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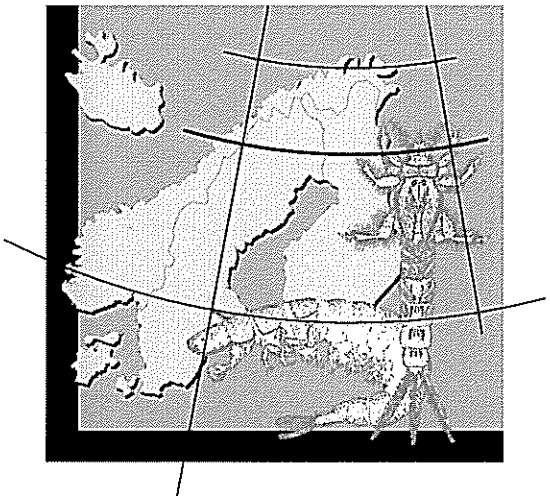

Danish Stream Fauna Index (DSFI) as an indicator of rare and threatened benthic macroinvertebrates

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Danish Stream Fauna Index (DSFI) as an indicator of rare and threatened benthic macroinvertebrates

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Abstract

The Danish Stream Fauna Index (DSFI) is the official Danish standard for routine biological stream assessment. The invertebrate fauna is only identified to family or genus level. DSFI index values range from 1 (impacted condition) to 7 (non impacted condition). Macroinvertebrate species lists from 446 Danish stream sites have been analyzed to determine if DSFI index values are related to the occurrence of red list species and the total number of species from selected taxonomic groups. Red list species were never present in very impacted streams (DSFI index values 1 and 2). Contrarily, red list species were found in the majority of streams with DSFI index values of 6 and 7. Stream width was also found to play an important role, as red list species were more frequent in larger streams.
In conclusion, DSFI appears to be a good overall indicator of stream nature quality as expressed by the number of red list species and total number of Ephemeroptera, Plecoptera, Trichoptera and Coleoptera species.

Introduction

The Danish Stream Fauna Index (DSFI) was developed for rapid biological assessment of watercourses in Denmark (Danish Environmental Protection Agency, 1998). The index (Table 1) uses macroinvertebrates, and is based on the same principles as the Trent Biotic Index (Woodiwiss, 1964). The Danish Stream Fauna Index (DSFI) incorporates both indicator species and the diversity of the invertebrate community. The original version of the DSFI was introduced to evaluate the degree of organic pollution (Andersen *et al.*, 1984). The indicators most sensitive to organic pollution have also been shown to reflect impact from ochre (Skriver, 1984; Rasmussen & Lindegaard, 1988), which is a serious problem in many streams in the western part of Denmark. Other types of human impact such as physical changes due to regulation and weed cutting, can change the animal communities and thus the DSFI index value (Olsen & Friberg, 1999). The original term "degree of pollution" used by Andersen *et al.* (1984) has therefore been changed to "fauna class" (Kirkegaard *et al.*, 1992; Danish Environmental Protection Agency, 1998).

The general nature quality of different terrestrial and aquatic environments has in recent years been in focus in Denmark, consequently efforts are being made to express environmental quality in a standardised manner. This investigation focuses on biotic indicators of high stream quality, demonstrated by the 1) occurence of pollution sensitive species, 2) occurrence of rare and threatened species, and 3) medium to high diversity of specific taxonomic groups (Ephemeroptera, Plecoptera, Trichoptera and Coleoptera).

Rare and threatened species are registered on a so called "red list". The Danish red list is revised every 5 to 10 years, and species are either added or removed, according to their current status of occurence. During the past 20 years many investigations in Danish streams have been undertaken, and thus knowledge about the ecology and distribution of individual freshwater macroinvertebrate species has improved considerably (Skriver *et al.*, 1997). During the same period, efforts in construction and improvement of sewage plants, reduction of manure outlets, and the introduction of more gentle weed cutting in order to improve habitat quality, have contributed to better water and ecological quality. Trout have become more abundant, and sensitive invertebrate species more widespread (Wiberg-Larsèn *et al.*, 1994; Nielsen, 1996; Skriver *et al.*, 1997; Baattrup-Pedersen *et al.*, 1998). Accordingly, many previously rare and threatened species have been removed from the red list.

