10 TEMPERATURE EFFECTS ON AQUATIC AND TERRESTRIAL ECOLOGY

10.1 Temperature and macro-invertebrates

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10.1.1 Introduction

Temperature changes will directly and indirectly affect macro-invertebrates inhabiting lowland streams in the Netherlands. The temperature in natural streams is determined by a number of interrelated key factors (Ward 1985). The key factors acting in natural lowland streams are included in Figure 10.1.

The stream temperature characteristics determined by hydrology depend on the location in the tributary system (upper-, middle-, or lower-course) and the relative contributions of surface runoff and groundwater. Spring-fed streams receive a proportionately large inflow of groundwater, which has a constant temperature and thus causes these streams to be thermally very constant. Insolation is also an important key factor for stream temperature regime, but that will not change through climate change.

Figure 10.1 Key factors determining the temperature regime of a natural lowland stream (altered after Ward 1985).

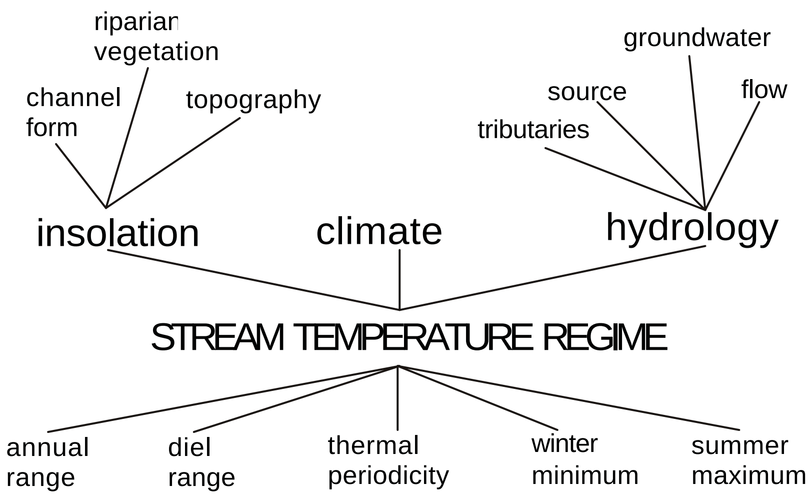
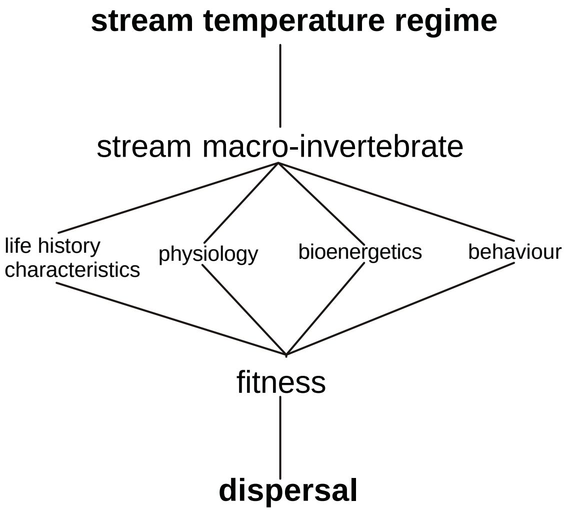


Figure 10.2 Conceptualization of the effect of stream temperature on the dispersal of macro-invertebrates.



The effect on a stream of the increasing level of atmospheric CO_2 acts through the chemical quality of the leaf litter entering the stream. Leaf litter produced under conditions of elevated CO_2 have both higher C:N ratios and lignin content. Therefore, leaf litter that falls into the stream will be decomposed more slowly because of decreased microbial colonization. This in its turn causes a reduction in detritivore and filter-feeding macro-invertebrate abundance (Wahtera et al. 2000).

