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The Freshwater Animal Diversity Assessment: an overview of the results

E. V. Balian · H. Segers · C. Lévèque · K. Martens

Abstract We present a summary of the results included in the different treatments in this volume. The diversity and distribution of vertebrates, insects, crustaceans, molluscs and a suite of minor phyla is compared and commented upon. Whereas the available data on vertebrates and some emblematic invertebrate groups such as Odonata (dragonflies and damselflies) allow for a credible assessment, data are deficient for many other groups. This is owing to knowledge gaps, both in geographical coverage of available data and/or lack of taxonomic information. These gaps need to be addressed urgently, either by liberating date from inaccessible repositories or by fostering taxonomic research. A similar effort is required to compile environmental and ecological information in order to enable cross-linking and analysis of these complementary data sets. Only in this way will it be possible to analyse information on freshwater biodiversity for sustainable management and conservation of the world's freshwater resources.

Keywords Biodiversity · Continental aquatic ecosystems · Endemicity · Biogeography · Freshwater · Global · Assessment

Guest editors: E. V. Balian, C. Lévêque, H. Segers & K. Martens
Freshwater Animal Diversity Assessment

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Introduction

The fifty-eight chapters in this compilation aim to present a comprehensive and up-to-date review of animal (plus one chapter on macrophyte) diversity and endemism in the continental waters of the world. The treatises are diverse, and this is a consequence of the specific features of the different taxa they deal with. Nevertheless, owing to the standard approach all experts agreed to follow, it has, for the first time, become possible to compare patterns in the biodiversity of groups as diverse as nematodes, dragonflies and freshwater turtles. Clearly, one can imagine numerous approaches to study these data, and an in-depth analysis will be presented elsewhere. Here, we restrict ourselves to presenting a summary overview of the results.

The present overview focuses on species diversity and endemism. Data on the genus level are available and presented for all taxa except molluscs.

An overview of freshwater animal diversity

When we calculate the total number of described freshwater animal species, we obtain a total of 125,531 species (Tables 1, 2; plus one micrognathozoan) or approximately 126,000 species. This figure, obviously, represents present knowledge and significantly underestimates real diversity. Most authors, especially those dealing with less emblematic groups, point out that significant fractions of species remain to be discovered, and/or caution that cryptic diversity, the importance of which we can only speculate about, remains concealed because of the almost exclusive morphological approach to taxonomy. The record of 126,000 species represents 9.5% of the total number of animal species recognised globally (i.e., 1,324,000 species: UNEP, 2002). If it is taken into account that freshwaters (lakes, rivers, groundwater, etc.) take up only about 0.01% of the total surface of the globe, then it becomes evident that a disproportional large fraction of the world's total biodiversity resides in freshwater ecosystems.

The majority of the 126,000 freshwater animal species are insects (60.4%), 14.5% are vertebrates, 10% are crustaceans. Arachnids and molluscs represent 5 and 4% of the total, respectively. The remainder belong to Rotifera (1.6%), Annelida (1.4%) Nematoda (1.4%), Platyhelminthes (Turbellaria: 1%), and a suite of minor groups such as Collembola (the estimate of this taxon is based on a restricted subsample of species, see Deharveng et al., 2008, present volume) and some groups that are predominantly marine (e.g., Bryozoa, Porifera). On a regional scale, the Palaearctic appears to be the most speciose for most taxa, except for insects and vertebrates. The record for insects is fairly similar in the Palaearctic, the Oriental and the Neotropical regions, whereas vertebrates are most diverse in the Neotropical, followed by the Afrotropical, and Oriental regions.

Of freshwater macrophytes, there are 2,614 species distributed over 412 genera. This amounts to ca. 1% of the total number of vascular plants known to date (270,000: Chambers et al., 2008, present volume). This constitutes a considerable fraction, taking into account that macrophytes are primarily terrestrial. On the other hand, macrophytes play a key role in structuring freshwater ecosystems, as they provide habitat and food to many organisms. Macrophyte species diversity is highest (ca. 1,000 species) in the Neotropics, intermediate (ca. 600 species) in the Oriental, Afrotropical, and Nearctic, and relatively low (ca. 400–500 species) in the Australasian and the Palaearctic regions.

