UDK/*UDC*: 502.51:004.65(282)(4)
Pregledni znanstveni članek – *Review scientific paper*

Prejeto/*Received:* 08.11.2018
Sprejeto/*Accepted:* 20.12.2018

REVIEW OF EUROPEAN DATABASES OF INLAND WATERS USED IN THE MARS SPATIAL DATABASE DEVELOPMENT FOR THE PURPOSE OF MULTIPLE PRESSURE ANALYSIS

PREGLED EVROPSKIH PODATKOVNIH ZBIRK O CELINSKIH VODAH, UPORABLJENIH PRI RAZVOJU PROSTORSKE BAZE MARS, ZA NAMEN ANALIZE VEČ PRITISKOV HKRATI

Lidija Globevnik[1,2,*], Maja Koprivšek[2], Luka Snoj[2]

[1] Fakulteta za gradbeništvo in geodezijo, Univerza v Ljubljani, Jamova cesta 2, Ljubljana, Slovenija

[2] Tematski center za raziskave, študije in razvoj projektov na vodah, Trnovski pristan 10, Ljubljana, Slovenija

Abstract

With respect to the various European polices for water and environment protection, EU member states report to the European Commission through national monitoring programmes a wide variety of data on the pressures that aquatic ecosystems are facing. They further report data on the quality and quantity of water ("State of Environment") at monitoring sites, and on the ecological and chemical status of surface waters under the Water Framework Directive. Many other databases on European waters (hydrographical databases as well as databases on state of water) were developed as a result of different European projects. There are also several sources about climatic data, data on river discharges, and data on pressures the water system is facing. All these databases are a welcome source of information, needed to analyse the pressures on and state of European inland waters, but they must be interlinked, harmonised, and entered into a common spatial database first. This was done within the MARS project, where we have interlinked and unified relevant available databases into a new spatial database. Data are now available in a new form to be used in analysis of state of inland aquatic ecosystems as a response to multiple pressures.

Keywords: hydrography, spatial database, European rivers and lakes, pressures on waters, ecological status.

Izvleček

V okviru različnih politik za varstvo voda in okolja države članice EU preko nacionalnih programov spremljanja poročajo Evropski komisiji in drugim evropskim institucijam najrazličnejše podatke o pritiskih na vodne ekosisteme. Poročajo tudi, kakšno je kakovostno in količinsko stanje voda (»State of Environment«) na točkah monitoringa ter ekološko in kemijsko stanje površinskih voda po Okvirni vodni direktivi. V okviru različnih evropskih projektov so nastale tudi številne druge zbirke o evropskih vodah (tako hidrografske kot baze o stanju voda). Dostopnih je tudi več virov podatkov o podnebju, pretokih vodotokov in pritiskih na vode.

[*] Stik / *Correspondence*: lidija.globevnik@fgg.uni-lj.si

https://doi.org/10.15292/acta.hydro.2018.07

Vse te zbirke podatkov so zelo dobrodošel vir informacij, ki jih potrebujemo za analize pritiskov in stanja na evropskih celinskih vodah, vendar jih moramo pred tem povezati in poenotiti njihovo osnovno prostorsko enoto. To smo naredili v okviru projekta MARS, kjer smo v prostorski bazi povezali in poenotili vse razpoložljive zbirke podatkov v novo prostorsko bazo, imenovano »MARSgeoDB«. Podatki so zdaj na voljo v novi obliki in pripravljeni za uporabo v analizah odzivov kopenskih vodnih ekosistemov na več pritiskov hkrati.

Ključne besede: hidrografija, prostorska baza, evropske reke in jezera, pritiski na vode, ekološko stanje.

1. Introduction

Water resources around the world are affected by a complex mixture of stressors resulting from a range of drivers, including urban and agricultural land use, hydropower generation, and climate change. Understanding how stressors interact and impact ecological states and ecosystem services is essential for developing River Basin Management Plans (RBMP) and for shaping future environmental policy (Hering et al., 2015). European political regimes for water management are set by the Water Framework Directive. Scientific support for its efficient implementation is crucially needed, mainly because there are multiple stressors acting upon aquatic ecosystems. The MARS research project (2014-2018), supported by the 7th Framework Programme of the EU (MARS, 2018), addresses multiple stressors and incorporates three scales of research: the water body scale, the catchment scale, and the pan-European scale. The basic assumptions are the following. On the water body scale, we need a mechanistic understanding of how stressors interact with and impact upon water. At the river basin scale we characterise relationships between multiple stressors and ecological responses and assess the effects of future land use and mitigation scenarios. Relationships among stress intensity, statuses, and service provision are identified at the pan-European scale. With exploration and inter-linkage of large-scale data we might understand how different stress combinations impact water resources, ecological status, and ecosystem services.

According to Hering et al. (2015), the MARS project is based on a framework that explicitly connects the assessment of risk, status, and ecosystem services under RBMPs (Figure 1).

• Risk assessment combines the magnitude of a stressor (or a combination of stressors) with the consequences of being exposed to it. The consequences are based on the sensitivity of the targeted indicators, e.g. species, habitats, and ecosystem processes and services.

• WFD status assessment fits centrally within the DPSIR-framework: Drivers (D, e.g. intense land use) cause pressures (P, equivalent to stressors; e.g. increased nutrient concentrations) and consequently affect water body state (S, e.g. chemical or ecological status or water quantity). This has impacts (I) on ecosystem functioning and consequently ecosystem services, which may require a management or policy response (R, e.g. restoration actions).

• Ecosystem services are generally considered through the "cascade model", which links the capacity of ecosystems (i.e. their structures, processes and functions) to flow of a specific service, which can be translated into benefits and values associated with human wellbeing (Haines-Young and Potschin, 2010). For example, river systems have the potential for denitrification and sedimentation, which determine nutrient and organic matter removal, or in other words water purification. The resulting benefit for human well-being is the provision of clean drinking water and safe recreation, which can be valued through a variety of methods (Wallis et al., 2011).

There are obvious links between these three frameworks (Figure 1), through indicators of a water body's sensitivity or resilience to stressors, its status, and its capacity to provide services. Further, management decisions ("response") are not only based on the state-impact chain through the DPSIR model, but also must consider ecosystem service values, too. Working in the MARS conceptual

model it is possible for the first time to support management decisions and test scenarios explicitly through the ecosystem services paradigm by examining interactions between the structure and functioning of ecosystems, as well as benefits for human wellbeing (e.g. provision of drinking water, self-purification, flood and drought regulation, and recreation).

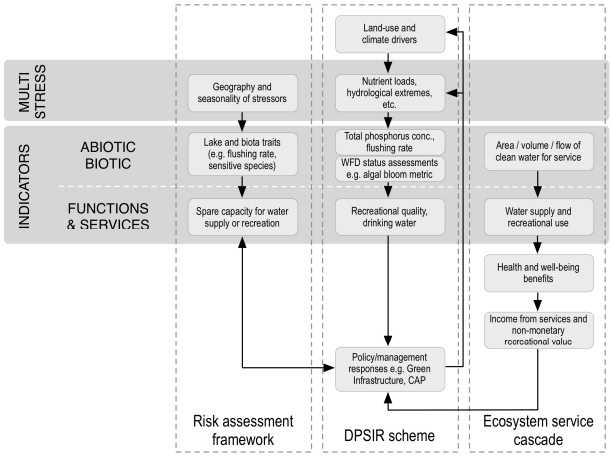

Figure 1: *The MARS conceptual model for an integrated assessment framework (Hering et al., 2015).*

Slika 1: *Konceptualni model MARS za celoviti okvir ocenjevanja (Hering et al., 2015).*

For the purpose of analysing the impacts of various pressures on the state of inland waters at the European scale, we developed the georeferenced European database "MARSgeoDB". There is a variety of data reported under various European polices and activities for water and environment protection by EU member states. Many other databases on European waters were developed as a result of European projects. Most of these datasets can be characterised as information on the pressures affecting aquatic systems, their state, and impacts on them.