In stream ecosystems, it has long been realized that temperature plays an important role in determining the distribution and abundance of macro-invertebrates (e.g. Kamler 1965, Vannote & Sweeney 1980, Ward & Stanford 1982). Temperature is one of the most important factors affecting the life history characteristics and biogeography of aquatic insects (Sweeney 1984). Macro-invertebrates are poikilothermic (cold-blooded) animals whose metabolism, rate and magnitude of growth, development, and overall behavioral activities respond significantly to thermal change on a diel, seasonal, and annual basis (Ward & Stanford 1982). As macro-invertebrates are found in a wide range of waters with different thermal regimes, they clearly possess bioenergetic, physiological, developmental, and/or behavioral mechanisms that enable them to survive, reproduce (Sweeney et al. 1992) and disperse (Figure 10.2).

The major goal of this part of the study is to reach a better understanding of the potential effects on macro-invertebrates in lowland streams that occur if climate changes towards a warmer atlantic regime. That regime presently occurs in the northern half of France. The study comprises two parts. The first part focuses on the expected temperature change and answers the question: ‘What temperature change is to be expected in lowland streams in the Netherlands?’. The second part focuses on the question: ‘Which macro-invertebrate species will decrease or disappear, will not change, or will increase or colonize the lowland streams in the Netherlands due to climate change?’.

10.1.2 Methods

Temperature regimes

Five of the ten streams described in Chapter 6 were intensively monitored for temperature from July 1997 until October 1998, over a 15-month period. Temperature was recorded each 15 minutes. Measurements were expressed in daily and monthly averages. Based on one year, the temperature of the studied streams was summarized in percentiles of twenty-five percent each. The temperature values of these classes, expressed in ^{o}C, represent temperature quartiles.

Two climate scenarios are used to predict the future temperature regime, the so-called RIVM scenario (Können, Fransen & Mureau 1997) and the Hadley scenario *Cur_Had* described in Section 2. The air temperatures predicted in both scenarios are used to calculate the water temperatures. To do so, linear regression is used to relate the measured daily average water temperature to the measured daily air temperature per stream. The resulting regression coefficients are used to calculate the future water temperature on the basis of the future air temperature.

Macro-invertebrates were sampled 3 times in all ten streams in autumn (1997), spring (1998) and autumn (1998). The samples were taken by means of a micro-macrofaunashovel of 10 by 15 cm (sampled surface area 150 cm^2). At each site the five major substrate types were sampled, sorted and preserved in alcohol (70% dilution), except for oligochaetes and watermites which were preserved in formalin (4% dilution) and Koenike fluid, respectively. If possible, all macro-invertebrates were identified down to the species level. Macro-invertebrate distribution is related to the stream temperature regimes. Number of taxa, number of individuals and some ecological characteristics of macro-invertebrates are calculated (Verdonschot 1990, Nijboer & Verdonschot 2001).