Table 1. Danish Stream Fauna Index (DSFI). The index value (fauna class) is a function of the occurrence of specific invertebrate indicators in combination with the number of selected diversity groups (Skriver *et al.*, 1998).

Danish Stream Fauna Index (DSFI)		Number of diversity groups			
Indicator groups (IG)		≤ -2	-1 to 3	4 to 9	≥ 10
Indicator group 1 (IG 1): *Brachyptera, Capnia, Leuctra, Isogenus, Isoperla, Isoptena, Perlodes, Protonemura, Siphonoperla,*	≥ 2 groups	-	5	6	7
Ephemeridae, *Limnius,* Glossosomatidae, Sericostomatidae.	1 group	-	4	5	6
Indicator group 2 (IG 2): *Amphinemura, Taeniopteryx,* Ametropodidae, Ephemerellidae, Heptageniidae, Leptophlebiidae, Siphlonuridae, *Elmis, Elodes,* Rhyacophilidae, Goeridae *Ancylus* If *Asellus* ≥ 5 go to IG 3 If *Chironomus* ≥ 5 go to IG 4		4	4	5	5
Indicator group 3 (IG 3): *Gammarus* ≥ 10, Caenidae Other Trichoptera ≥ 5 If *Chironomus* ≥ 5 go to IG 4		3	4	4	4
Indicator group 4 (IG 4): *Gammarus* ≥ 10, *Asellus,* Caenidae, *Sialis,* Other Trichoptera	≥ 2 groups	3	3	4	-
	1 group	2	3	3	-
Indicator group 5 (IG 5): *Gammarus* < 10 Baetidae Simuliidae ≥ 25 If Oligochaeta ≥ 100 go to IG 5, 1 group If Eristalini ≥ 2 go to IG 6	≥ 2 groups	2	3	3	-
	1 group or if Oligochaeta ≥ 100	2	2	3	-
Indicator group 6 (IG 6): Tubificidae Psychodidae Chironomidae Eristalini		1	1	-	-

The original version of DSFI (Andersen *et al.*, 1984) was developed to reflect the effects of organic pollution by incorporating invertebrate indicators with varying sensitivity to organic pollution.

The ability of DSFI to describe overall ecological quality, with special reference to the occurence of rare and threatened macroinvertebrate species and species richness of selected taxonomic groups, has never been investigated and is the objective of this investigation.

Materials and methods

Macroinvertebrate species lists from 446 stream sites were provided by two private consultancy firms on contract with regional water authorities. A few lists originated from other sources, and a few additional lists of surveys undertaken in large streams in 1996 were added because large streams were underrepresented in the available material.

The majority of samples were collected in the Spring, however, some samples were also collected

in the other seasons. The following criteria had to be met:

- The standard protocol from ordinary biological stream assessment had to be used, including standardized kick sampling (Danish Environmental Protection Agency, 1998).
- Identification of the macroinvertebrates Ephemeroptera, Plecoptera, Odonata, Coleoptera, Trichoptera and Simuliidae had to be to the species level, because these taxonomic groups are represented in the Danish list of rare and threatened species.
- Macroinvertebrate data from small, medium-sized and large streams were to be representative for streams in all of Denmark. Unfortunately, species lists with sufficient identification levels were not available from northern Jutland and the Island of Bornholm.

Most stream sites in this investigation had DSFI index values of 4 to 7 (Table 2) because stream sites with index values of 1, 2 and 3 rarely contained red list species.

The most up-to-date red list, used as a reference to define rare and threatened species during this investigation, was an unofficial list from 1995 (Appendix 1).

The number of red list species was used as a measurement for the presence of rare and threatened species. Both the total species number of Ephemeroptera, Plecoptera, Trichoptera and Coleoptera species (EPTC-taxa) and the number of selected diversity groups in DSFI (Skriver *et al.*, 1998) were used as a measurement of biodiversity. The number of diversity groups in DSFI are determined to the genus or family level, and includes other taxonomic groups than the EPTC-taxa.

