RIVERS AND DAMS
IN THE WIDER MEDITERRANEAN BASIN

Overview of hydropower plants and projects, hydromorphological status and protected areas

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Preface

This study is the first comprehensive attempt to provide a large-scale overview of hydropower plants and rivers in the extended Mediterranean basin using a methodology based on European standards. The study analyses and ranks the hydromorphological intactness of main rivers and integrates the results with data on protected areas and key biodiversity areas according to IUCN.

The extensive preparatory work and experience of the Balkan – Blue Heart of Europe project initiated by RiverWatch and EuroNatur since 2012, increased the comprehensiveness of this inventory.

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List of Acronyms

AD	Andorra
AL	Albania
BA	Bosnia and Herzegovina
BG	Bulgaria
BI	Burundi
CD	Democratic Republic of Congo
CEN	European Committee for Standardization
CH	Switzerland
DZ	Algeria
EG	Egypt
EH	Western Sahara
EIA	Environmental Impact Assessment
ER	Eritrea
ES	Spain
ET	Ethiopia
FFH-D	Flora Fauna Habitat Directive (Natura 2000 network)
FR	France
FR-D	Flood Risk Directive
GR	Greece
HPP	Hydropower plant (visualized as dam on the rivers)
HR	Croatia
IHA	International Hydropower Association
IL	Israel
IT	Italy
IUCN	International Union for the Conservation of Nature
IQ	Iraq
JO	Jordan
KE	Kenya
KV	Kosovo
LB	Lebanon
LY	Libya
MA	Morocco
MC	Monaco
ME	Montenegro
MK	Nord-Macedonia
MT	Malta
MW	Megawatt (installed power)
PT	Portugal
rkm	River Kilometer
RS	Serbia
RW	Rwanda
SD	Sudan
SI	Slovenia
SM	San Marino
SS	South Sudan
SY	Syria
TN	Tunisia
TR	Turkey
TZ	Tanzania
UG	Uganda
WFD	EU Water Framework Directive
WWF	World Wide Fund for Nature

Executive Summary

This study provides the first comprehensive overview of hydropower plants in the wider Mediterranean basin. In total, 11,864 hydropower plants (HPP) were recorded, of which 5,269 were “existing”, 6,393 were “planned” and 202 were “under construction”. The major hotspot of dam construction and planned HPPs in the Mediterranean basin is the Balkan peninsula with 58% and 78% of the planned and under-construction projects, respectively.

The HPP study was overlaid with the protected areas (PA) network and the IUCN Key Biodiversity Areas (KBA) to identify conflicts. Of the newly planned HPP, 31% were inside a PA and 12% were inside a KBA. In total, 2,091 planned HPP are in a protected area, of which 503 are in the most protected category such as national parks, World Heritage sites, Ramsar sites and biosphere reserves. 825 are in KBAs.

The hydromorphological condition of 66,791 river km were also assessed. 23% of those rivers had a near-natural condition, 27% had a slightly modified hydromorphological condition, 28% had moderately modified condition, and the remaining 22% had either extensively or severely modified condition. The latter two categories are most affected by hydropower, namely impoundments. The analysis results in significant regional differences and larger near-natural rivers can be found only sparsely in Europe, e.g. with spots in Albania and the largest share of the “best” quarter can be still find in the Nile basin.

Project region and covered river network: the project area comprises the Mediterranean Sea hydrographic basin, and additional catchments in Spain, Portugal, Morocco, and Turkey. As the study builds on the Balkan inventory of hydropower plants and river assessments (Schwarz 2012, 2015, RiverWatch & EuronNatur 2018) and to be entirely consistent in method and inventory development, it was decided to include entire Balkan countries (compare figure ES1). For a better understanding and readability in total 6 geographical sub-regions were defined, beginning with the Iberian Peninsula and following clockwise to Central Western Mediterranean region, the Balkan region (incl. whole Greece), the Eastern Mediterranean region, the Nile basin, and the Maghreb region.

The project area comprises three areas: first, the hydrographic basin of the Mediterranean Sea; second, the “Mediterranean” climatic zone, including central Spain and Portugal, and western Anatolia and the Atlantic catchments of Morocco; third, the Balkan countries. The methodology used from the previous Balkan assessment (compare overview map figure ES 1 on next page), was also used in this assessment. For this report, we present the results altogether, an area of 6,506,990 km² (the hydrographic basin has a size of 5,024,809 km²) and a drainage network of roughly 400,000 rkm. The drainage network includes both intermittent and temporal streams, of which 66,791 rkm were stretches of major rivers and were considered in the hydromorphological assessment[1].

