecosystems. Therefore, also the use of historical data (from the same of adjacent water bodies) and other relevant sources is strongly advocated.
Furthermore, it should be noted that a ‘best site’ or ‘reference’ that is used for diagnosis is not the same as an ecological target (e.g. GEP: Good Ecological Potential). Sometimes, the ‘best sites’ or ‘reference’ conditions are far beyond the possibilities for what measures are (financially, politically) feasible in a water body. In other cases, best site conditions may be used to improve ecological conditions, without knowing what the exact goal or end-result (and additional measures) will be. Ideally, the conditions of ‘best site’ of a reference could be formulated in terms of abiotic conditions, as well as in species composition. Note that water managers often only have the possibility to improve abiotic conditions on the short term, while subsequent recolonisation by ‘desired ‘ species may take a long time (up to decades), depending on their dispersal capacity and distance to source populations.

**5. Diagnosis**

There is a need for methods of habitat diagnosis of shorelines based on biotic diversity and/or indicator groups. The method should identify whether presence, extent, and/or configuration of habitat elements within a water body explain insufficient ecological status. Diagnosis cannot be made in isolation from other ecological key factors, because of interaction / interdependence / complementarity of physical, chemical and biological habitat factors.

Diagnosis involves the analysis of which biotic elements are not in good state as the result of insufficient habitat structure. To answer this question, first it has to be established whether the other EKF's are not limiting the diversity and abundance of species and communities. Schoelynck (Appendix 1) gave as an example of the possible hierarchy of EKF's that habitat creation can result in worse ecological state when water quality has not been improved yet.

The key issue for diagnosis is to explain the absence of certain species (groups) as the result of specific habitat deficiencies. With reference to the presence and distribution of habitat types within a water body, diagnosis should reveal the critically lacking or under-represented habitat types. In essence, the ecological state should be linked to the hydromorphological state to allow for the identification of which habitat types are to be restored.

The hydromorphological structure in the present situation should be identified, as well as which habitat types (or elements) are missing/not functional. Is the extent (area) and configuration of current habitat types limiting the development of biotic communities? For this 'best site' or reference conditions can be used, although it is strongly recommended strongly to include knowledge about a particular lake, while not constructing a generalised reference for habitats to be restored (see above, and Irvine, appendix I).

Habitat types may be directly and/or indirectly relevant to organisms (Verdonschot, Appendix 1). Both direct (e.g. presence of vegetation) and indirect (e.g. oxygen %) habitat factors can be linked to habitat types. Other steering factors are on higher hierarchical levels than these morphological factors ('structure' in the 5S model). It is essential that diagnosis is conducted at the scale proper to the organisms that are included in the analysis.

Verdonschot pointed out that when analysing the potential for organisms/communities to establish themselves when habitat structure is created, the historical and stochastic components should be taken into account. Often the biotic composition of a site does not reflect the environmental conditions present, but is a remnant of conditions in the past. Also, presence of certain species can be due to the chance process of having arrived and survived at a particular site.

In addition, Verdonschot indicated that diagnosis also includes the identification of locations with highest restoration potential ('hotspots'), as well as thresholds in the scale of habitat structures (i.e. the scale of presence at which the restored structure will have impact in a wider area).

## 5. Prognosis

> To allow prognosis of efficacy of shoreline restoration measures, tools should be developed that take into account the probability of reaching a certain state (diversity), provided the extent and spatial configuration of habitat types under given hydromorphological conditions.

The concept of "Ecological Key Factors" currently mainly applies to 'diagnosis' or 'system analysis' of the ecological condition of a water body. For water managers however, there is also a strong need for prognosis of the effects of management actions, because they want to know if they can fulfil the ecological goals for the water bodies with the measures they have planned. During the interviews, several comments were made with regard to prognosis.

