AQUATIC INSECTS AS TARGET ORGANISMS FOR THE STUDY OF EFFECTS OF PROJECTED CLIMATE CHANGE IN THE BRITISH ISLES

J. MALCOLM ELLIOTT

(Dr J. M. Elliott, NERC Institute of Freshwater Ecology, The Ferry House, Far Sawrey, Ambleside, Cumbria LA22 OLP, England)

Introduction

The Terrestrial Initiative in Global Environmental Research (TIGER) is a five-year, NERC Community Programme on the role of the terrestrial biosphere in the science of global change. TIGER is organised into four main themes, one of which deals with "Impacts on Ecosystems". A change in climate will alter the geographical range and species composition of ecosystems, and therefore one objective is to assess the sensitivity of British plant and animal species to climate change.

The first phase of the programme involved the identification of criteria for selecting species suitable for the study of effects of projected climate change in the British Isles. This brief review is part of that exercise and its chief objectives are to collate and synthesise quantitative information on the temperature requirements of aquatic insects, and to identify species, and groups of species, that could be useful indicators of climate change and useful predictors of the ecological effects of change.

Apart from shallow ponds, annual temperature ranges of 0-25°C in temperate freshwater habitats are narrower than those in most temperate terrestrial habitats. The temperatures of streams and rivers vary more rapidly than those of lakes. Apart from spring-fed streams, water temperatures in running water are strongly influenced by changes in air temperature, and are usually higher or lower than air temperatures when the latter are low or high respectively. The point of equality is usually between 8 and 10°C in upland streams. Temperature changes as a consequence of climate change would therefore be expected to be more marked in streams and rivers than in other freshwater habitats.

Although freshwater organisms have to exist within a narrower range than their terrestrial equivalents, few species can survive throughout their life cycle over the whole temperature range (0-25°C). This is especially true of aquatic insects and their rather narrow thermal requirements vary considerably between species and between life stages of the same species (eggs, larvae, pupae, adults). Aquatic insects will therefore be affected by any temperature changes that occur as a result of climate change. Species in streams and rivers will also be affected by possible changes in the temporal distribution of rainfall because this could affect

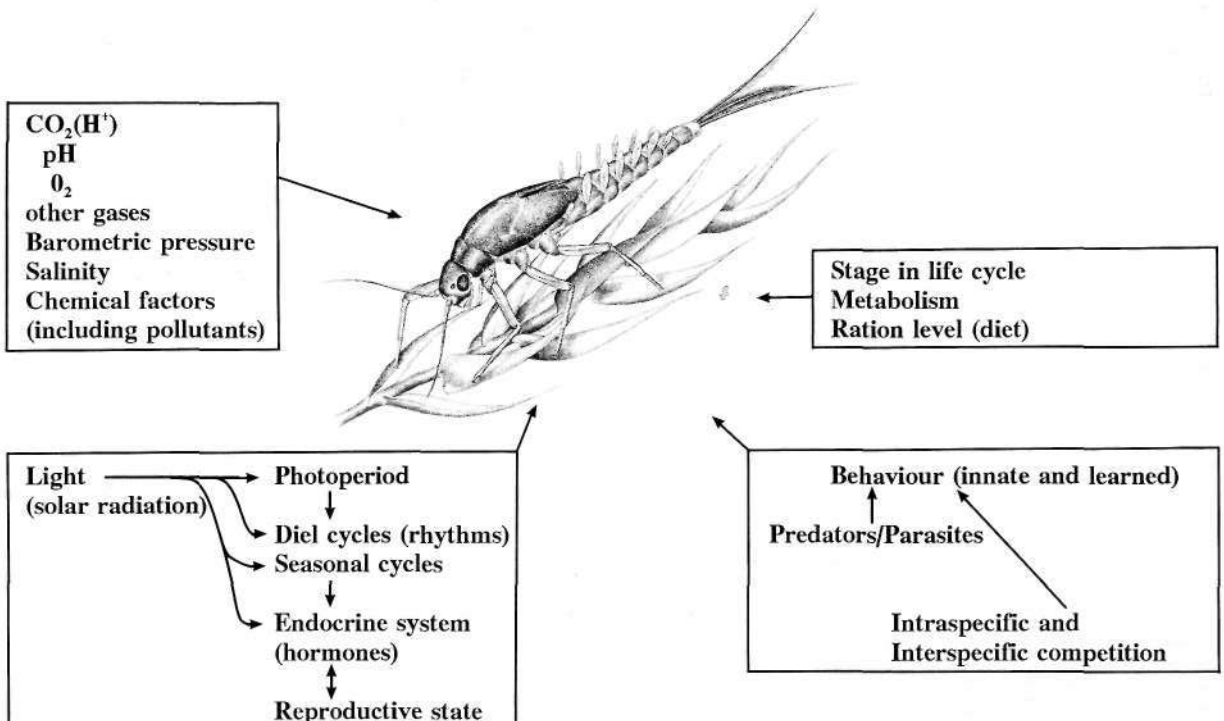

FIG. 1. Some factors that interact with temperature and may influence the thermal tolerance of aquatic insects. The original drawing of *Baetis muticus* (Ephemeroptera) is by Prof. M. Mizzaro-Wimmer, from Elliott et al. 1988.

the frequency of spates and droughts. Aquatic insects, especially species in running water, could therefore be both useful indicators and useful predictors of the ecological effects of climate change.

