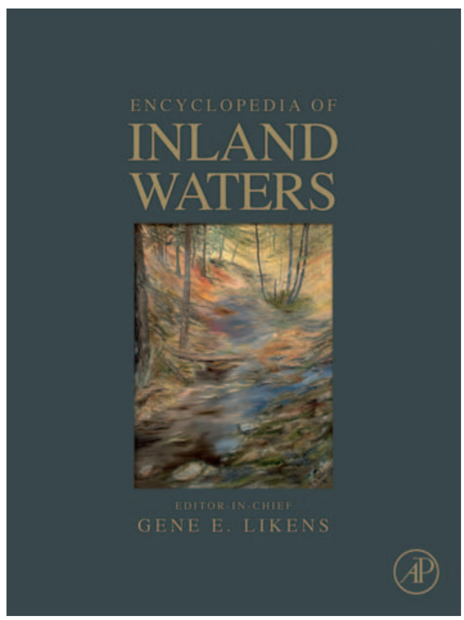

Tockner K, Uehlinger U, Robinson C T, Siber R, Tonolla D and Peter F D. (2009) European Rivers. In: Gene E. Likens, (Editor) Encyclopedia of Inland Waters. volume 3, pp. 366-377 Oxford: Elsevier.

European Rivers*

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Introduction

Rivers recognize no political boundaries. This is particularly true for Europe, which has more than 150 transboundary rivers. For example, the Danube is the 29th longest river globally, yet it flows through 18 countries and 10 ecoregions. Further, 8 of the 10 largest catchments in Europe are in the eastern plains of Russia and information on their present status is highly limited. Europe also has a long history in river training with most rivers being severely fragmented, channelized, and polluted. Recently, the European Union launched an ambitious program called the Water Framework Directive (WFD) that requires a catchment management plan for all major European rivers for achieving 'good ecological status' by 2015. In this chapter we provide a comprehensive overview of all major European catchments (Figure 1), starting with the biogeographic setting with an emphasis on physiography, hydrology, ecology/biodiversity, and human impacts.

Biogeographic Setting

Europe forms the northwestern physiographic constituent of the larger landmass known as Eurasia. Europe covers an area of ~11.2 million km^2 that includes the European part of Russia, parts of Kazakhstan (Ural River Basin), the Caucasus, Armenia, Cyprus, and Turkey (Figure 1). Armenia and Cyprus are considered as transcontinental countries; and Turkey is included because of political and cultural reasons. The average altitude of Europe is 300 m asl compared with 600 m asl for North America and 1000 m asl for Asia. Only 7% of Europe is above 1000 m asl. Europe has a highly extensive and deeply penetrating network of water bodies. Its 117 000 km convoluted coastline facilitated easy access to the interior, and it is this feature that contributed to the rapid development of its southern shores along the Mediterranean Sea.

Cultural and Socioeconomic Setting

There are distinct cultural, demographic, socioeconomic, and political gradients across Europe. Today's human population is 780 million with an average population density of 69 people per km^2. At the catchment scale, the population density ranges from <2 people per km^2 (Pechora Basin) to 313 people per km^2 (Rhine Basin). The annual Gross Domestic Product (GDP; US$/person) ranges over two-orders-of-magnitude, from 600$ (Dniester Basin in Moldova) to 65 000$ (Aare Basin in Switzerland). Human life expectancy ranges from 61 (Ural Basin) to 80 years (river basins in Iceland, Italy, Spain, Sweden, and Switzerland). More than 100 languages are spoken across Europe; with the greatest number (27 languages) spoken in the Caucasus region.

Hydrogeomorphic and Human Legacies

Last Glacial Maximum and Holocene Distribution of River Networks

Many European rivers have substantially changed in length, catchment area and flow direction over the past 20 000 years. For instance, at the onset of the last glacial maximum about 20 000 year BP, a paleo-river known as the 'Channel River' (located between the present France and Britain) extended across the raised continental margin. Most major rivers in northwestern Europe (e.g., Rhine, Meuse, Solent, and Thames) contributed to its waters. In addition, damming by the Fennoscandian ice sheet caused the development of southward-flowing melt-water valleys and ice-margin spillways running westward. These spillways collected proglacial waters from rivers east of the Elbe basin that drained into the Channel River. The Channel River was the largest river system that drained the European continent, thereby affecting the hydrology of much of Europe as well as that of coastal ecosystems.

The long-term evolution of European rivers during the Holocene can be placed into four regional categories:

1. Rivers recently developed on areas formerly covered by ice sheets and affected by isostatic uplift;
2. Rivers of the former periglacial zone partly influenced by ice sheets;
3. Rivers of the former periglacial zone with lower reaches influenced by eustatic sea-level changes; and
4. Rivers of southern Europe within the region of former cold steppe and forest-steppe.

* This text is a shortened version of the chapter 'Introduction to European Rivers' in Tockner K, Uehlinger U and Robinson CT (eds) *Rivers of Europe*. San Diego: Elsevier/Academic Press (2008).