[1] The hydromorphological assessment considered rivers longer than 200 km and with a watershed larger than 500 km².

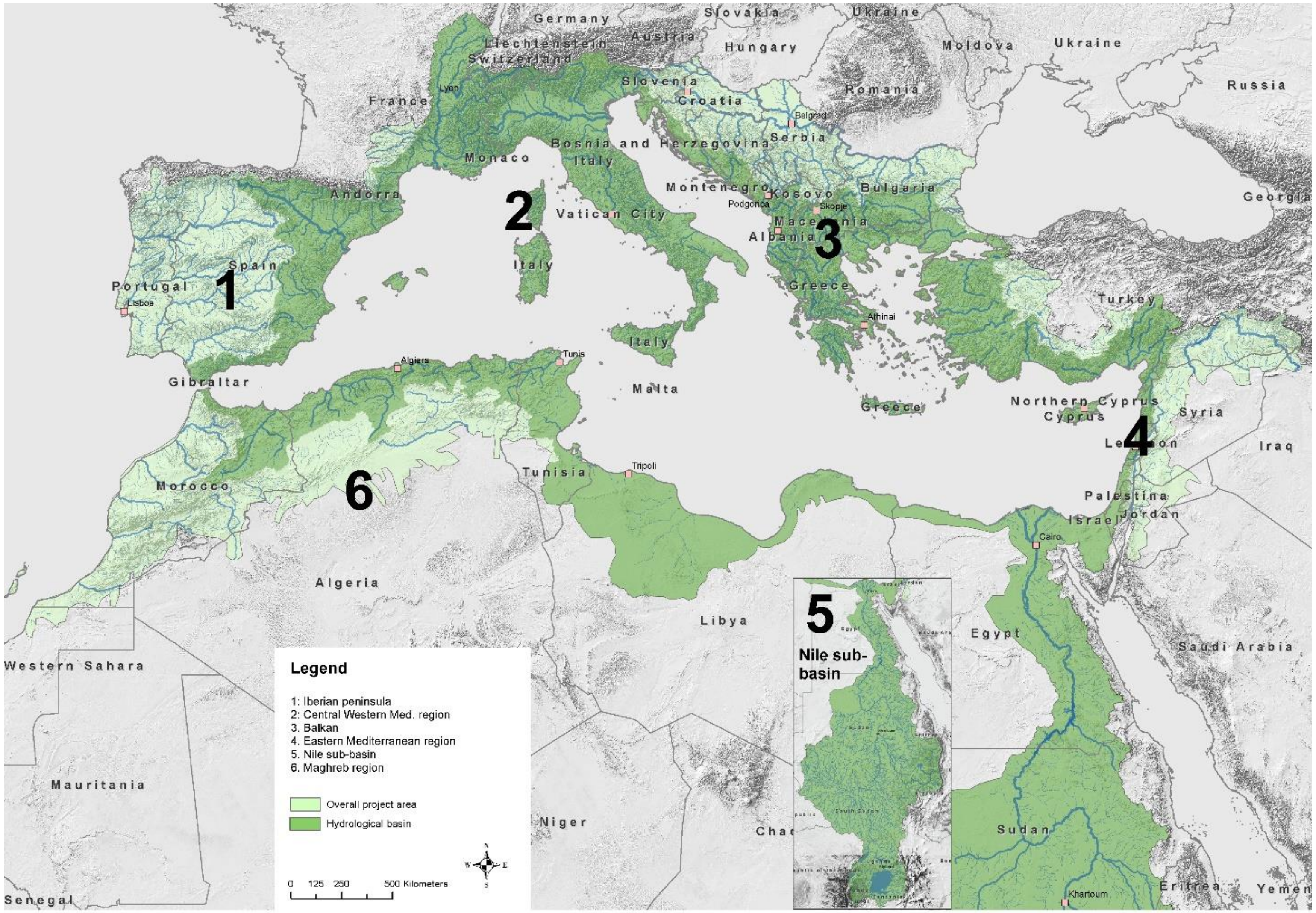


Figure 1: Overview of the six geographic regions included in the study area

The results are summarized by “Hydropower”, “Hydromorphological Assessment”, and “Dams in Protected Areas and Key Biodiversity Areas”.

Hydropower

In total 11,864 HPP have been recorded, of which 6,393 are planned, 202 are under construction and 5,269 exist.

