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Title**: The impact of climate-induced distributional changes on the validity of biological water quality metrics.**

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Abstract

We present data on the distributional changes within an order of macroinvertebrates used in biological water quality monitoring. The British Odonata (dragonflies and damselflies) have been shown to be expanding their range northwards and this could potentially affect the use of water quality metrics. The results show that the families of Odonata that are used in monitoring are shifting their ranges poleward and that species richness is increasing through time at most UK latitudes. These past distributional shifts have had negligible effects on water quality indicators. However, variation in Odonata species richness (particularly in species-poor regions) has a significant effect on water quality metrics. We conclude with a brief review of current and predicted responses of aquatic macroinvertebrates to environmental warming and maintain that caution is warranted in the use of such dynamic biological indicators.

Keywords: biological indicators, climate change, dragonfly, Odonata, range shifts, water quality.

1. Introduction

Freshwater systems are vital for life and the strain that increasing human population densities place upon them means that careful monitoring is required to avoid over-exploitation (Chapman, 1996; Dudgeon et al., 2006). Biological monitoring of rivers has been used in Europe for over 100 years (see Hawkes, 1997, for a history of biological monitoring, particularly in Britain) but it is only in the past 40 years that Britain has adopted such a system to compliment other forms of environmental monitoring.

The monitoring scheme in use in Britain consists of a set of families of macroinvertebrates which are scored from 1 to 10 based on their sensitivity to pollution (Biological Monitoring Working Party, 1978; hereafter "BMWP"). The scores for all families present in a given stretch of river are totalled and then divided by the number of contributing families to find an average score per taxon (ASPT). This is then compared to an ideal, "pristine" ASPT generated using the river invertebrate prediction and classification system (RIVPACS; Moss *et al.*, 1987). Since the original scheme was designed, scores for each taxon have been revised in light of computer analyses by Walley and Hawkes (1996; 1997), leading to a reduction in the uniformity of scores between same-order families.

There are a number of issues arising from this system of biological monitoring; chiefly that different pollutants have different effects on each taxon (Moss, 1998). However, another potential confounding factor that has arisen from recent research is the changing distributions of those organisms that contribute to the BMWP scores. A wide range of freshwater macroinvertebrates have been shown to be responding spatially to climate change (Burgmer et al., 2007; Heino, 2002; Hickling et al., 2006).

Included among these macroinvertebrates are the Odonata (the dragonflies and damselflies) which, being of tropical origin (Pritchard & Leggott, 1987), are potentially sensitive to environmental warming (e.g., Hassall *et al.*, 2007). However, the Odonata have also been identified as being sensitive to a range of pollutants and are used as indicators of water quality both within the BMWP system and elsewhere (Clark & Samways, 1996; Foote & Hornung, 2005; Menetrey et al., 2005).

This study will test whether changes in the distributions of odonate families have varied sufficiently over the current period of warming as to introduce an error into calculations of water quality that are based on their presence/absence. We then conclude with a discussion concerning the merits of the use of this taxon and other macroinvertebrates in the monitoring of water quality in light of widespread responses to environmental warming.

2. Materials and Method

The British Dragonfly Society maintains an extensive dataset of records of British Odonata. This database contains reported sightings of larvae, adults and exuviae of resident and immigrant odonates in the UK dating back to the early 19th century. Most of the ca. 270,000 records are concentrated at lower latitudes and between 1980-2000 (for more details, see Hassall *et al.*, 2007). Each species in the database was coded according to its family. The presence of each species and each of the 7 families contained in the BMWP scores (Aeshnidae, Coenagrionidae, Calopterygidae, Cordulegastridae, Lestidae, Libellulidae and Platycnemidae) was then tested for in 1º latitudinal bands across England, Wales and Scotland, from 50ºN to 60ºN, and, within those geographical areas, in time periods from 1960-4, 1965-9, 1970-4, 1975-9, 1980-4, 1985-9, 1990-4 and 1995-9.

The years from 2000-04 were excluded because of doubts over the completeness of the database. The Corduliidae (*Somatochlora metallica*, *S. arctica* and *Cordulia aenea*) and Gomphidae (*Gomphus vulgatissimus*) are excluded from the analysis because they are not found in the BMWP scores. Also, these species are all relatively rare and exhibit highly fragmented distributions.

