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ORDINATION OF SIMULIIDAE AND CLIMATE CHANGE IMPACT

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ABSTRACT – Simuliidae species and some physical parameters (altitude, turbidity, current velocity, channel width during the dry period, maximum water temperature in summer and three nominal variables, the running-water zone, substratum structure, and riparian vegetation) were assessed for 21 sites in the Büyük Menderes, Sakarya, Kızılırmak, Göksu, Fırat, and Dicle River systems. It is obvious that climate change has impacts on the aquatic ecosystems of Turkey.

Strong warming trends (increase of average annual temperature by around 2-3°C) have been determined for the whole of Turkey. Climate changes will alter the hydrological characteristics and quality of running waters and affect species composition and ecosystem functions. Relationships between Simuliidae assemblages and environmental variables were explored by canonical correspondence analysis for prediction of climate change impacts on distribution of species. The Simuliidae communities in these river systems varied in relation to the given variables. The obtained results indicate that *Simulium (Simulium) bukovskii*, *Simulium (Simulium) kerisorum*, *Simulium (Simulium) variegatum*, and *Prosimulium (Prosimulium) pronevitschae* cannot tolerate temperature increase and loss of riparian vegetation caused by climate change. On the other hand, *Simulium morsitans*, *Simulium (Nevermannia) vernum aestivale*, *Simulium (Obuchovia) transcaspicum*, and *Simulium (Nevermannia) cryophilum* cannot tolerate decreasing flow velocity and water volume caused by climate change.

KEY WORDS: Simuliidae, CCA, climate change, multivariate analysis, species composition, Turkey.

INTRODUCTION

Simuliidae are widespread and their larvae are an important component of the benthic fauna in running waters. The first evaluation of the detailed faunal structure of Turkish Simuliidae with many new records (22 species records, 20 of them new) and a detailed biogeographic discussion are given in KAZANCI & CLERGUE-GAZEAU (1990). Seven additional records and some ecological properties of 26 species were published by CLERGUE-GAZEAU & KAZANCI in 1992. Zoogeographical analysis indicates that the Turkish fauna is essentially an European Palaearctic fauna. The oriental faunal elements present belong to the subgenus *Wilhelmia* Enderlein, 1921.

Simuliid communities broadly reflect environmental conditions and are used as indicators of environmental degradation or restoration. The composition of simuliids is closely related to physico-chemical variables and morphological characteristics of running waters.

Most studies of climate change impacts on freshwater ecosystems (mainly lakes) were predictive due to the lack of long term data (GEORGE, 2000; SORVARI ET AL., 2002). Few studies examined impacts of climate change on invertebrates of running waters (ELLIOT ET AL., 2000; BRADLEY & ORMEROD, 2001).

Climate change effects on community structure of aquatic insects and other benthic macroinvertebrates have recently received considerable attention in Turkey (KAZANCI, 2006a, 2006b, 2006c).

Increases of water temperature and the flow regime as a result of climate change will affect ecological processes and the geographic distribution of aquatic species, causing extinction of species and loss of biodiversity. Climate changes will alter hydrological characteristics and the quality of running waters and will affect species composition and ecosystem functions.

Increasing evidence shows that climate change has serious impacts on the aquatic ecosystems of Turkey. Strong warming trends (increase of average annual temperature by around 2-3 °C) was determined for the whole Turkey. A noticeable decrease of mean annual precipitation has also been observed, mostly in Western and Southern Turkey, as well as along the coast of the Black Sea (PARTAL & KAHYA, in press). According to KAHYA & KALAYCI (2003), the flow of streams in Western Turkey shows significant decreasing trends. Seasonal shifts would have significant impacts on benthic communities with Simuliidae species in the ecosystems of streams.

In this study, 22 Simuliidae species from 21 sites in different hydrographic networks e.g., the Büyük Menderes, Sakarya, Kızılırmak, Göksu, Fırat, and Dicle Rivers, were considered. Simuliidae composition is related to various physical environmental variables. While several species inhabit different types of habitats, some species are restricted to particular habitats.

Relationships between species assemblages and environmental variables (altitude, transparency, mean current velocity, channel width during the dry period, maximum water temperature in summer, the running water zone, substratum structure, and riparian vegetation) were explored by canonical correspondence analysis.

The aims of this study were to determine the composition of Simuliidae species and relationships between their distribution and some physical characteristics of collecting sites and use this information to predict climate change impacts on species distribution and existence.