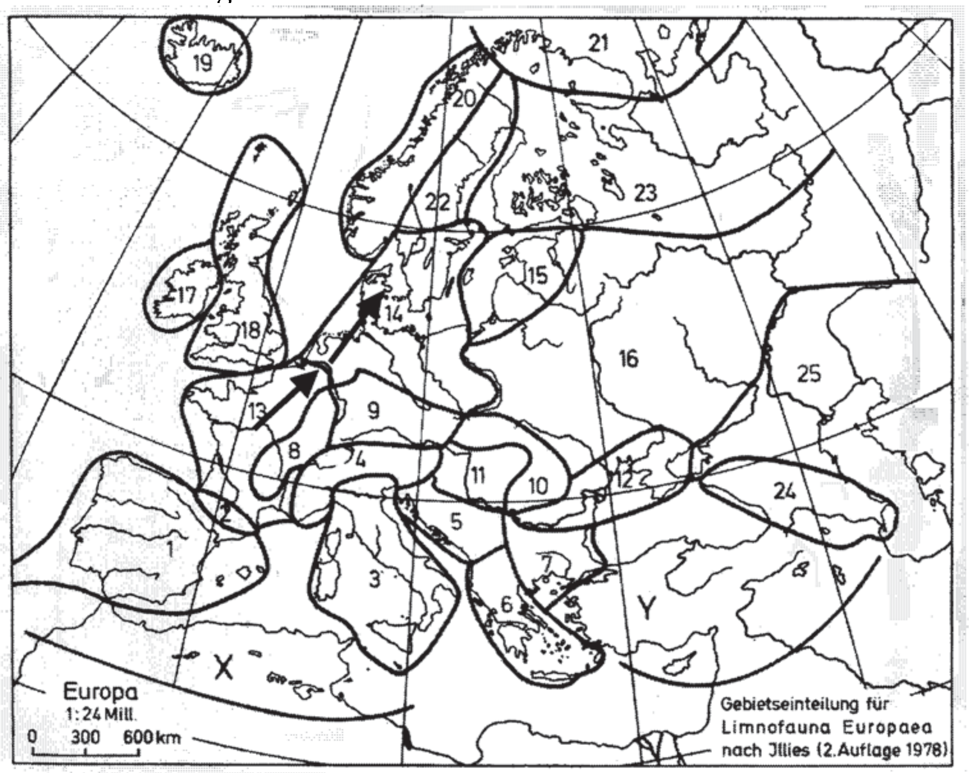
Dispersal

To study the present and expected dispersal patterns of macro-invertebrates the biogeographic information listed by Illies (1978) is used. The criteria to select suitable macro-invertebrate species are:

- the species must occur in lowland streams
- the species must be present in the atlantic region of the north-western European lowland plain

The latter criterion implies that only species occurring in ecoregion 13 and 14 (Figure 10.3) will be used. The first criterion is met by selecting only running water species. Ecoregion 13 'Western European lowland plain' covers the western parts of France and Belgium up to the southern part of the Netherlands, south of the river Rhine. Ecoregion 14 'Central European lowland plain' covers the Netherlands, north of the river Rhine, northern Germany, Denmark and southern Scandinavia. Macro-invertebrates currently occurring in ecoregion 13 concern the species to be expected in the Netherlands in the future. The dispersion of macro-invertebrates currently occurring in ecoregion 14 will shift towards the north. A number of

Figure 10.3 Ecoregions in Europe (Illies 1978). The arrows indicate the expected direction of change in macro-invertebrate distribution.



species will disappear from the Netherlands. Three classes of biogeographical change are defined:

- class I : extinction, in which a taxon occurs in ecoregion 14 and lacks in ecoregion 13
- class II , introduction, in which a taxon lacks in ecoregion 14 and occurs in ecoregion 13
- class III, constant, in which a taxon occurs in both ecoregions

The number of species are scored for each macro-invertebrate group.

10.1.3 Temperature regimes

The temperature regimes of the five studied streams show two temperature groups of streams (Figure 10.4). The first group, Springendalse stream north, Cold stream and Old stream, show minor fluctuations daily as well as over the seasons. The daily averages fluctuate from 3.4 ^{o}C up to 13.3 ^{o}C. These values indicate streams which are fed by deep ground water (left-hand side of Figure 10.5). This groundwater has a constant temperature and together with the small size of the streams, stream temperature does not vary much throughout the year. Figure 10.5 also shows that in future temperature will especially rise in winter by about 2 ^{o}C.

Two other streams, Tongerense stream and Forest stream, show larger fluctuations in time (right-hand side of Figure 10.5). The daily averages fluctuate from -0.2 ^{o}C up to 19.4 ^{o}C. Both streams are fed by rainwater or shallow subsurface runoff. Furthermore, both streams are slow flowing. Flow velocity together with water source cause this temperature regime. Figure 10.5 also shows that in future temperature will rise throughout the year by about 4^{o}C. The same pattern is visible in all five streams comparing daily minimum and maximum values.

Figure 10.4 The average daily temperature in five lowland streams.