To test for significant correlations, a Spearman correlation analysis (Snedecor & Cochran, 1989) was used if nothing else is mentioned.

Results

Species richness in selected taxonomic groups

The DSFI will, according to its design, more or less reflect the number of species of Ephemeroptera, Plecoptera, Trichoptera and Coleoptera (EPTC-taxa). This was apparent in the significant correlation between the number of species of EPTC-taxa and index values of DSFI ($p<0.0001$). Thus, DSFI gives a good overall indication of species richness in these four selected taxonomic groups (Fig. 1), which are also normally used as indicators of high ecological quality.

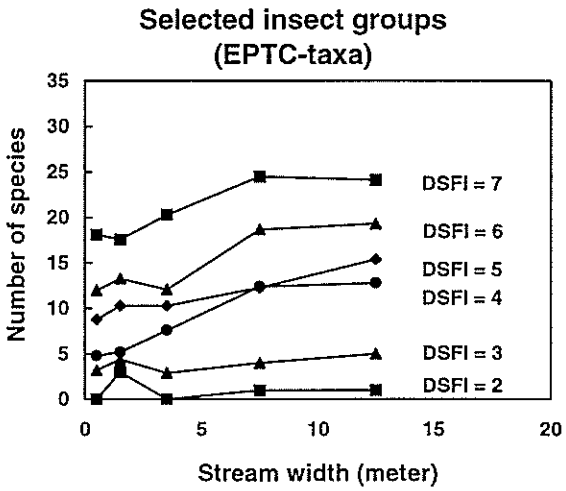

Figure 1. The number of species in the four taxonomic groups; Ephemeroptera (E), Plecoptera (P), Trichoptera (T) and Coleoptera (C) in relation to Danish Stream Fauna Index (DSFI) and stream width.

The species richness of EPTC-taxa was also found to be significantly correlated to stream width ($p<0.008$), as the number of species increased with increasing stream width.

Occurence of red list species

A total of 51 red list species were found in the 446 stream sites investigated (Appendix 1). Trichoptera contributed with 19 species, followed by Ephemeroptera and Plecoptera with 15 and 10 species, respectively (Table 3). The number of red list species was significantly correlated to both DSFI index values ($p<0.0001$), and to stream width ($p<0.008$) (Fig. 2).

Table 2. The number of localities within the seven DSFI index values. The streams have been divided in 5 groups according to their width in meters.

Stream width (m)	DSFI index values						
	1	2	3	4	5	6	7
0-1	2	1	5	22	28	25	29
1-2	5	7	10	34	36	12	16
2-5	3	2	16	50	31	9	18
5-10	-	2	2	20	15	7	6
> 10	-	1	2	9	8	4	9
Number of localities	10	13	35	135	118	57	78

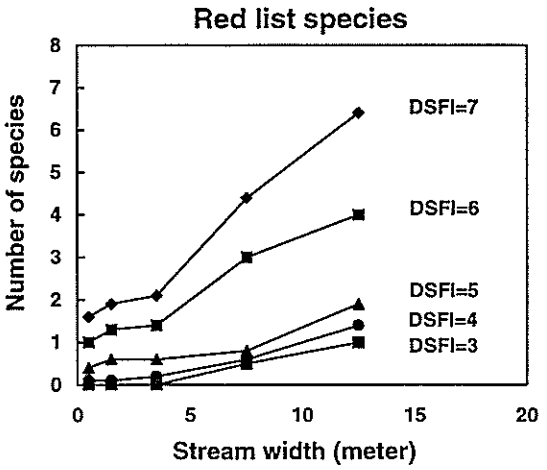

Figure 2. The number of red list species from 446 Danish stream sites. The number of species is shown as a function of Danish Stream Fauna Index (DSFI) values and stream width.

No red list species were found at the 23 stream sites with index values of 1 and 2. Depending on the stream size, red list species were found in 56-100 % and 88-100 % of the stream sites having index values of 6 and 7, respectively. The highest absolute number and percentage of red list species were observed in the largest (widest) streams. Red list species were in fact registered in all 26 streams wider than 5 meters and with index values of 6 and 7.