Encyclopedia of Inland Waters (2009), vol. 3, pp. 366-377

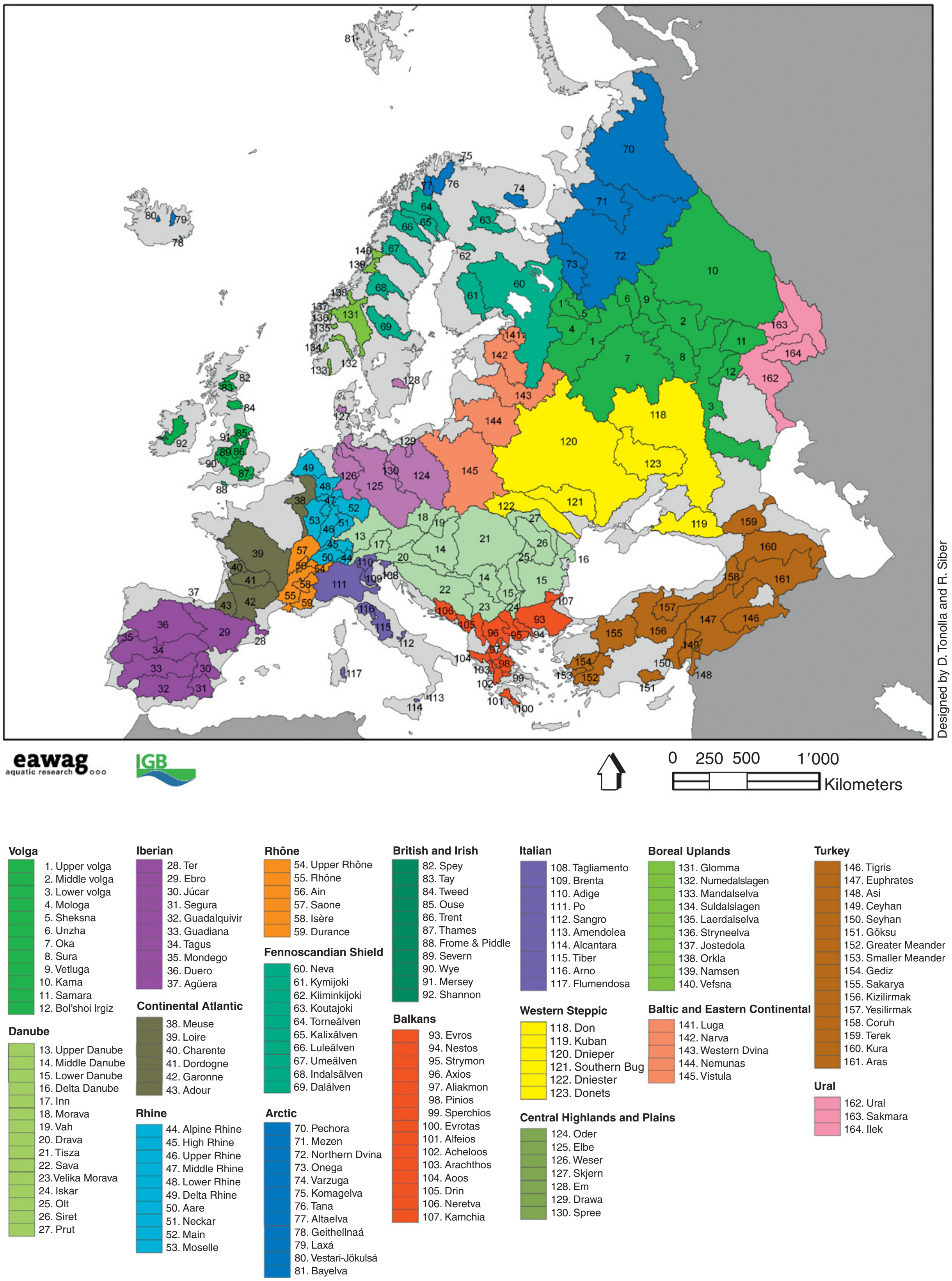

Figure 1 Spatial distribution of European catchments from 12 different geographic regions and subcatchments from the Volga, Danube, Rhine, Rhone, and Ural Rivers. Source – Tockner K, Uehlinger U, and Robinson CT (eds), *Rivers of Europe.* San Diego: Elsevier/ Academic Press (2008).

Central European rivers show 3–6 separate alluvial fills that correlate well with stages of glacial advance and treeline lowering in the Alps. In the European lowlands, 2–3 fills are at times recorded, although major lateral channel shifts are more common as a consequence of fluctuations in discharge and sediment flux. In southern Europe, the tendency towards braiding has anthropogenic (deforestation and subsequent increases in sediment transport) and natural origins (higher flood frequency during the Little Ice Age, 1450–1850). In piedmont zones, the tendency towards braiding was repeated during cooler and moister stages. In the western Siberian river valleys, e.g., the Pechora and Mezen valleys, braided channels probably changed to a more meandering style after the retreat of permafrost and then towards braiding during permafrost advances.

Early and Recent Human Impacts of European Rivers

Deforestation and cultivation of soils were the main human activities that caused major changes in discharge and sediment transport. In southern and central Europe, distinct stages of sediment deposition have been recorded from the late Bronze Age and even more extensively in Roman times. General aggradation of European valley floors occurred in medieval times and is reflected in the rising of channel forms. Prior to the 11th century, river works were still primitive, consisting mostly of embankments built for flood control and land reclamation. There were two European centers of technological advance in river regulation during the medieval period. The Netherlands developed dredging technologies, designed floodgates, and built groynes and retaining walls. In Italy, land reclamation (‘*La bonifica*’) was common with most large rivers being partly channelized by 1900. The greatest single engineering effort in the nineteenth century was the regulation of the lower Tisza River, the largest tributary of the Danube River, where 12.5×10^6 ha of flood plain marsh were drained and the river course shortened by 340 km.

Today, European catchments are highly fragmented by >6000 large dams. Reservoirs behind these dams can store about 13% of the mean annual runoff of Europe. The highest number of dams occur in Spain (1196) and Turkey (625). Of the 20 largest European rivers, only the Pechora River in Russia, draining to the White Sea, is considered free-flowing. Of the 165 catchments included in this chapter, only 30 have free-flowing large rivers. Most of these free-flowing rivers are in northern Europe (Arctic and Fenno-Scandinavian Shield) or drain relatively small catchments (e.g., Amendolea in Italy, Frome and Piddle in Great Britain, and Sperchios in the Balkans.

Among the major factors influencing water quality and quantity at the catchment scale is the change in land use intensity. Around 60% of the combined catchment area of the 165 examined rivers has been transformed into cropland and urban area. The proportion of developed area exceeds 90% for Central European and Western Steppic Rivers (Table 1). Over 70% of the European population lives in urban areas and the total number of cities with a population >100 000 is >360.

Water Availability, Runoff, and Water Stress

Water availability, defined as the annual long-term average renewable water resource derived from natural discharge including consumptive water use, shows a large spatial variation among river basins. Annual water availability ranges from >1000 mm year^{-1} (western Norway, Britain’s west coast, southern Iceland) to <100 mm year^{-1} (parts of Spain, Sicily, large parts of the Ukraine, Southern Russia, large parts of Turkey). In most of Europe this reflects patterns of precipitation, whereas available water is transferred by rivers into more dry regions in other parts. Hungary, for example, attains most of its water from outside the country via the Danube and Tisza.

