Ecological Indicators 11 (2011) 1366–1374

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Forest proportion as indicator of ecological integrity in streams using Plecoptera as a proxy

J. Törnblom[a,*], E. Degerman[b], P. Angelstam[a]

[a] School for Forest Management, Faculty of Forest Sciences, Swedish University of Agricultural Sciences, SE-739 21 Skinnskatteberg, Sweden
[b] National Board of Fisheries, SE-702 15 Örebro, Sweden

ARTICLE INFO

Article history:
Received 21 June 2010
Received in revised form 29 January 2011
Accepted 20 February 2011

Keywords:
Forest proportion
Ecological integrity
Plecoptera
Bioindicator
Ecological threshold

ABSTRACT

An assessment system suitable to support implementation of the EU Water Framework Directive's local water management plans should build on quantitative knowledge about a suite of well-documented indicator and umbrella species' requirements for different stream orders. Assuring high communication value for improving local public awareness and participation for restoring ecological integrity in impaired headwater streams is critical. Loss and fragmentation of forests are major threats to ecological integrity. The aquatic macroinvertebrate order Plecoptera is commonly used as an indicator of the ecological integrity of streams. We measured abundance and taxonomic richness of Plecoptera in relation to land cover and water chemistry in second and third order catchments' in 25 headwater streams in Central Europe's Carpathian Mountains. Plecoptera abundance and Plecoptera taxa richness were positively correlated to each other, as well as to forest proportion in the catchments, but negatively correlated to catchment area, inorganic carbon, alkalinity and conductivity. Segmented linear regression was then used to identify thresholds associated to forest proportion as a surrogate for catchment integrity. No threshold was found for Plecoptera abundance, but for taxa richness a threshold of 54% forest cover was found, below which Plecoptera was affected in second order streams. Using Plecoptera as a proxy for ecological integrity this study indicates that forest cover is an effective bioindicator in headwater catchments for predicting the ecological status of headwater streams. The non-linear relationship between forest cover and Plecoptera can be used as a science-based norm whereby land cover monitoring can be used to assess the ecological status of streams.

1. Introduction

The use of benthic macroinvertebrates to assess the ecological status of streams has a long history, and their use in biomonitoring and bioassessment studies is widely accepted (Resh et al., 1994; Davies, 2001; Smith et al., 2005). Taxonomic richness of EPT-species (Ephemeroptera, Plecoptera, and Trichoptera) reflects different types of ecological degradation. Hence, indices like the proportion of EPT (percent of all taxa) have traditionally proven to be among the best indicators of aquatic ecosystem degradation (*e.g.*, Resh and Jackson, 1993; Barbour et al., 1996; Fore et al., 1996; Somers et al., 1998). Among macrozoobenthos orders, Ephemeroptera, Plecoptera (Soldán et al., 1998) and Trichoptera (Dohet, 2002) have been selected for evaluation of long-term changes in European rivers, and Plecoptera was considered as one of the best bioindicators of human interventions in streams (AFNOR, 2004; Krno, 2007). Plecoptera taxon tend to decline at less intense levels of human disturbance than Trichoptera and Ephemeroptera (Lenat, 1993; Karr and Chu, 1999; Gage et al., 2004), and is thus the most sensitive taxon in the EPT group.

Plecoptera, commonly called stoneflies, is a small and homogenous order of hemimetabolous insects (Giller and Malmqvist, 1998). More than 3497 species and 16 families (Fochetti and Tierno de Figueroa, 2007) are distributed over all continents except Antarctica, and constitute a significant ecological component of headwater ecosystems (Fochetti and Tierno de Figueroa, 2007). Plecoptera larvae are characteristic inhabitants of high altitude cool, clean streams of low orders, and they are poor flyers, which limits their dispersal ability (Brittain and Saltveit, 2005). Plecoptera in general are sensitive to organic pollution and low oxygen concentration often associated to organic decay, though rather tolerant to acidic conditions (Giller and Malmqvist, 1998). Plecoptera is an important component in rivers and streams in terms of biomass and diversity of ecological roles, acting as primary or secondary consumers and as prey for other macroinvertebrates and fishes (Giller and Malmqvist, 1998; Brittain and Saltveit, 2005; Fochetti and Tierno de Figueroa, 2007). Most stonefly nymphs are detrivores and the distribution of several species has been related to the

* Corresponding author. Tel.: +46 222 349 59; fax: +46 222 349 70.
E-mail address: Johan.Tornblom@smsk.slu.se (J. Törnblom).

1470-160X/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2011.02.011

amount of terrestrial leaf litter as the major food resource (Brittain and Saltveit, 2005), even if the Plecoptera families Perlidae, Perlodidae and Chloroperlidae are primary predators (Stewart and Harper, 1996).

Due to the growing anthropogenic influence and alteration of headwaters and associated catchments together with the narrow range of habitat selection of Plecoptera, numerous Plecoptera species have been reduced to small isolated populations and many others have already gone extirpated (Zwick, 2004; Fochetti and Tierno de Figueroa, 2007). Fochetti and Tierno de Figueroa (2004) point out Plecoptera as probably one of the most endangered groups of insects.

Freshwater conservation is dependent on maintaining the ecological integrity of existing relatively intact and functioning habitat in the catchment area (Frissel and Bayles, 1996; Frissell, 1997). Regarding habitats for species "How much habitat is enough?" is probably a more relevant question than ever in the context of the European Water Framework Directive (WFD) (Directive, 2000/60/EC), which can be viewed as a policy established in response to imperilled freshwater habitats from a catchment perspective.