Verdonschot indicated that it is important to know which areal extent of habitat is required for a population that is sustainable in the long term. In this respect, the 'Ausstrahlungswirkung' of rehabilitated areas is of importance. As an example, for streams it has been estimated that the probability of ecological recovery of the whole stream is greatly enhanced if the natural temperature regime is restored over about 50% of the length of the stream. Similar questions could be posed for lakes, canals and ditches, e.g. for what length or surface area is recovery of habitats necessary to improve the ecological condition in the non-restored parts of the water body.

An probabilistic approach may be desirable, for which also bayesian techniques may be applicable (as suggested by Feld). This implies establishing probabilities of reaching a target state after applying certain certain habitat restoration measures. This may be desirable even more as many management actions may have cascading effects on the foodweb. A classic example of cascading effects implies the areal extent of emergent macrophytes providing reproduction habitat for pike; when the pike population can increase to a high density, benthivorous fishes will be reduced to the benefit of macrophyte and macro-invertebrate communities. Hence, increasing the emergent vegetation area is not linearly related to the effects on the whole-lake ecological state.

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# APPENDIX: INTERVIEW REPORTS

**Interview Kenneth Irvine (IHE, Delft)**

Datum: 8-12-2015
Aanw.: Kenneth Irvine, Gerben van Geest, Hugo Coops

In the interview, the issues listed in a preparatory note were addressed broadly:

1. Are existing habitat-classifications (such as LHS) and habitat-tools potentially relevant and useful?

KI indicates the Lake Habitat Survey methodology may be a very useful tool for NL. LHS is WFD compliant. It has been tested in the UK, Ireland, and also works well for Norfolk Broads, which are comparable with e.g. Loosdrecht Lakes.
Regarding a decision tool for water managers, KI advocates strongly the inclusion of local knowledge about a particular lake, and not construct a generalised reference for habitats to be restored. Whether certain “reference” habitats should be “restored” seems to be a philosophical question, water managers could pick their choice of restoration from a “sweetshop” depending on what they want to restore.
“Restoration”: purist view vs. water manager view.
Question of where to restore habitats dependent on local conditions; KI refers to exclosure experiments to restore macrophytes (Norfolk Broads, Loosdrecht).

2. Which habitat-factors do you consider useful / relevant (scale, available data)?

Considering the relevant habitats in a lake, KI puts main focus on the littoral parts of the lake. Main habitats are determined by whether you have solid sediment vs. loose mud, or presence of vegetation (different growth forms may be important for invertebrate community). Reedbed vegetation can be regarded as a separate habitat. Each have their characteristic species / species groups. One could argue that species diversity (number of species?) of species groups stands for the quality of habitat, for example:

- loose mud: tubificids
- solid substrates: oligochaetes, chironomids
- tall growth forms vegetation: snails, beetles, mayflies
- low growth forms (charophytes): particular indicator species for charophyte communities
- reedbed: copepods (also dragonflies and birds)

By assessing what is missing of these groups and which are dominating may give an indication of habitat quality.
Growth form of macrophyte vegetation may be sufficient, as there is little difference in invertebrate community composition between macrophyte species of the same growth form.
Side comment: WFD focus on restoration, not conservation. Consider Natura2000 Habitat types? In a review KI did some time back for the National Parks and Wildlife Service in Ireland on the Habitats Directive compliance and approach in Ireland, it was very clear that the Natura 2000 lake descriptors were not very effective. (see also ref. 1)

3. Can habitat-factors possibly be incorporated in analytical tools, or has this already been done?
4. Which habitat-related factors should be included in water system analysis?

What should an EKF4 tool include?
KI indicates that the monitoring process is the start for any water system analysis.

It is important to note that the Lake Habitat Survey method was not designed by ecologists, but for hydromorphological monitoring. LHS units may be useful as a basis for measuring ecological (macro-invertebrate, but also fish etc.) “quality”. Important is to include fringing habitats.
Don’t forget the context.