METHODS AND MATERIALS

The experimental design called for recording of physical variables and collection of Simuliidae species from 21 sites on tributaries and the main stem of Büyük Menderes, Sakarya, Kızılırmak, Göksu, Fırat, and Dicle Rivers (Fig. 1). Complementarly to the biological sampling for each point, a general survey was conducted that included altitude, turbidity, current velocity, channel width during the dry period, maximum water temperature in summer, and three nominal variables, the running-water zone, substratum structure, and riparian vegetation. At each site, larvae and pupae were hand collected from all available substrata over the course of 40 min.

Relationships between Simuliidae species and environmental variables were explored by canonical correspondence analysis (CCA; TER BRAAK, 1987).

RESULTS AND DISCUSSION

Twenty two species of Simuliidae were found at the 21 sites (Table 1). The distribution of species was influenced significantly by environmental variables. According to CCA, the physical variables affecting species distribution, in order of importance, were: channel width during the dry period, altitude, turbidity, maximum water temperature in summer, and mean current

Table 1. List of Simuliidae species and their abbreviations.

	Species	Abbreviations
1	*Prosimulium (Prosimulium) pronevitschae* Rubtsov, 1955	Pro pro
2	*Simulium (Eusimulium) reginae* Terteryan, 1949	Eus reg
3	*Simulium (Nevermannia) latigonium* (Rubtsov, 1956)	Nev lat
4	*Simulium (Nevermannia) vernum aestivale* (Rubtsov, 1962)	Sim aes
5	*Simulium (Nevermannia) cryophilum* (Rubtsov, 1959)	Sim cry
6	*Simulium (Nevermannia) vernum* Macquart, 1826	Sim ver
7	*Simulium (Obuchovia) transcaspicum* Enderlein, 1921	Sim tra
8	*Simulium (Simulium) aureofulgens* Terteryan, 1949	Sim aur
9	*Simulium (Simulium) bukovskii* Rubtsov, 1940	Sim buk
10	*Simulium (Simulium) ornatum* Meigen, 1818	Sim orn
11	*Simulium (Simulium) caucasicum* Rubtsov, 1940	Sim cau
12	*Simulium (Simulium) baracorne* Smart, 1944	Sim bar
13	*Simulium (Simulium) reptans* (Linnaeus, 1758)	Sim rep
14	*Simulium (Simulium) variegatum* Meigen, 1818	Sim var
15	*Simulium (Simulium) morsitans* Edwards, 1915	Sim mor
16	*Simulium (Simulium) alajense* Rubtsov, 1938	Sim ala
17	*Simulium (Simulium) bezzii* (Corti, 1914)	Sim bez
18	*Simulium (Simulium) kerisorum* (Rubtsov, 1956)	Sim ker
19	*Simulium (Wilhelmia) balcanicum* (Enderlein, 1924)	Wil bal
20	*Simulium (Wilhelmia) paraequinum* Puri, 1933	Wil par
21	*Simulium (Wilhelmia) pseudequinum* Séguy, 1921	Wil pse
22	*Simulium (Wilhelmia) turgaicum* Rubtsov, 1940	Wil tur

