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Development of a multimetric index based on macroinvertebrates for drainage ditch networks in agricultural areas

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ABSTRACT

Drainage ditches are a prominent feature of many intensively managed agricultural areas. These small, shallow, line-shaped waterbodies could harbor a rich macroinvertebrate community, resembling that of natural small lentic ecosystems. Despite their high biodiversity potential, many ditch ecosystems are degraded due to nutrient enrichment, resulting in a shift from a mesotrophic system characterized by a diverse vegetation of emergent-, submerged-, and floating macrophytes to a hypertrophic state dominated by Lemnaceae or phytoplankton.

Tools to assess the ecological quality of drainage ditches are currently lacking. Therefore, a multimetric index based on macroinvertebrates was developed to assess the ecological quality of drainage ditch systems in The Netherlands. Based on a large dataset from regional water district managers, who conduct routine sampling of macroinvertebrates in drainage ditches, a degradation gradient composed of 223 samples was derived, which represented the combined stressors eutrophication, organic pollution and salinity.

We used a stepwise process to evaluate the discriminatory efficiency of a variety of diversity, abundance/composition, tolerance/sensitivity, and functional metrics for assessing ecological degradation in drainage ditches. After evaluating metric range, strength of correlation to the stressor gradient, degree of redundancy, and sample- and seasonal repeatability, five metrics were selected for the drainage ditch multimetric index: number of Trichoptera families, percentage of Gastropoda families, percentage of taxa preferring fresh water ($Cl^- < 300\,mg\,L^{-1}$), Dutch Saprobic index, and the percentage of predator taxa. The relationship of these single metrics with the stressor gradient is discussed.

1. Introduction

Drainage ditches are small, stagnant, line-shaped water bodies, dug to improve rainwater run off and regulate the groundwater level of surrounding agricultural areas. They are a prominent feature in the landscape of the lowlands of northwestern Europe; in The Netherlands alone, total ditch length is approximately 300,000 km. To retain the drainage function of ditches, dredging and mowing of vegetation takes place regularly. Despite intensive maintenance by man, ditches can harbor a high species diversity, which closely resembles natural communities found in marshlands, oxbows, and the littoral zone of shallow lakes (Verdonschot and Higler, 1989; Verdonschot, 1992).

Recent studies point out the importance of drainage ditches as drivers of biodiversity in agricultural areas (Painter, 1999; Armitage et al., 2003; Herzon and Helenius, 2008). Drainage ditches have a high potential in terms of biodiversity, as described in historical records and which is still observed in some extensively managed areas (e.g. Higler and Verdonschot, 1989; Armitage et al., 2003). In The Netherlands most ditches do not reach this potential because they are severely degraded due to runoff of nutrients and organic matter from the neighboring, intensively managed meadows and croplands (Janse and Van Puijenbroek, 1998). Apart from this, nutrient concentrations are further increased by the common practice of the inlet of river water during summer. This is done to retain a constant water level to make farming as efficient as possible. The inlet of river water also results in increased chloride concentrations (Higler, 1989). Overall, a considerable number of drainage ditches in The Netherlands has reached a hypertrophic and polysaprobic state, sustaining a system dominated by Lemnaceae or bluegreen algae.

Ecological consequences of an increase in nutrient concentrations are profound. The vegetation of mesotrophic drainage ditches is characterized by a species-rich mosaic of submerged, emergent and floating plant species. A slight increase in nutrient load induces the dominance of 'weedy' submerged plant species, such as *Elodea nuttallii* (Portielje and Roijackers, 1995). Ongoing enrichment eventually leads to frequent filamentous and epiphytic algal

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blooms and dominance of Lemnaceae or *Azolla filiculoides*, resulting in decreased light penetration, hindering the development of submerged vegetation (Janse and Van Puijenbroek, 1998). Furthermore, it results in the impoverishment of the macroinvertebrate fauna (Clare and Edwards, 1983).

In The Netherlands, regional water district managers conduct routine surveys of the flora and fauna inhabiting drainage ditch networks. Assessment of the ecological quality of these sampling locations is mainly based on national assessment and Water Framework Directive criteria. We refer to good ecological quality as a state of ecological integrity, in which all appropriate (a)biotic elements are present in the ecosystem and processes occur at appropriate rates (Angermeier and Karr, 1994), reflecting the conditions under which human influence is limited to periodic ditch cleaning. Although sites with a good ecological quality as well as heavily degraded systems are easily discerned, both in terms of vegetation and macroinvertebrate assemblage composition, recognition of the patterns of loss of ecological integrity proved to be difficult. One of the reasons why detecting ecological degradation of drainage ditch ecosystems is problematic results from an only basic understanding of the relationships between the structure and functioning of ditch ecosystems and the impact of anthropogenic activities. This lack of knowledge of ditch ecology is not restricted to The Netherlands alone, but appeared to apply across Europe and North America (Herzon and Helenius, 2008).