5. Which concepts, knowledge, and/or data are necessary for further development of a tool for ESF4?

LHS was developed for lake managing authorities EA and SEPA. They use LHS in their monitoring programme. References LHS monitoring: John Rowan (Dundee University) has developed concept/method; Phil Boon (Scottish Natural Heritage)
A lot of data collection was done in the WISER project. Reports online, relevant species lists.
Various papers and theses relating LHS to biodiversity (Oliver Miler, Tamara Jurca, Elaine McGoff)
Also worthwile paper by Jonathan White 2003
Jeremy Biggs (Pondwatch).
Ref.: Irvine K 2009 Harmonizing assessment of conservation with that of ecological quality: fitting a square peg into a round hole? Aquat.Conserv.Mar.Freshw.Ecosyst. 19: 365-369

**Interview Piet Verdonschot (Alterra, Wageningen)**
Datum: 18-12-2015
Aanw.: Piet Verdonschot, Hugo Coops

Voor het gesprek waren de volgende vragen geformuleerd:

1 Welke habitat-classificaties en habitat-tools zijn mogelijk relevant voor ESF 4? Is een vergelijkbare aanpak voor stromende wateren en stagnante wateren mogelijk, wat zijn verschillen?

2 Welke (fysische) habitatfactoren in stagnante wateren zijn bruikbaar en relevant voor ESF 4?

3 Sluiten deze factoren aan bij reeds ontwikkelde instrumenten of zijn ze onderdeel hiervan?

4 Zou een watersysteemanalyse kunnen worden uitgevoerd op basis van de relevante habitatfactoren?

5 Op welke manier kan ruimtelijke en temporele habitatvariatie worden benaderd?

6 Welke elementen uit de beschouwde methodes en kennis kunnen (evt. in combinatie) voor de verdere uitwerking van ESF 4 worden gebruikt?

1 PV geeft aan dat het belangrijk is dat de termen Habitat, Sleutelfactoren, Systeemanalyse volgens de definitie worden gebruikt. Met de ‘Ecologische Sleutelfactoren’ voor stilstaande wateren worden eigenlijk Stuurknoppen bedoeld. Sleutelfactoren zijn de factoren die vanuit het organisme gezien bepalend zijn. Ook het begrip Habitat moet ook vanuit het organisme gedefinieerd worden (hoe ervaart het organisme zijn omgeving?).
Habitatbeschrijving wordt echter vaak vanuit de geomorfologie gedaan (vanuit de vraag: ‘wat ziet de morfoloog?’, dus met een sterke bias naar de menselijke factor).
De belangrijke habitatfactoren voor organismen in stilstaande wateren zijn: vorm (profiel), littoraal, diepte, 3D-structuren en substraat (fysisch). Voor verschillende organismen is het schaalniveau verschillend.
Morfologische factoren zijn direct of indirect relevant. Te beginnen met de direct relevante factoren.

Het gaat erom wat er echt toe doet: bijv. zuurstofgehalte, of de aanwezigheid van planten (structuur voor fauna).
Daarna pas de hogere stuurfactoren, stressfactoren, en conditionerende factoren. Voor de stuur- en stressfactoren kun je de DPSIR aanpak gebruiken.
In stromende wateren gaan we uit van het 5S model, in meren kan dat net zo goed maar is de volgorde mogelijk omgekeerd (stoffen boven structuren). Maar het verschil tussen meer en rivier is in wezen niet groot. Alleen de weging/hierarchie is enigszins verschillend.

2 Welke habitatfactoren zijn primair van belang voor organismen?
Structuur: Het is gebleken dat de hardheid van het substraat van belang is, bewortelbaar tegenover hard sediment, structuur planten tegenover structuur hout/steen en niet het type materiaal of de soort plant.
Voorspellen van welke organismen ergens gaan komen heeft als probleem dat er steeds nieuwe omstandigheden komen, met andere soortcombinaties. Als je maatregelen neemt om organismen te stimuleren moet je rekening houden met een veranderende toekomst.
Voor het vaststellen van streefbeeld / referentie, moet de vraag zijn: wat is een goed functionerend systeem. Hiervoor moet je kijken naar parameters voor voedselwebrelaties, 'habitat'heterogeniteit.
Bij het formuleren van streefbeeld/doel kom je uit bij (deels) niet-objectiveerbare criteria.
Opmerkingen hierbij zijn:

