Where hides the aquatic biodiversity of macroinvertebrates in the Canton of Geneva (Switzerland)?

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Abstract

The conservation of biodiversity constitutes an important stake in agreement with the Convention of Rio signed by Switzerland and the inventory of this biodiversity is necessary to monitor the quality of aquatic ecosystems. This study aims to draw up a state of knowledge of the aquatic macroinvertebrates of the Canton of Geneva and to highlight the respective biological potentialities of four waterbody types: rivers (Rhone and Arve), streams, ponds and the Lake (western part of Lake Geneva). We compiled more than 18000 data, concerning 358 stations prospected through various investigations conducted between 1980 and 2006. Seven taxonomic groups were selected: Coleoptera, Odonata, Trichoptera, Plecoptera, Ephemeroptera, Gastropoda and Bivalvia. The results evidence that rivers and ponds have the greatest biodiversity (number of species) and also the highest number of unique species (i.e. species found in only one type of ecosystems). Ponds also present the highest number of Red List species. The watersheds of the Rhone and the Allondon are the richest areas according to their species number and Red List species. An assessment of sampling efficiencies showed that all types of waterbodies were relatively well sampled (more than 80% of species have been collected). Nevertheless gaps of knowledge remain highest for rivers and ponds. From the seven investigated taxonomic groups, the Trichoptera and Coleoptera were undersampled, and a quarter of the species still remains to be discovered.

Keywords: *macroinvertebrates, Red List, odonata, ephemeroptera, mollusca, plecoptera, trichoptera, coleopteran.*

Résumé

Où se cache la biodiversité en macroinvertébrés aquatiques du Canton de Genève (Suisse)? - *Signée par la Suisse, la Convention de Rio sur la biodiversité formule, entre autres, les objectifs suivants: conservation de la biodiversité et exploitation durable de ses éléments. Appliqués au Canton de Genève, ces objectifs impliquent notamment de connaître la valeur biologique des différents types de milieux aquatiques afin de mettre en place des stratégies de conservation des milieux et des espèces. Cette étude a pour but de dresser un état des lieux de la biodiversité des macroinvertébrés aquatiques du Canton de Genève et de mettre en évidence les potentialités biologiques respectives de quatre types de milieux: les fleuves (dans le sens anglo-saxon du terme, i. e. Rhône et Arve), les rivières et les ruisseaux, les étangs ainsi que le lac (partie occidentale du Léman). Plus de 18000 données provenant de diverses sources et concernant 358 stations, toutes prospectées entre 1980 et 2006, ont été compilées. Nous avons focalisé notre travail sur sept groupes taxonomiques: Coléoptères, Odonates, Trichoptères, Plécoptères, Ephéméroptères, Gastéropodes et Bivalves. Cette étude montre que les rivières et les étangs hébergent la plus grande biodiversité (nombre d'espèces) et le plus grand nombre d'espèces uniques, espèces que l'on ne rencontre que dans un seul des quatre types d'écosystèmes étudiés. Le bassin versant du Rhône et son sous-bassin de l'Allondon possèdent la plus grande biodiversité et le plus grand nombre d'espèces sur Liste Rouge. Une analyse des efforts de prospection montre que les écosystèmes étudiés ont été relativement bien échantillonnés puisque plus de 80% des espèces potentiellement présentes dans le Canton ont déjà été recensées. Néanmoins, des lacunes de prospection ont été mises en évidence au niveau des fleuves et des étangs, ainsi que pour les Trichoptères et les Coléoptères, chez lesquels un quart des espèces resteraient à découvrir.*

Mots clefs: *macroinvertébrés, Liste Rouge, odonates, éphéméroptères, mollusques, plécoptères, trichoptères, coléoptères*