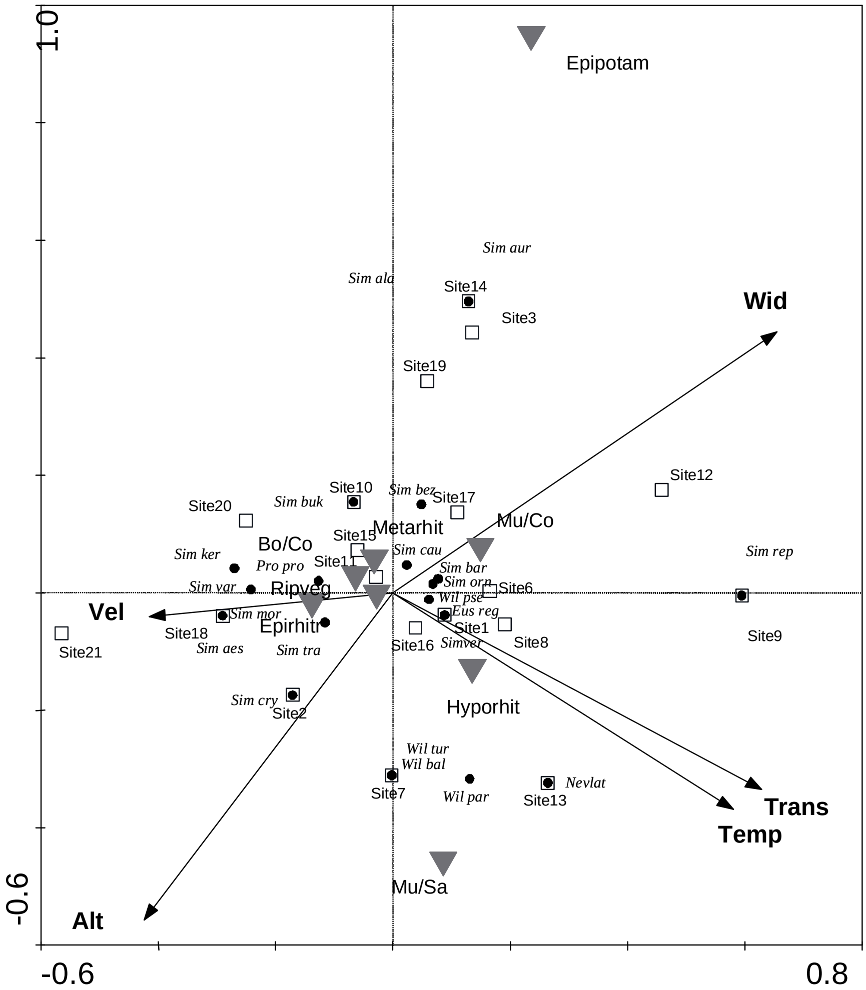

Fig. 1. Canonical correspondence analysis diagram for 21 sites for the various hydrographic networks. Collecting sites are indicated by squares; species are indicated by circles.

Abbreviations of variables
Altitude= Alt; Transparency= Trans.; Mean velocity= Vel.; Dry season channel width= Wid.; Maximum water temperatures in summer= Temp.; Riparian vegetation=Ripveg.; Epirhitron= Epirhitr.; Hyporhitron= Hyporhit.; Metarhitron= Metarhit.; Epipotamon=Epipotam.; Boulder/cobble= Bo/Co; Mud/Sand=Mu/Sa; Mud/Cobble=Mu/Co.

List of collecting sites
1. Burdur: Yeşilova, 1350 m , 23.7.1987; 2. Muğla: Dirmil Pass, 1500 m, 22.7.1987; 3. Fethiye-Antalya Road: Tributary of Eşen Stream, 200 m, 20. 7. 1987; 4. Muğla: Köyceğiz, Yuvarlak Stream, 900 m, 19. 7. 1987; 5. Muğla-Fethiye Road: Çırpı, 210, 20. 7. 1987; 6. Muğla: Fethiye: Gölderesi, 200 m, 21.7.1987; 7. Muğla: Kemer, Seki Stream, 1100 m, 21.7.1987; 8. Muğla-Marmaris Road: Datça Stream, 50 m, 24.4.1987; 9. Aydın- Çine Road: Dipsiz Stream, 50 m, 24. 4. 1987; 10. Bursa: Mezit Stream, 700 m, 18. 7. 1986; 11. Ankara: Akyarma Pass, 1500 m, 29.5.1987; 12. Ankara: Güdül, 800 m, 27. 4. 1983; 13. Kayseri: Pınarbaşı, Zamantı Stream, 1500 m, 30.7.1987; 14. Çorum: Osmancık, 650 m, 7. 5. 1983; 15.Mersin: Mut-Silifke Road, Sertavul Pass, 900 m, 23.4.1983; 16. Mersin: Mut-Silifke Road, 650 m, 23.4.1983; 17. Mersin-Çamlıyayla Road, 450 m, 25.5. 1984; Malatya: Fırat River, 1150 m, 31.7.1987; 19. Malatya:Beylerderesi, Fırat River, 900 m, 31.7.1987; 20. Erzincan: Kemaliye, Tarhanik Stream, 900 m, 2.8.1997; 21. Hakkari: Yukarı Otluca, Zap River, 2000 m, 24.7.1984.

velocity (Fig. 1). The running water zone, substratum structure, and riparian vegetation were used as nominal variables.

Simulium (Simulium) bukovskii, *Simulium (S.) kerisorum*, *Simulium (S.) variegatum*, and *Prosimulium (Prosimulium) pronevitschae* correlated positively with the epirhitron and metarhitron of streams (at 900-2000 m) with boulder/cobble substrate and riparian vegetation. These species were also correlated positively with current velocitiy. However, they were correlated negatively with turbidity and maximum summer water temperature. The given species cannot tolerate temperature increase and loss of riparian vegetation caused by climate change.