The present assessment of freshwater diversity is incomplete. Our focus is on animal taxa, and only vascular plants, of all other kingdoms, are also included. Micro-organisms such as bacteria (s.l.), viruses, Protozoa, Fungi, and algae are not treated although these groups clearly are as significant to freshwater ecology and diversity as the taxa here considered. Most of these groups, with the exception

Table 1 Total species diversity of the main groups of freshwater animals, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Other phyla	3,675	1,672	1,188	1,337	1,205	950	181	113	6,109
Annelids	870	350	186	338	242	210	10	10	1,761
Molluscs	1,848	936	483	759	756	557	171	0	4,998
Crustaceans	4,499	1,755	1,536	1,925	1,968	1,225	125	33	11,990
Arachnids	1,703	1,069	801	1,330	569	708	5	2	6,149
Collembolans	338	49	6	28	34	6	3	1	414
Insects[a]	1,5190	9,410	8,594	14,428	13,912	7,510	577	14	75,874
Vertebrates[b]	2,193	1,831	3,995	6,041	3,674	694	8	1	18,235
Total	30,316	17,072	16,789	26,186	22,360	11,860	1,080	174	125,530

[a] The distribution of species by zoogeographic regions is incomplete for several families of Dipterans; as a result, the sum of the regional species numbers is lower than the number of genera known in the world (See chapter on Diptera families excluding Culicidae, Tipulidae, Chironomidae and Simulidae)

[b] Strictly freshwater fish species only are included (there are an additional ~2,300 brackish waters species)

Table 2 Total genus diversity of the main groups of freshwater animals, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Other phyla	573	372	286	300	284	205	76	42	778
Annelids	190	121	78	109	90	77	4	11	354
Molluscs[a]	137	351	117	226	150	43	2	0	1,026
Crustaceans	634	294	288	424	381	325	76	25	1,533
Arachnids	152	148	171	120	102	139	5	2	456
Collembolans	71	22	5	15	10	3	2	1	78
Insects[b]	1,366	1,160	871	1,269	1,159	909	132	10	4,395
Vertebrates[c]	497	426	590	974	626	183	6	1	2,768
Total	3,620	2,894	2,406	3,437	2,802	1,884	303	92	11,388

[a] Gastropoda genera are not included

[b] The distribution of genera by zoogeographic regions is incomplete for several families of Dipterans; as a result, the sum of the regional genus numbers is lower than the number of genera known in the world (See chapter on Diptera families excluding Culicidae, Tipulidae, Chironomidae and Simulidae)

[c] Strictly freshwater fish genus number is estimated at around 2,000 (there are an additional $\sim$500 brackish waters genera)

of algae and cyanobacteria, are dramatically understudied in aquatic biodiversity. As the key role of micro-organisms in ecosystem functioning and health is becoming more and more obvious, it is to be hoped that future assessments of micro-organismal diversity in freshwaters will complete the picture of freshwater biodiversity. Estimates on some groups are available, for example, there are 3,047 species on record for aquatic Fungi, 2,000 of which are probably restricted to freshwater (Shearer et al., 2007), and 2,392 species of freshwater protozoans (Finlay & Esteban, 1998).

Problems and knowledge gaps: state of the art

As noted above, the Palaearctic region has the highest number of species on record, for all taxa except vertebrates. For most groups, this remarkable result is very likely not factual, as indicated by many experts. The purported overwhelming biodiversity of the Palaearctic probably results from the fact that most taxonomic expertise and research efforts are centred in this region. Similarly, several authors highlight the lack of data from the Afrotropical and Oriental realms (e.g. Central Africa, parts of South America and Southeast Asia) The geographical gaps in knowledge are often linked to the extent (or limitation) of taxonomic expertise, which is greatly unequal from one group to another. On the other hand, there are several groups for which the current, Holarctic-centred distribution of species richness is suspected to be accurate: amphipods are typical of cool temperate climates and are notably rare in the tropics. Ephemeroptera or Plecoptera are predominantly Palaearctic and also this is congruent with the environmental preferences of these groups.

Similarly, a lack of knowledge on autecology of many species makes it difficult to decide whether a taxon is a true freshwater species or not, and hence whether they are to be included in the count. Such is the case for springtails, many water beetles and rotifers, amongst others. The current estimate for Collembola is based on the subset of species for which ecological information exists. It is likely that this number is an underestimate of the global number of freshwater-dependent springtails. In rotifers the problem is especially acute for bdelloids, often semi-terrestrial, many of which are known from single records only.