The ASPT for the Odonata was calculated for each combination of latitude and time using the revised BMWP scores in Walley and Hawkes (1996). The simplifying assumption was made that all species present in a latitude-time combination were present throughout that combination. The BDS database is biased both temporally and spatially in terms of recorder effort and so the number of records was also noted for each combination. The number of species and the ASPT were then analysed in an ANCOVA with latitude and time as factors and the log of record number as a covariate. A model of exponential increase to a maximum was fitted to the ASPT data with respect to species richness.

In addition to this, a range shift analysis was performed (as per the methods in Hickling *et al.* (2005)) for the 7 families to estimate the extent of movement over the period of sampling. Previous concerns have been raised about the impact of unbalanced recorder effort between two periods in an analysis such as this (Shoo *et al.*, 2006), so the range shift results were analysed using non-parametric statistics (Spearman's rank correlation; because of the small sample size, n=7) to look for an impact of recorder effort.

3. Results

The number of species recorded at each latitude/time combination was highly significantly correlated with the log of the number of records for that combination (r=0.918, p<0.001). The GLM of species richness showed that there was a significant effect of both latitude and time when recorder effort (log number of records) was controlled for (latitude: $F_{10,69}$=214.25, p<0.001; time: $F_{7,69}$=20.28, p<0.001). This result was also found when ASPT was analysed, although the significance was not so strong (latitude: $F_{10,69}$=20.84, p<0.001; time: $F_{7,69}$=2.86, p=0.011).

Figure 1 shows a comparison between the temporal variation in species richness across a latitudinal range and the variation in ASPT across the same temporal and spatial scale. It is clear from this figure that the trend in ASPT, although statistically significant, does not mirror the changing species richness. The fit of the model of exponential growth to an asymptote was highly significant (F=85.02, p<0.001). At low species richness the odonate ASPT is relatively low and it is not until species richness increases that this equilibrates.

The range shift analysis suggested a consistent poleward shift in all 7 families (Table 1). Spearman's rank correlation analyses of range shifts and recorder effort showed no significant correlations between (i) absolute difference in record number (ρ=-0.464, p=0.294), (ii) log difference in record number (ρ=-0.571, p=0.180) or (iii) ratio of record numbers (ρ=-0.571, p=0.180). It is thus concluded that the shifts in distribution are real and not an artefact of recording bias.

4. Discussion

The range margins of British Odonata have been shown to be advancing poleward and this is thought to be a response to increases in environmental temperature and subsequent increases in amenable habitat. However, this study has shown that these changes in the distributions of both individual species and higher order taxonomic groups have not impacted on the portion of water quality metrics (as defined by the BMWP) contributed by the Odonata. Despite this result, it is important to note that, there are some highly species-poor regions of Scotland (between 59°N and 61°N) which could soon be colonised by a much wider range of Odonata. These regions stand out from the rest of Britain as having particularly low odonate ASPT scores. Indeed, the band from 58°N to 59°N contained only 2 or 3 species until 1975-9 when the number leapt to around 10 species (Figure 1).

At these low levels of species richness, a potential error enters into the data. It is unlikely that the low ASPT values at higher latitudes are the result of pollution, as the population densities in those regions are far lower than those at lower latitudes. Instead, odonate populations inhabiting higher latitudes happen to be largely Coenagriidae, which have a low ASPT value. Under predicted range shifts, other taxa will invade those regions, causing an increase in ASPT and, as a result, an apparent increase in water quality.

There two potential problems with the use of Odonata as indicators of water quality. Firstly, while this taxon appears to favour water bodies that contain relatively low levels of pollutants, a small number of species have been shown to tolerate relatively high levels of some substances (see Corbet, 2004 chapter 6 for a review). However, sensitivity to organic pollution is almost ubiquitous in the order and this makes them ideal as indicators of this kind of pollution (Menetrey *et al.*, 2005).

A second complicating factor with Odonata (and, potentially, other aquatic macroinvertebrates) is their reported propensity for using different types of habitat in different parts of their range (Buchwald, 1989, 1995; as cited in Corbet, 2004). A variation in habitat use between core and marginal sites within a species' range has been documented in Lepidoptera (Roy & Thomas, 2003) and this phenomenon requires more study in other taxa.

The classification in the BMWP scores is at the level of the family which serves to pool species that exhibit particular habitat associations such as habitat structure, and hydrology. The RIVPACS scheme has been highlighted in this study as an example of a scheme that uses macroinvertebrate communities in determining water quality. Despite that fact that relatively few of the British Odonata are obligate rheophiles, a large proportion of British species also make use of lotic habitats as well as their more typical lentic habitats. These two facts combined with the high density of recording of Odonata in the UK make this taxon ideal as an exemplar for other taxa undergoing similar climate-induced change.