- Er is onzekerheid over hoe lokale habitats zich herstellen (morfologisch) bijv. in beken wordt herstel beperkt door veiligheid en wat er verder gebeurt in het beeksysteem. Focus op procesgestuurd systeemherstel betekent dat je lokale ontwikkelingen moet laten gaan, niet lokaal ingrijpen.
- De belevingswereld van soorten is veel kleiner dan het schaalniveau van de stressfactoren

Voor de relevante habitatfactoren is de schaal afhankelijk van het organisme. Parametrisering moet dus gebeuren op de schaal van het organisme zelf, m.a.w. op dat wat er echt toe doet voor het organisme, oftewel de fysische drager.
Voor wat betreft vegetatie als habitat (fysische drager): het type doet er niet toe, wel bijvoorbeeld het verschil tussen dichte en open vegetatie.
Organismen gebruiken meerdere habitats. Daarom is de habitatconfiguratie van belang. Uit proefschrift Ralf Verdonschot blijkt de afstand tussen patches bepalend. Afstand tussen habitatpatches lijkt fitness te bepalen. (PhD Judith Westveer: voor kokerjuffers max. enkele m, daarentegen Simuliidae verspreiden zich gemakkelijk overal).
Welke habitatoppervlakte nodig is voor een duurzame populatie is onbekend. De 'Ausstrahlungswirkung' is van belang. Voorbeeld als het natuurlijke temperatuurregime in 50% van beek hersteld wordt, kunnen de populaties de hele beek herkoloniseren.
Bij de analyse van bronpopulaties wordt de historische en stochastische component vaak niet beschouwd (d.w.z. dat de ontwikkeling van een populatie in het verleden soms de aanwezigheid van de soort nu verklaart; maar ook 'toevallig' lokaal vestigen of uitsterven).
Hoe moet je habitats meten? Op het niveau van de drager; mesoschaal lijkt voldoende, niet fijner en misschien grover.
Voor het meten van configuratie moeten de meetmethoden nog ontwikkeld worden. Wellicht kun je de optimale configuratie van habitats afleiden van goed functionerende wateren.

4 Belangrijk om meren te beschouwen als open systemen, je moet dus het geheel bekijken. Als systeemherstel wordt ingezet, volgen de kleinschalige habitats.
Vb. streefbeeld/maatregelen Peel en Maasvallei: tijd nemen om kansrijke keuzes te kunnen bepalen. Inzetten op zorgvuldig bepaalde kansrijke locaties heeft meer zin dan het blind grijpen van alle

mogelijkheden die zich voordoen (kansrijke locaties = plekken waar herstel bijdraagt aan herstel van het hele systeem).
In het algemeen ontbreken de gegevens voor een (habitat)systeemanalyse.
Wat & hoe meten is een kennisvraag.
Over ruimtelijke variatie (interacties) is veel te weinig bekend. Voor vogels wel, vissen een beetje, andere groepen niet.
Temporele variatie: patches veranderen, soorten komen en gaan. Stabiliteit betekent dat habitats (patches) altijd ergens aanwezig zijn. In een soortenrijk systeem kunnen metapopulaties voortbestaan als aan die voorwaarde van stabiliteit is voldaan.

**Interview Christian Feld (University of Duisburg-Essen)**
Datum: 20-1-2016
Aanw.: Christian Feld, Gerben van Geest, Hugo Coops

Ecological Key Factor 'Habitat'
For the ecological key factor 'Habitat', a distinction should be made between Habitat quality, habitat suitability, and habitat diversity.

Habitat quality
Is information of the dominant habitat sufficient, or all habitats? For benthic macroinvertebrates the most relevant part is the bottom.
Absence of certain habitats is also an aspect of habitat quality (e.g. wood).

Habitat suitability
Not feasible for each species, one has to use organism groups.

Habitat diversity
Is this just the number of habitats, compared with reference?
Parameters that define habitat diversity are for example the habitat diversity index (e.g. Shannon-Wiener index). A major question is, what are the determinants of habitat diversity?