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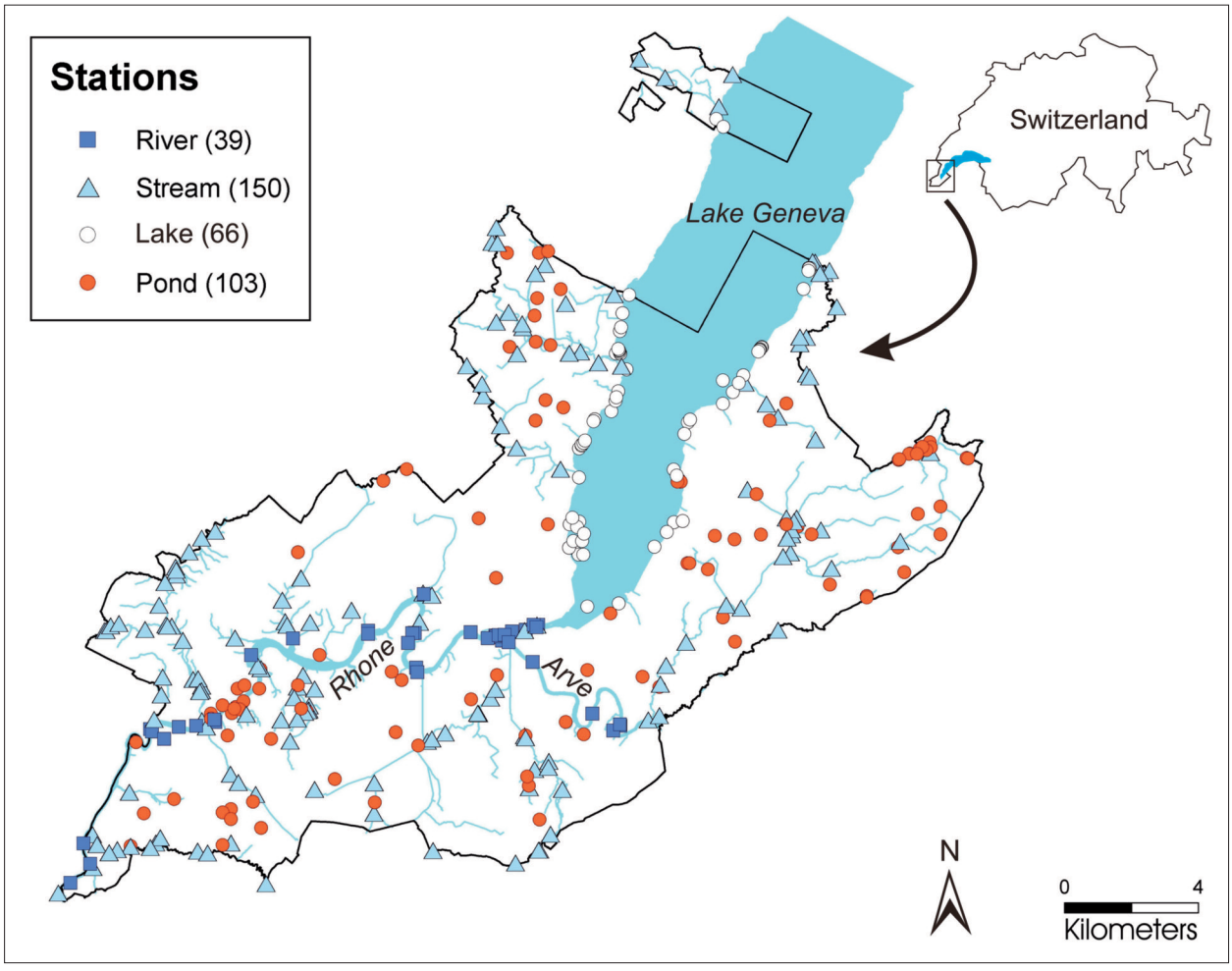
Introduction

The conservation of biodiversity, including the aquatic one, and the sustainable exploitation of its elements constitute an important stake, in agreement with the Convention of Rio signed by Switzerland. Applied to the Canton of Geneva, this implies an inventory of the biodiversity in order to assess the conservation value of the different aquatic ecosystems. Moreover, this inventory is necessary to monitor the quality of aquatic ecosystems. Macroinvertebrates are excellent overall indicators of both recent and long-term environmental conditions (Patrick and Palavage 1994). The immature stages of aquatic macroinvertebrates have relatively short life cycles and often several generations per year. Thus, when environmental changes occur, the species must endure the disturbance, adapt quickly, or die and be replaced by more adapted species. Macroinvertebrates are very useful to monitor aquatic ecosystems quality (see Rosenberg and Resh 1993) because of their fast response to environmental variations and their ability of informing about habitat intrinsic quality. Moreover, they are a major link in the aquatic and terrestrial food chain. They are consequently essential to the development of other guilds such as amphibians, fish and birds for example.

This study was aimed to draw up a state of knowledge of the biodiversity of aquatic macroinvertebrates in the Canton of Geneva and to compare the four major types of aquatic ecosystems: rivers (Rhone and Arve), streams, ponds and the Lake (western part of Lake Geneva). To this end, we will first study the species richness and the conservation value (species listed on the Swiss Red Lists) of the aquatic macroinvertebrates in the Canton of Geneva. Secondly, we will compare the biodiversity of the different freshwater ecosystems using species richness, number of unique species (i.e. species found in a single type of ecosystem) and number of endangered species. We will also highlight the taxonomic groups for which gaps of knowledge exist and emphasize the type of ecosystems for which the sampling effort remains insufficient. Finally, we will focus on lotic sites to compare the biodiversity between watersheds.

Fig. 1: Location of the 358 stations investigated: rivers, streams, ponds, lake. The black line represents the limit of the Canton of Geneva.