A large amount of criticism has been levelled at the use of species distribution models and their application in predicting future ranges based on changing climate (Pearson & Dawson, 2003). This criticism stems from the fact that they only consider abiotic factors. A similar problem besets the current state of biological indicators of water quality: there is more to their habitat requirements than simply more or less pollution.

It is worth pointing out that, although the Odonata have been the focus of this study, similar poleward shifts in distributions have been reported in British aquatic bugs (Hickling *et al.*, 2006). Climate has also been implicated in the determination of species richness of Plecoptera, aquatic beetles and Odonata in Scandanavia (Heino, 2002), in agreement with work by Burgmer *et al*. (2007), who also add Diptera to the list. These five groups (Odonata, Coleoptera, Hemiptera, Plecoptera and Diptera) comprise 35 out of 81 families in Walley and Hawkes' (1996) revised BMWP scores, suggesting that the impact of climate-induced range shifts on biological water quality indices may need to be assessed in all groups of interest.

The Plecoptera are worth highlighting, since they have been allocated some of the highest BMWP scores. This group has been shown to be "cold-adapted" (Pritchard & Leggott, 1987) and its species richness declines with increasing temperature (Heino, 2002, although cf. Burgmer *et al*., 2007). This means that, while other invertebrate taxa may exhibit an increase in species richness, the number of Plecoptera species at a given site is likely to decrease. If this predicted decline in species richness is mirrored by a decline in family-richness then the ASPT for a given site would decline.

The net effect of boreal taxa becoming extinct in the south of their range and colonisation of the same regions by southern species as a result of climate-induced shifts in their fundamental niches requires further investigation. The problem of shifting distributions could be circumvented by a simple measure: the redefinition of the RIVPACS standards at regular intervals to ensure that it is representative of the macroinvertebrate communities of the "pristine" sites controlling for the state of current climatic flux. This analysis has shown a relatively rapid increase in species richness of odonate species at a range of latitudes, but the ASPT metric has remained robust. If other orders show similarly small changes in ASPT then there is no need to update the RIVPACS scheme frequently. However, the repetition of such a survey would be of immense interest to those studying community composition and environmental change.

5. Conclusions

The Odonata (dragonflies and damselflies) have exhibited poleward shifts in their northern range margin. Projected changes in distribution and concurrent increases in species richness will affect indices of water quality (ASPT). Care must be taken when using biological indicators of water quality to acknowledge and accommodate the dynamic nature of species' ranges under climate change. Many of the taxa used in the BMWP scheme have been shown to be responding to climate change (Hickling et al., 2006) and the continuation of the current trend in distributional change may still result in artefacts in these metrics, if they are not already apparent. Since the method outlined above for the monitoring of water quality in streams and rivers was influential in the generation of the Water Framework Directive (European Commission, 2000), this is a potentially wide-reaching issue.

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Table

Table 1 – Poleward range shifts of the northern range margins of each of the 7 BMWP odonate families between 1960 and 1999.

Family	Range shift (km)
Aeshnidae	70
Calopterygidae	89
Coenagrionidae	19
Cordulegastridae	53
Lestidae	175
Libellulidae	38
Platycnemidae	55