Within the MARS project we developed European matrix of pressures, state and their impact, and integrated available datasets into one georeferenced, that is spatial database. The most of the used databases come from EU-wide reporting or modelling activities at various scales from point data, to different polygon data as catchments, river basin districts (RBD), territorial units for statistics (NUTS), countries, or grid cells. All these data were converted to the same unit, which is ECRINS FECs – European Catchments and Rivers Network System Functional Elementary Catchments (see explanation in the following chapter).

Using the MARS spatial database we analysed pressure and response relations, identifying the most important pressures and producing European multi-pressure maps (Globevnik et al., 2017).

This paper gives an overview of European databases integrated into "MARSgeoDB". They are grouped as a) hydrographical, b) pressure, c) state and impact data, and d) spatial aggregation data sets of existing European biological and hydrological regionalization systems. Climatic data on air temperature, precipitation, evapotranspiration, humidity, and wind are included as a supplementary dataset, since these factors are indirect physical indicators of the state of inland waters. With their inclusion we opened the possibility for future ecological and hydrological modelling.

2. Hydrographical databases

There are three publicly available hydrography in Europe: "CCM – Catchment Characterisation and Modelling", "ECRINS – European Catchments and Rivers Network", and "EU HYDRO". Table 1 presents their basic characteristics and gives comparisons among them.

2.1 CCM2

In 2003, the Joint Research Centre (JRC) at the European Commission developed a pan-European database of river networks and catchments. This was done as a part of "Catchment characterisation and modelling", wherefore the database was named "CCM1" (representing version 1.0). In July 2007 they released a geographically extended and improved database "CCM2" (representing version 2.0). (EC JRC, 2018b). The current Version 2.1 of July 2008 is an update of version 2.0 (EC JRC, 2018a).

It consists of river segments and nodes, catchments (primary catchments and their aggregations in higher level watersheds), lakes, and coastline.

CCM2 was developed on the basis of newly generated pan-European DEM mosaic, based on Space Shuttle Topography Mission (SRTM) data (up to 60°20' northern latitude) with 3'' spatial resolution, national elevation data from Norway, Sweden and Finland with 100 m spatial resolution and USGS GTOPO30 data with 30'' spatial resolution for the remaining areas of north-western Russia, Iceland, and the Shetland Islands (Vogt et al., 2007).

2.2 ECRINS

ECRINS v1.1 is the acronym for the European Catchments and Rivers Network system developed by the European Environment Agency (EEA) in 2012 on the basis of the CCM2 database. It consists of functional elementary catchments (FECs), river segments and nodes, lakes, and dams. FECs are linked to countries, RBD units, and subunits (to which the largest part of FEC belongs), and are aggregated into some higher-order catchments. The ECRINS river segments are linked to FECs. Both feature classes have a lot of attributes, expressing connectivity between objects. We found very useful attribute "Code_Arbo", which helps us simply find all FECs in the upstream drainage area (hinterland).

2.3 EU-Hydro

EU-Hydro beta was developed at EEA in year 2016 (EEA, 2015a) and is divided into:

- River Network dataset, which includes point feature classes (culverts and nodes), line feature classes (rivers, canals and ditches), and polygon feature classes (rivers, canals, ditches, inland waters, transitional waters, coastal waters, and river basins) and
- Drainage Network dataset, which consists of basins and elementary catchments with corresponding drainage lines not being the same as rivers in River Network.

It is more precise than CCM2 and ECRINS, since the River Network was derived from 20-m resolution imagery. Feature data was extracted by photointerpretation of Very High Resolution Image Data (2011 – 2013) with a resolution of 2.5 m, whereas the Drainage Network was derived from 25-m resolution DEM (EEA, 2015a).

A comparison between all three hydrographical databases is shown in Table 1. Because all these three hydrographical databases are based on topographical models, underground flow in the karstic area is not considered

3. Databases used for information on pressures, state and impacts

Human activities are drivers of pressures on aquatic systems, e.g. increased nutrient concentrations in water or higher organic pollution of water and consequently affect a water body's chemical or ecological status. The impact, and deteriorated ecological status, might be measured or determined by biological indexes. Table 2 gives an overview of datasets integrated into the MARS spatial database. Details are available on the dataset's owner, its name, DPSIR thematic group, a short description of content, and the spatial object that holds the contextual information.

3.1 Databases of drivers and pressures

Urban and industrial waste water emissions are polluting water, and are therefore characterised as pressures. Since they are more or less concentrated to single locations, they are described as point pressures. An adverse effect on aquatic ecosystems is also wrought by dispersed emissions from agricultural practices and livestock farming. These are characterised as diffuse pollution sources of nutrients. The proxies of these pressures are data on land cover and data on fertilizer application and excreta. They are related to population density, which is a driver of pressures.

3.1.1 Waterbase – UWWTD (Urban waste water emissions)

The Council Directive 91/271/EEC concerning urban waste-water treatment (shorter Urban Waste Water Treatment Directive) concerns the collection, treatment and discharge of urban waste water and

the treatment and discharge of waste water from certain industrial sectors. Waterbase – UWWTD dataset (EEA, 2014; 2018a) contains data selected from the reporting of Member States as part of the UWWTD implementation and consists of 12 data tables on: reported period, receiving areas, agglomerations, urban waste water treatment plants (UWWTPs), links agglomerations – UWWTPs, discharge points, and (at Member State level) sludge handling and treated waste water re-use. Locations of UWWTD discharge points across Europe are shown in Figure 2.

Table 1: *Comparison between different hydrographical databases.*

Preglednica 1: *Primerjava različnih hidrografskih zbirk.*

	CCM2	**ECRINS**	**EU HYDRO**
year of development	2007	2012	2016
developer	JRC	EEA	EEA
spatial extent	Geographical Europe	Geographical Europe	EU-28 + AL, BA, IS, XK, LI, MK, ME, NO, RS, CH, TR
catchments resolution	100 m	100 m	25 m
catchment unit	WSO (WaterShed Order) polygons: from WSO1 as the most precise and aggregations to WSO11	functional elementary catchment (FEC)	large basins (68 river basins in European territory)
catchment scale	more detailed as in ECRINS	combination of CCM2 WSO2 and WSO3 polygons	basins, usually finer or the same scale as WSO1 polygons, but is some cases coarser than WSO1
river feature type	polylines	polylines; almost the same as at CCM2	presented as polylines and as polygons; more detailed and more precise than in CCM2 and ECRINS, ditches and canals included; resolution of 20 m
lake feature type	polygons	Polygons; similar to CCM2 but with better resolution	more detailed as ECRINS, also very small lakes and ponds are included
river ID	WSO1_ID	TR	WCOURSE_ID (linked to ECRINS TR)
catchment ID	WSO1_ID	ZHYD	"OBJECT_ID"
catchments connectivity	Pfafstetter code; NextDown_ID	Code_Arbo; NextDown_ID	Pfafstetter code (different from CCM2 Pfafstetter code); not unique for river segments; NextDown_ID
linkage to WFD water bodies	no	not included in ECRINS, but done by EEA as separate exercise	included in the database
inconsistencies	divide line between Adriatic and Black Sea Catchment in karstic area	divide line between Adriatic and Black Sea Catchment in a karstic area; route of the Sava river between Zagreb and Bosanska Gradiška, Kolpa, and Una River Catchments	divide line between Adriatic and Black Sea Catchments in a karstic area