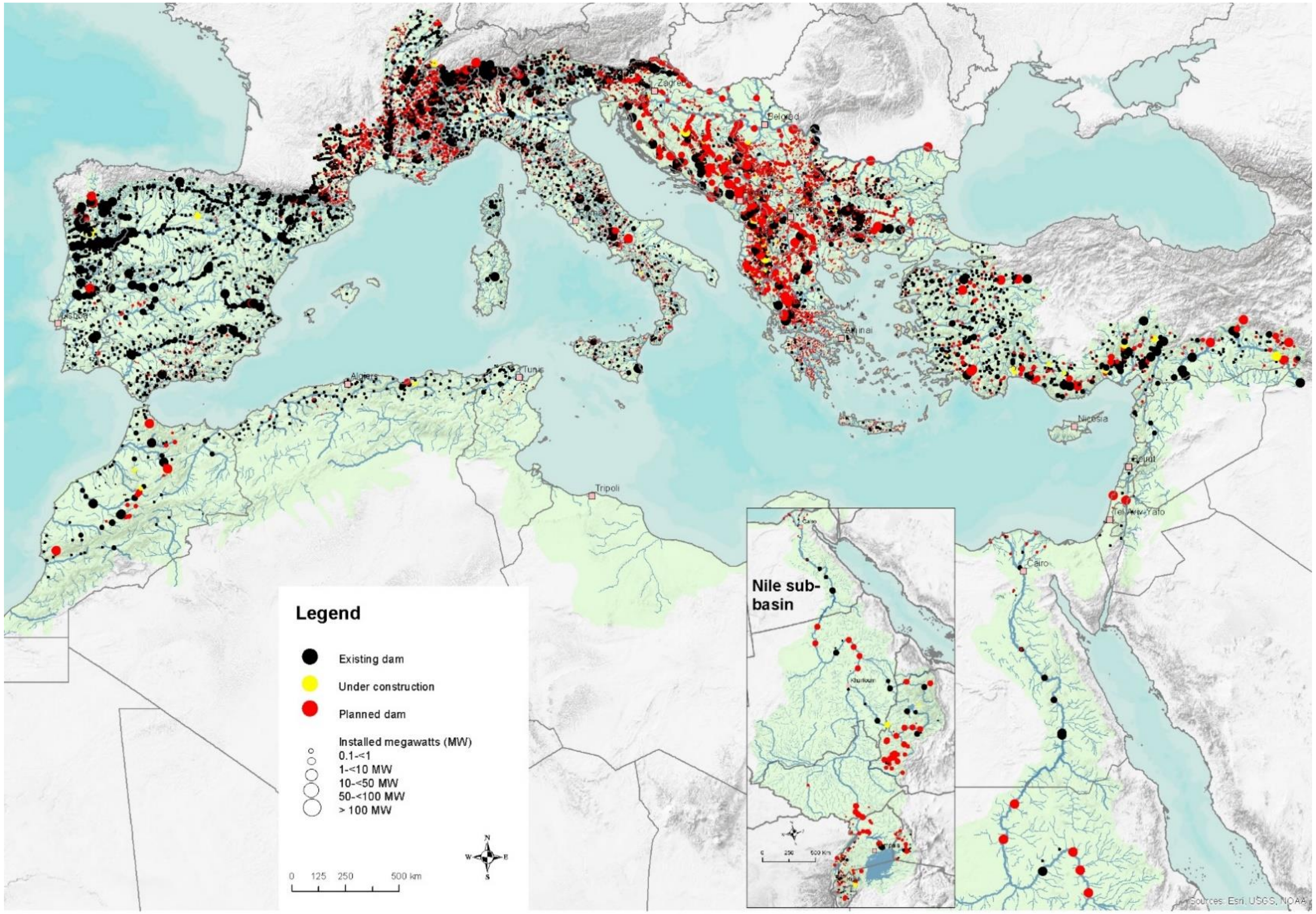


Figure 2: Distribution of recorded hydropower plants

Figure 2 summarises the distribution of all recorded hydropower plants (HPP). The most common size class in this study were small hydropower plants (SHP). SHP range from 0.1-<1 MW, and comprise 48% of all HPP, directly followed by the size class of 1-<10 MW. 76% of SHP are "planned", however their distribution is inconsistent in some countries, such as Portugal and Turkey, focus on large hydropower plants. Large HPP in Europe, those greater than > 100 MW, are mainly used as pumping storage systems. Altogether, there are more planned HPP (6,393) than existing and under construction combined (5,471).