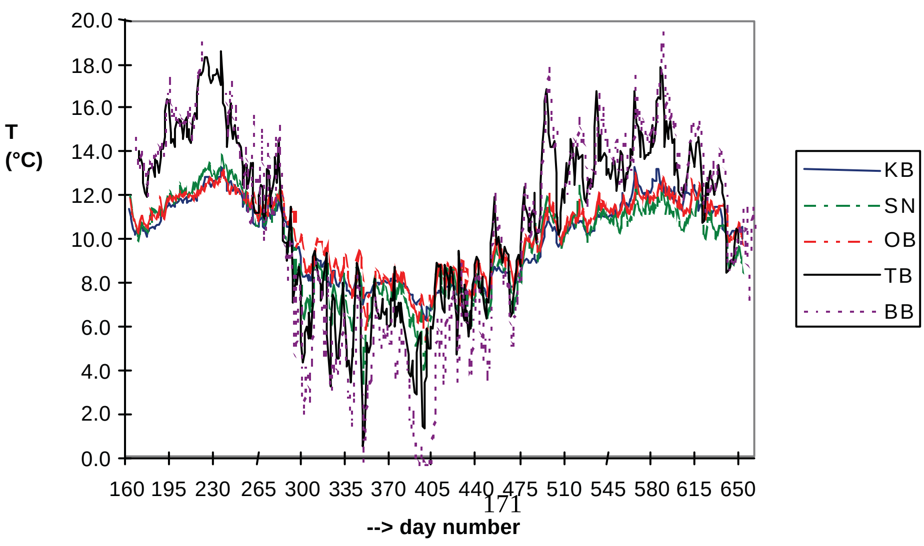
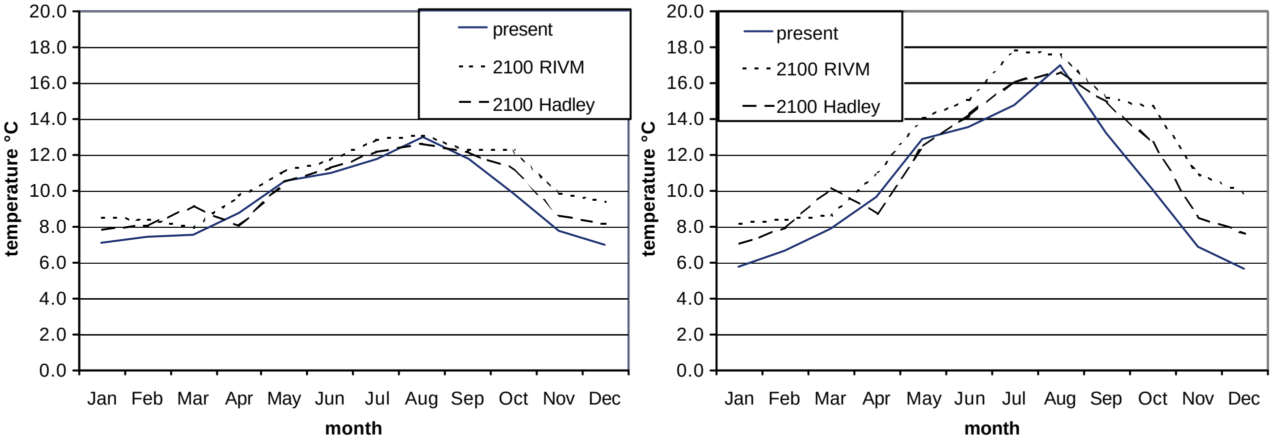


Figure 10.5 Present and predicted temperature regime in groundwater fed (left: Springendalse stream north) and a rainwater fed lowland stream (right: Tongerense stream).



The macro-invertebrate composition of both groundwater fed and rainwater fed streams is compared (Table 10.1). This comparison is based on two major criteria:

1. Species with a narrow temperature range will, because cold waters are rare in the Netherlands, be rare
2. Species with a narrow temperature range, especially, will occur in springs and small upper courses of streams

The relative number of rare species and species characteristic for springs and small upper courses is much higher in groundwater fed streams (Table 10.1). This result supports the hypothesis that a number of running water macro-invertebrates, often more common in alpine areas, can occur in the lowlands because of the constant supply of those streams with cold groundwater. It also implies that these species are vulnerable to climate change, especially, when higher air temperatures in the long term also affect the groundwater temperature.