Diversity and distribution of vertebrates are clearly better documented than for other groups and even though it can be seen that new species of freshwater fish or even amphibians are still being described regularly, experts of all vertebrate groups are able to supply a fairly reliable estimate of the true number of extant species. Molluscs and crustaceans are generally also quite well documented, despite some geographical gaps in tropical areas. For insects, the situation is very different from one group to the next. The emblematic dragonflies are exemplary of an

extensively studied group, and the current estimate of ca. 7,000 species can be considered reliable. Heteroptera and Culicidae (Diptera) also seem well documented. On the other hand, the knowledge and taxonomic expertise available for most of the numerous dipteran families vary a lot depending on the group, and it is clear that our current estimate of their diversity should be interpreted with care.

Amongst the least known groups are some phyla of primitive invertebrates such as Platyhelminthes/Turbellaria, Gastrotricha or Nematoda, to name a few, for which taxonomic knowledge and available data are critically limited. Problems relate to data mass, reliability and repeatability: unique, unvouchered or plainly dubious records are common in these little-studied groups. In addition, some of these taxa are often primarily marine or terrestrial and most of the available knowledge therefore concerns these habitats. Nematodes, for example, are likely to be the least known of all metazoan phyla. Experts currently estimate that the total diversity of extant nematodes stands at about one million species, 97% of which are undescribed (Hugot et al., 2001). As freshwater nematodes are relatively poorly studied when compared to marine or terrestrial ones, and as they represent only 7% (1,800 species) of the total number of described nematode species (27,000 species), the true diversity of freshwater nematodes is likely to be one or two orders of magnitude higher.

First results of the Freshwater Animal Diversity Assessment

In the following sections we summarise the information on species diversity and endemicity for five major groups above the level of the different chapters: vertebrates, insects, crustaceans, molluscs and a collection of several primitive phyla. Further, in-depth analyses on the FADA data will be presented elsewhere. All information and data have been extracted from the different contributions included in this special issue.

Vertebrates

The total number of freshwater vertebrate species, including water birds but excluding brackish fish species, is 18,235 species (Tables 3, 4). This represents 35% of all described vertebrates (52,000 species). Of these, a majority (69%) are fishes, followed by amphibians (24%). Considering that the total global number of fish species is presently estimated at ca. 29,000 species (Lévêque et al., 2008, present volume), this means that nearly 50% of all fish species inhabit fresh and brackish waters (15,062 species, 12,470 of which are strictly freshwater). Freshwater habitats support 73% of all amphibian species; other groups are less represented in freshwaters. Freshwater vertebrates are most diverse in the Neotropical region, followed by the Oriental and the Afrotropical regions, and this holds for both generic as well as species diversity (Fig. 1). The Palaearctic is more speciose than the Nearctic, but this holds for fishes and birds only; amphibians, reptiles and mammals are more diverse in the Nearctic. Australasia stands out by its relatively low vertebrate diversity, especially of fishes (Tables 3, 4).

The highest number of vertebrate endemics is found in the Neotropics, and, again, regards mostly fishes. Here, the Amazonian province is an endemicity hotspot for fishes: 2,072 of the 2,416 species recorded from the region are endemic. The Afrotropical ichthyofauna is notorious for the presence of several endemic species-flocks in a number of ancient lakes, complemented by high rates of endemicity in certain invertebrate groups. For birds, amphibians and reptiles, endemicity is highest in the Afrotropical region. The Oriental region is richest in endemic turtles, which also have an endemicity hotspot in the eastern Nearctic. Most species of mammals, amphibians and reptiles are endemic to a single continent or zoogeographical region; hence their diversity hotspots coincide with endemicity hotspots, which, for mammals, are the Neotropical and Afrotropical regions.

On a subregional scale, the island fauna's are notable as centres of endemicity for birds and amphibians. The Malagasy example is significant by its endemicity rates of 90–100% for fishes, amphibians and birds.

Insecta

Diptera, Coleoptera and Trichoptera are the major representatives of freshwater insects with 43, 18 and

Table 3 Species diversity of the main groups of freshwater vertebrates, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Amphibia	160	203	828	1,698	1,062	301	0	0	4,294
Crocodilians	3	2	3	9	8	4	0	0	24
Lizards	0	0	9	22	28	14	2	0	73
Snakes	6	22	19	39	64	7			153
Turtle	8	55	25	65	73	34			260
Fish (FW only)	1,844	1,411	2,938	4,035	2,345	261			12,740
Mammals	18	22	35	28	18	11	0	0	124
Aves	154	116	138	145	76	62	6	1	567
Total	2,193	1,831	3,995	6,041	3,674	694	8	1	18,235