The total average runoff of European rivers is ~3100 km^3 year^{-1} for 11 million km^2 (8% of the world average). The 20 largest rivers (total area: 5.9 million km^2) contributes more than 1/3 to the total continental runoff (Table 1). The average annual specific runoff ranges from 68 mm year^{-1} (Asi River in southeast Turkey) to 1150 mm year^{-1} (River Tay in Scotland). High seasonality in runoff is typical for rivers in southern Europe and Turkey such as the Guadalquivir (Iberian peninsula) and Upper Euphrates, and for Boreal and Arctic rivers such as the Glomma (Norway) and Pechora (Russia). Low runoff variability is characteristic for central European rivers (e.g., Elbe) and Steppic rivers (e.g., Dnieper) (Figure 2).

A recent assessment of Europe’s environment by the European Environmental Agency indicated that high levels of water stress, both quantity and quality, exist in many areas throughout Europe and identified several significant ongoing pressures on water resources at the European scale. Total water withdrawal has generally increased in the last decades. By 1995, a total of ~476 km^3 water was being withdrawn

Table 1 The 20 largest catchments in Europe (including Turkey and the Caucasus)

	Area (*km²*)	*Discharge* (*km³ year⁻¹*)	*Relief* [a] (m)	*Population*[b] (*people per km²*)	*Cropland and urban*[c](*%*)	*GDP*[d] (*$ year⁻¹*)	*Protected*[e] (*%*)	*Fish* (*native*)	*Fish* (*nonnative*)
Volga	1 431 296	261.8	1536	45	58.5	2340	5.7	66	18
Danube	801 093	202.4	3651	102	65.3	7007	2.4	99	32
Dnieper	512 293	42.6	411	64	94.1	1388	3.2	29	5
Don	427 495	25.5	804	46	90.6	1508	3.2	64	7
N Dvina	354 298	107.5	422	5	10.2	2873	5.2	34	7
Pechora	334 367	150.9	1604	2	0.2	2928	12.2	34	3
Neva	281 877	79.1	390	17	25.9	6181	5.1	43	1
Ural	252 848	10.6	1094	15	61.6	2205	0.9	55	1
Kura	193 802	17.1	4816	74	58.6	1267	5.5	33	8
Vistula	192 980	32.9	2316	127	90.8	3789	2.6	54	18
Rhine	185 263	73.0	3786	313	76.4	31 822	0.4	46	25
Elbe	148 242	22.4	1456	164	83.6	14 068	4.3	38	8
Euphrates[f]	121 554	31.6	3557	57	43.0	1535	0.0	45	1
Oder	120 274	17.2	1468	132	91.3	5583	1.5	42	11
Loire	115 980	26.4	1704	67	88.1	22 196	1.5	32	26
Nemunas	98 757	17.0	354	52	93.0	2680	5.2	46	4
Rhône	98 556	53.8	4452	105	63.8	24 462	8.9	50	21
Duero	97 406	17.3	2359	37	75.6	15 058	1.2	18	13
Ebro	85 823	13.6	3104	34	63.4	19 587	1.5	29	19
W Dvina	83 746	13.6	307	32	87.6	2598	8.0	39	2

Relief: Calculated difference between highest and lowest point (resolution: 1000×1000 m) in catchment; Human population density: People per km^2; GDP: Annual Gross Domestic Product per person and year; Protected: National parks, Ramsar sites, nature reserves, and other nationally protected areas.

[a]http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html.

[b]http://gis.ekoi.lt/gis/.

[c]http://edcsns%2017.cr.usgs.gov/glcc/tablamberteuraseur.html.

[d]ESRI.

[e]http://sea.unep-wcmc.org/wdbpa/.

[f]only Turkey.

annually; 45% of this water is used for industry, 41% for agriculture, and 14% for domestic needs. There is a large difference between countries in how much and for what purpose water is withdrawn. Industrial uses dominate water withdrawals in most of Europe, whereas irrigation use is highest in southern and southeastern countries with low precipitation. Total withdrawal per catchment ranges from nearly zero (in the less populated areas of subpolar Scandinavia and Russia) to >400 mm year^{-1} (in densely populated urban areas). In total, annual water withdrawal in Europe (excluding Turkey) is projected to rise from 415 km^3 today to ~660 km^3 by 2070. Although the annual total withdrawal in Western Europe will decrease from 236 km^3 to 190 km^3, it will increase considerably in eastern Europe from 180 to 470 km^3. In southeastern Europe, growth in water demand is complemented by reductions in water availability owing to climate change, which eventually will increase water stress. Overall, severe water stress is predicted to increase from 19% today to 34–36% by 2070. Since 1970, the total annual discharge of Balkan rivers already decreased by up to 70%, mainly due to water abstraction for irrigation.

Riverine Flood Plains

Owing to the development of agriculture in alluvial pains, the conversion of rivers for navigation, and the protection of settlements, flood plains have been ‘trained’ for centuries. Today, about 50% of the total European human population lives on former flood plains. As a consequence, ~50% of the original wetlands and up to 95% of riverine flood plains have been lost. In 45 European countries, 88% of the alluvial forests have disappeared from their potential range. The Seine River (France) shows the highest impact of all European rivers with 99% of its former riparian flood plains lost. Of the former 26 000 km^2 flood plain area along the Danube and its major tributaries, ~20 000 km^2 have been isolated by levees and have thus become ‘functionally’ lost; meaning that the basic attributes that sustain flood plains such as regular flooding and morphological dynamics are missing. Switzerland has lost about 95% of its original flood plains over the last two centuries. The remaining flood plains included in the inventory of ‘flood plains of national importance’ are far from being pristine, being heavily influenced by water abstraction, gravel