Table 2: *European databases on pressures, state, and impacts.*

Preglednica 2: *Evropske podatkovne zbirke o pritiskih, stanju in vplivih na vode.*

Data owner	Database name	Thematic group	Content	Spatial object to relate
EU-28 (EC and EEA responsible)	Waterbase – UWWTD	pressure	yearly quantities of treated water, population equivalent (PE) for all UWWTPs, yearly loads of BOD5, total phosphorus, and total nitrogen	locations of UWWTPs, discharge points (locations of emissions from UWWTP) and agglomerations
EC	E-PRTR	pressure	Emissions from large industrial facilities to water	emission point of large industrial and communal installations
EUROSTAT	Eurostat database – agriculture and environment	pressure	data on fertilizer application and livestock excreta	NUTS polygons representing EU-28
EEA	Corine land cover, Globe Corine	pressure (proxy)	land use categories of Corine nomenclature for land cover	polygons of land cover for the territory of EEA members
EEA	Copernicus – Riparian Zone LC/LU dataset;	pressures (proxy)	all levels categories of MAES nomenclature for land cover	polygons of
JRC	Population density disaggregated with Corine land cover 2000	driver	Data are available at 100 meters resolution.	EU-28 territory (raster format)
EEA	Waterbase –Water Quality	state	physico-chemical parameters (1992-2015); EQR values, EQR normalised values	points of monitoring locations
EU-28 (EC and EEA responsible)	Bathing water quality	state	microbiological parameters	points of monitoring locations NUTS polygons representing EU-28
EEA	Waterbase – Water quantity	state	river discharges (different periods and time resolution)	points of monitoring locations
EU-28 (EC and EEA responsible)	WISE WFD Database	impact	environmental status and status of four groups of quality elements	water bodies (by code; spatial objects in WISE WFD reference spatial data sets)
EFI+ consortium	EFI+	impact	deviation between predicted (reference conditions) and observed fish assemblages	points of monitoring locations
BfG	GRDC and EWA	climatic	river discharge data	points of monitoring locations
JRC	Agri4cast	climatic	daily temperature, precipitation, evapotranspiration, and wind speed	Europe and Mediterranean Sea; raster format data (25*25 km)
Global Climate Data	WorldClim	climatic	monthly temperature and precipitation	world; raster format data (1 *1 km)
GPCC	Global Precipitation Analysis Products	climatic	gauge-based monthly precipitation data	world, raster format
NCAS	BADC	climatic	monthly data on precipitation, mean temperature, wet-day frequency, vapour pressure, cloud cover, and ground frost	world; raster data (0.5° LL)

Legend: ***EU-28****: European Union 28 Member States;* ***EC****: European Commission;* ***EEA:*** *European Environmental Agency;* ***WISE****: Water Information System for Europe;* ***WFD****: Water Framework Directive;* ***UWWTP****: Urban Waste Water Treatment Plant;* ***BOD5****: Biochemical Oxygen Demand;* ***E-PRTR****: The European Pollutant Release and Transfer Register;* ***NUTS****: Nomenclature of territorial units for statistics;* ***LC/LU****: Land Cover/Land Use;* ***MAES****: Mapping and Assessment of Ecosystems and their Services;* ***JRC****: Joint Research Center;* ***EQR****: Ecological Quality Ration;* ***WFD****: Water Framework Directive;* ***EFI+****: European Fish Index+;* ***BfG****: Bundesanstalt für Gewässerkunde;* ***GRDC****: Global Runoff Data Center;* ***EWA****: European Water Archive;* ***GPCC****: Global Precipitation Climatology Centre;* ***NCAS****: NERC Centres for Atmospheric Sciences;* ***BADC****: The British Atmospheric Data Centre;* ***LL****: Longitude Latitude.*

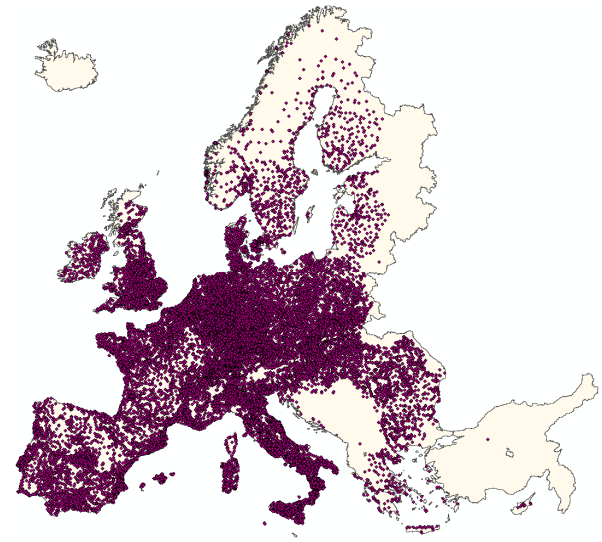

Figure 2: *UWWT Directive discharge points across Europe*

Slika 2: *Lokacije izpustov po Direktivi o čiščenju komunalne odpadne vode v Evropi.*

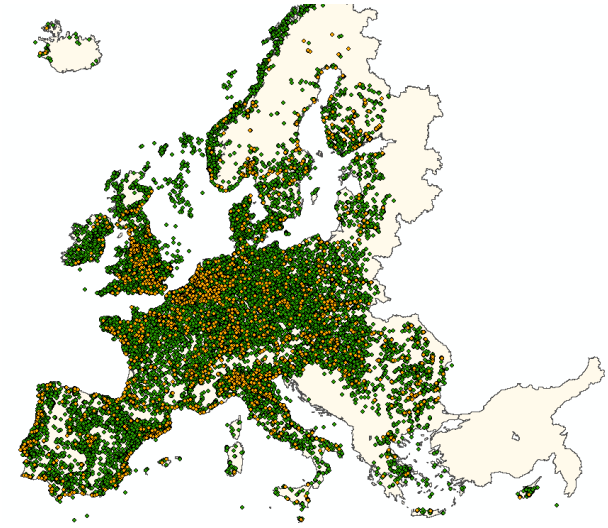

Figure 3: *E-PRTR facilities with releases in the ground (green) and with releases in water (orange).*

Slika 3: *Lokacije industrijskih objektov z izpustom v tla (zeleni) in vode (oranžni).*

3.1.2 E-PRTR (Emissions from industry)

The European Pollutant Release and Transfer Register (E-PRTR) is the Europe-wide register that provides easily accessible key environmental data from industrial facilities in European Union Member States and in Iceland, Liechtenstein, Norway, Serbia and Switzerland. It replaced and improved upon the previous European Pollutant Emission Register (EPER). The new register contains data reported annually by more than 30,000 industrial facilities covering 65 economic activities across Europe (Figure 3). For each facility, information is provided concerning the amounts of pollutant releases to air, water and land as well as off-site transfers of waste and of pollutants in waste water from a list of 91 key pollutants including heavy metals, pesticides, greenhouse gases and dioxins for years 2007 onwards (EEA, 2018b; 2018c).