Diagnosis
Biotic response is expressed as an Index value, which is a generalised response to all key factors.
For diagnosis more than 1 metric is needed responding differently to pressures/stresses. With one metric you can only tell there is something wrong.
Some metrics are closely related to stressors, others less.

Using species themselves as metrics has disadvantages: a long list of potential species, a lot of lacking species, species with identical requirements. State – organism response relationships are often not clear.
Using trait groups may be possible ("Traits" such as feeding types, e.g. shredders).

Habitat characteristics (describing 'habitat quality'):
- % substrate
- nr. Of substrates
- macrophytes

**Diagnosis tool for Macrozoobenthos**

In the interview CF explained the diagnosis tool that is being developed by him in the framework of the MARS-project. The tool, which in this stage is developed for running waters, may also be applied to other type of water (lakes, estuaries, coastal waters). The tool uses Bayesian Belief Networks (BBN), and starts with well-informed guesses of the probabilities of the effects to be caused by a set of ecological key factors.

The Bayesian method works from effect to cause, instead of cause → effect.

CF is attempting to set up a Bayesian network for diagnosis of Macrozoobenthos in rivers. First learning points:

- Asking the right questions is important
- It is not a prognostic or assessment model
- Start with the symptoms, not with causes
- To fill the probability table, too many nodes is problem

In the current stage the probabilities are applied in the draft network model. Next stage will be the actual testing of the model.

Software: Nedica (NEtwork Detection using ICA;  ICA = Independent Component Analysis).

With the current model, one can identify that habitat diversity is a / the problem, not which habitat. For now, the key factor ‘Habitat diversity’ is not elaborated further.

Perhaps habitat diversity/quality could also be evaluated using the BBN approach.

The choice of metrics is important. Currently used metrics may be biased e.g. towards eutrophication.

Using this type of diagnosis for developing restoration measures is a problem, because system often does not respond as expected.

The outlook is that this approach may be very useful for water managers, and could provide tailor-made diagnosis tools (per water type?).

One particularly relevant question for water managers is to know the probability of a change in quality class (ecological status transition e.g. Moderate → Good).

An alternative approach would be Regression Tree Analysis or C-tree (conditional inference trees).

Usually statistical models are preferred when one has all the data (data-driven modelling).

Caution for using any model: it depends on the aim of the analysis.

**Questions**

*1. Do you think there is a fundamental difference in approach required for flowing waters (rivers, streams) and standing waters (lakes, canals, ditch networks)? Or may a similar approach be feasible?*

An important difference between rivers and lakes is that lakes show seasonality. Rivers are characterised by flow, and the upstream-downstream gradient (river continuum: increase in species in downstream direction. Lakes don’t show a continuum, instead they show stratification.

Also characteristic of lakes is nutrient cycling, in contrast to nutrient spiralling in rivers.

The general approach for diagnosis / analysis will be similar, albeit with different ecological key factors.

An important difference is the time factor. For lakes data are often time series. This could be tackled in a diagnosis tool (temporal vs. non-temporal Bayesian approach).

*2. Definition, delimitation, parametrization of 'Habitat diversity'*

Habitat diversity can be expressed in different indices, e.g. the proportion of a substrate. Macro-invertebrate species have specific habitats. Data is needed on how much of shoreline is habitat x.

Germany has a Lake Habitat Protocol, as a non-official assessment system. Developed by IGB (Martin Pusch, WISER).
Research on habitat diversity for macro-invertebrates in rivers: AQEM, STAR (Hydrobiologia 516, 566).
The German Fauna Index also includes a habitat structure index.

WISER approach: species lists of degraded habitats and natural habitats were used to derive indicator values for species, which formed the basis for a multimetric index, used to determine the EQR.
Species diversity on itself is not a good indicator for quality. E.g. Dipterans and Oligochaetes always occur in degraded systems, and a high diversity of these groups doesn't indicate high status.