Table 10.1 Macro-invertebrate distribution in groundwater and rainwater fed lowland streams.

stream type	no. taxa (no. unique taxa)	no. of individuals	no. rare taxa	no. spring taxa	no. upper course taxa
Groundwater fed	504 (unique 31 (7.4%))	9923	19 (61%)	6 (32%)	11 (58%)
Rainwater fed	699 (unique 52(6.2%))	9423	23 (44%)	3 (13%)	9 (39%)

10.1.4 Dispersal

It is clear that climate change will influence the life history characteristics and biogeography of aquatic macro-invertebrates. Changes in temperature regime will affect the fitness of individual species in terms of survival/mortality, growth/fecundity and production of viable offspring. If macro-invertebrates are unable to endure changing conditions, the only option to avoid extinction is dispersal to a location with a more suitable climate. Thus species can become extinct (class I), they can show no changes (class III) or they can newly colonize an area (class II). Figure 10.6 illustrates an overall change in macro-invertebrates composition in lowland streams to be expected under influence of climate change.

The numbers of taxa are listed per macro-invertebrate group in Figure 10.7. Climate change will cause a disappearance of species belonging to the groups of Oligochaeta (44%) and Orthocladiinae (31%). The change in the oligochaete fauna can be due to the lack of knowledge on the dispersal of oligochaete taxa when compiling the 'Limnofauna Europea' (Illies 1978). The extinction of a number of Orthocladiinae with a temperature increase is less surprising. This sub-family of the Chironomidae mainly inhabits cold waters, thus this group is relatively over-represented in small lowland streams. Other groups characteristic for this environment, e.g. the Plecoptera, do not show a strong decrease in number of species. This could be due to the fact that most of these species are already extinct from the Netherlands.

Figure 10.6 Number of species per biogeographical class of change per macro-invertebrate group.

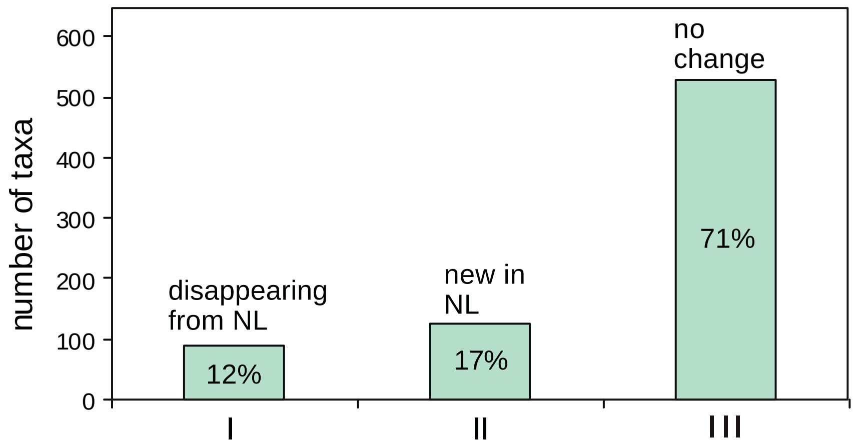
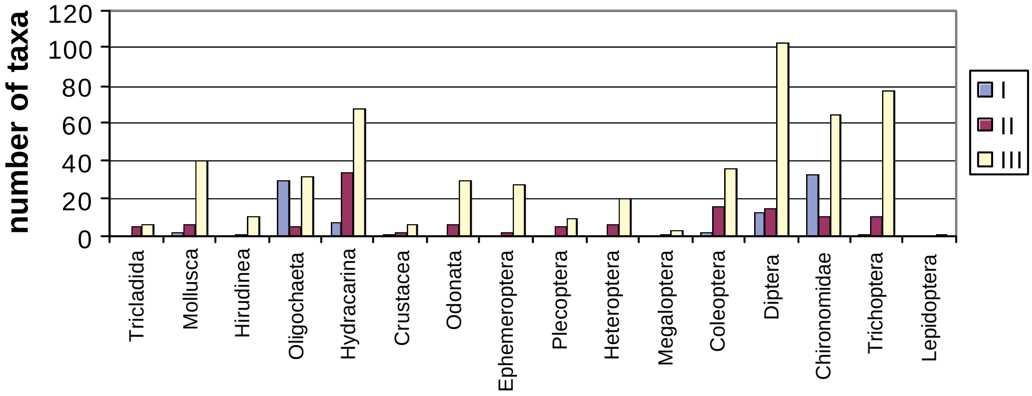