3.1.3 Eurostat Database – Agriculture and environment (diffuse emissions of nutrients)

Eurostat is the statistical office of the European Union. It provides high quality statistical data (EC Eurostat, 2018a). Data under "agriculture and environment" are used as an approximation for nutrient emissions (diffuse pressures), which cannot be measured. Various statistical data are reported in the statistical unit NUTS (Nomenclature of territorial units for statistics) levels 1, 2, and 3. Moreover, shapes as well as codes and names of NUTS regions are constantly being changed every few years (see history of NUTS on EC, Eurostat webpage). In the NUTS feature class in MARS we included NUTS 2003, NUTS 2006, NUTS 2010, and NUTS 2013 regions (EC Eurostat, 2018b).

3.1.4 Land Cover datasets Corine, GlobCorine, and Riparian Zone Land Data

There are three freely available land cover data sources for Europe. The Corine Land Cover (CLC) programme was initiated in the European Union in 1985 (reference year 1990). Corine stands for 'Coordination of information on the environment' and it was a prototype project working on many different environmental issues. The Corine programmes have been taken over by the EEA. One of these is an inventory of land cover in 44 classes, presented as a cartographic product, at a scale of 1:100,000 and minimum mapping unit of 25 hectares. This database is operationally available for most areas of Europe (EEA, 1995). New versions

were produced for the reference years 2000, 2006, and 2012. The spatial extent of the Corine Land Cover database is 33 EEA member countries and six cooperating countries (Figure 4).

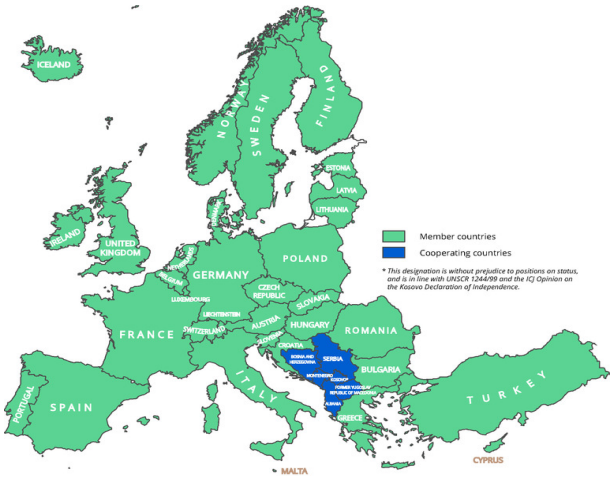

Figure 4: *EEA member countries and cooperating countries (EEA, 2017).*

Slika 4: *Države članice EEA in sodelujoče države (EEA, 2017).*

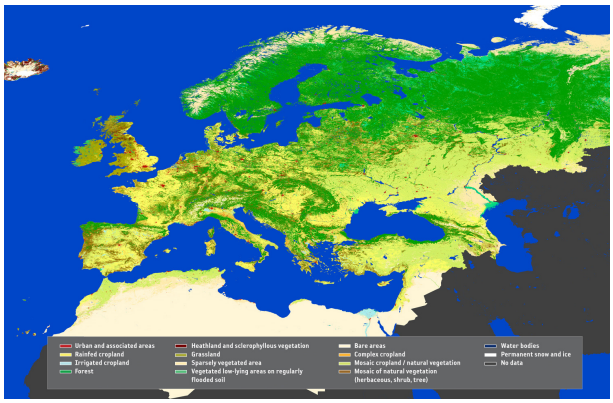

Figure 5: *GlobCorine2009 extent (source: http://www.esa.int/About_Us/ESRIN/Express_map_delivery_from_space).*

Slika 5: *Prostorski obseg GlobCorine2009 (vir: http://www.esa.int/About_Us/ESRIN/Express_map_delivery_from_space).*

GlobCorine 2009 is a joint project of the EEA and ESA for monitoring operational land dynamics at the pan-European scale. The resolution is less precise than that of Corine Land Cover (300 m), but its advantage is that it also covers the area outside EEA countries (whole European continent extended to the Mediterranean basin). The GlobCorine 2009 land cover map has been generated using the Medium Resolution Imaging Spectrometer Instrument (MERIS) with Full Resolution Full Swath (FRS) time series over the period spanning the entire year 2009 (Defourny et al., 2010). The extent of the GlobCorine map is shown in Figure 5. Its nomenclature has less detailed classes as nomenclature from Corine Land Cover, but its labels are aggregations of the CLC level 3 label; hence, all CLC level 3 labels can be converted into GlobCorine2009 nomenclature. Correspondence between these two nomenclatures is given by Defourny et al. (2010).

The Copernicus Riparian Zone Land Use/ Land Cover is the most precise (the highest number of classes as well as the highest resolution) land cover/ land use database. It covers a modelled 100-year return period flood hazard (JRC, 2018) and buffer strips along rivers where no modelling results exist. The classification is tailored to the needs of biodiversity monitoring for large and medium-sized European rivers (with Strahler levels larger than 3derived from EU-Hydro). Unfortunately, there is no data for Strahler order 1 and 2 rivers. Land use/land cover data is extracted from VHR satellite data, whose main objective is to support the mapping and assessment of ecosystems and their services (European Commission, 2018) as part of the EU Biodiversity Strategy to 2020. The classes follow the pre-defined nomenclature on the basis of MAES typology of ecosystems (EEA, 2015b), providing 80 distinct thematic classes with a Minimum Mapping Unit (MMU) of 0.5 ha and a Minimum Mapping Width (MMW) of 10 m. Data is available at the Copernicus program website (Copernicus Riparian Zone land data, 2018).

3.1.5 Population density disaggregated with Corine land cover 2000

Based on various databases such are Corine Land Cover and population census in 2001 provided by Eurostat and data of commune-level population densities, JRC has developed dataset “Population density disaggregated with Corine land cover 2000” (EEA, 2018d). Data are disaggregated to 100 m resolution. Detailed description of method is given in Gallego (2010).

3.2 State and impact databases

3.2.1 Waterbase – Water Quality (Freshwater quality)

The Water Information System for Europe (WISE) is a partnership between the European commission (DG Environment, Joint research Centre and Eurostat) and the European Environment Agency. Through WISE system countries are reporting data on water quality. The reporting scheme is named "WISE SoE – Water Quality (WISE-4)" where "SoE" means "State of Environment". The database updated by EEA each year is named "Waterbase – Water Quality" (EEA, 2018e). It comprises data on the physical characteristics of the river monitoring stations and proxy pressures on the upstream catchment areas, as well as chemical quality data on nutrients, organic matter, and hazardous substances in rivers. The locations of WISE SoE river quality stations are presented in Figure 6. Data is available for the period 1960–2017.

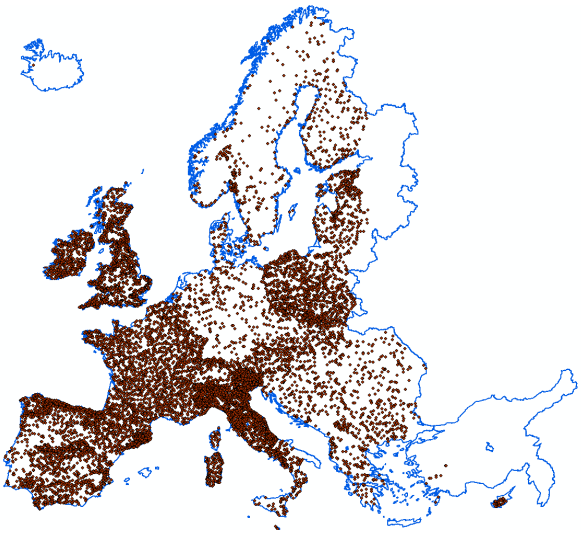

Figure 6: *Waterbase – Water Quality monitoring stations on rivers.*

Slika 6: *Merilne postaje na vodotokih Waterbase – Water Quality.*

3.2.2 Waterbase – Water Quantity, GRDC and EWA (River discharges)

There are three data sources of gauged river discharge: Waterbase – Water Quantity, Global Runoff Data Centre (GRDC), and European Water Archive (EWA).