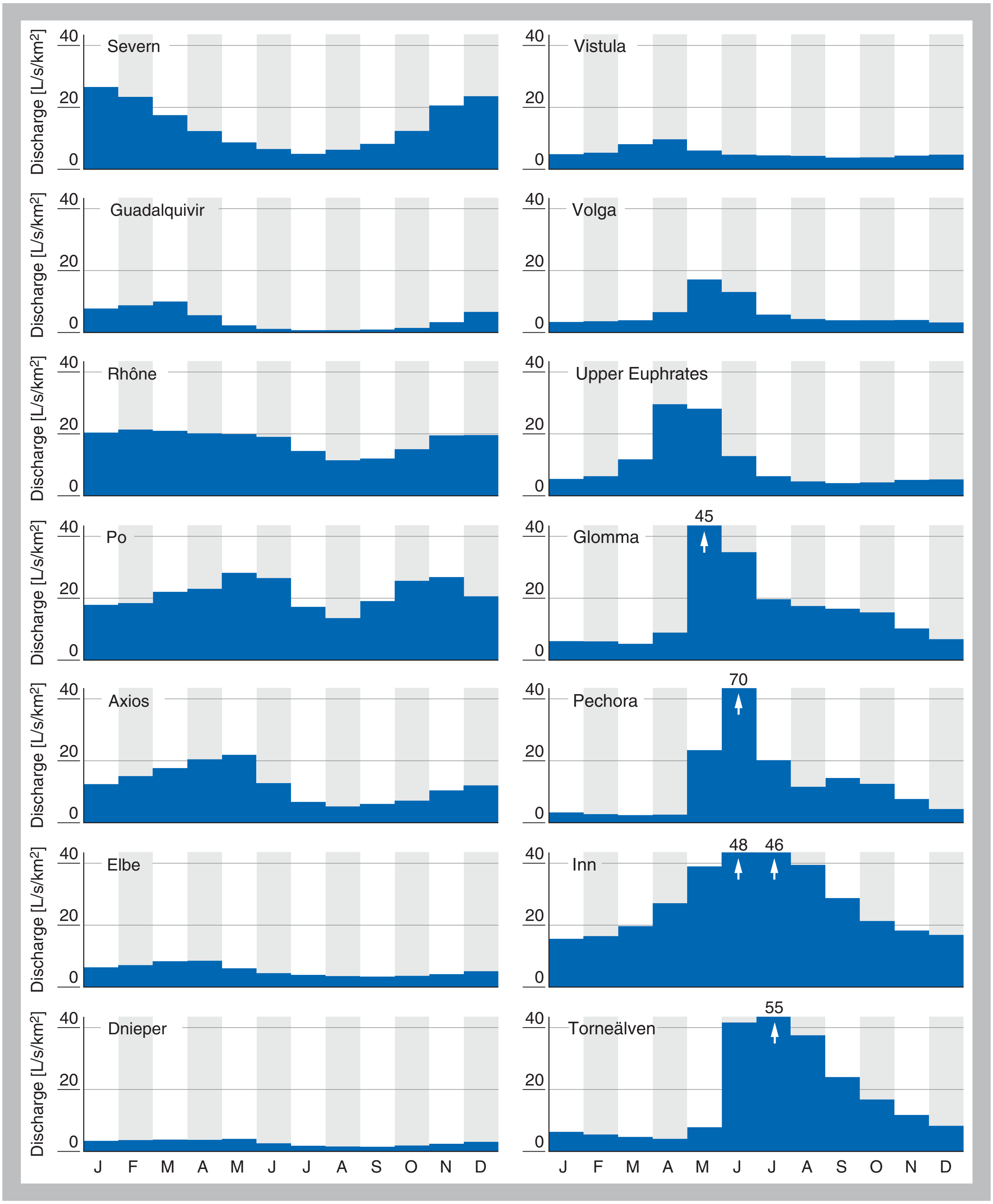

Figure 2 Seasonal distribution in catchment runoff ($l\ s^{-1}\ km^{-2}$) for selected rivers distributed across Europe. Runoff includes the difference between precipitation, evapotranspiration, and catchment topography. Data source: Global Water Runoff Data Center, GRDC, www.GRDC.bafg.de.

mining, and fragmentation. Today, the largest remaining flood plain fragment in Switzerland covers an area of only 3 km^2. Because most European flood plains are already 'cultivated,' even impacted systems that retain some natural functions, such as those along the Oder River (Poland/Germany), the Danube River, and eastern European river corridors (Figure 3), are extremely important to protect. This is especially true for the river corridors in Eastern Europe because of ever increasing pressures from development (gravel exploitation, damming, dredging for navigation, road constructions).

River Deltas

Deltas are integral features of many catchments, being important depositional landforms where the river mouth flows into an ocean, sea, or lake. The geometry, landform, and environment of deltas result from the accumulation of sediments added by the river and the reworking of these sediments by marine forces. Because many European rivers discharge into isolated and inland seas (Baltic, Black, and Mediterranean Seas), characterized by low tides and moderate wave powers, they can form extensive deltas (Table 2). The 35 major European deltas cover a total area of $\sim$90 000 km^2. Despite their ecological and socioeconomic importance, European deltas are among the least investigated aquatic ecosystems.

Deltas are highly productive environments and, as a consequence, they have been extensively transformed into cropland and urban areas. Today, the human density in European deltas is often much higher than in the respective upstream catchment (Tables 1 and 2), although the opposite pattern can be found such as for the Danube catchment and the tributaries to the White Sea. Deltas formed by the Pechora, the N. Dvina (despite having a large seaport, Archangelsk, with a population of 350 000), and the Volga are among the few remaining relatively pristine deltas. Deltas are biologically diverse ecosystems, thus major efforts are underway to conserve and restore them. Several large deltas are already protected by the Ramsar Convention (e.g., Nestos, Axios, Kuban, Dnieper, Volga, Danube, Rhone). Around 90% of the Danube delta today is officially protected (Ramsar site and Unesco Biosphere heritage). Other large deltas such as those of the Ural and Terek Rivers in Russia, and the Seyhan and Kizilirmak Rivers in Turkey are not protected.

