



Non-biting midges in biodiversity conservation and environmental assessment: Findings from boreal freshwater ecosystems

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ABSTRACT

Non-biting midges (Diptera: Chironomidae) are frequently overlooked in freshwater biodiversity surveys and environmental assessment, yet they are commonly the most abundant and the most diverse taxon in freshwater ecosystems. We reviewed the diversity patterns and assemblage–environment relationships of non-dipterans and chironomids mainly in boreal freshwater ecosystems building on previously reported findings. Although generally the same environmental gradients are correlated with assemblage structure, their relative importance varies between chironomids and non-dipterans. Chironomid assemblage response to and recovery from human impacts are also likely to differ from that of other common benthic taxa. Thus, environmental assessments may be biased if chironomids are not included. Different surrogacy approaches have thus far shown little success in accounting for chironomid species richness and assemblage structure, and there appears to be no easy short-cut for the examination of chironomids as part of freshwater surveys. However, we show that genus-level identification of pupal exuviae provides a reliable and rapid way of estimating chironomid species richness at least in boreal freshwater ecosystems. In addition, we demonstrate that the inclusion of chironomids may increase the signal-to-noise ratio in bioassessment data sets, and that this information can be obtained with modest increases in costs.

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1. Introduction

Conservation planning (i.e. prioritising areas or sites for conservation action) and environmental assessment (i.e. estimating the degree of anthropogenic impairment) are of critical importance in the world where increasing anthropogenic development and disturbance threaten the biodiversity and integrity of natural ecosystems. Due to practical difficulties, taxonomically difficult groups are often completely ignored from such surveys as if they do not incorporate important value at all. However, several authors have stressed the importance of conservation and assessment approaches that also consider poorly known taxa (Pimm and Gittleman, 1992; Oliver et al., 1998; Hughes et al., 2000; Hodgkinson and Jackson, 2005).

Amongst such difficult organisms are many groups of insects. These groups include various taxa of hymenopterans (Hymenoptera) and dipterans (Diptera), which are typically poorly known taxonomically and ecologically, yet they comprise much of the global biodiversity (e.g. Gaston, 1991). In freshwater ecosys-

tems, non-biting midges (Diptera: Chironomidae) in particular constitute one such poorly known group, which may nevertheless comprise much of the biodiversity in terms of species richness, ecological function and abundance in these ecosystems (Ashe et al., 1987; Pinder, 1986; Cranston, 1995). In fact, chironomid midges are the most widespread and species-rich family in freshwater ecosystems, with their estimated diversity amounting to 20,000 species worldwide (Giller and Malmqvist, 1998), with considerable regional (e.g. Nilsson, 1997) and local diversity (e.g. Ferrington, 2008). In general, chironomid diversity is often higher than that of other common macroinvertebrate groups combined (Marziali et al., 2010).

Chironomids play a significant role in the functioning of aquatic ecosystems. For example, they provide food resources for many other groups of macroinvertebrates and vertebrates (Armitage, 1995), and recycle autochthonous and allochthonous organic matter (Hirabayashi and Wotton, 1998; Jones and Grey, 2004). Thus, they have been considered as keystone members (Jones and Grey, 2004; Péry et al., 2004) and ecosystem engineers in aquatic ecosystems (Hirabayashi and Wotton, 1998; Ólafsson and Paterson, 2004). Despite their important ecological roles, surprisingly few spring, stream and lake littoral surveys and ecological experiments contain species- or genus-level information on chironomids.

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This is unfortunate, given that the exclusion of such an important taxonomic group may lead to biased findings about the biodiversity–ecosystem functioning relationships (i.e. the importance of species diversity in ecosystem functioning) in freshwater ecosystems, flawed estimates of local diversity of macroinvertebrates, and insufficient information for conservation biology and environmental assessment (Heino and Mykrä, 2008; Heino et al., 2009a,b; Ilmonen et al., 2009).

We reviewed the spatiotemporal variation of diversity and factors affecting the assemblage structure of chironomids and non-dipterans, as well as the importance and applicability of chironomids in environmental assessment building on previously reported findings from mainly boreal freshwater ecosystems. We also considered different sampling methods in order to efficiently incorporate chironomids into monitoring and assessment programs. Finally, we demonstrate that the cost-efficiency of lake and river assessments could be improved by including chironomid data.

2. Conservation biology: surrogacy approaches and chironomids

Different surrogacy approaches have been suggested for cost-effective conservation planning and monitoring of biodiversity. These approaches include indicator species (e.g. McGeogh, 1998), indicator groups (e.g. Hess et al., 2006), environmental surrogates for biodiversity (e.g. Faith and Walker, 1996) and higher taxa (e.g. Balmford et al., 1996). In the following, we will consider different surrogacy approaches with regard to understanding and explaining variation in the assemblage patterns of chironomids.