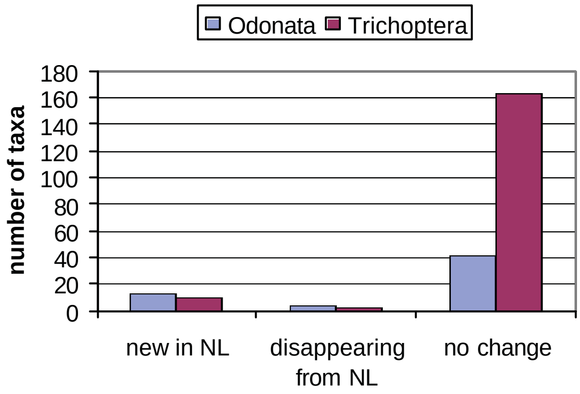
Figure 10.7 Percentage change of macro-invertebrate species in the Netherlands due to climate change (expressed in class I or III as explained in the text).



On the other hand new species will colonize our lowland streams. The percentage of new species within a group is highest for the Tricladida (46%), high for the Plecoptera (36%), Hydracarina (31%) and Coleoptera (30%), and reasonable for the Heteroptera (23%) and Odonata (17%). The relatively high percentages for Tricladida and Plecoptera are somewhat flattered because of the low numbers of species. Most of the macro-invertebrates show no change, with the most constant groups being the Ephemeroptera (93%) and the Hirudinea (91%). This only means change in the qualitative sense of colonizing or becoming extinct. The increase or decrease of populations will surely occur and probably even affect the function of the stream ecosystem considerably. But this impact is difficult to predict because of the lack of knowledge on population dynamics and life history characteristics of the species. Furthermore, the present often-deteriorated state of many Dutch streams is not included.

The method used is based on the dispersal data in the 'Limnofauna Europea' from 1978. More recently, for at least two macro-invertebrate groups more accurate updates of dispersal data became available. These groups concern the Odonata (Bos & Wasscher 1997) and the Trichoptera (Tobias & Tobias 1981). The criteria used were defined stricter by refining ecoregion 13 and to consider only those species within this region which already occur up to about 600-700 km south of the Netherlands. The same distance measure was used for the species to become extinct because of a shift towards the North. Species already extinct from the Netherlands and species which are only observed as adults are taken apart. Furthermore,

Figure 10.8 Percentage of change of Odonata and Trichoptera species in the Netherlands due to climate change.



the selection in this analysis included all species and was not restricted to only the running water representatives.

The percentages of species colonizing or disappearing from the Netherlands are listed (Figure 10.8). Thirteen new odonates (ten of which are running water species) and ten new trichopterans are to be expected while seven (four running water species) respectively two (both running water species) will become extinct. Both groups will take advantage from climate change, their number of species will increase. This more detailed analysis shows some differences with the Illies data and indicates how careful these first results should be handled.

10.1.5 Conclusions

Lowland streams in the Netherlands can be fed by mainly groundwater or mainly rainwater. The relative shares of both determine the temperature regime of a stream. A clear difference in macro-invertebrate composition, especially in rare species and species indicative for springs and small upper courses, is seen between mainly-groundwater and mainly-rainwater fed lowland streams. Climate change will affect the macro-invertebrate composition of springs and upper courses in the Netherlands.

If climate changes to a temperature regime comparable to that of the northern part of France and macro-invertebrates are able to disperse, especially the groups of Tricladida, Hydracarina, Plecoptera, Odonata, Coleoptera and Heteroptera will profit. Their number of species will increase in the Netherlands. The numbers of Orthocladiinae and Oligochaeta will decrease. The first corresponds with literature data (Rossaro 1991, Oswood 1989, Beckett 1992, Milner

1994). The conclusion on the oligochaetes is not supported, and probably due to lack of biogeographical knowledge. The more precise approach for odonates resulted in a higher number of expected species. The same approach for trichopterans also showed some inconsistencies in the ‘Limnofauna Europea’ already noted.