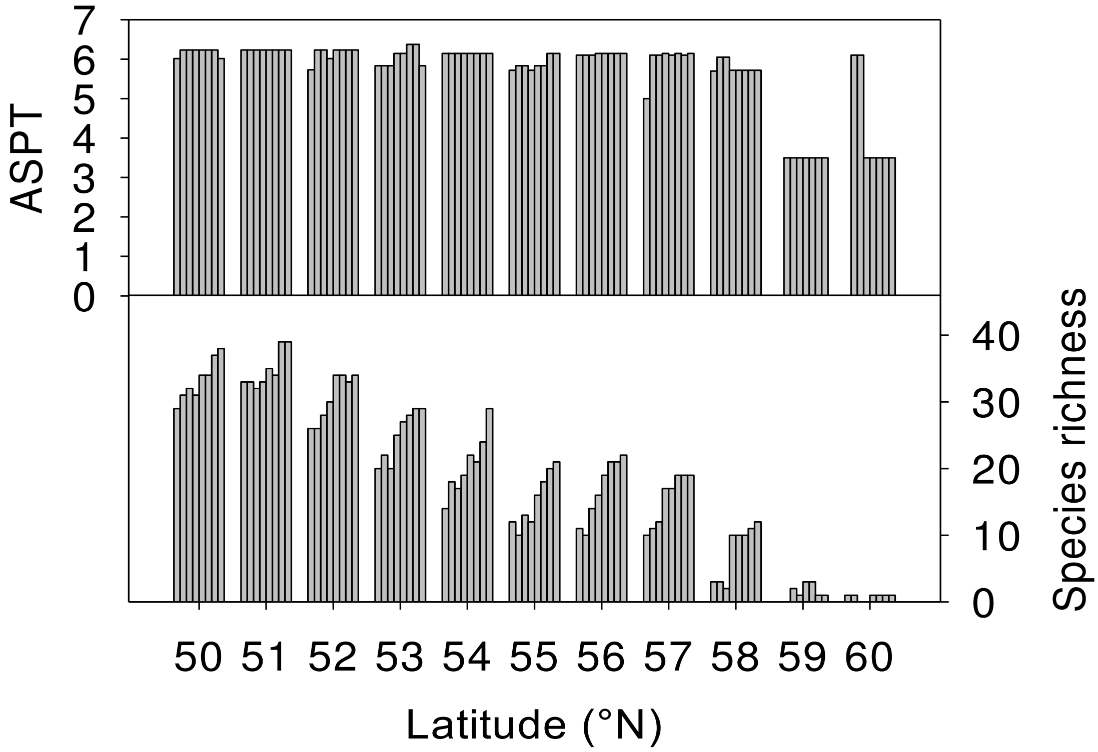

Figure 1 – A comparison between temporal and latitudinal variation in species richness (top) and in water quality metrics (average score per taxon (ASPT), below). Bars within each latitude represent, from left to right, the time periods 1960-64, 1965-69, 1970-74, 1975-79, 1980-84, 19858-9, 1990-94 and 1995-99.

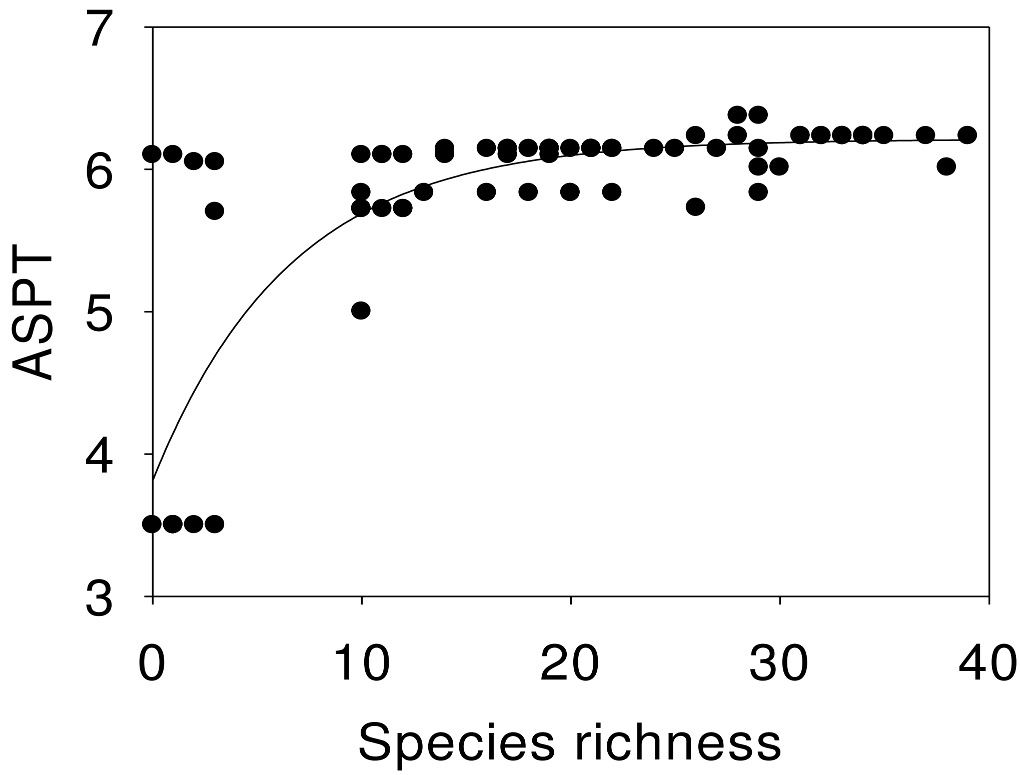

Figure 2 – Variation in average score per taxon (ASPT) with increasing species richness.