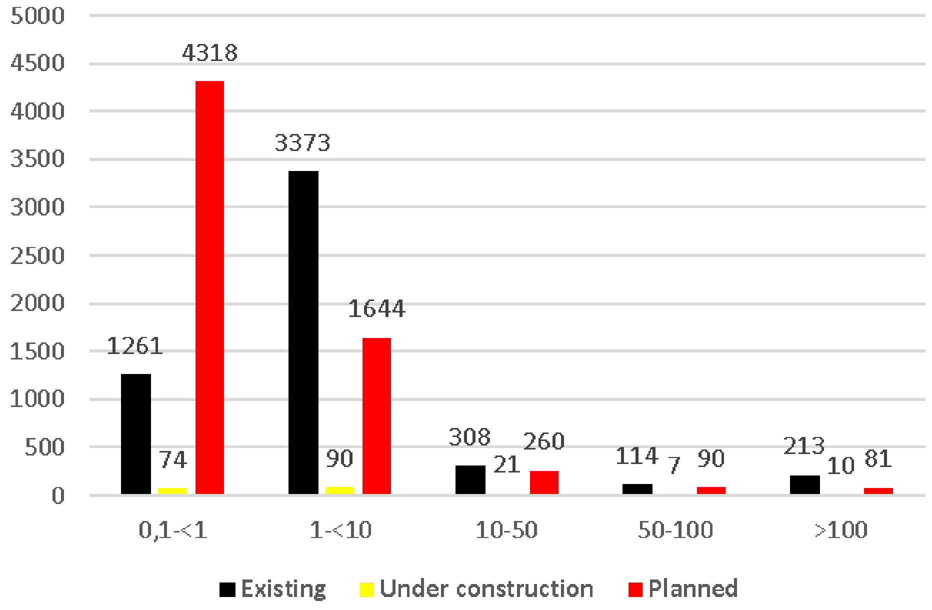


Figure 3: Distribution of all recorded hydropower plants by status and size

By visualising the distribution by region, hydropower development hotspots can be identified. However, countries vary by average HPP class and development characteristics. Greece for example has a large number of potential SHPs, yet the development has been slow in comparison to Serbia, Albania and Bosnia & Herzegovina. Turkey and partially Portugal increased the number of large HPP in recent years. Several organisations and EU initiatives[2] promote the development of SHPs in countries like France, Italy and Spain where larger rivers are increasingly exploited. However, the development of SHPs in European countries is slow due to legislative and administrative obstacles.

[2] http://www.restor-hydro.eu/

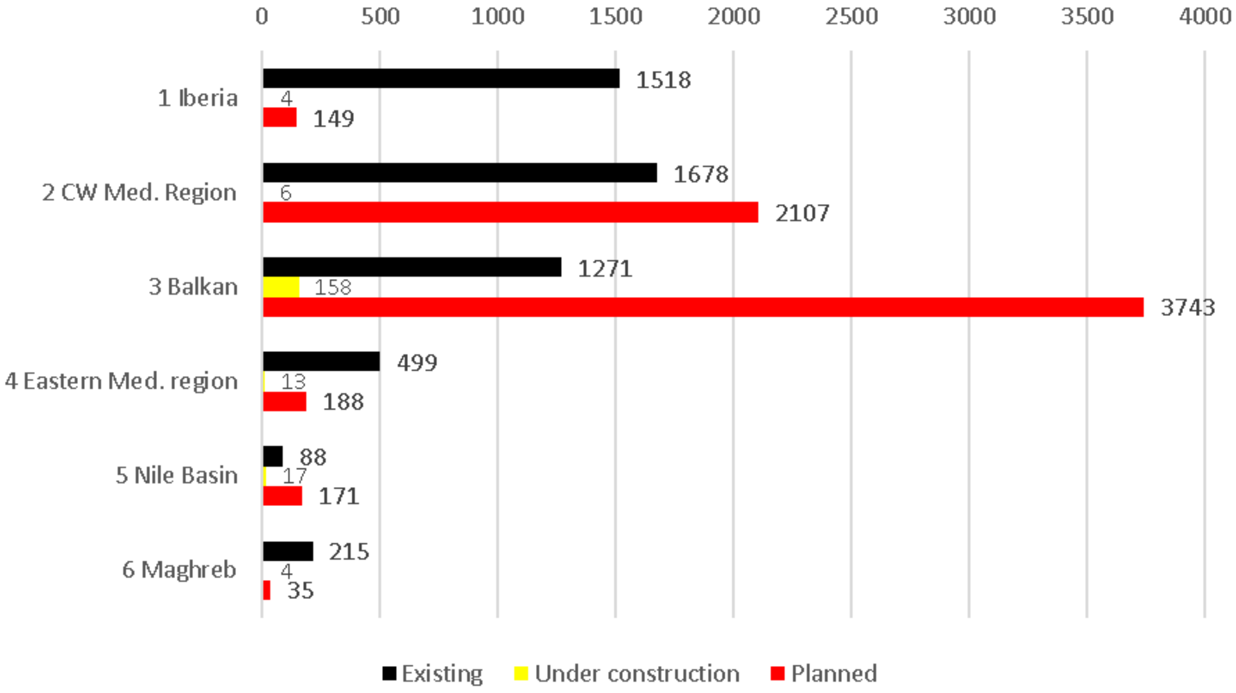


Figure 4: Distribution of hydropower plants in the six regions included in this study