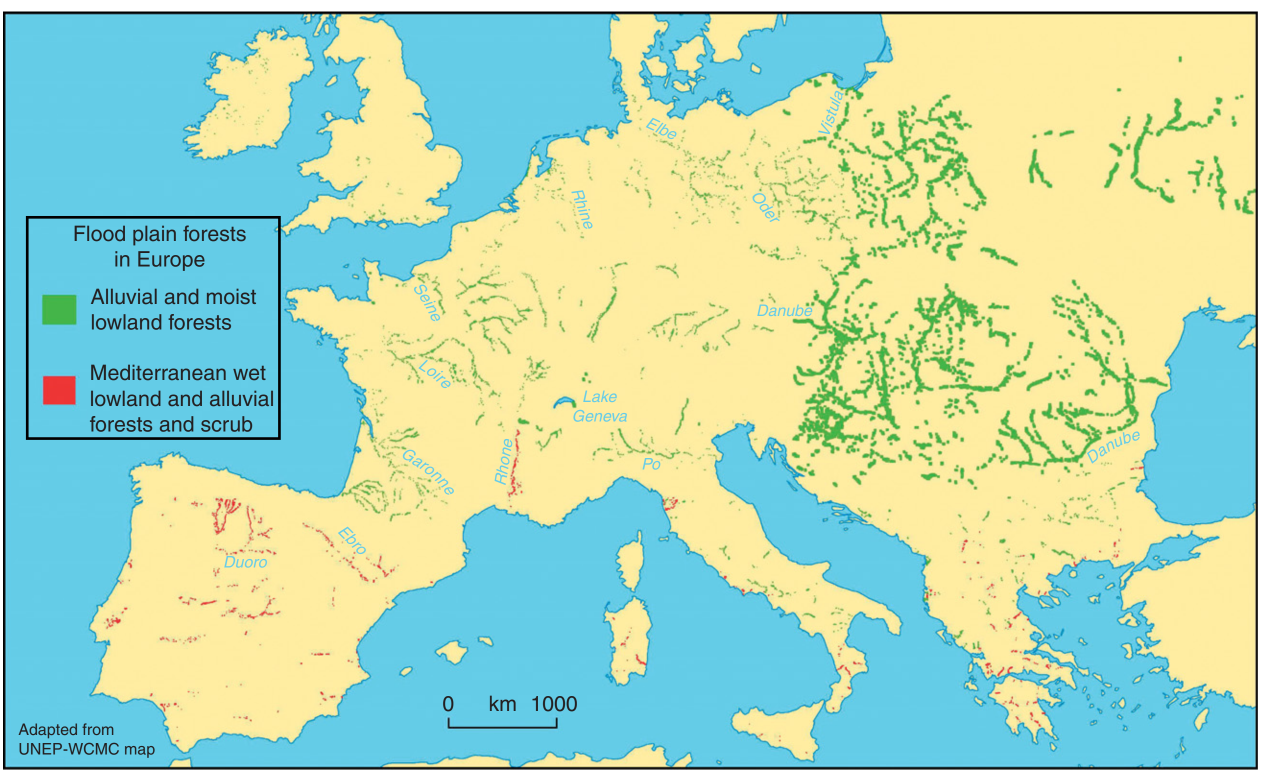

Figure 3 Distribution of the remaining riparian forests along European rivers (note the difference between eastern and western Europe. Hughes FMR (ed) (2003) *The Flooded Forest: Guidance for policy makers and river managers in Europe on the restoration of flood plain forests*. FLOBAR2, 96 pp. European Union and Department of Geography, University of Cambridge: UK, with permission.

Table 2 The 20 largest river deltas in Europe (including Turkey and the Caucasus)

	Area (km^2)	*Average temperature[a] (°C)*	*Population[b] (people per km^2)*	*Cropland[c] (%)*	*Protected[d] (%)*
Rhine	25 347	9.2	493	89.7	0.9
Volga	11 446	10.3	53	70.0	24.7
Ural	8586	9.1	24	13.6	0.0
Pechora	5490	−4.0	<1	<0.1	26.3
Kuban	5422	11.7	63	73.9	20.3
Danube	4560	10.7	34	56.0	89.1
Kura	4175	15.5	78	57.4	20.6
Terek	4026	11.6	46	86.3	3.3
Po	2878	12.8	119	86.9	10.0
Dnieper	2833	8.7	80	76.2	7.4
N Dvina	2229	0.6	118	3.4	5.9
Guadalquivir	2213	17.6	152	69.2	31.9
Seyhan	1903	17.1	116	86.0	0.0
Vistula	1858	7.7	187	93.5	0.0
Rhône	1783	13.5	64	63.7	59.7
Neman	1088	6.7	24	57.1	18.6
Don	604	10.1	541	71.9	80.8
Kizilirmak	474	11.1	126	84.6	0.0
Ebro	331	15.9	116	49.3	22.3
Nestos	319	12.5	53	83.3	14.6

Average annual temperature (1961–1990). Human population density: People per km^2. Protected: National parks, Ramsar sites, nature reserves, and other nationally protected areas.
[a]http://www.ipcc-data.org/obs/get30yr_means.html.
[b]http://gis.ekoi.lt/gis/.
[c]http://edcsns 17.cr.usgs.gov/glcc/tablamert_euras_eur.html.
[d]http://sea.unep-wcmc.org/wdbpa/.

Water Quality

European rivers show a wide variety of pollution problems. In Scandinavian rivers, acidification remains a major problem due to acid rain deposition that is not neutralized in the non-carbonated soils of the Fennoscandian Shield, while other contaminants are relatively minor. Eutrophication and nitrate deposition pose the greatest challenge in western and central Europe, whereas organic matter loads, pesticides, and nitrogen inputs are major issues in southern and eastern Europe. From 1992–1996, over 65% of European rivers had average annual nitrate concentrations exceeding 1 mg l^{-1} and 15% of the rivers had concentrations >7.5 mg l^{-1}. The highest nitrate concentrations are in northwest Europe where agriculture is intense. Ammonium levels have decreased in European rivers since around 1990 (Figure 4). Phosphorous concentrations also have generally declined since the 1990s as a result of reductions in organic matter and phosphorous loads from wastewater treatment plants and industry and of severe reduction or ban of phosphate detergents as in Switzerland and Germany.