Table 4 Genus diversity of the main groups of freshwater vertebrates, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Amphibia	26	27	89	127	71	20	0	0	348
Crocodilians	2	2	2	4	4	1	0	0	8
Lizards	0	0	4	7	7	4	2	0	19
Snakes	5	6	8	13	12	7			44
Turtle	6	16	6	16	34	8			86
Fish (FW only)	380	298	390	705	440	94			2,000
Mammals	10	15	18	15	10	7	0	0	65
Aves	68	62	73	87	48	42	4	1	198
Total	497	426	590	974	626	183	6	1	2,768

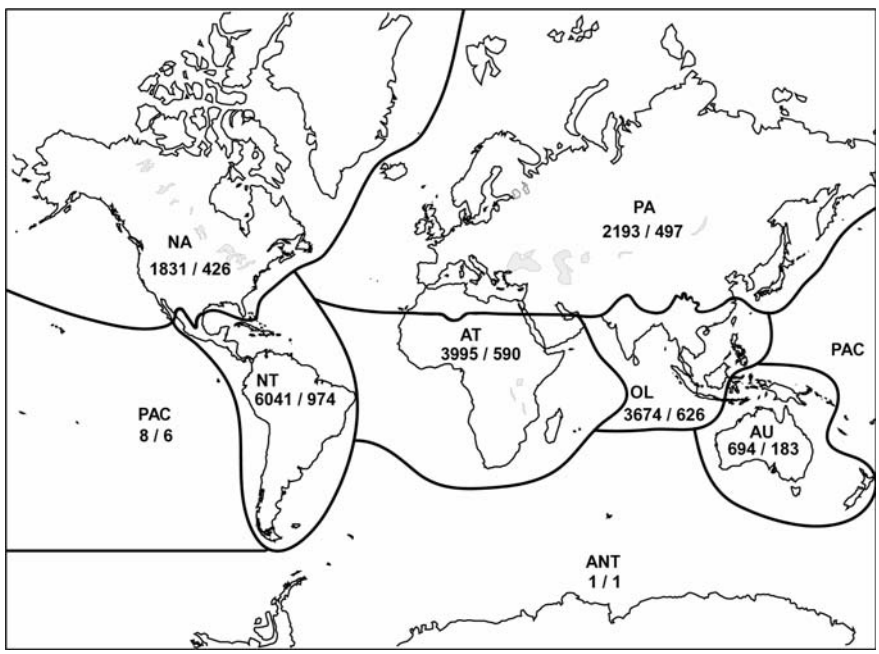

Fig. 1 Distribution of freshwater vertebrate species and genera, by zoogeographic regions (number of species/number of genera). Numbers include strictly freshwater fish (not brackish), amphibians, mammals, reptiles and water birds as defined in each specific contribution

15%, respectively, of the total of almost 76,000 freshwater insect species (Tables 5, 6). These numbers include some families of Diptera, such as Tabinidae, which are not addressed in specific chapters and whose diversity is estimated at around 5,000 species. Other important taxa are Heteroptera (6%), Plecoptera (5%), Odonata (7%) and Ephemeroptera (4%). In insects, there is a remarkable discrepancy between species- and genus-level diversity: Diptera account for 43% of total insect species-level diversity, against only 22% for genera. On the other hand, in Ephemeroptera, Odonata and Heteroptera, the genus-level diversity contributes about twice that of species-level diversity to total insect diversity.

The highest diversity of freshwater insects is recorded from the Palaearctic (20%), closely followed by the Neotropical (18.5%) and the Oriental realms (18.3%) (Fig. 2). The Afrotropical and Australasian regions represent 12 and 10%, respectively, of extant insect species diversity. As several experts did not treat the Pacific Oceanic Islands and Antarctic region separately, we here refrain from further commenting on the insect diversity of these regions.

The data on insect diversity should be interpreted with caution, as many experts report a strong sampling and study bias. Especially, the Holarctic insect fauna is notoriously better studied than that of the Neotropical, Afrotropical and Oriental regions, and this for most groups. This bias is less pronounced in two emblematic insect groups, namely butterflies and moths (Lepidoptera) and dragonflies (Odonata), and is reflected in the fact that for these groups, the Holarctic is not the most diverse region: Lepidoptera species diversity is highest in the Neotropical (30%), Australasian (23%) and Oriental (23%) realms, whereas for Odonata the Neotropical and Oriental regions have the most diverse fauna. In contrast, the fact that Hymenoptera are most diverse in the Holarctic region (Table 5) is most likely owing to a study bias. For insects, there are few species that occur in more than one region; hence hotspots of endemicity and diversity largely coincide.