Waterbase – Water Quantity dataset consists of data reported via WISE SoE Water Quantity (WISE-3) dataflow by EEA member states and its collaborating countries. Reported data are quality checked and then published EEA (EEA, 2013; EEA 2018f). This data covers the time period 1990–2015 on a daily interval, depending on monitoring site. The locations are unevenly distributed across the Europe (Figure 7) and are mostly different from Waterbase – Water Quality locations.

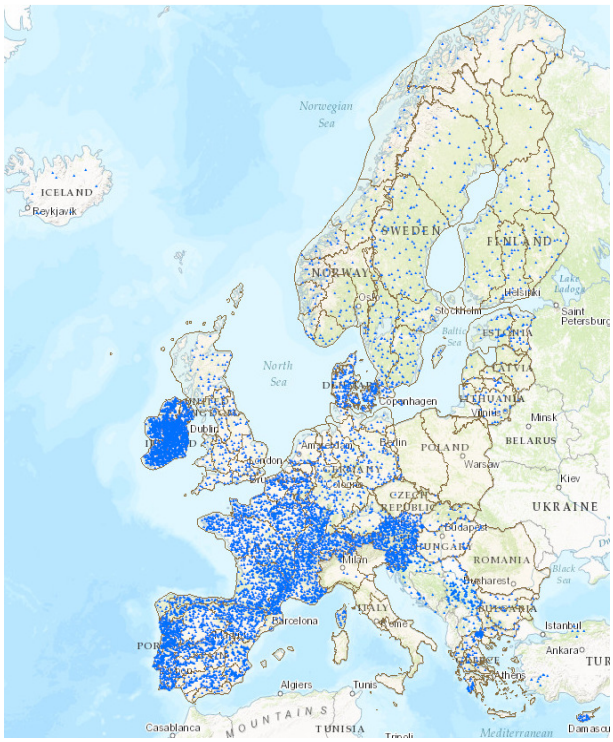

Figure 7: *Locations of Waterbase – Water Quantity stations on rivers.*

Slika 7: *Lokacije merilnih postaj pretokov na vodotokih Waterbase – Water Quantity.*

Global Runoff Database at Global Runoff Data Centre (GRDC) is a unique collection of river discharge data collected on a daily or monthly basis from more than 8000 gauging stations in 157 countries throughout the world, with more than 5000 located within the MARS spatial extent (BfG, 2018a). It includes also European Water Archive (EWA) monitoring stations (BfG, 2018b). In many cases WISE SoE river quantity and GRDC or EWA monitoring sites are overlapping or are representing the same station, but their locations slightly differ.

3.2.3 Bathing water quality

The bathing water database consists of data reported under the Bathing Water Directive (2006/7/EC). This database holds information on bathing water locations, their characteristics, and the values of two microbiological parameters: intestinal enterococci and *Escherichia coli*. Data is submitted on an annual basis by EU Member States and two collaborating countries, Albania and Switzerland. Reported data are checked for quality and disseminated annually as a database (EEA, 2018g). The temporal range of the database is 1991–2017 on an annual interval. In 2017, there were 21,801 bathing waters reported, of which 15,037 are coastal and 6,764 are inland, situated on rivers and lakes bathing water sites (EEA, 2018h).

3.2.4 WISE WFD Database (Ecological status and quality elements of inland water bodies)

The most extensive and prominent data on the state of European waters are collected through Water Framework Directive implementation process in all EU Member States and reported to European Commission via the system EIONET. The WISE WFD database (EEA, 2017b; 2018i) contains data from the 1st and 2nd River Basin Management Plans reported by EU Members States according to article 13 of the Water Framework Directive (WFD). The database includes information about surface water bodies (number and size, water body category, environmental status, and the status of four groups of quality elements: a) biological quality elements (phytoplankton and other aquatic flora, benthic invertebrates, fish), b) hydromorphological quality elements (hydrological or tidal regime, river continuity conditions, morphological conditions), c) chemical and physico-chemical quality elements, and d) river basin specific pollutants.

The spatial datasets as collected through the Water Framework Directive are stored separately as "WISE WFD reference spatial data sets" (EEA, 2018j). This database include information about European river basin districts (RBD), river basin district sub-units (SURBD), surface water bodies, groundwater bodies, and monitoring. It is a compilation of information reported by the EU Member States and Norway to the European Commission (EC) and the European Environment Agency (EEA) since 2010. Data on River Basin Districts (RBDs) that were first available in 2011 (EEA, 2011), are the main units for the management of river basins and have been delineated by Member States under Article 3 and updated by reporting to Article 13 of the Water Framework Directive.

For the purpose of the MARS project we extended the RBD units and subunits to the MARSgeoDB spatial extent, considering the sea catchment of the Black sea lying in Turkey and the sea catchment of the Baltic Sea belonging outside the EU-28 as shown in Figure 8. Additionally, we assigned codes to regional sea catchments and sub-catchments to all RBD subunits (SURBD) outside EU-28 countries. Slovenia has been divided into subunits as reported under WFD Article 3.

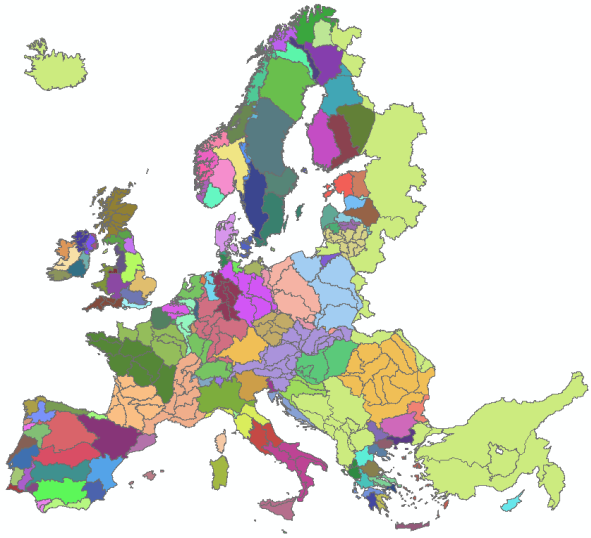

Figure 8: *RBD units and subunits as in MARS spatial database (MARSgeoDB).*

Slika 8: *Enote in podenote RBD v prostorski bazi MARS (MARSgeoDB).*

3.2.5 EFI+ Database (European fish index)

The European research project FAME was a research project that developed a methodology for assessing the ecological status of rivers based on fish species and in accordance with the WFD. One of the results is the European Fish Index ("EFI"), (FAME consortium, 2004). In the project that

followed, the index was upgraded to "EFI+" (EFI+ consortium, 2009). It quantifies the deviation between predicted (reference conditions) and observed fish assemblages and as such evaluates ecological status. The EFI+ database collects a lot of other data about the environmental characteristics of fish sampling sites and human pressures. It also has data on more than 14000 sites on 2700 European rivers (Figure 9).