While water quality has considerably improved over recent decades in many western European rivers (Figure 4), serious problems still exist in eastern and southern countries. For instance, 75% of the water in the Vistula, Poland's largest river with many seminatural flood plains, is unsuitable even for industrial use. The range of specific fluxes of river borne material (tons km^2 year^{-1}) is in general high at the continental scale; it is even wider in Europe due to human impacts. Annual yields of total suspended solids (TSS) range over more than two orders-of-magnitude from <1 ton km^2 year^{-1} to >300 tons km^2 year^{-1}. Very high values occur in the Alps, reflecting natural erosion. Dissolved inorganic nitrogen yields from European catchments range over two orders-of-magnitude from <10 kg N km^2 year^{-1} for rivers in the remote north (e.g., Finish rivers) to >2200 kg N km^2 year^{-1} for the Rhine River (Table 3). Yields of dissolved organic carbon range from ~200 kg C km^2 year^{-1} (Steppic Rivers) to >3000 kg C km^2 year^{-1} in the Po River. Dissolved organic nitrogen, which primarily originates from anthropogenic sources in Western and Southern Europe, can reach 300 kg N km^2 year^{-1}. For all

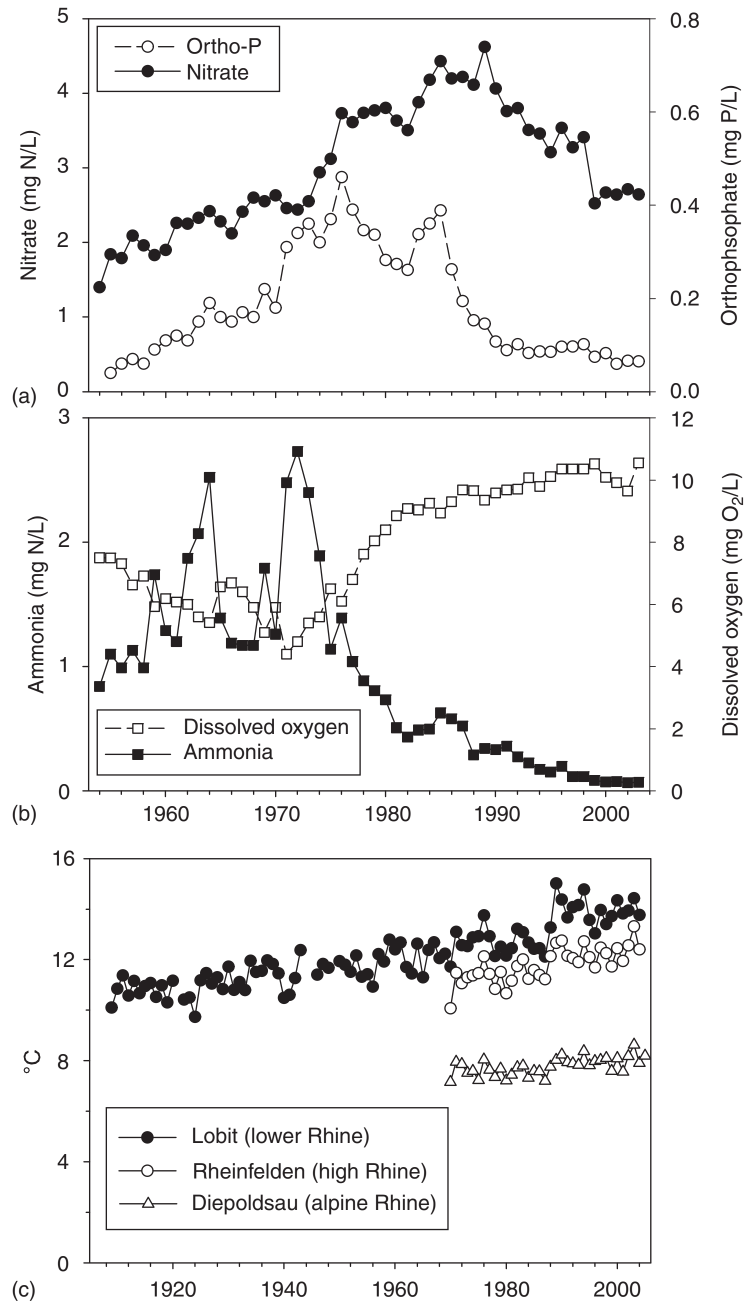

Figure 4 Temporal trends in (a) nutrients and (b) oxygen at Lobith, and (c) temperature (three stations) in the Rhine River. Note different scales of *x*-axes.

of Europe, estimated annual export rates were 1 Pg for inorganic suspended solids (ISS), 7 Tg for particulate organic carbon (POC), 1.1 Tg for particulate nitrogen (PN) and 0.3 Tg for particulate phosphorus (PP). Toxic substances as metals, polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCBs) have reached some of the highest values ever recorded for Europe. Because their survey is costly, the recent trends are generally reconstructed from cores taken in deltas and flood plains. In Western Europe Rivers, bordering the Atlantic coast, very high levels of cadmium, mercury, lead, zinc, and of PAHs and PCBs have been recorded, with peaks from 1930 to 1970. Record contaminations are observed in rivers basins with high industrial and/or mining activities, megacities inputs (e.g., Paris, Berlin), often in combination with limited dilution by river sediments, as for the Seine, the Scheldt, Lot (France), Meuse,

Table 3 Predicted/measured catchment yields for particulate and dissolved organic matter and nutrients for selected European Rivers