Table 5 Species diversity of insect orders, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Coleoptera	3,346	1,419	2,507	2,693	2,189	1,334			13,514
Diptera other families[a]	2,458	2,045	2,623	933	909	945	143	2	13,454
Diptera—Chironomidae	1,231	1,092	618	406	359	471	155	9	4,147
Diptera—Culicidae	492	178	1,069	795	1,061	764			3,492
Diptera—Simulidae	699	256	355	214	321	195	55	2	2,000
Diptera—Tabanidae[b]									5,000
Diptera—Tipulidae	1,280	573	805	339	925	385			4,188
Ephemeroptera	787	650	607	390	390	219			3,043
Heteroptera	496	424	1,289	799	1,103	654	37		4,801
Hymenoptera	57	53	17	1	28	8	9		147
Lepidoptera	81	49	219	64	169	170	9		737
Mecoptera			3			5			8
Megaloptera-Neuroptera	78	99	52	18	144	50	1	0	446
Odonata	560	451	1,636	889	1,665	870	168	1	5,680
Orthoptera	9	10	54	14	98	5			188
Plecoptera	1,156	650	474	95	828	295			3,497
Trichoptera	2,370	1,461	2,100	944	3,723	1,140			11,532
Total	15,190	9,410	14,428	8,594	13,912	7,510	577	14	75,874

[a] The distribution of species by zoogeographic regions is incomplete for several families of Dipterans; as a result, the sum of the regional species numbers is lower than the number of species known in the world (See chapter on Diptera families excluding Culicidae, Tipulidae, Chironomidae and Simulidae)

[b] Estimated

Table 6 Genus diversity of insect orders, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Coleoptera	209	152	175	204	167	138			710
Diptera other families[a]	227	158	114	198	107	115	29	2	457
Diptera—Chironomidae	181	211	104	154	105	116	29	6	339
Diptera—Culicidae	19	13	15	24	25	22			42
Diptera—Simulidae	12	13	2	10	1	2	1	1	26
Diptera—Tipulidae	45	38	23	36	45	30			115
Ephemeroptera	77	94	93	84	78				405
Heteroptera	60	67	96	105	123	87	16		553
Hymenoptera	29	33	1	10	13	6	5		51
Lepidoptera	12	17	11	21	14	21	4		53
Mecoptera				1		2			2
Megaloptera-Neuroptera	14	10	5	11	16	10	1	0	45
Odonata	137	89	132	186	235	169	47	1	642
Orthoptera	7	6	5	20	20	2			50
Plecoptera	108	102	8	57	41	46			286
Trichoptera	229	157	87	148	169	143			619
Total	1,366	1,160	871	1,269	1,159	909	132	10	4,395

[a] The distribution of genera by zoogeographic regions was not complete for several families of Dipterans, (See chapter on Diptera families excluding Culicidae, Tipulidae, Chironomidae et Simulidae)

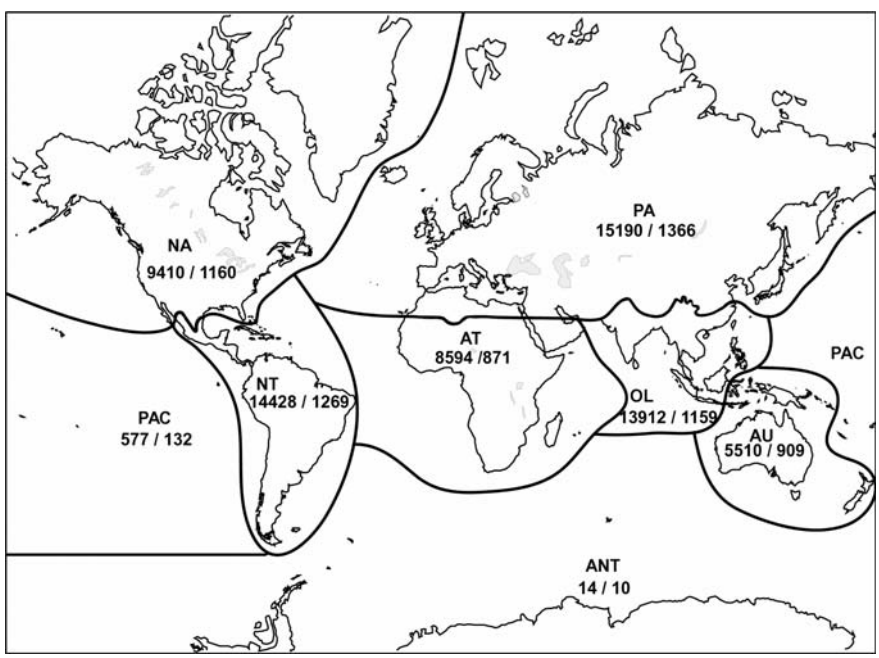

Fig. 2 Distribution of total insect species and genus diversity by zoogeographic regions (number of species/number of genera). Numbers do not include some dipteran families (i.e. Tabanidae) that are not addressed in the specific contributions