Some red list species, mainly Ephemeroptera and Plecoptera, together with a number of common species, are used in DSFI as indicators of good ecological quality (Skriver *et al.*, 1998). A total of 22 red list species belonging to the taxa in indicator groups 1 and 2 (Table 1) were found at the 446 stream sites in this investigation. The presence of any of these species in the fauna sample has a significant influence on the attained DSFI index value because indicators from IG 1 and IG 2 are necessary in order to obtain index values of 5, 6, and 7 (Table 1). Therefore, it is not surprising that there is a strong tendency for a greater number of red list species to occur at greater DSFI index values (Fig. 3). In contrast, Odonata, most of the Trichoptera, some Coleoptera, a few Ephemeroptera and one Plecoptera representing the remaining 29 red list species found in this investigation, do not or only slightly influence the index value.

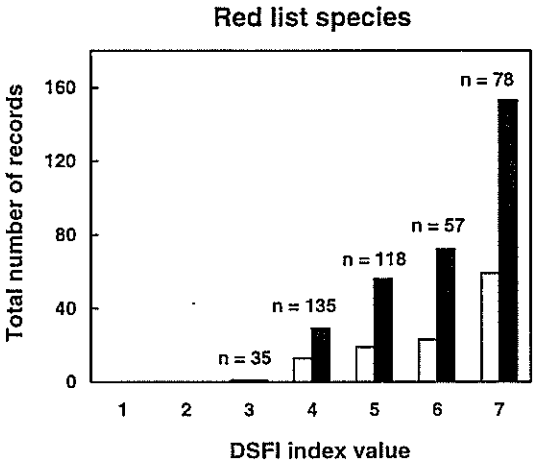

Figure 3. The distribution of red listed invertebrate species in relation to Danish Stream Fauna Index (DSFI) values. All records with the same index value are summed, regardless of stream width. The red list species are divided into two groups; 1) Black bars = red list species having a direct influence on the index value (i.e. members of IG 1 and IG 2 in Table 4), and 2) White bars = red list species having no or only a limited influence on the index value. n = number of stream sites within each DSFI index value.

The significant relationship between the total number of red list species and the DSFI index value was also found when red list species were separated into the two groups 1) red list species significantly influencing the index value (22 species), and 2) red list species without or with only a limited influence on the index value (29 species), respectively. The occurrence of these two groups of red list species (Appendix 1) showed no significant difference in relation to the DSFI index value (X^2-test, p=0.84).

Table 3. The total number of species and number of rare and threatened species (unofficial red list from 1995) of selected benthic macroinvertebrates. Number of red list species found at the 446 investigated stream sites are compared to the total number of red list species known from all Danish freshwater habitats and the total number of red-list species (invertebrates) in streams.

Taxonomic groups	Total number of species in Denmark	Number of red list species in Denmark		
		Total in all freshwater habitats	Total in streams	Total in 446 streams
Ephemeroptera	40	26	23	15
Plecoptera	25	16	16	10
Odonata	50	28	10	4
Coleoptera	3674	954	21	2
Trichoptera	167	62	39	19
Simuliidae	25	9	9	1

Table 4. The number and frequency of red list species from stream localities with Danish Stream Fauna Index values of 7 (indicating highest ecological quality). It is necessary to have at least 10 DSFI-diversity groups to get an index value of 7.

Number of DSFI-diversity groups	Number of red list species (± 95% C.L.)	Stream width in meters (median)	Number of stream sites
10 - 11	1.9 ± 0.6	1.0	26
12 - 14	2.7 ± 0.7	1.5	35
15 - 20	4.2 ± 1.4	2.0	17

Furthermore, it is possible to confirm the occurrence of red list species in streams with DSFI-index values of 7 by analyses of the DSFI diversity groups which are used for DSFI index value computation (Skriver *et al.*, 1998). Results showed the number of red list species increased as a function of the number of DSFI-diversity groups. Generally, localities with a very high DSFI-diversity (≥ 15 groups) had a high number of red list species (Table 4). The number of red list species was correlated with both the number of DSFI diversity groups and the stream width ($p<0.001$, Linear multiple regression). Stream width was in fact the most important single parameter, explaining 41% of the variation in the number of red list species. In comparison, the number of diversity groups only accounted for 12% of the variation in the number of red list species.