Information from field studies

Field studies on the effects of natural and artificial thermal discharges into streams and rivers have shown that increases in water temperature affect aquatic insects at both the species and community level (reviews by Humpesch et al. 1982, Langford 1983, Wiederholm 1984, Hellawell 1986). However, it is often difficult to interpret such field data because of all the other factors that also change and interact with temperature (Fig. 1).

Field studies on regulated rivers provide valuable information on the effects of spates and droughts on aquatic insects (reviews by Armitage 1984, Gore 1987, Saltveit et al. 1987). Severe spates produce an impoverished fauna with the elimination of some species, whilst severe droughts can have even more disastrous effects. The survivors are those insects that can burrow into the hyporheic zone to avoid the effects of a spate or to remain in water during a drought. Another survival mechanism during droughts is to enter a dormant stage as eggs or larvae and it is therefore important to determine which species can do this.

Information from laboratory studies

Although field data provide valuable information, a more productive approach is to determine experimentally the requirements of different species. If the ecological effects of climate change are to be predicted accurately, a wide range of information is required on the effects of temperature on the different life stages of each species (Table 1). Such information is not yet complete for any species of aquatic insect.

Although there are just over 1850 species of aquatic insects in the British Isles, detailed quantitative information on the relationship between temperature and development of eggs, larvae and pupae is available for relatively few species (Table 2). There is clearly a need for more information, especially on the thermal requirements of eggs. If eggs fail to hatch, then a population is extinct, and if few eggs hatch, then a population is unlikely to be sustained. In the few species studied, the temperature limits for the eggs are narrower and lower than those for larvae, a situation similar to that in fish. The eggs of aquatic insects are therefore particularly sensitive indicators of the ecological effects of climate change.

Table 1. Information required on the direct effects of temperature on aquatic insects.

EGGS
- Temperature range for survival and hatching
- Optimum temperature for hatching
- Relationship between development time and temperature
- Relationship between length of hatching period and temperature
- Temperature requirements for facultative or obligatory dormancy

LARVAE
- Temperature ranges for survival, feeding, and growth
- Relationship between temperature and size at emergence (exopterygotes) or pupation (endopterygotes)
- Relationship between temperature and timing of emergence or pupation
- Temperature requirements for dormancy

PUPAE
- Temperature range for survival
- Temperature range and optimum for metamorphosis
- Relationship between temperature and size at emergence
- Relationship between temperature and timing of emergence

ADULTS
- Temperature ranges for survival, and feeding
- Temperature range and optimum for mating
- Temperature range and optimum for oviposition
- Temperature requirements for dormancy

Table 2. Total numbers of British species in different orders of aquatic insects and the numbers of species for which the thermal requirements of eggs, larvae and pupae have been defined quantitatively.

Order	*British species*	*Species with information on:*			*References*
		Eggs	*Larvae*	*Pupae*	
Ephemeroptera	48	8	8	–	Elliott & Humpesch 1983; Elliott et al. 1988.
Plecoptera	32	27	6	–	Khoo 1968; Brittain 1983; Brittain et al. 1986; Lillehammer et al. 1989; Elliott 1984, 1986, 1987a, b, 1988 a, b, c, d, 1989, 1991 a, b.
Odonata	39	1	1	–	Waringer & Humpesch 1984.
Hemiptera	63	2	1	–	Savage 1989.
Megaloptera	3	1	0	3	Kaiser 1961; Elliott 1977.
Trichoptera	199	1	1	1	Wagner 1986, 1990; Elliott 1982.
Coleoptera	300	1	0	0	Blunck 1916.