*3. Diagnosis tool*

The Abiotic State variable 'Habitat diversity' has an effect on several Biotic State variables (metrics).
A single metric cannot be stressor specific. Metrics must be correlated to some degree.
All stressors are related (multistressors), so metrics are connected too.

Crossvalidation of chemical and hydromorphological monitoring
Check diagnosis with available abiotic data

Using species as biotic state variables has several disadvantages. There are too many species, and in a particular case also many potential species are lacking. Using community metrics also averages out the seasonal effects
In some cases however, indicator species might be useful as biotic state variables.

*4. Habitat factors in lakes and other standing waters*

Habitat diversity, habitat quality (see above).
Habitat suitability is a function of habitat (organism view: structure and proportion)

*5. Development of the Macrozoobenthos-diagnosis tool*

The bottleneck for diagnosis is the connection between key factors and causes. The DPSIR table (Tom Buijse) presents a cross matrix that could be helpful.

Probabilities for Drivers → key factors → metrics
Is it possible to identify the link between causes and identifyable states?

The data for lakes (hydrology, water quality) are available, except data on habitat quality.

*6. Knowledge / data / publications / experience relevant for EKF4*

Special reference to WISER deliverable 334 (see website): Lake habitat quality assessment.

**Interview Jonas Schoelynck / Kerst Buis (Universiteit van Antwerpen)**
Datum: 17-2-2016
Aanw.: Jonas Schoelynck, Kerst Buis, Hugo Coops

Voor het gesprek waren de volgende vragen geformuleerd:

1 Welke habitat-classificaties en habitat-tools zijn mogelijk relevant voor ESF 4? Is een vergelijkbare aanpak voor stromende wateren en stagnante wateren mogelijk, wat zijn verschillen?

2 Welke (fysische) habitatfactoren in stagnante wateren zijn bruikbaar en relevant voor ESF 4?

3 Sluiten deze factoren aan bij reeds ontwikkelde instrumenten of zijn ze onderdeel hiervan?

4 Zou een watersysteemanalyse kunnen worden uitgevoerd op basis van de relevante habitatfactoren?

5 Op welke manier kan ruimtelijke en temporele habitatvariatie worden benaderd?

6 Welke elementen uit de beschouwde methodes en kennis kunnen (evt. in combinatie) voor de verdere uitwerking van ESF 4 worden gebruikt?

7 Aanvullende suggesties voor een mogelijke aanpak, belangrijke (literatuur-)referenties, lopende projecten die kunnen bijdragen aan de uitwerking van ESF4? Datasets met milieupreferenties van soorten (waterplanten, macrofauna, vissen)?

De vragenlijst is gedurende het gesprek losjes gevolgd. Het onderzoek vindt vooral plaats in stromende wateren. Jonas Schoelynck is in 2011 gepromoveerd op interacties tussen waterplanten-patches en hydrodynamiek in kleine rivieren (Nete), en is sindsdien verder gegaan met het onderzoek aan aanpassingen van waterplanten aan stroming en ‘ecological engineering’ door waterplanten in stromende wateren. De nadruk bij dit gesprek ligt daarom vooral bij macrofyten in stromende wateren.

Qua stilstaande wateren is in Vlaanderen enig onderzoek gedaan ten behoeve van KRW-statusrapporten. UA heeft in de priode 2012-2014 enkele rapporten opgesteld met de toestandsbeschrijving (MEP/GEP) van twee kunstmatige wateren (zandwinplassen). Dit betrof fytoplankton, macrofyten en macrofauna.

Het fundamentele verschil tussen stromende en stilstaande wateren is de stroming, en de hydrodynamische stress op planten die daar het gevolg van is. Dezelfde soort kan in stromend water een afwijkende groeivorm hebben van die in stilstaand water. Voorbeeld: Gele plomp in rivier en in naastgelegen, stilstaand oxbow lake (artikel Schoelynck et al 2014). Licht is in meren de absolute sturende factor, terwijl dit in (ondiepe) rivieren veel minder belangrijk is. Dieptepatroon in rivieren wordt door stroming gestuurd: in het midden wordt een meanderende strook waterplantenvrij gehouden door de stroming.