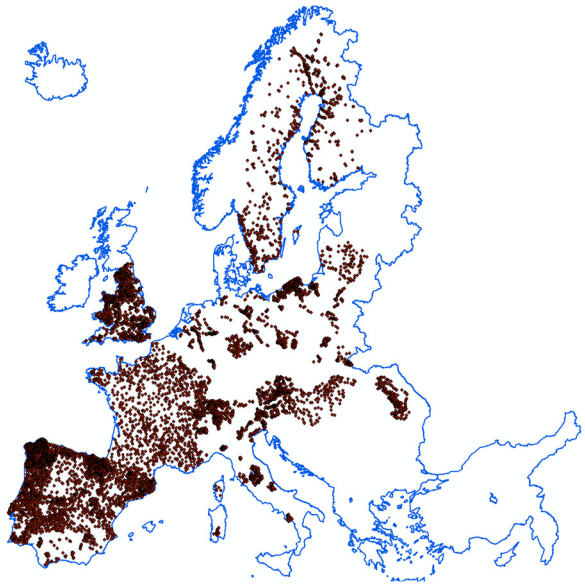

Figure 9: *EFI+ sampling sites.*

Slika 9: *Vzorčna mesta projekta EFI+.*

4. Data on climatology

Agri4cast is a collection of meteorological datasets available on a regular 25×25 km grid developed by Joint Research Centre – JRC (EC JRC, 2018b). Among others, the Interpolated Meteorological Datasets include daily maximum/minimum temperature, cumulated daily precipitation, evapotranspiration and wind speed (Biavetti et al., 2014). The temporal period is 1975–2014, while spatial availability is between -15° and 60° of Longitude and between 25° and 80° of Latitude.

WorldClim – Global Climate Data is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 km^2 (WorldClim, 2018). It is derived as an interpolation of observed data. In the first version, monthly precipitation and temperature data (average, min., max.) are available for the time period 1960–1990. The modelled data for past and future conditions are also available (Hijmans et al. (2005) and Fick and Hijmans (2017).

Global Precipitation Analysis Products of the Global Precipitation Climatology Centre – GPCC (GPCC, 2018) are gauge-based, monthly precipitation data available as gridded datasets of three different resolutions (2.5 × 2.5°, 1.0 × 1.0°, and 0.5 × 0.5°) (Schneider et al., 2015). Monthly data for the whole world are available from year 1901 to year 2009.

BADC (The British Atmospheric Data Centre) is one of the centres and facilities in the NERC Centres for Atmospheric Sciences (NCAS, 2018). It provides gridded monthly data on precipitation, mean temperature, diurnal temperature range, wet-day frequency, vapour pressure, cloud cover, and ground frost frequency (New et al., 2000) for the period 1901–2014. Datasets are available in 0.5° Latitude – Longitude grid cells over all land areas, including oceanic islands but excluding Antarctica. The primary variables (precipitation, mean temperature, and diurnal temperature range) were interpolated directly from station observations, while the remaining climatic elements, termed secondary variables, were interpolated from merged datasets comprising station observations and, in regions where there were no station data, synthetic data estimated using predictive relationships with the primary variables (New et al., 2000). Additionally, a high-resolution dataset of surface climate over global land areas with 10' latitude/longitude resolution are available as normal for period 1961-1990 (New et al., 2002). Wind speed was added to the climate parameters listed above.

5. Regions

Biotic communities depend not only on anthropogenically caused pressures on aquatic ecosystems but also on natural circumstances. It is therefore important to group freshwater ecosystems into regions when comparing biotic responses to pressures. Several different regionalisations were done, depending on the investigated biological groups and purposes of each investigation (larger or smaller regions).

5.1 Ecoregions for rivers and lakes

Ecoregions are based on fauna living in European inland waters, considering the outline by Illies (1978). Geographical extent is Pan-Europe, excluding Turkey (EEA, 2004). The layer consists of 25 ecoregions, 24 of them are fully or partially included inside the MARS database's spatial extent (Figure 10).

Figure 10: *Ecoregions for rivers and lakes (EEA, 2004).*

Slika 10: *Ekološke regije za vodotoke in jezera (EEA, 2004).*

5.2 Biogeographical regions

Natura 2000 biogeographical regions[2] are compiled, processed and published by EEA (2016). The biogeographical regions dataset contains the official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). Spatial extent is Pan-Europe. The layer consists of 11 biogeographical regions, out of which 10 are fully or partially included in MARS spatial database extent (Figure 11).

Figure 11: *Biogeographical regions (EEA, 2016).*

Slika 11: *Biogeografske regije (EEA, 2016).*

5.3 European hydro-ecoregions

European hydro-ecoregions were developed within "REBECCA – Relationships between ecological and chemical status of surface waters" project (Finnish Environmental Institute, 2007). Hydro-ecoregions are primarily based on geology, relief and climate (Wasson et al., 2007). There is 133 hydro-ecoregions throughout the Europe without Turkey (Figure 12).

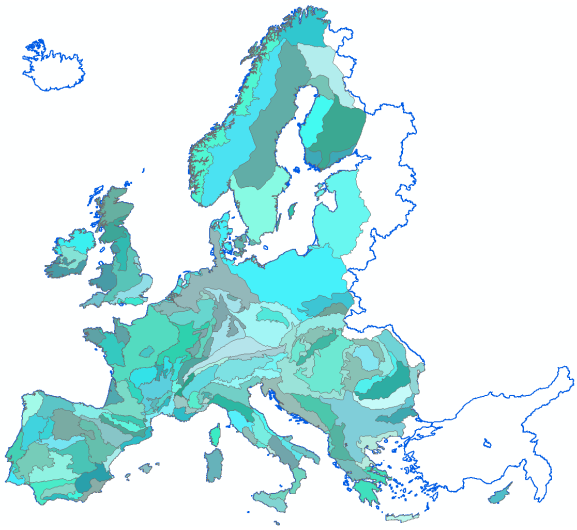

Figure 12: *Hydro-ecoregions (Wasson et al., 2007).*

Slika 12: *Hidroekoregije (Wasson et al., 2007).*

5.4 Broad hydro-regions

Broad hydro-regions were developed within MARS project, based on expert knowledge from the WFD inter-calibration exercise (Poikane et al., 2014). They are derived from the Natura 2000 biogeographical regions (chapter 5.2) and have five broad hydro-regions: Nordic, Eastern Continental, Alpine, Mediterranean, and Central and Baltic, the latest further divided into three hydro sub-regions: Atlantic, Mediterranean, and Continental (Figure 13).

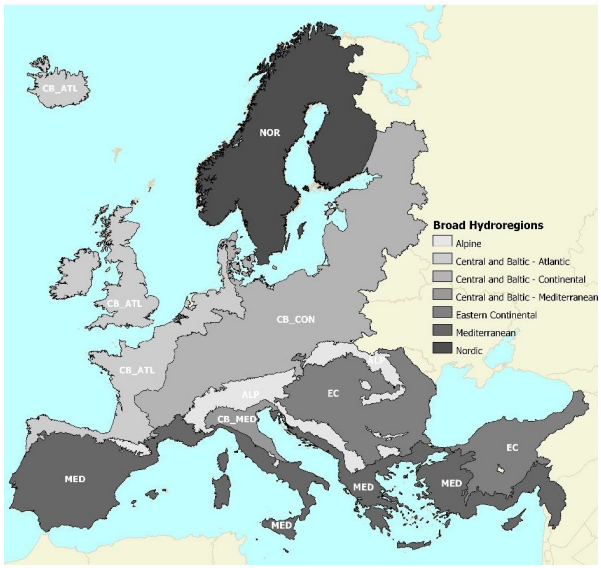

Figure 13: *Broad hydro-regions (MARS deliverable 5.1-1).*

Slika 13: *Evropske širše hidroregije (MARS deliverable 5.1-1).*

5.5 Freshwater ecoregions of the world by WWF (FEOW)

Freshwater ecoregions of the world (FEOW) were developed by World Wildlife Fund (WWF). They cover all freshwater habitats on Earth (449 regions); 35 of these regions are completely or partially included within the MARS spatial database's extent (Figure 14). Freshwater ecoregions are the first global biogeographic regionalization of Earth's freshwater systems and are based on the distributions and compositions of freshwater fish species, incorporating major ecological and evolutionary patterns (Abell et al., 2008).