Study sites & methods

The Canton of Geneva extends on 282 km^2. It includes 16 watersheds (14 main streams and 2 rivers), one lake (western part of Lake Geneva) and more than 150 ponds. In this study, we selected 358 sites investigated between 1980 and 2006. Rivers (Rhone and Arve) and streams were represented by 189 sampling sites (Fig. 1), among which 80 belong to the monitoring net of the Cantonal Service of Water Ecology (SECOE). The lentic sites were represented by 169 stations: 103 ponds and 66 stations located on the Lake Geneva (Fig. 1). The macroinvertebrates, defined by Cummins (1975) as having a size ranging from 3 to 5 mm at the last stage of their development, were sampled in the frame of studies most conducted by the Department of the Territory (DT), the Federal Office for the Environment (OFEV) and the University of Geneva (Antoine 1996, Bänziger 1991, Bänziger 1998, Chanon Miguel 1992, Crozet 1982, Mulattieri 2006). Moreover, the data bank of the Swiss Centre for Fauna Cartography (CSCF) allowed us to complete this information for taxonomic groups concerned by the Swiss Red Lists (Odonata, Ephemeroptera, Coleoptera and Mollusca) and for Trichoptera and Plecoptera.

The compiled data bank contained 18244 data, with taxa identified at various taxonomic levels (species, genus, family). Only the 8271 data keyed to species level were used to conduct the present work. These data concerned seven taxonomic groups: Bivalvia, Gastropoda, Odonata, Coleoptera, Trichoptera, Ephemeroptera and Plecoptera.
The degree of threat of the species was assessed through the use of the Swiss Red Lists: Gonseth and Monnerat (2002) for Odonata, and Duelli (1994) for the others taxonomic groups.
All the species richness taken into account in this study (for each kind of ecosystem and for each studied taxonomic group) were obtained through non exhaustive samplings. Therefore the real number of species that can be gathered in the Canton of Geneva through an exhaustive inventory would be much higher. To estimate this "real" regional species richness ("regional" refers here to the Canton of Geneva), we used Chao1 estimator (Chao 1984). Such non-parametric estimator performs better than others to estimate species richness (Walther and Moore 2005). Chao1 was calculated using the software EstimateS (Colwell 2005).

Results

The aquatic macroinvertebrates of the Canton of Geneva

The synthesis of the aquatic macroinvertebrates data collected between 1980 and 2006 in the Canton of Geneva produces a list of 320 species for the seven selected groups. The richest taxonomic groups were the Coleoptera and the Trichoptera with respectively 88 and 86 species, whereas the poorest were the Plecoptera (20 species) and the Bivalvia (12 species) (Tab.1); the Odonata, Gastropoda, and Ephemeroptera are represented respectively by 43, 36 and 35 species.

In terms of conservation value, 52 species are classified as vulnerable, endangered or critically endangered, on one of the five Swiss Red Lists (there is presently no Red List for Plecoptera and Trichoptera), i.e. 24.3% of the total number of species collected for the five taxonomic groups (see Table 2 for a list of the threatened species). Gastropoda and Coleoptera are particularly threatened (with respectively 20 and 18 Red List species) (Tab. 1). *Heptagenia longicauda* (Photo 1) is the only species being both classified in danger of extinction on the Red List and present in a single site in the Canton. *H. longicauda* had not been observed since 1983, but also the sampling has never focussed on this species. The last observation of seven of the threatened species is older than twenty years (*Bidessus delicatessus*, *Haliplus confinis*, *Peltodytes caesus*, and *Heptagenia longicauda* for example) (Tab. 2). Furthermore, six species (*Acilius canaliculatus*, *Graphoderus cinereus*, *Gyrinus paykulli*, *Hydroporus umbrosus*, *Ceriagrion tenellum* and *Ecdyonurus torrentis*) appeared in

Taxa Group	Number of species	Number of families	Number of unique species	Number of Red List species
Coleoptera	88	12	33	18
Trichoptera	86	17	29	ND
Odonata	43	9	3	4
Gastropoda	36	8	6	20.
Ephemeroptera	35	8	4	8
Plecoptera	20	6	9	ND
Bivalvia	12	3	2	2
Total	***320***	***65***	***86***	***52***

Table 1: Number of species, families, unique species (i.e. species found in a single type of ecosystem) and Red List species obtained through sampling for each taxonomic group. ND: No Data.