2.1. Spatial congruence and indicator groups

A number of recent studies have examined spatial congruence (i.e. the degree to which different taxa show similar patterns) in the biodiversity patterns of freshwater organisms (Allen et al., 1999; Briers and Biggs, 2003; Heino et al., 2005; Tolonen et al., 2005; Paavola et al., 2006; Bilton et al., 2006; Heino and Mykrä, 2008; Heino, 2010). An important question in this context is the degree to which chironomids show similar biodiversity patterns to those of other major taxonomic groups. For example, Heino et al. (2003a) found that the patterns of species richness (i.e. taxa richness) were weakly correlated between stream mayflies, stoneflies, caddisflies and chironomids at both the within-ecoregion and across-ecoregions scales. Considering the higher species richness of chironomids compared with other aquatic macroinvertebrate groups, the lack of strong cross-taxon congruence (e.g. caddisflies vs chironomids) in species richness patterns may be a general pattern in freshwater ecosystems. Thus, such an indirect estimation of chironomid species richness is probably no solution for conservation planning. However, rather few studies have compared the species richness patterns of chironomids in relation to all other aquatic macroinvertebrate taxa grouped together, and thus the degree to which chironomids show congruent species richness patterns with other macroinvertebrates combined is not yet understood well enough. Recently, Heino et al. (2009b) showed that a similar kind of low correlation was apparent between the species richness of chironomids and all other lake littoral benthic taxa combined.

It should be noted that species richness is only one measure of diversity. An additional measure is similarity in patterns of assemblage composition (i.e. the degree to which patterns in assemblage compositional variation are similar among different taxonomic groups). If congruence in assemblage similarity is a general pattern it may have obvious practical benefits, as it is turnover in assemblage composition rather than variation in species richness alone that is important for conservation planning (Oliver et al., 1998; Su

et al., 2004; Lovell et al., 2007). However, given that non-dipterans and chironomids often show a weak correlation in assemblage similarity, such cross-taxon congruence is no solution for estimating chironomid assemblages in freshwater ecosystems in general (Heino, 2010). In summary, there appears to be no easy short-cut for the examination of the biodiversity of chironomids as part of freshwater surveys (Heino et al., 2009b; Virtanen et al., 2009).

2.2. Assemblage–environment relationships

Habitat size, habitat structural characteristics, acidity and trophic state variables have generally been found to be the most important in studies of the assemblage–environment relationships of freshwater macroinvertebrates (Brodersen et al., 1998; Tolonen et al., 2001; Johnson and Goedkoop, 2002; Heino et al., 2003b; Sandin and Johnson, 2004; Brauns et al., 2007; Heino and Paasivirta, 2008). In addition, several studies have stressed the importance of altitude and temperature regime for chironomid assemblage composition (e.g. Rossaro, 1991; Puntí et al., 2009). Despite these globally important environmental features, their relative importance varies between chironomids and non-dipterans in springs (Virtanen et al., 2009), streams (Heino et al., 2003a) and lakes (Heino et al., 2009b). Typically, local environmental factors explain a relatively small proportion (i.e. <30%) of the variation in chironomid assemblages (Heino et al., 2009b; Puntí et al., 2009).

Such weak relationships between environmental gradients and assemblage structure limit the environmentally based prediction of assemblage structure beyond the sites sampled in a survey. This is unfortunate, because stronger environmental relationships would facilitate the use of predictive models, and provide a cost-effective means for assessing chironomid biodiversity and assemblage composition across freshwater ecosystems in a region. Thus, environmentally based prediction appears to be no solution to determine variation in the assemblage structure of chironomids.

There are several reasons that may explain the weak assemblage–environment relationships among chironomids, such as small size and short life cycle, rapid colonization and adaptation to changing environment conditions (Jernelöv et al., 1981; Groenendijk et al., 1999) and survival strategies (e.g. diapause and cocoon forming, Frouz et al., 2003). Chironomids also inhabit wider range of depths, microhabitats and sediment types within an ecosystem, and they often show considerable habitat separation among the species (Ferrington et al., 1995). It has been shown that most chironomid species are flexible in their feeding modes (Berg, 1995), and that competitive interactions among these organisms may be rare at least at the habitat and among-stream scales (Schmid, 1993; Heino, 2005). Thus, random patch formation may be a quite common phenomenon in chironomid assemblages (Tokeshi, 1986; Schmid, 1993). Random patch formation refers to a colonization model, where species form patches of aggregation independently of each other, and it also emphasizes the stochastically dynamic nature of the resultant patches. Random patch formation and the absence of strong interspecific competition are considered to facilitate the coexistence of species at small scales (e.g. leaves of aquatic macrophytes and stream cross-sections). Together with flexible utilization of food resources and habitat partitioning, such coexistence at small scales may also lead to a high diversity of chironomids detected at larger scales (e.g. whole streams or lakes). It is largely unknown, although unlikely, that other major macroinvertebrate groups behave similarly. Thus, chironomids may respond differently from other major macroinvertebrate groups to environmental gradients in space and time.

2.3. Higher-taxon approach

In contrast to cross-taxon congruence, some studies have indicated that multivariate descriptions of chironomid assemblage

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