Discussion

Biological methods based on macroinvertebrates are now in use in many countries (De Pauw *et al.*, 1992). These methods typically incorporate the biological information into a single score or index value to compare with reference conditions temporally or spatially. Some methods like the Saprobic index require species identification (Friedrich, 1990), whereas other methods only require identification to the genus, family or higher taxonomic levels (Armitage *et al.*, 1983; De Pauw & Vanhooren, 1983; NF T 90-350, 1992; Skriver *et al.*, 1998). These methods all incorporate biodiversity and indicators in one way or another.

Species richness in selected taxonomic groups

In North America, the total number of species in Ephemeroptera, Plecoptera and Trichoptera (EPT-taxa richness) has been used for several years as one measure in the evaluation of water quality (Resh *et al.*, 1995). Other measures of species composition and community structure are also used in North America, but the EPT-taxa richness has shown to be one of the best tools for rapid bioassessment of streams (Barbour *et al.*, 1992).

In Denmark, the EPTC-taxa richness was high at DSFI index values indicating good ecological quality. This was also expected as many of the invertebrates from indicator groups 1 and 2 (IG 1 and IG 2, Table 1) in the Danish Stream Fauna Index belong to these four taxonomic groups. Although identification is only made to the genus or family level, it can be concluded that rapid biological assessment still gives a good indication of species richness in selected ecological important taxonomic groups, and that the present results confirm conclusions from North America.

The River Continuum Concept predicts species richness to be a function of stream size, and that maximum species richness is found in fourth to sixth order streams (Vannote *et al.*, 1980). In Danish streams, the number of species of Ephemeroptera, Trichoptera and other taxonomic groups has also been found to increase with stream width (Jacobsen & Friberg, 1997; Wiberg-Larsen *et al.*, subm.). Similarly, the species richness in EPTC-taxa as well as the number of red list species also increased with stream width in this investigation. This is probably because of a higher spatial variability, and consequently a greater number of niches in larger streams (Townsend & Hildrew, 1994). In Denmark, the largest streams are fifth order streams, and although most of them have been regulated, many of them still have a relatively variable bed substrate with macrophytes covering most of the bottom (Baattrup-Pedersen & Riis T., 1999). Danish streams thus seem to fit well into the River Continuum Concept.

Red list species

Red list species were found mainly in streams with DSFI index values of 5, 6 and 7, which indicate a good overall ecological quality (Skriver *et al.* 1998). Index values of 5, 6 and 7 can only be obtained when taxa belonging to the two most sensitive indicator groups (IG 1 and IG 2, Table 1) are represented in the sample. These two indicator groups include 49 Danish species, of which the majority are red listed. However, the most common indicator species, *Leuctra hippopus, Amphinemura standfussi, Ephemerella ignita, Ephemera danica, Elodes spp., Elmis aenea, Limnius volckmari, Sericostoma personatum, Silo spp.* and *Ancylus fluviatilis* are not red listed, consequently, DSFI index values of 5, 6 and 7 can easily be obtained without red list species in the fauna sample. Nevertheless, the high mean number of red list species found at high DSFI index values, is partly due to the overlap between the sensitive indicators used in DSFI and species from the red list. Separation of red list species into

two groups based on their influence on the computation of the DSFI index value, and that there is no significant difference between the distributions of the two groups of red list species in relation to the DSFI index value, clearly shows that red list species can generally be expected to occur at DSFI index values indicating good ecological quality.

The actual number of red list species found at a single stream site seems to be rather high considering they should be representing rare and threatened species. It is therefore necessary to point out that only approx. 10 % of Danish streams have DSFI index values of 6 and 7 (Skriver *et al.*, 1997). Furthermore, most streams in Denmark are rather small, and streams with a width greater than 5 meters only make up about 16 % of total stream length. Thus, streams with high numbers of red list species only make up 1-3 % of total stream length, and can be characterised as large streams in the western part of Denmark, where the human population density is relatively low.