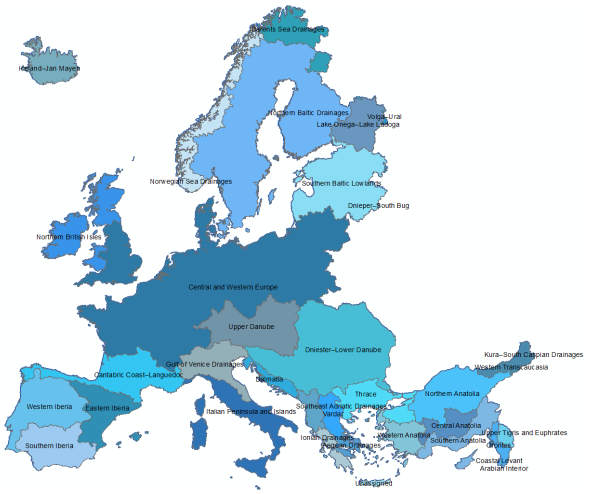

Figure 14: *WWF Freshwater ecoregions in Europe.*

Slika 14: *Kopenske ekoregije WWF v Evropi.*

6. MARS spatial database (MARSgeoDB)

The MARS spatial database, named "MARSgeoDB", unites and interlinks spatial elements from the databases described. It is divided into a vector part and raster part, each containing 55 or 56 feature classes (layers) respectively. Additionally, there is an associated non-spatial database consisting of 36 tables with additional attributes to spatial layers. The spatial extent of MARSgeoDB are river basins belonging to EU-28 countries, Norway, Iceland, Switzerland, Liechtenstein, Andorra, Serbia, Bosnia and Herzegovina, Former Republic of Macedonia, Montenegro, Kosovo, and Turkey in the Black Sea basin region and the non EU-28 drainage area of the Baltic Sea.

The MARS spatial database is built on the basis of ECRINS FEC, therefore all the data from other spatial units (polygons) are transformed (recalculated) to FECs. Point data are linked with FECs (as well as with river segments) and can be summed by FECs. Spatial and associated attribute data were quality checked, in some cases modified or newly developed (attributes) and harmonised. Special effort was dedicated to spatially link SoE stations to their appropriate river segment, to find different possible river names referring to the same river, and to unify water body codes from different

sources. Point data related to rivers were not just linked but also shifted to ECRINS river segments.

7. Conclusions

In the past, a lack of data posed a big problem in conducting research. These days, however, there are more and more freely available databases. It is a challenge to evaluate the quality of the data and to select the most reliable and usable data for the purpose needed. After selecting different databases, the crucial and often very time-consuming step is to bring all to one common spatial system, to interlink spatial objects, and to harmonize their codes and names. Only then can databases be used in a study.

Moreover, it is important to consider that the majority of databases are being regularly updated and are expanding. New attributes to the same spatial objects are added, spatial objects are modified or newly added. Hence, it is recommended to arrange data in a way to be able to add new data or to replace data with updates.

Acknowledgements

This work was funded by the MARS project (Managing Aquatic Ecosystems and Water Resources under Multiple Stress), funded by the European Union under the 7th Framework Programme, contract no. 603378.

References

Abell, R., Thieme, M. L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Bakderas, S. C., Bussing, W., Stiassny, M. L. J., Skelton, P., Allen, G. R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J. V., Heibel, T. J., Wikramanayake, E., Olson, D., López, L., Reis, R. E., Lundberg, J. G., Pérez, M. H., Petry, P. (2008). Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation, *BioScience* **58/5**, 403–414. https://doi.org/10.1641/B580507

BfG (2018a). Bundesanstalt für Gewässerkunde. Global Runoff Data Base. Available at: https://www.bafg.de/GRDC/EN/01_GRDC/13_dtbse/database_node.html

BfG (2018b). European Water Archive (EWA) of EURO-FRIEND-Water. Available at: https://www.bafg.de/GRDC/EN/04_spcldtbss/42_EWA/ewa_node.html

Biavetti, I., Sotiris Karetsos, S., Ceglar, A., Toreti, A., Panagos, P. (2014). European meteorological data: contribution to research, development, and policy support. Proc. SPIE 9229, Second International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2014), 922907 (August 12, 2014). http://dx.doi.org/10.1117/12.2066286

Copernicus Riparian Zone land data (2018). https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image (accessed 15 March 2017, 11 December 2018).

Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC) (1991). Official Journal of the European Communities, No L 135/40.

Defourny, P., Bontemps, S., van Bogaert, E., Weber, J.-L., Steenmans, C., Brodsky, L. (2010). GLOBCORINE 2009. Description and validation report. UCL-Geomatics.

EC Eurostat (2018a). Eurostat Database. Website: https://ec.europa.eu/eurostat/data/database (accessed 14 March 2017, 11 December 2018).

EC Eurostat (2018b). NUTS – Nomenclature of territorial units for statistics. Available at: http://ec.europa.eu/eurostat/web/nuts (accessed 14 March 2017, 11 December 2018).

EC JRC (2018a). Catchment Characterisation and Modelling (CCM). Available at: http://inspire-geoportal.ec.europa.eu/demos/ccm/ (accessed 24 March 2017, 11 December 2018).

EC JRC (2018b). European Commission Joint Research Center. Agri4Cast Data. http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx. (accessed 24 March 2017, 11 December 2018).

EEA (1995). CORINE Land Cover. Available at: http://www.eea.europa.eu/publications/COR0-landcover (accessed 13 March 2017).

EEA (2004). Ecoregions for rivers and lakes. Available at: http://www.eea.europa.eu/data-and-maps/data/ecoregions-for-rivers-and-lakes#tab-gis-data (accessed 21 March 2017).

EEA (2011). WISE River basin districts (RBDs). Available at: http://www.eea.europa.eu/data-and-

maps/data/wise-river-basin-districts-rbds-1#tab-gis-data (accessed 13 March 2017).

EEA (2012). EEA Catchments and Rivers Network System ECRINS v1.1. (Rationales, building and improving for widening uses to Water Accounts and WISE applications). EEA Technical Report No7/2012. Copenhagen, 111 p.

EEA (2013). Waterbase – Water Quantity. Available online: http://www.eea.europa.eu/data-and-maps/data/waterbase-water-quantity-7 (accessed 24 March 2017).

EEA (2015). Copernicus Land Monitoring Service – Reference Data: EU-Hydro. Flyer [online]. Available at: file:///C:/Users/Mkoprivs/Downloads/EU-HYDRO%20FLYER.pdf (accessed 8 March 2017).

EEA (2014). Waterbase – UWWTD: Urban Waste Water Treatment Directive – reported data (website): http://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-4#tab-figures-produced (accessed 9 March 2017).

EEA (2015a). Copernicus Land Monitoring Service. EU-Hydro River Network. Metadata. https://land.copernicus.eu/imagery-in-situ/eu-hydro/eu-hydro-public-beta/eu-hydro-river-network?tab=metadata (accessed 12 December 2018).

EEA (2015b). Copernicus Initial Operations 2011–2013. Land Monitoring Service Local Component: Riparian Zones. FINAL NOMENCLATURE GUIDELINE. https://land.copernicus.eu/user-corner/technical-library/RZ_CS3_17_Nomenclature_Guideline_I30.pdf

EEA (2016). Biogeographical regions. Available at: http://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3 (accessed 22 March 2017).

