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Original Article

A long-term improvement in Danish stream fauna: Analyses of temporal dynamics and community alignment of a biotic index

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ABSTRACT

Danish streams have for some decades shown a significant improvement in ecological quality. This is based on a time-series of a subset of 247 sites from the nationwide monitoring program with reoccurring annual sampling. The ecological quality is determined using the benthic macroinvertebrate fauna as bio-indicators via the Danish Stream Fauna Index (DSFI), and expressed in categorically ranked scores, with 1 as the lowest, and 7 as the highest quality. We analysed a data set on DSFI scores and the associated taxon lists from 2004 to 2013, totaling to 2411 individual samples or communities. Our main objectives were to 1) examine the temporal multi-directional dynamics underlying the overall net improving trend in the DSFI scores, and 2) to elucidate how the DSFI responds to differences in faunal community composition. Our analysis showed that most sites exhibited unchanged DSFI over the 10 year period (53%), although inter-annual shifts were still observable within these sites. The DSFI interval 1–2 showed the highest proportion of positive shifts, whereas interval 3–4 the highest proportion of negative shifts. Improvement measures should therefore be directed more specifically towards intermediate quality streams. Sites with moderate to high scores (DSFI 4–7) were most stable. Turnover (i.e., replacement of taxa) was the dominating component of overall beta diversity, while the richness change component (i.e., loss/gain of taxa) was negligible. The specific DSFI scores encompassed wide ranges of community composition, and showed a weak, but significant correlation between differences in scores and the community composition. This is to a certain degree advantageous since it gives the categorical scores robustness and plasticity, and thus makes the DSFI capable of handling natural variation in communities. The ideal biotic index should allow for natural variation, but do so while maintaining the capability of separating ecologically different communities. Our findings consequently give rise to concern to whether the DSFI is too sensitive to stochastic variation in samples with insufficient precision to assign sites to correct ecological quality classes.

1. Introduction

Benthic macroinvertebrates are often used as bio-indicators in the monitoring and environmental management of streams (Bonada et al., 2006; Birk et al., 2012). The rationale behind this is their high diversity and widely differing eco-physiological tolerances towards environmental stressors (Dale and Beyeler, 2001; Gerhardt, 2002). The taxonomical composition of bio-indicator communities can accordingly be designated to certain ecological qualities (Metcalfe-Smith, 1994; Feld and Hering, 2007). The relation is typically expressed in biotic indices, which assigns the qualities to specific scores (Washington, 1984; Birk et al., 2012; Pander and Geist, 2013).

In Denmark, the official macroinvertebrate index to determine stream quality is the Danish Stream Fauna Index (DSFI), which classifies the ecological quality into seven categorical scores (Skriver et al., 2000; Wiberg-Larsen, 2011, 2013). DSFI data generated from the Danish nationwide monitoring program has during the last decade revealed an overall improvement in the ecological quality (Wiberg-Larsen et al., 2012, 2013) (Fig. 1). The temporal trend is illustrated by a 10% increase in sites with high-good environmental status, a 9% corresponding decrease in those with moderate status, and an almost unchanged proportion of those with bad and poor status.

The present study focuses on the dynamics underlying the overall trend in the DSFI over the last decade (2004–2013). The specific objectives were 1) to characterise and quantify the temporal multi-directional variability of sites and DSFI scores that is not revealed by the overall net improving trend, and 2) to elucidate how the DSFI responds to differences in macroinvertebrate community composition. The influence of environmental factors was not specifically taken into account, although reduction of organic loads (from wastewater) has

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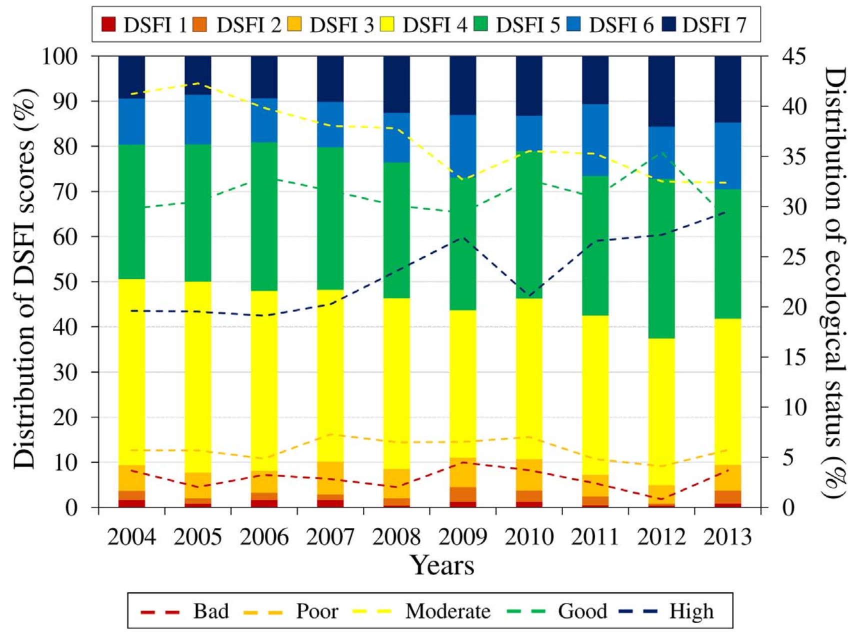