Crustacea

The different chapters dealing with freshwater crustaceans report on a total of 11,990 described species, distributed over 1,533 genera (Tables 7, 8). This constitutes 30% of the total known diversity of crustaceans, which is estimated at about 40,000 species (Groombridge & Jenkins, 2002). Amongst

Table 8 Genus diversity of crustaceans, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Amphipoda	185	23	17	35	10	34	9		293
Branchiopoda	28	20	14	18	14	12	2	1	43
Branchiura	1	1	3	3	1	2	1	0	4
Cladocera	60	52	46	50	44	52	21	7	95
Copepoda	134	87	60	104	79	50	15	14	257
Cumacea & Tanaidacea	10	2		2		2	1		14
Isopoda	45	18	8	42	11	50	4		194
Mysidacea	15	7	1	6	6	1	0	0	26
Ostracoda	87	57	73	55	46	57	4	3	189
Spelaeogriphacea	–	–	1	1	–	1	–		3
Syncarida	30	6	18	18	9	15	0	0	78
Thermosbaenacea	5	1	1	2	1	1	–		6
Aeglidae			1						*1*
Astacidea	6	11	1	6		9			33
Brachyura	14	4	27	65	139	24	13		238
Caridea	14	5	17	17	21	15	6	–	59
Decapoda	34	20	46	88	160	48	19	0	331
Total	634	294	288	424	381	325	76	25	1,533

Table 7 Species diversity of crustaceans, by zoogeographic region

	PA	NA	AT	NT	OL	AU	PAC	ANT	World
Amphipoda	1,315	236	56	127	17	107	10		1,866
Branchiopoda	175	93	81	61	47	75	2	1	508
Branchiura	8	18	40	33	16	3	1	0	113
Cladocera	245	189	134	186	107	158	33	12	620
Copepoda	1,204	347	405	561	381	205	29	17	2,814
Cumacea & Tanaidacea	20	2		2		3	1		25
Isopoda	475	130	22	109	31	134	5		942
Mysidacea	39	11	1	20	7	1	0	0	72
Ostracoda	702	298	455	275	199	176	5	3	1,936
Spelaeogriphacea	–	–	1	1	–	2	–		4
Syncarida	128	12	27	29	12	33	0	0	240
Thermosbaenacea	6	1	1	8	1	1	–		18
Aeglidae		63						63	
Astacidea	38	382	9	64		151			638
Brachyura	97	19	149	340	818	89	24		1,476
Caridea	47	17	92	109	349	87	25	–	655
Decapoda	182	418	313	513	1,167	327	49	0	2,832
Total	4,499	1,755	1,536	1,925	1,985	1,225	135	33	11,990

freshwater crustaceans, the most speciose taxa are the decapods (24%) and copepods (23%), closely followed by the ostracods and amphipods (both 16%). Branchiopods, Isopods and syncarids represent 9, 8 and 2%, respectively, of the total number of species. The remaining 2% is composed of representatives of

smaller groups: mainly Branchiura and Mysidacea, with a few species of Cumacea, Tanaidacea, Spelaeogriphacea and Thermosbaenacea.

Again, the region with the highest number of species is the Palaearctic (37%). Second and third are the Oriental and Neotropical regions (both ca. 16%). This holds for most crustacean taxa, except for Brachyura and Caridea decapods, which are most diverse in the Oriental region, and Astacidea, which exhibit a diversity and endemicity hotspot in the Nearctic, and which are absent from the Oriental region. Aeglidae (Anomura) crabs form an endemic family in the Afrotropical region. All other crustacean taxa (Copepoda, Ostracoda, Branchiopoda, Isopoda, Amphipoda, Syncaridea) are most diverse in the Palaearctic. As for insects, sampling and study gaps most likely account for this.