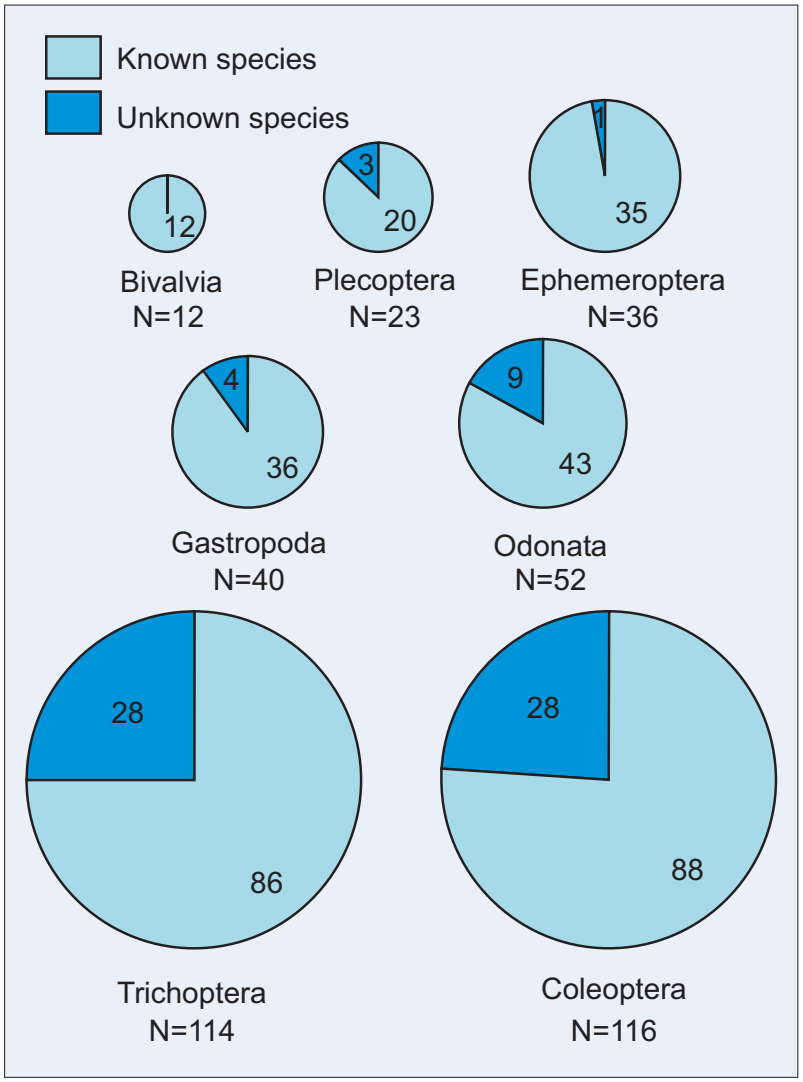


Fig. 2: Regional species richness of each taxonomic group estimated by Chao1 (N). The numbers in the pie charts indicate the number of known and unknown species. The size of the pie charts is proportional to the total number of species (N).

The real regional species richness

A total of 320 species have been sampled and identified. Using the Chao1 estimator (Magurran 2003), we can estimate the "real" regional species richness of each taxonomic group and deduce the proportion of potentially unknown species (Fig. 2). In the whole Canton, nearly a fifth of the species (19%) remains to be discovered. Coleoptera and Trichoptera are the less well known taxonomic group and about a quarter of species are potentially still to be discovered. On the contrary, Bivalvia and Ephemeroptera are very well known.

The invasive species

Two invasive species, *Dreissena polymorpha* (Pallas) (Zebra mussel, Bivalvia) and *Potamopyrgus jenkinsii* (Gray) (New Zealand mudsnail, Gastropoda) have durably colonized the Canton of Geneva. *Dreissena polymorpha* is known to be present in the Lake Geneva since 1962 (Boucard et al. 2004, Matthey 1966). Crozet et al. (1980) published the first record of *Potamopyrgus jenkinsii* within the French Switzerland and it appeared in the Lake Geneva in 1977. In the whole Canton, 83 sites were colonized by at least one of these two species which represented 23% of the studied stations. Among these 83 colonized sites, 92% were located on the Lake Geneva or the river Rhone.

the Canton only after the year 2000; therefore the colonization of the Canton by these species is perhaps not perennial. Consequently, some of the endangered species listed are probably no longer present in the Canton of Geneva.

Photo 1: Heptagenia longicauda *larvae (Ephemeroptera). Photo: J. L. Gattolliat.*

Table 2: List of the most threatened species (listed on the Swiss Red Lists) in the Canton of Geneva, number of sites and type of habitat where the species are present and last year of recorded presence. L: Lake, P: Ponds, R: Rivers and S: Streams.