Simulium (S.) bukovskii prefers shaded regions in running waters and dense riparian vegetation, while *S. (S.) kerisorum* and *P. (P.) pronevitschae* prefer cold mountain streams (RUBTSOV, 1956). *Simulium (S.) variegatum* is appears to be dependent on high current velocities and oxygen levels (FELD ET AL., 2002) and thus frequently occurs at higher altitudes. *Prosimulium* species are known to be intolerant of higher water temperatures (DAVIES & SMITH, 1958). According to ZWICK & ZWICK (1990), there is a strong correlation between riparian vegetation and oviposition sites of the female in *Prosimulium*.

Simulium (Simulium) aureofulgens, *Simulium (S.) alajense*, *Simulium (S.) bezzii*, *Simulium (S.) caucasicum*, *Simulium (S.) baracorne*, and *Simulium (S.) ornatum* were associated with dry season channel width, the epipotamal zone, and muddy-cobble substratum. But these species were correlated negatively with current velocity and altitude. The given species can tolerate decreasing channel width due to climate change effects on running water ecosystems.

Simulium (S.) aureofulgens and *S. (S.) alajense* prefer the potamon of lowland rivers (RUBTSOV, 1956). In this study these species were collected from lowland rivers. *Simulium (S.) ornatum*-gr. [e.g., *S. (S.) caucasicum = S. (S.) baracorne*] is known to be tolerant of habitat degradation and organic pollution (FELD ET AL., 2002).

Tetisimulium bezzii occurs over a wide range of altitudes from lowlands to about 2500 m in Morocco (GUIDICELLI AND DIA, 1986). This species is hemi-stenothermal and eurystenothermal and it is widely distributed over Mediterranean Europe in middle and lower regions of mountain rivers in Italy and France (GUIDICELLI AND DIA, 1986; DORIER, 1963). Specimens of *T. bezzii* were collected from the hyporhitron of streams between altitudes of 650 and 900 m in this study.

Simulium (Simulium) reptans, Simulium (Wilhelmia) pseudequinum, Simulium (Eusimulium) reginae, Simulium (Nevermannia) vernum, Simulium (Wilhelmia) turgaicum, Simulium (Wilhelmia) balcanicum, Simulium (Wilhelmia) paraequinum, Simulium (Nevermannia) latigonium were in positive correlation with turbidity, maximum summer temperature, the hyporhitral zone, and a muddy-sandy substratum. These species can tolerate increasing temperature caused by climate change.

Nevermannia latigonia prefers low current velocity and is tolerant of organic pollution and high temperature (CLERGUE-GAZEAU, 1988). *Wilhelmia pseudequina* prefers eutrophic regions of main rivers and large tributaries. This species is tolerant of organic pollution and occurs over a wide altitudinal range (from 40 to 1060 m) (GUIDICELLI AND DIA,1986). Specimens of *W. pseudequinum* were collected from streams between altitudes of 50 and 1100 m in this study. *Simulium reptans* colonizes the rhitron or potamon of streams and rivers (OFENBÖCK ET AL., 2002). This species was collected from the hyporhitron of Dipsiz Brook.

Simulium (Simulium) morsitans, *Simulium (Nevermannia) vernum aestivale*, *Simulium (Obuchovia) transcaspicum*, and *Simulium (Nevermannia) cryophilum* were correlated positively with velocity, altitude and the epirhitral zone, but negatively with dry season channel width and a muddy-sandy substratum. These species cannot tolerate decreasing channel width and flow velocity caused by climate change.

Simulium morsitans occurs in the potamon of lowland rivers in Europe (OFENBÖCK ET AL., 2002), but was collected at 1500 m from a tributary of the Fırat River in this study.

Simulium cryophilum and *S.* (*O.*) *transcaspicum* prefer cold mountain streams (DORIER, 1963). According to GUIDICELLI AND DIA (1986), *Obuchovia* species appear to be lowland-stream blackflies but they were also found in the riffle area of a stream in Lebanon. These species were collected in the epirhitron of a tributary of the Esen Brook in a mountainous region in this study.

CONCLUSION

The use of aquatic insects as indicators of climate change effects on running-water ecosystems provides valuable information owing to their narrow thermal ranges. They will also be affected by possible changes in the flow regime and physico-chemical habitat degradation resulting from climate change.

Simuliidae species are an important component of the fauna of aquatic insects in most types of running waters and can serve as indicators of structural and physico-chemical quality of habitats (FELD ET AL., 2002).

In this study, Simuliidae species distribution varied in relation to some physical and morphological properties of running waters. They can therefore be used to predict climate change impacts on the structural and physico-chemical quality of running water habitats.

More detailed information, including new records of species and data on the chemical and morphological properties of collecting sites, is needed to identify relationships between habitat quality and species composition.

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