Fig. 1. The ecological quality of Danish streams based on the acquired data from the National monitoring program (NOVANA). Columns show the DSFI scores ranged from 1 to 7, the latter denoting high environmental quality. Dashed lines represent the corresponding ecological status as applied in the European Water Frame Directive. The ecological status rates from high to bad and translates to DSFI as following: High status = DSFI 7, Good status = DSFI 5 and 6, Moderate = 4, Poor = 3, and Bad = DSFI 1 and 2. Both measures are colour-coded according to general standards (Baattrup-Pedersen et al., 2004; Naturstyrelsen, 2013).

been acknowledged as the main driving force behind the improvements (Wiberg-Larsen et al., 2012). For the first objective we hypothesised that the ecological quality would show a stable pattern with minor temporal fluctuations and a slight predominance of positive shifts, i.e., achievement of higher score (Wiberg-Larsen et al., 2013). Sites belonging to intermediate DSFI scores may shift in both directions, i.e. both increase and decrease in score, thus, providing that resistance to impacts is similar at high and low quality sites, we might expect individual intermediate quality sites to show the highest degree of temporal variation, though not necessarily the highest net change in score (Mykrä et al., 2008; Wiberg-Larsen et al., 2013). The DSFI allows for three ways of changing scores. One is through replacement of taxa, a second by an increase in the number of taxa, and a third is conversely by reduction of taxa. Replacement of taxa is attributable to a turnover component, and does not inherently coincide with a change in the number of taxa (Qian et al., 2005; Baselga, 2010). Transitions due to loss/gain of taxa conversely reflect a richness change component (Atmar and Patterson, 1993; Gaston and Blackburn, 2000; Heino, 2011). For the second objective we anticipated that replacement (i.e., turnover) of taxa would be more important for the categorical transitions between DSFI scores than loss or gain in number of taxa (i.e., richness change) (Wright et al., 1998; Malmqvist et al., 1999; Monaghan et al., 2005). Further, sites with a high degree of similarity in community composition should expectedly have similar index scores. We also anticipate that a higher number of taxa would permit more combinations of community compositions and therefore cause a decrease in similarity between communities towards high DSFI scores. Thus, DSFI is expected to capture structural alterations in the macroinvertebrate community (Baattrup-Pedersen et al., 2004; Wiberg-Larsen, 2011; Huttunen et al., 2012).

2. Methods

2.1. The Danish stream fauna index

Each stream site or reach is sampled following a standardized procedure including a semi-quantitative kick-sample and a qualitative sample. The kick-sample is collected by kicking twice in the substrate in front of a D-net (mesh size 500 µm, width 25 cm) placed on the stream bottom at each of four places along three transversal transects separated by 10 m (i.e. 12 places in total). The qualitative sample consists of handpicking from boulders and logs during 5 min. The sampling results in a quantitative and qualitative taxon list, which is used to obtain the score in the Danish Stream Fauna Index (DSFI) (Skriver et al., 2000; Wiberg-Larsen, 2011).

The assessment by DSFI is a categorical scale from 1 to 7, with a score of 7 indicative of high ecological quality (Skriver et al., 2000; Wiberg-Larsen, 2011, 2013). The DSFI is conceptually based on the saprobic system and developed from the Trent Biotic Index (Woodiwiss, 1964; Wiberg-Larsen et al., 2013). The current index is, nevertheless, a newer, modified version of the original Viborg-Index (Andersen et al., 1984; Miljøstyrelsen, 1998). Further initiatives have recently been taken to convert the categorically based DSFI scale to a numerical EQR value, as part of the European intercalibration process (Van De Bund, 2009; Larsen et al., 2014).

The index is structurally arranged as to consider both diversity and taxonomic composition of the fauna, with a slight quantitative element for a few specific taxa. It operates at taxonomic resolution from genus to class. As many taxa are not used in the DSFI, the obtained score will in practice be based on a fraction of the entire sample (Baattrup-Pedersen et al., 2004; Jones, 2008; Wiberg-Larsen et al., 2013). The index thus incorporates indicator groups (IG) and diversity groups of specifically listed taxa. The indicator groups set the initial hierarchic scale with very sensitive groups (IG 1–2) primarily associable to good and high ecological quality, and less sensitive/very tolerant groups (IG 5–6) associated with low ecological quality. Within each indicator group further differentiation is based on the number of occurring diversity groups. The diversity groups are subdivided and classified into positive and negative groups according to tolerances towards organic pollution. A summation of the total number of diversity groups constitutes the only calculation included in the assessment, and determines the final status, i.e., the DSFI score (Skriver et al., 2000; Wiberg-Larsen, 2011; see supporting material, S1).