Remarkable endemic crustacean faunas occur in the ponto-caspian basin and in Lake Baïkal. These are identified as hot spots of richness and endemicity for several crustacean taxa, including amphipods, ostracods, copepods and branchiopods. In amphipods, there is a large group of endemic taxa inhabiting subterranean habitats in the west Palaearctic, whereas crayfish exhibit a different pattern of endemicity, with a centre in the southeast of the Nearctic region, notably in the south of the Appalachean range.

Mollusca

The ca. 5,000 species of freshwater molluscs represent 4% of the total number of freshwater animal species, and account for only about 7% of the global total of described mollusc species, estimated at about 80,000 species (Groombridge & Jenkins, 2002). Eighty percent of the freshwater molluscs are gastropods, whereas 20% are bivalves. Gastropods and bivalves attain their highest diversity in the Palaearctic and Nearctic regions, respectively. However, the bivalve Unionidae family, of great economic importance, is most diverse in the Oriental region.

Freshwater gastropod faunas of underground systems, springs and small rivers are particularly rich, both in terms of species diversity and endemicity. Further noteworthy habitats are ancient oligotrophic lakes (e.g. Baikal, Ohrid, Tanganyika), which are key hotspots of gastropod diversity. The lower reaches of some river basins (e.g. Congo, Mekong, Mobile Bay) are also identified as areas of high species richness.

Minor invertebrate phyla

The most speciose amongst the "minor" invertebrate phyla are Rotifera (1,948 species), Nematoda (1,808 species), Annelidae (1,761 species) and Turbellaria (Platyhelminthes: 1,297 species). Gastrotricha, Nematomorpha and Porifera are less species rich in freshwater habitats (200–300 sp.), although they are very successful in marine environments. The same holds for Bryozoa and Tardigrada (60–80 species). The least diverse groups in freshwater are Nemertea (22 species) and Cnidaria (18 species). Rotifera, Nematomorpha and Annelida-Hirudinea are mainly freshwater, but there are also generally species-rich groups like Cnidaria (7,000+ species), or Annelida-Polychaeta (9,000+ species) that are, however, poorly represented in freshwater (Fig. 3).

All of these groups are generally ill-studied, and this was clearly emphasised by all experts. Nevertheless, Lake Baikal appears to have been studied more intensively for most of these groups and is identified as a hotspot of endemicity. Further generalisations are hard to make considering the lack of data, although the analysis of rotifer diversity and endemism reveals some intriguing patterns (Segers & De Smet, 2007; Segers, 2008, present volume).

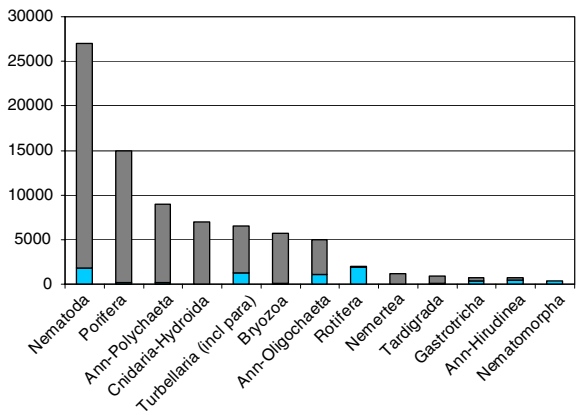

Fig. 3 species diversity in freshwater compared to total number of described species

Comparison with marine and terrestrial species diversity

As early evolution of all major animal phyla took place in the sea, it is not surprising that marine systems show higher diversity at the phylum and class level than terrestrial or freshwater systems. Of the total 33 metazoan phyla, 31 are found in the sea, with 11 being exclusively marine; whereas 17 phyla are present in freshwater and 12 on land (only 2 phyla, freshwater Micrognathozoa and terrestrial Onychophora have no marine species). At the species level, the diversity of terrestrial ecosystems, with more than 1.5 million species, largely exceeds the 280,000 species of marine organisms currently known. At habitat levels, the most diverse marine habitats—coral reefs—are far less diverse in terms of species number than the moist tropical forests that are often taken as their terrestrial counterparts.

Conclusion

A clear result of our survey is that increased sampling efforts are needed to address the obvious gaps, both geographical and taxonomical, the current assessment of freshwater biodiversity reveals. Especially in terms of richness and endemicity, hot spots are often located in less-studied areas of the Oriental, the Neotropical and the Afrotropical regions. The situation is especially critical for the least-known groups such as Nematoda. One possible cost-effective way to improve this situation is to make better use of the existing knowledge, shelved in museum collections, local laboratories or in scientists' drawers. This ongoing task is being carried out by several international initiatives including GBIF and the IUCN Freshwater Biodiversity Assessment Programme. However, additional surveys are also needed and will require a new generation of taxonomic experts and increased financial means.