EEA (2017a). Countries and Eionet. Available at: http://www.eea.europa.eu/about-us/countries-and-eionet (accessed 14 March 2017).

EEA (2017b). WISE WFD Database (Water Framework Directive Database. Available at: https://www.eea.europa.eu/data-and-maps/data/wise-wfd (accessed 14 March 2017).

EEA (2018a). Waterbase – UWWTD: Urban Waste Water Treatment Directive – reported data. Available at: https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-5 (accessed 11 December 2018).

EEA (2018b). European Pollutant Release and Transfer Register. Available at: http://prtr.ec.europa.eu/#/home (accessed 10 March 2017).

EEA (2018c). European Pollutant Release and Transfer Register (E-PRTR) – Microsoft Access database and text format. Available at: https://www.eea.europa.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-21/european-pollutant-release-and-transfer-register-e-prtr-data-base. (accessed 11 December 2018).

EEA (2018d). Population density disaggregated with Corine land cover 2000. Available at: https://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2#tab-methodology (accessed 23 March 2017, 11 December 2018).

EEA (2018e). Waterbase – Water Quality. Available at: https://www.eea.europa.eu/data-and-maps/data/waterbase-water-quality-1. (accessed 11 December 2018)

EEA (2018f). Waterbase – Water Quantity. Available at: https://www.eea.europa.eu/data-and-maps/data/waterbase-water-quantity-10 (Accessed 11 December 2018).

EEA (2018g). Bathing Water Directive – Status of bathing water. Available at: https://www.eea.europa.eu/data-and-maps/data/bathing-water-directive-status-of-bathing-water-10. (accessed 12 December 2018).

EEA (2018h). EEA report – European Bathing Water Quality in 2017. Available at: https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/state-of-bathing-water. (accessed on 12 December 2018).

EEA (2018i). WISE WFD Database (Water Framework Directive Database) Available at: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2. (accessed 12 December 2018).

EEA (2018j). WISE WFD reference spatial data sets. Available at: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-spatial-1 (accessed on 12 December 2018).

EFI+ consortium (2009). Manual for the application of the new European Fish Index – EFI+. A fish-based method to assess the ecological status of European running waters in support of the Water Framework Directive. June 2009.

FAME consortium (2004). Manual for the application of the European Fish Index - EFI. A fish-based method to assess the ecological status of European rivers in support of the Water Framework Directive. Version 1.1, January 2005.

Fick S. E., Hijmans, R. J. (2017). WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. International *Journal of Climatology* **37/12**, 4302–4315. https://doi.org/10.1002/joc.5086.

Finnish Environmental Institute (2007). REBECCA – Relationships between ecological and chemical status of surface waters. Final Report Summary of the project. EU 6th FP. Available at: https://cordis.europa.eu/result/rcn/47775_en.html

Gallego F. J. (2010). A population density grid of the European Union, *Population and Environment*. 31: 460–473. https://doi.org/10.1007/s11111-010-0108-y.

GlobCorine2009 map on ESA website: http://www.esa.int/About_Us/ESRIN/Express_map_delivery_from_space (accessed 15 March 2017).

Globevnik, L., Koprivsek, M., Snoj, L. (2017). Metadata to the MARS spatial database. *Freshwater Metadata Journal*, 21, 1–7. https://doi.org/10.15504/fmj

GPCC (2018). Global Precipitation Climatology Centre (GPCC) https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre (accessed 11 December 2018).

Haines-Young, R., Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being. In D.G. Raffaelli & C.L.J. Frid (Eds.) Ecosystem Ecology: a new synthesis. Cambridge: Cambridge University Press: 110–139.

Hering, D., Carvalho, L., Argillier, C., Beklioglu, M., Borja, A., Cardoso, A. C., Duel, H., Ferreira, T., Globevnik, L., Hanganu, J., Hellsten, S., Jeppesen, E., Kodeš, V., Solheim Lyche, A., Nõges, T., Ormerod, S., Panagopoulos, Y., Schmutz, S., Venohr, M., Birk, S. (2015). Managing aquatic ecosystems and water resources under multiple stress — An introduction to the MARS project, *Science of the Total Environment* **503–504**, 10–21. https://doi.org/10.1016/j.scitotenv.2014.06.106.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**: 1965–1978. https://doi.org/10.1002/joc.1276.

Illies, J. (ed.) (1987). *Limnofauna Europaea*. Gustav Fischer Verlag Stuttgart, 532 p.

MARS (2018). MARS – Managing Aquatic ecosystems and Water Resources under multiple stress. Website: http://www.mars-project.eu/.

MARS (2018). MARS - Managing Aquatic ecosystems and Water Resources under multiple stress. http://www.mars-project.eu (accessed 6 March 2017; 12 December 2018).

NCAS (2018). NERC National Centre for Atmospheric Science webpage: https://www.natureindex.com/institution-outputs/united-kingdom-uk/nerc-national-centre-for-atmospheric-science-ncas/524cc549140ba02660000000/Earth%20&%20Environmental%20Sciences. (accessed 12 March 2017, 11 December 2018).

New, M., Hulme, M., Jones, P. (2000). Representing Twentieth-Century Space–Time Climate Variability. Part II: Development of 1901–96 Monthly Grids of Terrestrial Surface Climate, *Journal of Climate* **13**, 2217–2238. https://doi.org/10.1175/1520-0442(2000)013<2217:RTCSTC>2.0.CO;2.

New, M., Lister, D., Hulme, M., Makin, I. (2002). A high-resolution data set of surface climate over global land areas, *Climate Research* **21**, 1–25. https://doi.org/10.3354/cr021001.

Poikane, S., Zampoukas, N., Borja, A., Davies, S. P., Bund, W., Birk, S. (2014). Intercalibration of aquatic ecological assessment methods in the European Union: Lessons learned and way forward, *Environmental Science and Policy* **44**, 237–246. https://doi.org/10.1016/j.envsci.2014.08.006.

Schneider, U., Ziese, M., Becker, A., Meyer-Christoffer, A., Finger, P. (2015). Global Precipitation Analysis Products of the GPCC. Deutscher Wetterdienst, Offenbach a. M., Germany, May 2015, 14 p. Available at: ftp://ftp-anon.dwd.de/pub/data/gpcc/PDF/GPCC_intro_products_2008.pdf.

Vogt, J., Sollie, P., de Jager, A., Rimavičiūtė, E., Mehl, W., Fosineau, S., Bódis, K., Paracchini, M. L., Haastrup, P., Bamps, C. (2007). A pan-European River and Catchment Database. Joint Research Centre, Italy. 124 p.

Wallis, C., N. Séon-Massin, F. Martini, Schouppe, M. (2011). Implementation of the Water Framework Directive. When ecosystem services come into play. 2nd "Water Science meets Policy" Event. Brussels, 29–30 September 2011. ONEMA and DG R&I: Brussels.

Wasson, J.-G., Chandesris, A., Garcia-Bautista, A., Pella, H., Villeneuve, B. (2007). Relationships between ecological and chemical status of surface waters. European Hydro-Ecoregions. REBECCA, EU 6th Framework Programme, Contract No. SSPI-CT-2003-502158, Cemagref, Lyon, France, 44 p.

WorldClim (2018). WorldClim – Global Climate Data. Free climate data for ecological modelling and GIS. Available at: http://www.worldclim.org/version1 (accessed 15 March 2017, 11 December 2018).