In 2019 in northern Africa[3] 62 projects are under construction and 621 projects planned. The installed capacity will be increased from 16,109 by additional 76,786 MW. This magnitude of HPP planning can be compared with the development in South-America and Asia.

[3] https://www.africa-energy.com/database

Hydromorphological assessment

A basic hydromorphological assessment of major rivers (66,791 rkm) was prepared to increase understanding of alterations to river systems and to delineate the last remaining intact river stretches. For several regions, this was the first such delineation based on European Standards (CEN 2004 and 2010) which define five alteration classes: class 1 (near-natural, blue colour), class 2 (slightly modified, green), class 3 (moderately modified, yellow), class 4 (extensively modified, orange) and class 5 (severely modified/impoundments, red). The assessment was completed using remote sensing and publicly available documentation.

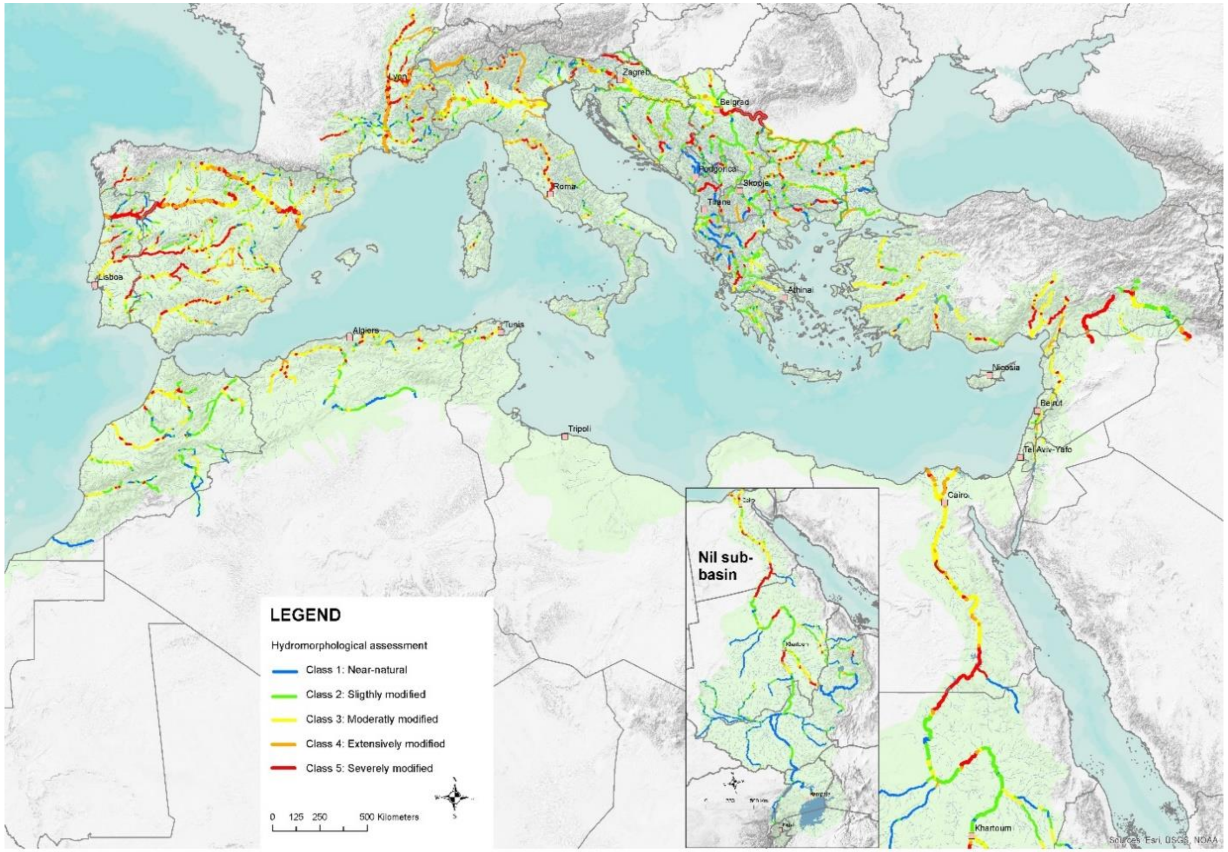


Figure 5: Hydromorphological assessment of the entire study area

The hydromorphological analysis, indicates the general high level of alteration to all sizes of rivers. The main driver of alterations is hydropower. In total 66,791 km of large rivers were evaluated. Roughly half of the rivers fall in class 1 and class 2, another quarter fall in class 3, and the rest fall into the most altered classes 4 and 5. Nearly 10,000 km out of some 15,000 km in class 1 and 5,000 km out of some 18,000 km in class 2 were found in the southern Nile basin, highlighting the poor situation in Europe. The general alterations for class 3 include navigation, land