* The identification has to be confirmed

** Only an adult has been observed in Canton of Geneva. The breeding site is probably situated in neighbouring France.

Red List category	Order	Species	Nb. of sites where the species is present	Type of habitats where the species is present	Last year of recorded presence
"Critically endangered" or "1"	Gastropoda	Gyraulus laevis (Alder)	13	L, P, R	1994
		Valvata macrostoma Mörch	2 *	R	1993
	Ephemeroptera	Heptagenia longicauda (Stephens)	1	R	1983
	Odonata	Leucorrhinia albifrons (Burmeister)	2 **	P, S	2003
"Endangered" or "2"	Gastropoda	Ferissia wautieri (Mirolli)	15	P	2002
		Physa fontinalis (L.)	7	L, R, S	1993
		Segmentina nitida (O.F. Muller)	1	P	1987
		Viviparus contectus (Millet)	1	L	1982
	Coleoptera	Bidessus delicatulus (Schaum)	1	S	1984
		B. minutissimus (Germar)	3	P, R	2002
		Graphoderus cinereus (L.)	1	P	2003
		Gyrinus paykulli Ochs	1	P	2003
		Hygrobia hermanni (Fabricius)	1	S	2004
		Orechtochilus villosus (O.F. Muller)	6	L	1991
		Stictotarsus duodecimpustulatus (Fabricius)	2	L, S	1994
	Ephemeroptera	Electrogena lateralis (Curtis)	12	R, S	2004
		E. ujhelyii (Sowa)	2	S	1991
	Odonata	Ceriagrion tenellum (de Villers)	1 **	P	2002
		Orthetrum albistylum (Selys)	5	P, S	2004
"Vulnerable" or "3"	Gastropoda	Acroloxus lacustris (L.)	7	P	2002
		Anisus leucostoma (Millet)	6	P, S	2002
		A. spirorbis (L.)	1	P	2003
		A. vortex (L.)	8	L, R, S	2004
		Aplexa hypnorum (L.)	2	P	1987
		Bathyomphalus contortus (L.)	2	L	2004
		Gyraulus crista (L.)	7	P	2003
		Hippeutis complanatus (L.)	10	L, P	2003
		Physella acuta (Draparnaud)	31	L, P, R	2005
		Planorbarius corneus (L.)	13	L, P	2003
		Planorbis carinatus (O.F. Muller)	22	L, P, R	2004
		Stagnicola fuscus (C. Pfeiffer)	1	P	1991
		Valvata cristata (O.F. Muller)	14	L, P, R, S	2003
		Viviparus ater (Cristofori et Jan)	12	L, S	2004
	Bivalvia	Musculium lacustre (O.F. Muller)	7	L, R	1994
		Pisidium amnicum (O.F. Muller)	5	L, P, S	1994
	Coleoptera	Acilius canaliculatus (Nicolai)	1	P	2002
		Agabus biguttatus (Olivier)	2	S	2004
		Haliplus confinis Stephens	1	P	1984
		H. fulvicollis Erichson	1	P	1987
		H. obliquus (Fabricius)	3	P	2005
		Hydroporus angustatus Sturm	3	P	2005
		H. ferrugineus Stephens	1	S	2001
		H. umbrosus (Gyllenhal)	1	P	2002
		Nebrioporus depressus (Fabricius)	5	L, P	1994
		Peltodytes caesus (Duftschmidt)	1	P	1984
		Yola bicarinata (Latreille)	4	P	2002
	Ephemeroptera	Ecdyonurus dispar (Curtis)	9	S	2000
		E. torrentis Kimmins	1	S	2000
		Potamanthus luteus (L.)	2	R	1996
		Procloeon pennulatum (Eaton)	2	S	1983
		Siphlonurus aestivalis (Eaton)	3	S	1982
	Odonata	Gomphus pulchellus Selys	16	P	2005

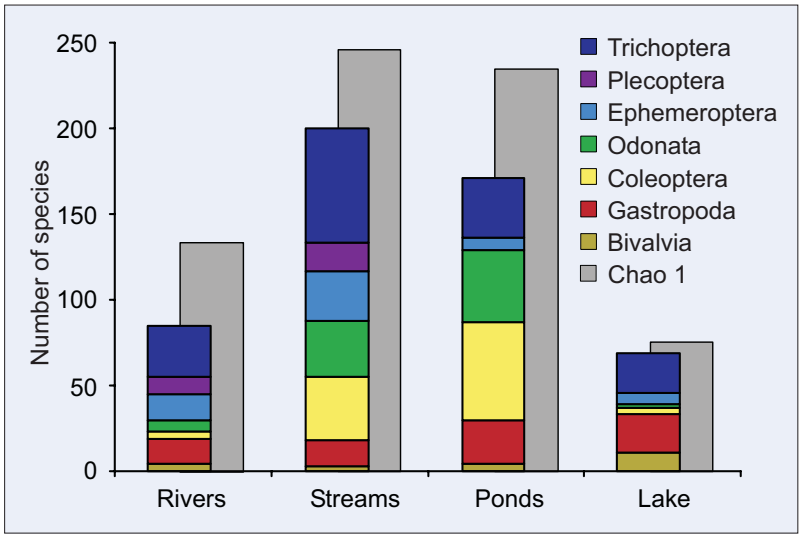


Fig. 3: Species richness per ecosystem type and estimation of the "real" richness using Chao1 estimator (in grey). The regional species pool observed is 320 species (estimation of the real species pool: 393 species).

Species diversity per freshwater ecosystem

Among the four types of freshwater ecosystems investigated in the Canton of Geneva, streams and ponds were the richest with respectively 63% and 53% of the regional species pool (Fig. 3) whereas the rivers and the Lake sheltered respectively only 27% and 22% of the regional species pool. Moreover, sampling effort remains insufficient on rivers, ponds and streams with respectively 35%, 27% and 18% of species which are still unknown. The Lake seems to be well prospected with only 8% of unknown species.