	DIP (kg km^{-2} year^{-1})	*DIN (kg km^{-2} year^{-1})*	*DOC (kg km^{-2} year^{-1})*	*TSS (ton km^{-2} year^{-1})*	*POC (ton km^{-2} year^{-1})*	*PN (ton km^{-2} year^{-1})*	*PP (ton km^{-2} year^{-1})*
Volga	2.39	n.d.	n.d.	18	0.2	0.0	0.0
Danube	30.21	n.d.	1152	86	1.0	0.1	0.0
Dnieper	2.96	n.d.	570	5	0.2	0.0	0.0
Don	13.60	19.1	245	5	0.1	0.0	0.0
N Dvina	5.65	n.d.	1494	10	0.4	0.1	0.0
Pechora	5.94	64.7	1954	21	0.5	0.1	0.0
Vistula	36.98	371.8	n.d.	14	3.1	0.4	0.1
Rhine	119.32	2200.4	1388	21	2.4	0.4	0.1
Elbe	63.94	795.4	753	6	1.6	0.2	0.1
Oder	32.61	389.8	n.d.	1	0.4	0.1	0.0
Loire	30.95	n.d.	1065	4	0.7	0.1	0.0
Kuban	25.88	330.9	1044	120	1.0	0.2	0.0
Neman	9.42	74.1	n.d.	7	0.6	0.1	0.0
Ebro	2.34	n.d.	n.d.	217	1.6	0.2	0.1
Glama	16.06	191.8	n.d.	321	1.5	0.2	0.1
Kymjoki	3.95	n.d.	n.d.	3	0.3	0.1	0.0
Po	77.18	n.d.	3046	147	3.2	0.4	0.1
Seyhan	4.21	n.d.	n.d.	151	n.d.	n.d.	n.d.

TSS: Total Suspended Solidsl; n.d.: no data.

Sources

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Dumont E, Harrison JA, Kroeze C *et al*. (2005) Global distribution of dissolved inorganic mitrogen export to the coastal zone: Results from a spatially explicit global model. *Global Biogeochemical Cycles* 19, GB4S02.

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Table 4 Global and European freshwater fauna species richness

Group	*World*	*Europe*	*Proportion of global (%)*
Bivalvia	1000	50	5
Gastropoda	4000	163	4
Ostracoda	2000	400	20
Copepoda	2085	902	43
Amphipoda	1700	350	21
Ephemeroptera	>3000	350	<10
Odonata	5500	150	3
Plecoptera	2000	423	21
Trichoptera	>10 000	1724	<17
Hemiptera	3300	129	4
Coleoptera	>6000	1077	<18
Diptera	>20 000	4050	<20
Lepidoptera	>1000	5	<1
Hymenoptera	>130	74	<56
Megaloptera	300	6	2
Pisces	>13 000	400	<3
Amphibia	5504	74	1
Ayes	1800	253	14
Total	*>82 500*	*10 580*	*<13*

Source – Lévéque C, Balian EV, and Martens K (2005) An assessment of animal species diversity in continental waters. *Hydrobiologia* 542: 39–67.

Rhine, Idrija (Slovenia), Elbe, and Upper Vistula. In most cases the contamination levels have markedly declined since the 1970s, but they remain at high levels compared with natural levels. The heritage of this type of pollution, associated with particulate material, will last for decades and more.

Freshwater Biodiversity

European freshwaters are relatively species-poor compared with other continents (Table 4). For example, continental waters provide habitat for <4% of the global freshwater fish fauna. The relative contribution of European freshwater fauna to global fauna is higher for groups with widespread species such as copepods and ostracods. It must be noted that the freshwater fauna (and flora) of Europe is much better described than the fauna of most other areas of the world. Around 25% of all European birds and 11% of all European mammals are dependent on freshwater for breeding or feeding, but only one species in each group is truly endemic to Europe (aquatic warbler, *Acrocephalus palustris*; southwestern water vole, *Arvicola sapidus*). Nine birds, 5 mammals and 25 fishes associated with European freshwaters are included in the International Union for the Conservation of Nature (IUCN) Red List of Globally Threatened Species, and two species are endangered by extinction (dalmatian pelican and ringed seal). One success story is the recent spread of the European beaver. At the beginning of the last century only a few hundred individuals survived in Norway, Germany, France, and the former Soviet Union. The population has now increased to at least half a million, and is attributable to large areas of suitable habitats and restricted hunting.

The European freshwater fish fauna includes 368 native species from 33 families (in the most recent inventory more than 500 species are listed including 59 species of the family Coregonidae. The most species (taxa) rich families are Cyprinidae (156 species), Gobiidae (40), Cobitidae (32), and Salmonidae (22; 64 species if all species and forms are considered). In comparison: North America contains ~1050 species, Africa >3000 species, and South America >5000 species. In Europe, a distinct west–east and north–south increase in species richness is found. The Danube River catchment has the highest diversity with ~100 fishes (~25% of the continental fauna). The mainstem of the Danube was unglaciated, and served as a 'refuge' during periods when the continental ice sheets advanced. As the ice sheets retreated, freshwater species expanded from this refuge to the rest of Europe (Figure 5(a)). Using area-corrected data (a power function of area and richness), the greatest diversity of fishes are in southeastern European catchments (Western Balkan, Turkey). River basins in Northern Europe, from Iceland to Northern Russia, have been covered by ice until 12 000 to 6000 years BP and therefore have low fish diversity.

At the continental scale, 13 fish species, including two fishes endemic to the River Drin (flowing into the Adriatic Sea in Albania/Croatia) and several salmon species are extinct. However, at the catchment scale, up to 40% of native fishes have disappeared, especially long-migrating species such as sturgeons, Allis shad (*Alosa alosa*) and lampreys. In contrast, 76 nonnative fishes belonging to 21 families have been introduced into European freshwaters, with ~50 of these having self-reproducing populations. Most nonnative fishes originated from North America (34 species) and from Asia (26 species), and between 30 and 50 fishes have been translocated within Europe. The proportion of nonnative fish exceeds 40% in some catchments, mostly in the Iberian Peninsula and the Atlantic region of France (Figure 5(b)). The highest proportion of irreplaceable fish (i.e., species with a limited geographic distribution), is found in the Iberian Peninsula, the southern Balkan, and Anatolia. These particular regions will face an even higher increase in water stress, pollution, and erosion in the near future.

The European Water Framework Directive

European catchments are under pressure of ever-increasing water stress and land-use change, especially those with high conservation value such as the Mediterranean area. The Water Framework Directive (WFD) creates a legislative framework to manage, use, protect, and restore surface water and groundwater resources in the European Union. The WFD approaches water management at the scale of the river catchment (river basin), which often includes several countries. The WFD requires the establishment of a 'river basin management plan' (RBMP) for each river catchment in the European Union. The RBMP is a detailed account of how environmental objectives (i.e., good ecological status of natural water bodies and good ecological potential of heavily modified and artificial water bodies) are to be achieved by 2015. For those countries that can demonstrate that this is not feasible without disproportionate economic and social costs, the WFD allows the possibility of delay to 2030. This sets a time scale for restoration of water bodies during which a considerable change in climate is expected. Although it is stated '*this Directive should provide mechanisms to address obstacles to progress in improving water status when these fall outside the scope of Community water legislation, with a view to developing appropriate Community strategies for overcoming them*' (WFD, Article 47), climate change and its possible impact on water bodies has been ignored in the scope of the WFD and the term 'climate' does not even appear in its text.