To assess the ecological quality of a water body, a combination of components reflecting the structure and functioning of the ecosystem should be used (Karr and Chu, 1999; Barbour et al., 1999). By combining parameters providing information on different ecosystem features into a multimetric index, the ecological quality of a water body can be derived. In case of drainage ditches, both macroinvertebrates and macrophytes can potentially be used to develop such an index. Nevertheless, most ditches in agricultural areas are poor in macrophyte species, whilst harboring a diverse macroinvertebrate assemblage. Therefore, in this study we chose to focus on macroinvertebrates. Assessment of ecological quality based on macroinvertebrates has a long history, mainly in streams, rivers and lakes. Only recently, several indices for small lentic ecosystems have been developed (e.g., Burton et al., 1999; Solimini et al., 2008; Trigal et al., 2009).

In this study, we investigated if it was possible to assess the ecological quality of drainage ditches, analogous to the multimetric indices developed for other aquatic systems. Aim of this study was to (1) select macroinvertebrate-based ecological indicators suited to confirm the best available status and to detect degradation in drainage ditches, and (2) combine these indicators into a multi-metric index to assess the ecological quality of drainage ditch systems. A large dataset collected by regional water district managers was used to evaluate a wide variety of taxonomic, compositional, tolerance, and functional characteristics of the macroinvertebrate assemblages. Based on their discriminatory efficiency with increasing degradation and their repeatability across samples and seasons, best performing metrics were combined into a drainage ditch multimetric index.

2. Methods

2.1. Data collection

In The Netherlands, drainage ditches are included in the surface water monitoring network of water district managers, and are sampled following a standardized sampling procedure: a stretch representative of the whole ditch (approximately 50 m) is chosen, of which the distribution of habitat types (e.g. bottom substrate type, emergent and submerged vegetation) is estimated. Subsequently, 10 ditch sections of 0.5 m in length are selected in proportion to the surface area covered by each of the major habitat types and sampled using a pond net (mesh-size 500 μm, width 30 cm), up to a total length of 4 m of vegetational habitats and 1 m bottom substrate habitats. Samples are transported to the laboratory, where they are sieved trough 1.0 mm and 500 μm sieves. Macroinvertebrates are sorted alive and identified to the lowest taxonomical level practical.

Data used were collected in 1980–2008, and included a wide variety of locations. Sampling sites ranged from ditches in nature conservation areas, considered as minimally impacted and of good ecological quality, to ditches located in intensively used agricultural areas. In total, the dataset contained 290 sites, sampled in spring, summer or autumn. Furthermore, 2 datasets collected as part of other studies, but according to the same sampling protocol, were used to test metrics for variability regarding repeated sampling of the same location (8 minimally impacted sites within one drainage ditch network) and seasonality (18 sites sampled in both spring and autumn within the same year).

Only sites where environmental variables were recorded during macroinvertebrate sampling were selected. Land use adjacent to the 50 m ditch stretches was recorded, as well as the soil type. Bank slope was estimated visually for both banks using three classes: level (<30°), intermediate (30–60°) or steep (>60°). Channel width and maximum water depth were measured at 5 randomly selected points along the ditch stretch. Data on ditch hydrology, in terms of influence of groundwater seepage and the inlet of river water during dry periods was derived directly from the water managers. Percentage cover of floating, submerged and emergent vegetation and floating algal mats was estimated visually for the ditch stretch. Measurements of pH, conductivity and dissolved oxygen were carried out in the field directly, whilst water samples were taken and analyzed in the laboratory for ammonium, nitrate, total nitrogen, total phosphate and chloride concentrations.

2.2. Data preparation

The macroinvertebrate datasets of different water district managers were combined into a single database. Inconsistencies in data formats and scientific nomenclature were resolved. The resulting taxon list showed considerable taxonomic overlap, mainly as a result of difficulties identifying early instar specimens. Since it was unknown if a specimen identified to, for example, genus level in one sample was actually an early instar of a species recorded in another sample a taxonomic adjustment procedure was necessary to avoid multiplication of the same information during analysis (Nijboer and Verdonschot, 2000; Schmidt-Kloiber and Nijboer, 2004; Vlek et al., 2004). When specimens were identified to species (lowest taxonomic level), apart from a few exceptions, which were only identified to genus or family (higher taxonomic levels), the higher taxonomic levels were omitted and the lowest taxonomic level was kept. When specimens identified to genus or family level were abundant compared to the specimens identified to species level (frequency of occurrence >20% of all the species belonging to this genus or family), the lower taxonomic level(s) were aggregated to the higher taxonomic level.

2.3. Definition of stressor gradient

Since drainage ditches are artificial water bodies, located in agricultural areas and maintained by dredging and mowing of the vegetation, 'natural' or reference sites do not exist. Therefore, we could not to evaluate the discriminatory ability of the metrics by comparing the distribution of each metric to a set of pre-classified reference sites (e.g. Barbour et al., 1999), but included a gradient of sites covering the whole range of degradation (Hering et al., 2006a).