In laaglandbeken lijken harde substraten niet evident van belang voor macrofyten.

In meren is licht de hoofdfactor voor waterplanten. De zandwinplas met zeer helder water (gevolg van P-zuivering) was tot grote diepte (8-9 m) begroeid met Potamogeton lucens. Om meer variatie (meer soorten) te krijgen is voorgesteld ondiepe oeverzones te creëren. In de andere, troebeler, plas leek dit juist geen goede optie omdat daardoor de kans op algenbloeien zou toenemen. De volgorde in het raamwerk van de ESF's lijkt hierbij aan te sluiten: habitats creëren nadat nutriëntenregime en lichtklimaat zijn verbeterd.

Met betrekking tot het creëren van habitats wordt ook nog gerefereerd aan een project uitgevoerd tezamen met Universiteit van Gent: maken van vooroeverstructuren in kanalen om habitats voor vissen te verbeteren.

De ruimtelijke heterogeniteit (waterplanten-patches) is onderwerp van studie: waar komen de planten vandaan, hoe vestigen ze zich, hoe werkt facilitatie waardoor patroon ontstaat? In stromende wateren lijkt het erop dat de talweg structurerend kan zijn. Patches komen voort uit toevallige vestiging van plant-fragmenten; echter de rivier heeft mogelijk ook een 'geheugen' in de vorm van zaden en begraven fragmenten e.d. In de Vlaamse rivieren speelt verstoring door maaien van de waterplanten daarnaast een belangrijke rol voor de stabiliteit van de patronen..

Kerst Buis noemt het lopende onderzoek aan ruimtelijke heterogeniteit in stromende wateren, waarbij de interacties tussen biogeochemie, sedimenthuishouding, vegetatie en ook de grondwaterhydraulica worden onderzocht. Voor het in kaart brengen van de ruimtelijke heterogeniteit wordt gewerkt met low-altitude luchtfoto's (scanning met drones). Hiermee worden plantenstructuren (diepte in vegetatie met Near Infrared), en stroomsnelheidspatronen (markers) vastgelegd. Uiteindelijk is het doel deze patronen ruimtelijk te modelleren.

Opgemerkt wordt nog dat het bij het volgen en modelleren van ruimtelijke heterogeniteit (vegetatie- of habitat-patronen) niet zozeer gaat om de soorten waterplanten, maar dat het onderscheid tussen groeivormen zeer relevant is.

Relevante literatuur en data:

Proefschrift Jonas Schoelynck (2011) Macrophyte patches as biogeochemical hotspots: what is the impact on river water quality?

Proefschrift Kris Bal (2009) Interactions between macrophyte ecology and hydraulic functioning of lowland rivers.

Rapport zandwinputten.

In het verleden zijn bij UA diverse studies aan habitatrelaties uitgevoerd. Er is een Access-dataset beschikbaar van waterplanten en milieuvariabelen in rivieren.

# APPENDIX 2. UITWERKING VAN DE ECOLOGISCHE SLEUTELFACTOR ‘HABITAT’

**Uitgangspunten en randvoorwaarden:**

- Het begrip ‘habitat’ heeft betrekking op hydromorfologische parameters, inclusief vegetatiestructuur.
- De methode moet onderscheidend zijn voor de ecologische functionaliteit van natuurvriendelijke oevers.
- Naast standplaatsniveau moet nadrukkelijk ook het belang van grotere ruimtelijke schaalniveaus in beeld gebracht worden. Zo’n aanpak geeft onder meer antwoord op de vraag wat de meest succesvolle locaties zijn voor de aanleg van natuurvriendelijke oevers.
- De ecologische sleutelfactor “habitat” kan niet los gezien worden van de invloed van andere sleutelfactoren. Vooral de factor nutriëntenrijkdom van het sediment in de oever speelt een belangrijke rol voor de ontwikkeling van de structuur (groeivorm, dichtheid) en successiesnelheid van de oevervegetatie, evenals de aanwezige hydrodynamiek (zoals al dan niet natuurlijke peilfluctuaties).
- Aanbevolen wordt om de uit te werken methodes zo min mogelijk complex te maken. In veel gevallen zijn de correlaties tussen structuurparameters en soorten namelijk onbekend, en zelfs als deze bekend zijn, dan is onduidelijk wat de causale relaties zijn. Hiernaast beschikken veel waterschappen (nog) niet over de benodigde data, waardoor een gedetailleerde methode niet aansluit bij hun werkwijze.