Among the 320 species listed, 168 (i.e. 52.5%) are unique to one type of ecosystem. Moreover, respectively 45 and 43% of these 168 species are unique to streams and ponds, against only 8% and 4% to rivers and the Lake (Fig. 4). Concerning taxonomic groups, the Coleoptera had the highest proportion of species found in only one type of ecosystem with 42% of unique species followed by the Trichoptera with 21% (Fig. 4).

Among the 52 Red List species, 31 were found in ponds against 19 in streams, 16 in the Lake and 12 in rivers (Fig. 5). The high conservation value of ponds is mainly due to the high number of Gastropoda, Coleoptera and Odonata threatened species; the lower conservation value of running waters (rivers and streams) is related to the absence of a Red List for Plecoptera and Trichoptera (groups well represented in running waters).

Among the 52 Red List species, 34 were found in only one type of ecosystem (Tab. 2). Ponds sheltered 56% of these unique and Red List species followed by streams (26%) and rivers and the Lake (9% each).

A focus on rivers and streams: analysis of the watersheds biodiversity

In this analysis, the Rhone basin corresponds to the main river catchment (i.e. not including its main tributaries (see Fig. 6 for catchments delineation). A classification of the 16 watersheds according to the magnitude of their species richness (taking into account only rivers and streams) indicated that the Rhone basin is the richest with 92 species, followed by the Allondon (86 species), the Versoix (68 species) and the Laire basin (66 species) (Fig. 6). For information, a classification (not presented here) taking into account the number of families gave approximately the same result: these 4 watersheds were also the richest but in a different order (Allondon, Laire, Versoix and Rhone). Although we

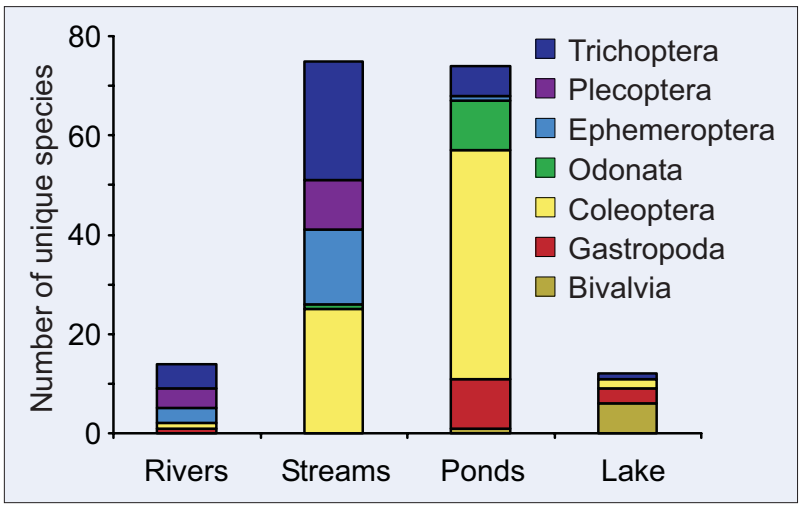


Fig. 4: Number of unique species to each type of ecosystems.

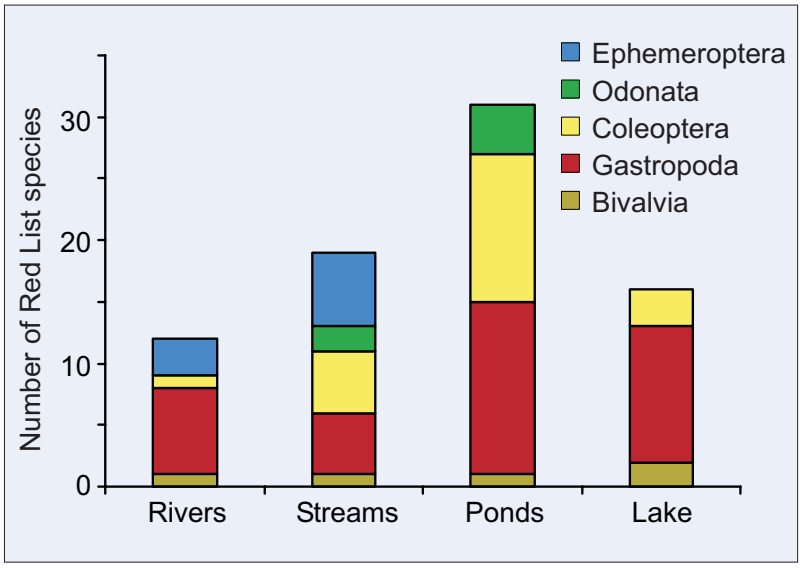


Fig. 5: Number of Red List species of each taxonomic group in the four types of freshwater ecosystems.

do not have the necessary data to correlate species richness and water quality, it should be noted that one of the poorest catchment (N: Nant des Crues, Fig. 6) is known to have a high chemical pollution index (DomEau 2004).