Knowledge Gaps

The catchment must be considered as the key spatial unit to understand and manage ecosystem processes and biodiversity patterns. However, biological information is mostly available at the country rather than the catchment level. In addition, available data are unevenly distributed across Europe and constrains potential comparability. Riverine flood plains and deltas are among the least studied ecosystems but yet the most threatened. As such, we need to identify and quantify the ecosystem services that these

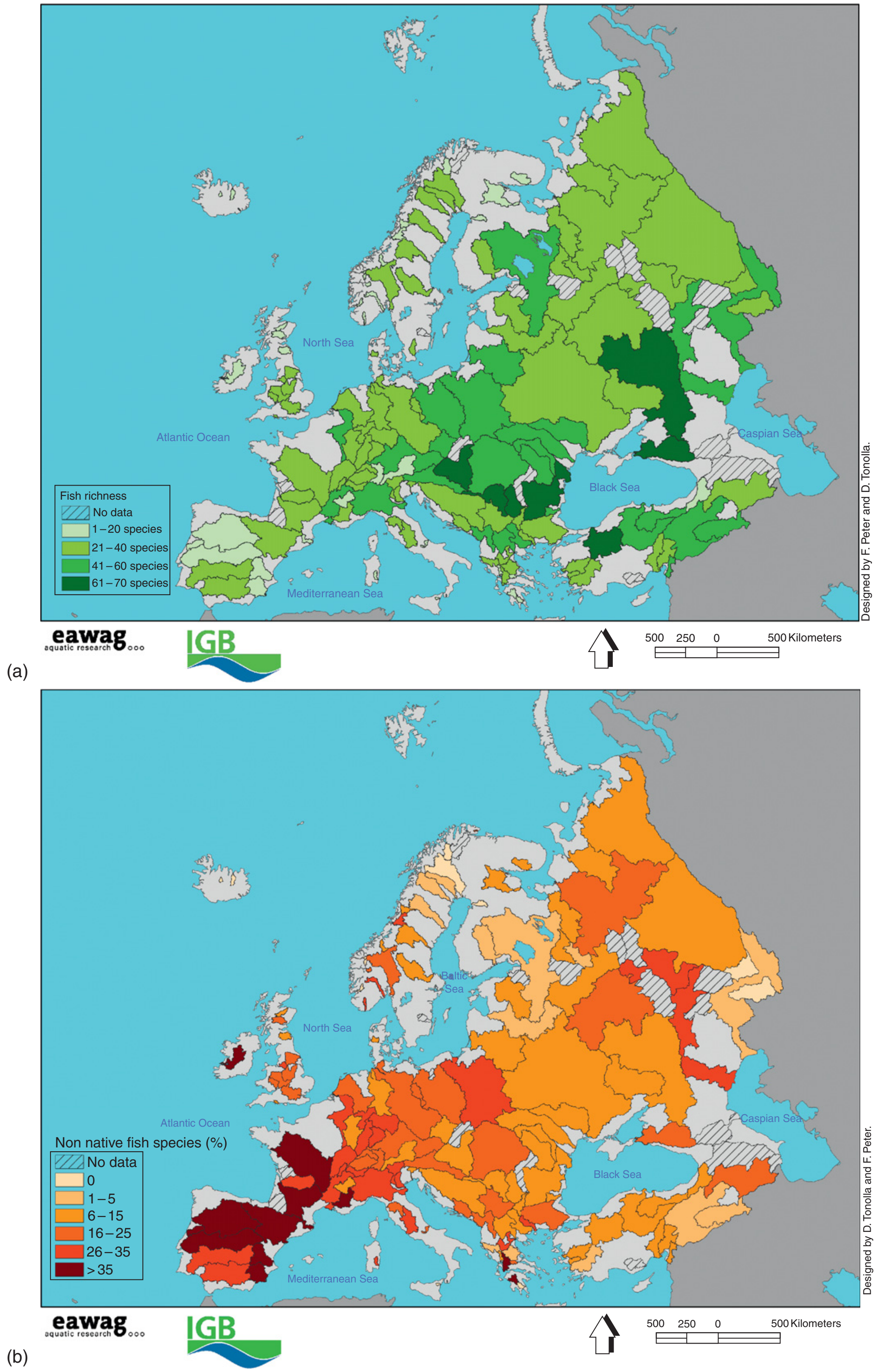

Figure 5 Species richness of fish in European catchments and sub-catchments: (a) native fish richness, (b) nonnative fish richness. Fabian P (2006) *Biodiversity of European Freshwater Fish – Threats and Conservation Priorities at the Catchment Scale*. Diploma thesis, 71 pp. Switzerland: University of Basel.

ecosystems provide in their natural state. Historic information and long-term data for freshwater organisms as well as key environmental drivers (e.g., temperature, habitat change) are rare, especially at the continental scale. While conservation planning is primarily driven by several native, endemic, and endangered species (so-called 'hot spot' areas), there is an urgent need to incorporate other ecosystem aspects such as the evolutionary potential of the system and its capacity to perform key ecological processes in conservation and restoration planning. Finally, there is an urgent need to establish a European network of 'reference' river systems against which human alterations can be assessed; and to better understand how rivers function in their (semi-)natural state. This provides pivotal baseline information for guiding future restoration and management programs.

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www.grid.unep.ch – United Nations Environment Programme/Division of Early Warning and Assessment.

www.GWSC.bafgf.de – Global Runoff Data Center (GRDC).

http://www.gwsp.org – ESSP Global Water System Project (GWSP).

http://ec.europa.eu/environment/water/water-framework/index_en.html – Water Framework Directive (WFD).