reclamation, agriculture, flood protection), and class 4 and 5 largely hydropower (i.e. impoundments). But the construction of larger dams in the middle of a river continuum has severe impacts on primarily downstream ecosystems, by changing hydrological and sedimentological conditions. Upstream, dams interrupt species' migrations as well as regional fragmentation of terrestrial and aquatic fauna. Therefore, many rivers are disturbed far up and downstream from a large dam.

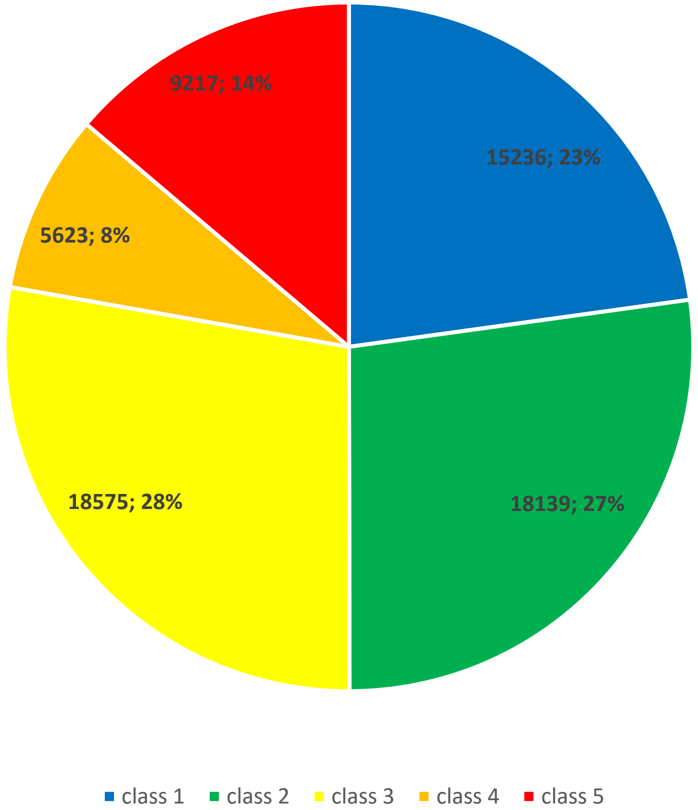


Figure 6: Overview of the hydromorphological assessment, by river kilometre and percentage, for the study area

Dams in protected areas and key biological areas

The protected areas fall into three main categories: the first category includes national parks, Ramsar sites, World Heritage sites and biosphere reserves; the second category includes Natura2000, Emerald areas for Eastern Europe, and nature reserves; the third category is the least strict and mainly includes landscape protections. Overlapping protected areas and planned hydropower plants indicate potential conflicts and could be used to prioritize rivers which to be excluded from further hydropower development. The IUCN Key Biodiversity Areas were also used to identify where such key biodiversity areas and planned hydropower projects intersect. Fish were also analysed as core indicator in an additional study.

For protected areas, the overall analysis indicated 31%, or 3,734 (2,091 planned (503 in the highest category), 64 under construction and 1,579 operating HPP), of all HPP were inside a protected area. 1,394 HPP can be find in key biological areas (825 planned).