Moreover, the Rhone basin had the highest conservation value with 13 Red List species followed by the Allondon and the Laire with respectively 8 and 6 threatened species.

Discussion

Based on our study, the Canton of Geneva has nearly 400 species of macroinvertebrates for the seven investigated taxonomic groups. This quantity represents only a part of the global macroinvertebrate diversity, as other groups, not investigated here, bring usually a big contribution to the macroinvertebrate diversity of freshwaters. Indeed, we did not study the number of Diptera species which is potentially the most diverse order of insects in aquatic habitats. Studies about Diptera are very scarce as their identification to species level is often very difficult. These insects are generally polluo-tolerant and used to estimate the water and sediment quality (Wiederholm 1978; Saether 1979; Ruse 2002). However, concerning Tipulidae (Diptera) there is some existing data as well as a Red List (Dufour 1994).

Among the observed species of macroinvertebrates, 52 are listed on one of the five Swiss Red Lists available (Coleoptera, Odonata, Ephemeroptera, Gastropoda and Bivalvia). A Red List of aquatic organisms for Switzerland is about to be drawn up by the CSCF (CSCF 2006), including the Plecoptera and Trichoptera. This new Red List will therefore enlarge the number of endangered aquatic macroinvertebrates of the Canton of Geneva.

Heptagenia longicauda, the only species being both classified in danger of extinction on the Red List and found in a single station in the Canton of Geneva, deserves some attention. Its current distribution in Switzerland is restricted to one station in the North of the country (Canton of Zurich) and one station on the Genevan part of the Rhone. Little studied, this species is mainly found in large rivers (Sowa 1975) and seems to be, among *Heptagenia* genus, the least sensitive to organic water pollution (Bauernfeind et al. 1995). As this species has not been seen since 1983, it deserves a more intensive sampling effort to clarify its status in Switzerland in order to implement appropriate conservation measure if necessary. In the UK, this species is classified as endangered and benefits from an Action Plan in order to maintain any discovered populations (UK Biodiversity Group 1999).

Our study also shows that Coleoptera and Trichoptera are the most diverse taxonomic groups. Nevertheless they have to be better studied; we evidence here that a quarter of species remains to be discovered in the Canton.

Concerning the different aquatic habitats, streams and ponds were the richest ecosystems. With the exception of the Lake, all the aquatic habitats should be more intensively sampled as they potentially shelter more species than recorded in the current study. This will allow i) the identification of rare species and ii) the implementation of conservation strategies focussed on species rich habitats and/or rare species.

In the Canton of Geneva, the value of ponds for the conservation of aquatic biodiversity, in terms of species number, is as high as the streams one, and much higher than the Lake or the rivers. The recognition of the high patrimonial value of ponds is a recent phenomenon. In France for example, ponds shelter nearly a third of the patrimonial species. The loss of only one pond can remove the only station of a

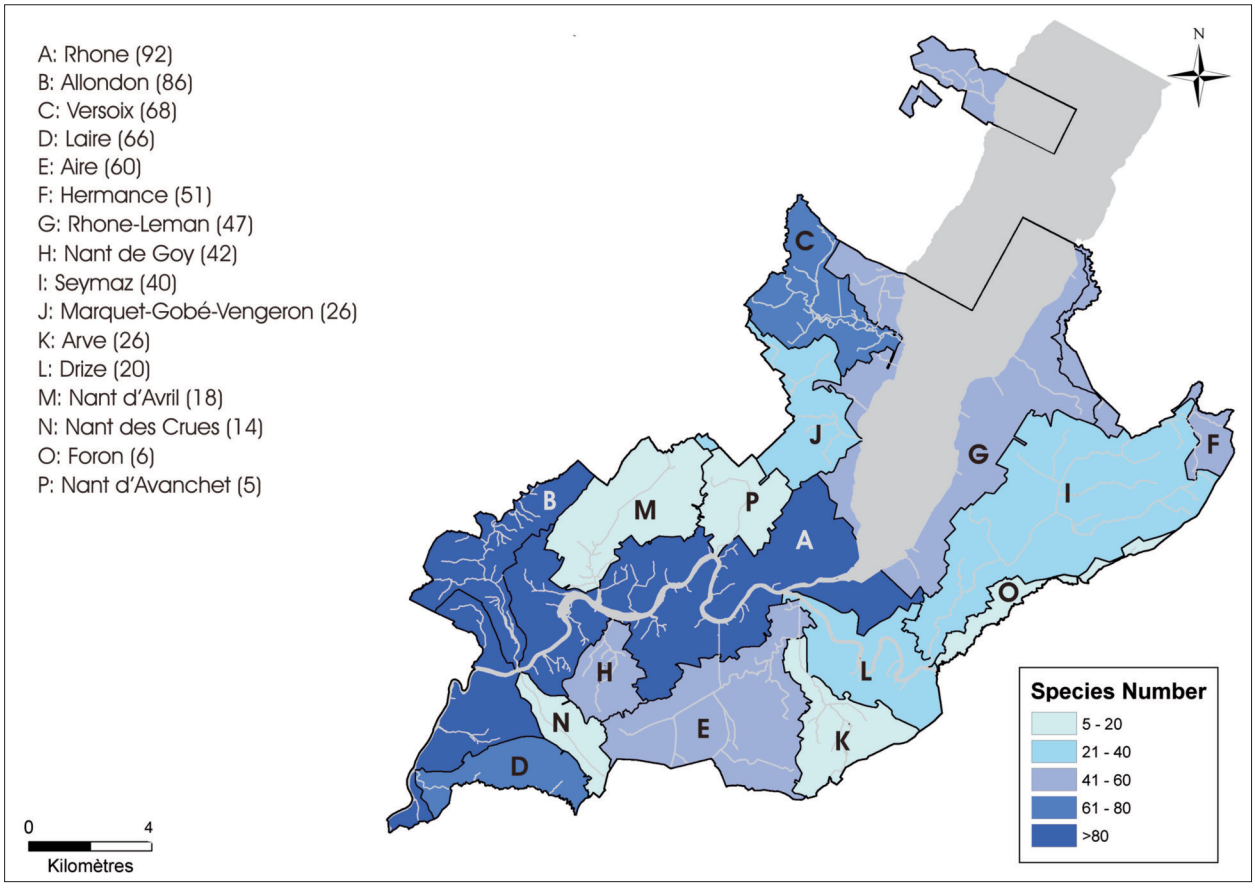
species on a territory as large as a region (Sajaloli and Limoges 2005). A study conducted in the UK (Williams et al. 2003) demonstrated that, at a regional level, ponds contributed most to biodiversity, supporting considerably more species, more unique species and more scarce species than other waterbody types such as rivers, streams and ditches. Recent studies conducted at a catchment scale in various parts of Europe (Biggs et al. 2006) have shown that, although lakes and rivers have high site (alpha) diversity, ponds consistently support a high proportion of aquatic plant and macroinvertebrates species found at a regional level (gamma diversity), typically in excess of 50% of the total number of species.