The pattern of impoverishment of population viability and ecological integrity as a function of habitat alteration is not always linear, but rather it is likely to exhibit thresholds beyond which the long-term maintenance of the elements of biodiversity is threatened (Fahrig, 2001, 2002). Such thresholds could be used for establishing habitat cover conservation targets that are easy to communicate, and thus providing norms (see Lammerts van Buren and Blom, 1997) for assessment of population viability or ecological integrity in catchment management in analogy to the assessment of the effects of forest and landscape management on habitat amount and configuration, and ultimately on populations of specialized species (Angelstam et al., 2004b). It should be noted that thresholds are rarely distinct; rather they are intervals of change along a gradient where, for example, species composition or function changes from one state to another (Guénette and Villard, 2004; Angelstam et al., 2004a). Empirical support exists for the effects of critical thresholds in habitat abundance on animal populations in terrestrial landscapes (Andrén, 1994; Angelstam et al., 2004b). Even if similar thresholds may occur in aquatic landscapes, such as for dead wood and brown trout (Degerman et al., 2004), there are so far too few studies available to support the formulation of performance targets or norms for ecological integrity, and thus the conservation of aquatic biodiversity.

Accepting that Plecoptera is a bioindicator for intact ecological integrity of catchments (Krno, 2007), we test the hypothesis that Plecoptera presence can be explained by the proportion of forest in headwater catchments, and that non-linear threshold can be identified. We made correlation analyses between catchment land cover and water chemistry on the one hand, and with Plecoptera taxa richness and Plecoptera abundance on the other. Segmented linear regression was used to assess if a break-point value existed with respect to forest cover for high taxonomic richness of Plecoptera.

2. Materials and methods

2.1. Study area

This study took place in 25 different 2nd or 3rd order streams in the Carpathian Mountain ecoregion located in four study areas: Maramures in Northern Romania, Turka in South-West Ukraine, as well as in the San are and the Bieszczady National Park in South-East Poland (Figs. 1 and 2). The Carpathian Mountains are situated in central Europe and reach 2500 m above sea level. They form the divide between three large catchments; the Vistula river to the north, the Dnestr to the east, and the Tisza of the Danube catchment to the south. This part of Central Europe is characterized by a continental climate with warm summers and cold winters. Due to the effect of elevation the Carpathian Mountains have a cooler and more humid climate than the surrounding lowland plains. The deciduous forests and cultural landscapes are situated at altitudes between 400 and 900 m a.s.l., while the natural coniferous forest and treeless mountain rims are found between about 900 and 2500 m a.s.l. However, slope and aspect provides additional diversity.

The geology of the Carpathians is highly variable. The northern and northeastern parts of the Carpathians are composed of Carpathian flysh, consisting of layers of sandstone and shale of variable thickness. The highest mountain ranges are built of crystalline rock, mainly granite. There are also areas where the bedrock is mostly limestone, particularly in the inner part of Western Carpathians. Despite similarities regarding physical conditions such as bedrock, soil, precipitation, and runoff there are clear differences between the studied landscapes regarding land use and land cover composition. Due to a dramatic political and social development (Chirot, 1989), adjacent catchments located on opposite sides of country and regional borders show high contrast in land use, land cover, practices and management intensity. The range of land cover types is extreme and ranges from forest remnants with high levels of naturalness to intensively managed agricultural land (Angelstam et al., 2003; Kuemmerle et al., 2006). The transition between these extremes includes 60-year old secondary deciduous forest succession stages after forced abandonment of (i.e. pre-industrial) cultural landscapes with wooded grassland with semi-natural forest, wooded grasslands that are mowed, grazed natural grasslands, and abandoned fields (Angelstam et al., 2003; Elbakidze and Angelstam, 2007). The Carpathian Mountains thus provide new information to the concept of reference conditions from a European perspective, as the "ghost of forest and land use past" (Angelstam, 1996; Harding et al., 1998). The four study areas in three countries were selected with the ambition to cover a wide span of anthropogenic impact on both catchments and headwater streams.

2.2. Invertebrate sampling

We used both quantitative and qualitative methods at each stream section. In the quantitative method the substratum was disturbed by a hand brush within the frame of a standard Surber sampler ($0.04\,m^2$, 0.25-mm mesh) for 90 s to sample macroinvertebrates. In each stream we arbitrarily selected 10 riffle-sites ($0.04\,m^2$) over a stream section at least 50 m long at the lower end of the catchment. In the qualitative method we used a "kick and sweep" water net (size of the hand net $0.25\,m \times 0.25\,m$ and mesh size 0.5 mm), which is routinely used in stream waters (EU ISO-7828 type). All the samples were then transferred to a 250 ml bottle containing 95% ethanol for conservation. The macroinvertebrates within each sample were then sorted and counted in the laboratory using a Stemi DRC microscope at $8\times$ magnification. The specimens were determined to lowest possible taxonomic level (family, genus or species) by professional taxonomists. Each stream was sampled once between 5 and 18 May 2003.

2.3. Land cover data

The land cover types (Fig. 2) in the catchments were determined using a combination of remote sensing-based land cover classification and field surveys (Naturvårdsverket et al., 1996; Ihse and Lindahl, 2000). These two approaches were chosen to estimate the cover of deciduous and coniferous forest, and to assess the authenticity of cultural landscapes dominated by wooded grass-