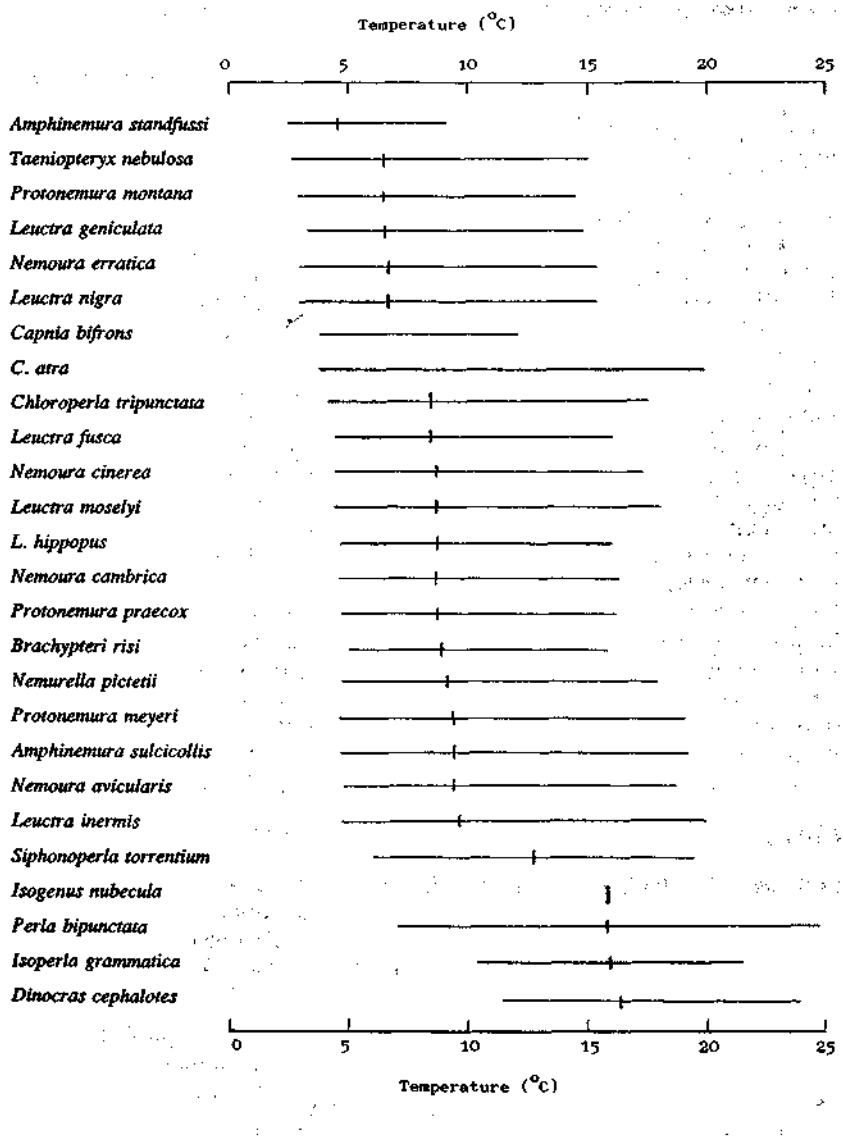

FIG. 2. Optimum temperatures (vertical bars) and ranges (horizontal bars) over which 50% of eggs hatch for different species of stoneflies.

Information on stonefly eggs

Although little information exists for most groups of aquatic insects, the one notable exception is the egg stage of stoneflies (Plecoptera in Table 2). All desirable objectives listed under eggs in Table 1 have now been fulfilled for nearly all the British species. The value of such information is illustrated by considering only two aspects, namely the optimum temperature for eggs to hatch and the temperature range over which at least 50% of the eggs in a batch will hatch (Fig. 2). It can be seen that the temperature requirements of the different species vary considerably within the range normally found in streams and rivers (0-25°C). The stoneflies, especially their eggs, clearly possess all the attributes of a group of aquatic insects that could serve as indicators and predictors of climate change.

The ranges for egg hatching in stoneflies (Fig. 2) clearly show that some species could be threatened whilst others could benefit from a defined increase in water temperature as a result of climate change. There are, however, other aspects of egg development that must be considered before the effects of climate change can be predicted accurately. Temperature affects both development time and the period over which eggs hatch. Both vary considerably between species and sometimes between populations of the same species. A critical review of the scattered literature is required to examine these interspecific and intraspecific variations in egg development in stoneflies. Such a review would be enhanced by considering work on Norwegian populations of species that have also been studied in Britain. It would be necessary to re-analyse the large amount of data in this field but the useful product would be a set of equations that could be used to predict the ecological effects of climate change on this important group of indicator species.

Criteria for selection and research projects

One of the objectives of this short review was to identify species that could be indicators and predictors of the ecological effects of climate change. Ideally, the following criteria should be fulfilled in selecting freshwater species for a study of the effects of projected climate change in the British Isles:

(i) Long-term data sets should be available on the population dynamics of the selected species and on associated climatic variables.

(ii) Ecophysiological information should be available on effects of climatic variables on the selected species (e.g. temperature).

(iii) Ecological information should be available on the functional role of the selected species within their ecosystem.

The literature survey has shown that no species of aquatic insect could be found to meet all these criteria but information on the British stoneflies and their eggs already satisfies criteria (ii) and (iii).

There are clearly many possible projects on aquatic insects in a programme designed to assess the sensitivity of British species to climate change. In the long-term, it is clearly desirable to obtain information from laboratory investigations on the temperature requirements of selected species of aquatic insects to discover if any other groups are suitable as useful biological indicators. Mayflies (Ephemeroptera), caddis-flies (Trichoptera) and alder-flies (Megaloptera) are obvious first choices because a few previous studies could serve as guides to the work.

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