**Werkzaamheden:**

1. In beeld brengen van (fysische) habitatpreferenties van verschillende soort(groep)en. Dit betreft in ieder geval de water- en oeverplanten, macrofauna en vis. Bij de ontwikkeling van deze typologie worden parameters afgebakend op meso- en hogere schaalniveaus voor de verschillende groepen. Ook dient de rol van configuratie en connectiviteit van habitat-elementen voor de organismen te worden meegenomen bij het opstellen van habitatpreferenties.

2. Ontwikkeling van een habitattypologie voor verschillende soortgroepen per KRW-watertype. Een habitattypen-indeling dient bij voorkeur gerelateerd te zijn aan het voorkomen van soortgroepen (of – eventueel – gemeenschappen) in plaats van soorten, omdat van veel individuele soorten de habitatvereisten niet bekend zijn. Deze stap maakt nauw gebruik van kennis uit stap 1. Bij de uitwerking is er veel aandacht voor (natuurvriendelijke) oevers, maar ook andere habitattypen worden meegenomen, bijvoorbeeld voor vissen, die van grotere schaalniveaus afhankelijk zijn.

3. Bij het opstellen van een habitattypologie wordt zoveel mogelijk gebruik gemaakt van reeds bestaande kennis. Voorbeelden hiervan zijn databases die beschikbaar zijn voor afzonderlijke soorten, zoals voor diatomeeën (dataset Herman van Dam), waterplanten (AqMaD, De Lyon & Roelofs, 1986, lopende project “Waterplanten en Waterkwaliteit”), macrofauna (WEW-dataset) en vis (recent bijgewerkte dataset voor AqMaD). Aanbevolen wordt om vooral de habitatpreferenties in beeld te brengen van soortgroepen, bijvoorbeeld

waterplanten (groeivormen, dichtheid), macrofauna (zie voorstel Irvine) en vis (visgemeenschappen).

4. Voor natuurvriendelijke oevers kan gebruik worden gemaakt van de STOWA-publicatie Handreiking Natuurvriendelijke Oevers: een standplaatsbenadering (Sollie et al, 2011). Deze handleiding bevat een eenvoudige beschrijving van vegetatietypen voor NVO's, die zijn ingedeeld naar KRW-type, nutrientenstatus van het sediment en waterpeilregime. Hierop kan worden voortgeborduurd om de invloed van hydromorfologische ingrepen te kunnen bepalen.

5. Ontwikkeling van een (veld)protocol, waarmee een ruimtelijk (vlakdekkend?) beeld kan worden verkregen van relevante habitatparameters in een watersysteem. De keuze van de parameters die in dit protocol worden opgenomen hangt nauw samen met de resultaten van stap 1 en 2.

6. Opstellen van referenties, best sites, Goed Ecologisch Potentieel (GEP), Goede Ecologische Toestand (GET) voor de verschillende watertypen en biologische groepen. Bij voorkeur wordt de waterbeheerder geen 'standaard' referentiebeeld opgelegd, omdat deze beelden vaak slecht aansluiten bij de mogelijkheden in een watersysteem. De gewenste beelden worden geformuleerd in termen van zowel 'abiotiek' als 'soortsamenstelling'. Voorgesteld wordt om 'best site' databases op te zetten, die als referentie kunnen dienen. Ook moeten waterbeheerders zelf referentiebeelden kunnen invoeren (in termen van abiotiek en/of soortenlijsten).

7. Ontwikkeling van een diagnosetool of -methodiek waarmee de huidige situatie vergeleken kan worden met een gewenste toestand.