Furthermore, it is important to notice that the present study did not take into account types of waterbodies that were missed from most previous studies: small drainage ditches, wet depressions, temporary ecosystems and springs. These ecosystems are often strongly impacted by anthropic actions and were forsaken a long time. However, they potentially shelter interesting species. For example, in the UK, ditches (most of them seasonal) were the least species-rich habitat, but supported uncommon species, including temporary water invertebrates not recorded in other waterbody types (Williams et al 2003). In a same way, in Northern Europe, the value and the ecology of temporary ponds have been less studied (Nicolet et al. 2004) although they have recently been recognized as a wetland type of international importance by the Ramsar Convention (Ramsar Resolution VIII.33). Moreover, it is recommended to gather information on the whole "Geneva basin" (which includes areas of both France and Switzerland) in order to have an overview of aquatic macroinvertebrates biodiversity based on natural rather than political boundaries.

Conclusion

The biodiversity of the aquatic macroinvertebrates of the Canton of Geneva is relatively well known as 82% of the species living in ponds, streams, rivers and the Lake are supposed to be known. However, in order to ensure an efficient regional policy for the conservation of the biodiversity, it is of prime importance to discover the species still unknown in the Canton, including the rarest species with a potentially important patrimonial value (Red Lists species). Rivers

Fig. 6: Species richness by watersheds. Only lotic stations were taken into account. In brackets, the number of species present in each watershed.



(Rhone and Arve) and ponds must be prospected more intensively. Coleoptera and Trichoptera are the taxonomic groups which have the best potential to reveal new species. The biodiversity of aquatic macroinvertebrates is distributed unequally between the four types of habitats (rivers, streams, the Lake and ponds). The greatest biodiversity is observed in streams and ponds. However, even though there are differences in species richness, each ecosystem type supports an interesting fauna with species being unique to each one. This demonstrates that the network of both streams and ponds is particularly important as a refuge for the aquatic diversity of macroinvertebrates in the Canton of Geneva. We can also note that small aquatic habitats (such as wet depressions, springs and temporary ditches) have been too little studied for the last 25 years. These ecosystems have not been taken into account in our study and it is now important to improve our knowledge of these small wetlands.

The community of aquatic macroinvertebrates in the Canton of Geneva has a lot of patrimonial species. In order to ensure good management practices of these species, it is important to continue the monitoring of aquatic habitats, and to concentrate on target groups (i.e. groups having a national Red List). Moreover, macroinvertebrates are likely to be highly responsive to perturbations and can be used to assess the effects of climate changes or rivers flow modifications for example. Monitoring programs are already well developed for running waters in the Canton and aim to control water quality. Present investigation underlines that this monitoring also has to focus on biodiversity (with identification of macroinvertebrates to the species level). Furthermore, it is essential to enlarge these monitoring programs to the lentic waterbodies.

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