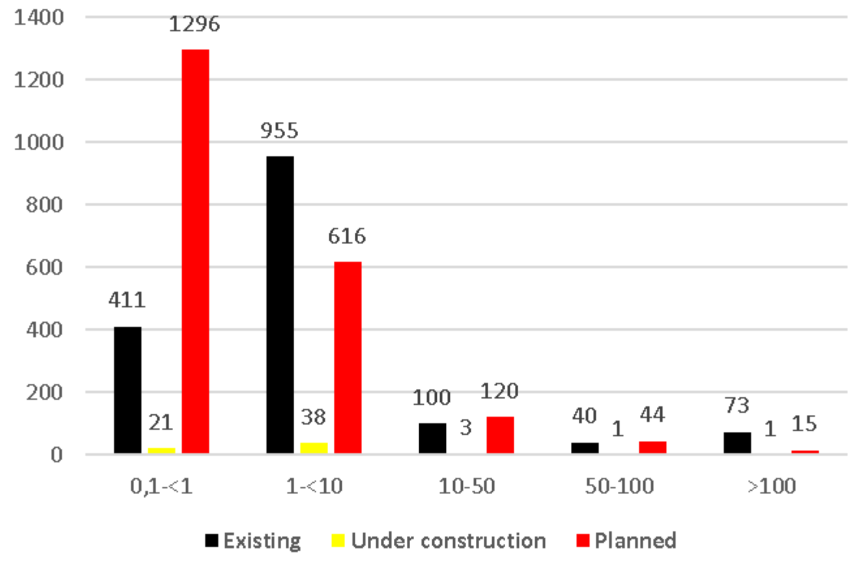


Figure 7: Hydropower plants inside of protected areas

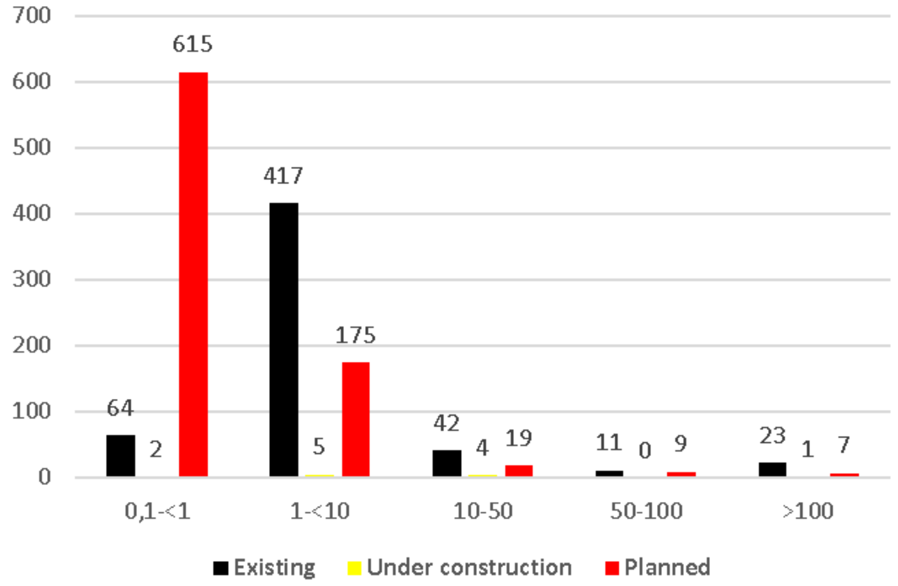


Figure 8: Hydropower plants inside of key biodiversity areas

Aside from HPP development in Natura2000 areas, the number of planned HPP in the first two core categories (best preserved and important protected areas) is alarming: 1,860 HPP (507 in national parks, heritage or Ramsar sites or biosphere reserves), 1,353 in Natura2000 or Emerald areas or nature reserves.).

Conclusions

- The first map of hydropower plants for the entire Mediterranean region is now available. The high number of existing HPP will further increase in some regions like the Balkans even though it is home to the last free-flowing river stretches.
- A significant number of main rivers were hydromorphologically assessed following the EU CEN standard. As expected, for western European countries most of the rivers are already utilised for hydropower. The Tagus, Duero or Rhône rivers comprise hundreds of km long chains of impoundments. The Balkan region however still host the most of near-natural rivers. African rivers (e.g., southern Nile catchment) host long near-natural rivers; however, large hydropower projects are accelerating the destruction that began with the Aswan dam in the 1970s.
- The overlap of protected areas and HPP indicates a large pressure on rivers. Even in the highest protection categories HPP are planned. Endemic fish and other species may not return after destruction.

Recommendations

- The high number of existing plans reflects the poor hydromorphological conditions of rivers across Western Europe. The number of planned HPP exceeds the number of existing HPP, underlining the ongoing pressure on rivers. Only a moratorium or stop of all major HPP and a reconsideration of numerous small HPP can decrease the process of destruction.
- Dams and HPP cause long-term deterioration (e.g., channel incision downstream of dams, altered hydrological conditions such as altered flood regimes and rivers with long residual water stretches). Therefore, existing HPP need rapid restoration by way of morphological improvements such as decommissioning of dams.
- No further dams should be constructed in protected areas. Many river valleys in south-eastern Europe are still without any protection, also many Emerald areas still missing for those important corridors.