The number of red list species also correlated with the number of DSFI diversity groups (Table 4). Considering only stream sites with DSFI index values of 7, stream size was the most important factor in predicting the presence of red list species. In fact it is necessary to identify the fauna to the species level in order to determine exactly which faunistic elements exist in streams where localities with a very high ecological and conservational quality have to be identified. It is insufficient to only use DSFI index values, including the number of DSFI diversity groups.

The biological stream assessment index DSFI makes it possible to assess a large number of streams by using only limited ressources. Although macroinvertebrate identification in DSFI is not performed to the species level, DSFI has been shown to give a good overall indication of biodiversity in important taxonomic groups which have been traditionally used in biological monitoring. Furthermore, DSFI has also been found to be a good indicator of the occurrence of rare and threatened species. DSFI is thus believed to satisfactorally express general nature and ecological quality in streams.

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Appendix 1. Unofficial red list from 1995 used as a reference for rare and threatened species. The number of records in each DSFI index value is shown. Species with a star (*) have no influence, or only a limited influence on the computation of the index value (Skriver et al., 1998).

Red list species in relation to the DSFI index value	DSFI index value					
	3	4	5	6	7	Total
Number of localities	n = 35	n = 135	n = 118	n = 57	n = 78	n = 423
Ephemeroptera:						
Siphlonurus aestivalis		3	1			4
Metretopus borealis					1	1
* *Baetis liebenauae*				1		1
* *Baetis niger*		1	1	5	8	15
* *Procloeon bifidum*					1	1
Rhitrogena germanica				1	2	3
Heptagenia flava		1	1	2		4
Heptagenia fuscogrisea		9	8	6	10	33
Heptagenia lateralis					1	1
Heptagenia sulphurea	1	4	7	10	25	47
Ephemerella notata				2	1	3
* *Brachycercus harisella*			1	1	1	3
Paraleptophlebia cincta					1	1
Paraleptophlebia submarginata		10	10	14	26	60
Ephemera vulgata				1		1
Plecoptera:						
Amphinemura sulcicollis			5	6	9	20
* *Nemoura avicularis*		2	2	7	8	19
Protonemura meyeri				4	3	7
Protonemura rhabei					2	2
Leuctra nigra		2	16	18	36	72
Capnia bifrons			1	2	12	15
Isoperla difformis			4	3	9	16
Perlodes microcephala					6	6
Isoptena serricornis				1	1	2
Siphonoperla burmeisteri					1	1
Odonata:						
* *Calopteryx splendens*		1	2		3	6
* *Calopteryx virgo*			1		3	4
* *Ophiogomphus ceciliae*			1		2	3
* *Cordulegaster boltoni*					1	1
Coleoptera:						
* *Deronectes latus*		1		1	1	3
* *Hydrana nigrita*			1	1	4	6

Appendix 1 continued

Red list species in relation to the DSFI index value	DSFI index value					
	3	4	5	6	7	Total
Number of localities	n = 35	n = 135	n = 118	n = 57	n = 78	n = 423
Tricoptera:						
Agapetus ochripes				1	6	7
* *Ithytrichia lamellaris*					2	2
* *Philopotamus montanus*				1	1	2
* *Wormaldia occipitalis*		1		2	8	11
* *Hydropsyche contubernalis*		2	1			3
* *Hydropsyche fulvipes*					2	2
* *Hydropsyche saxonica*			2		6	8
* *Cheumatopsyche lepida*		1				1
* *Neureclipsis bimaculata*	1	2	1			4
* *Psychomyia pusilla*				2	2	4
* *Apatania muliebris*			4		1	5
* *Potamophylax rotundipennis*		1				1
* *Hydatophylax infumatus*			1	1	1	3
Lithax obscurus			2			2
* *Lasiocephala basalis*					1	1
* *Ceraclea alboguttata*				1		1
* *Ylodes simulans*					1	1
* *Adicella reducta*			2	1	1	4
* *Odontocerum albicorne*					1	1
Simuliidae						
* *Simulium morsitans*		1			1	2
Total number of records	2	42	75	95	212	426