This global assessment of freshwater species diversity and distribution is thus but a first step in the process of compiling and upgrading our knowledge on freshwater biodiversity. The regional or global-scale approach used here allows for the identification of knowledge gaps and is critical to come to a better understanding of evolutionary patterns in freshwater diversity and endemicity, in particular, for less-known invertebrate taxa.

In order to complement the present database on diversity and endemicity, a similar effort focussing on environmental information, from geographical to sociological, will be needed. It is clear that the results presented in this volume, apart of their inherent scientific value, should be interpreted in a broader ecological and evolutionary context, if they are to play a role in the development or improvement of sustainable management and conservation of freshwater resources. Indeed, the challenges society is confronted with in the face of global change and increased human utilisation of natural resources, are daunting and can only be dealt with successfully on the condition that sufficient and credible scientific knowledge is made available as a basis for action, in addition to the political will to implement the necessary measures (Dudgeon et al., 2006).

To facilitate usage and analysis of the data collected during the present Freshwater Animal Diversity Assessment (FADA) project, an on-line database is presently being developed. This resource, which can be consulted on http://www.FADA.biodiversity.be, will offer additional services including extraction of name lists, visualisation of geographical (GIS) records in an interactive environment and link to other datasets containing information of freshwater systems. All data will be made freely and universally accessible through the Internet. For this, FADA is developing links with global initiatives in the field, like the Global Biodiversity Information Facility (GBIF), Catalogue of Life (CoL), SpeciesBase and Encyclopedia of Life.

References

Chambers, P. A., P. Lacoul, K. J. Murphy & S. M. Thomaz, 2008. Global diversity of aquatic macrophytes in freshwaters. In Balian, E. V., C. Lévêque, H. Segers & K. Martens (eds), Freshwater Animal Diversity Assessment, Hydrobiologia, present volume. doi: 10.1007/s10750-007-9154-6.

Deharveng, L., C. A. D'Haese & A. Bedos, 2008. Global diversity of springtails (Collembola; Hexapoda) in freshwater. In Balian, E. V., C. Lévêque, H. Segers & K. Martens (eds), Freshwater Animal Diversity Assessment, Hydrobiologia, present volume. doi: 10.1007/s10750-007-9116-z.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. -I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A.-H. Prieur-Richard, D. Soto, M. L. J. Stiassny & C. A. Sullivan, 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81: 163–182.

Finlay, B. J. & G. F. Esteban, 1998. Freshwater protozoa: biodiversity and ecological function. Biodiversity and Conservation 7: 1163–1186.

Groombridge, B. & M. Jenkins, 2002. World Atlas of Biodiversity: Earth's Living Resources in the 21st Century. University of California Press.

Hugot, J.-P., P. Baujard & S. Morand, 2001. Biodiversity in helminths and nematodes as a field of study: an overview. Nematology 3(3): 199–208.

Lévêque, C., T. Oberdorff, D. Paugy, M.L.J. Stiassny & P.A. Tedesco, 2008. Global diversity of fish (Pisces) in freshwater. In: Balian E. V., C. Lévêque, H. Segers & K. Martens (eds), Freshwater Animal Diversity Assessment, Hydrobiologia, present volume. doi:10.1007/s10750-007-9034-0.

Segers, H., 2008. Global diversity of rotifers (Phylum Rotifera) in freshwater. In Balian, E. V., C. Lévêque, H. Segers & K. Martens (eds), Freshwater Animal Diversity Assessment, Hydrobiologia, present volume. doi:10.1007/s10750-007-9003-7.

Segers, H. & W. H. De Smet, 2007. Diversity and Endemism in Rotifera: a review, and *Keratella* Bory de St Vincent. In W. Foissner (ed.), Protist diversity and geographic distribution. Biodiversity and Conservations. doi:10.1007/s10531-007-9262-7

Shearer, C. A., E. Descals, B. Kohlmeyer, J. Kohlmeyer, L. Marvanov, D. Padgett, D. Porter, H. A. Raja, J. P. Schmit, H. Thornton & H. Voglmayr, 2007. Fungal biodiversity in aquatic habitats. Biodiversity and Conservation 16, 49–67.

United Nations Environmental Programme, 2002. Global Environmental Outlook 3. Earthprint Ltd., Stevenage, Hertfordshire, England.