- Ecosystem services and natural-based solutions should be increasingly used to reduce flood risks and coastal erosion, to complement considerably or even substitute “grey” infrastructures such as dams (mostly for hydropower) and embankments.
- Cultural benefits of main free-flowing rivers should be considered in all development of plans for future HPPs.

1. Introduction

The Mediterranean basin is rich in natural and cultural heritage formed by its lifelines, the rivers and valleys being a source for civilisation and agriculture over millennia. Aside of the last remaining wild European rivers as such as the Vjosa in Albania, some of the North African rivers in Morocco and Algeria also keep natural treasures. The Nile’s continental or global function spans several climatic zones and nearly the entire repertoire of fluvial landforms and river types. However, along its desert route, the Nile is intensively used for irrigation and hydropower. Both (e.g., Aswan dam impoundment and irrigation) have led to significant evaporation, bringing attention to the fragility of rivers in semiarid and arid climate zones, before considering the further effects of climate change.

The WWF has identified the Mediterranean region and Nile basin as key places for biodiversity conservation (i.e. Global 200 ecoregions) and IUCN has identified many of the Mediterranean rivers assessed in this study as Key Biodiversity Areas (KBA). The biodiversity found in the Mediterranean is capital that the region could build its future upon. To ensure that economic development goes hand-in-hand with the conservation of this natural treasure, a wise and forward-looking approach in planning is needed.

The geographic bounds of this study span the entire hydrologic basin of the Mediterranean Sea, including the Nile sub-basin, Atlantic catchments (Western Sahara, Portugal and Central Spain), some catchments in the Levante region, and Anatolia (*see* Figure 1). The intent is to cover all areas influenced by the Mediterranean, as well as areas under investigation for threatened fish species by the IUCN. Although the Nile sub-basin is not in the focus of the analysis, the comparison of this basin with the rest of the Mediterranean region provides landscape-level awareness of hydropower development.

The Mediterranean basin is highly variable and the rivers flow from high mountains down to large lowlands. Ranked according to annual discharge (*see* Table 1), the ten largest rivers contributing to the Mediterranean Sea include: the Rhône (FR), Po (IT), Drin-Bojana (AL, ME, KV), Nile (EG, SD, SS, ER, ET, KE,UG, TZ, RW, BI, CD), Neretva (HR, BA), Ebro (ES), Tiber (IT), Adige (IT), Seyhan (TR), and Ceyhan (TR):

Table 1: Overview of main rivers in the study area				
Name	**Length in km**	**Catchment size (km²)**	**Mean discharge (m³/s)**	**Countries**
Nile	6,650	3,255,000	2,660*	EG, SD, SS, ER, ET, KE,UG, TZ, RW, BI, CD
Rhône	812	95,590	1,700	FR, CH, IT
Po	652	75,000	1,540	IT, CH, FR
Drin/Bojana	379	25,160	672	AL, ME, MK and KV
Ebro	910	85,362	426	ES
Neretva	225	10,380	378	BA, HR
Mariza	525	52,900	234	BG, GR
Ceyhan	474	21,200	230	TR
Orontes	571	22,300	80	SY, TR, LB
Moullouya	550	74,000	50	MA
Shellif	725	59,150	49	DZ
Euphrat**	2,736	673,000	356	TR, IR**
Tigris**	1,900	375,000	1,014	TR, IR**

*before delta, discharge entering the Mediterranean Sea is about 1,500 m³/s
**only headwaters are subject of the study (outside Mediterranean basin)

From North to South, this study covers three global climatic zones: temperate (including the upper Rhône catchment in Switzerland and France), sub-arid/arid or dry temperate zone (including the entire Mediterranean area and Sahara), and tropical (in the southern Nile). Using climatic zones and hydrologic basins, we have split the study area into the following six sub-regions (*see* Figure 1):

1. Iberian Peninsula (PT, SP, AD)
2. Central Western Mediterranean region (FR, MC, CH, IT, SM, MT)
3. Balkan region (SI, HR, BA, ME, RS, KV, AL, MK, GR, BG); the project includes whole Greece in difference to previous projects
4. Eastern Mediterranean region (TR, LB, SY, IQ, IL, JO)
5. Nile basin (EG, SD, SS, ER, ET, KE,UG, TZ, RW, BI, CD)
6. Maghreb Region (LY, TN, DZ, MA)

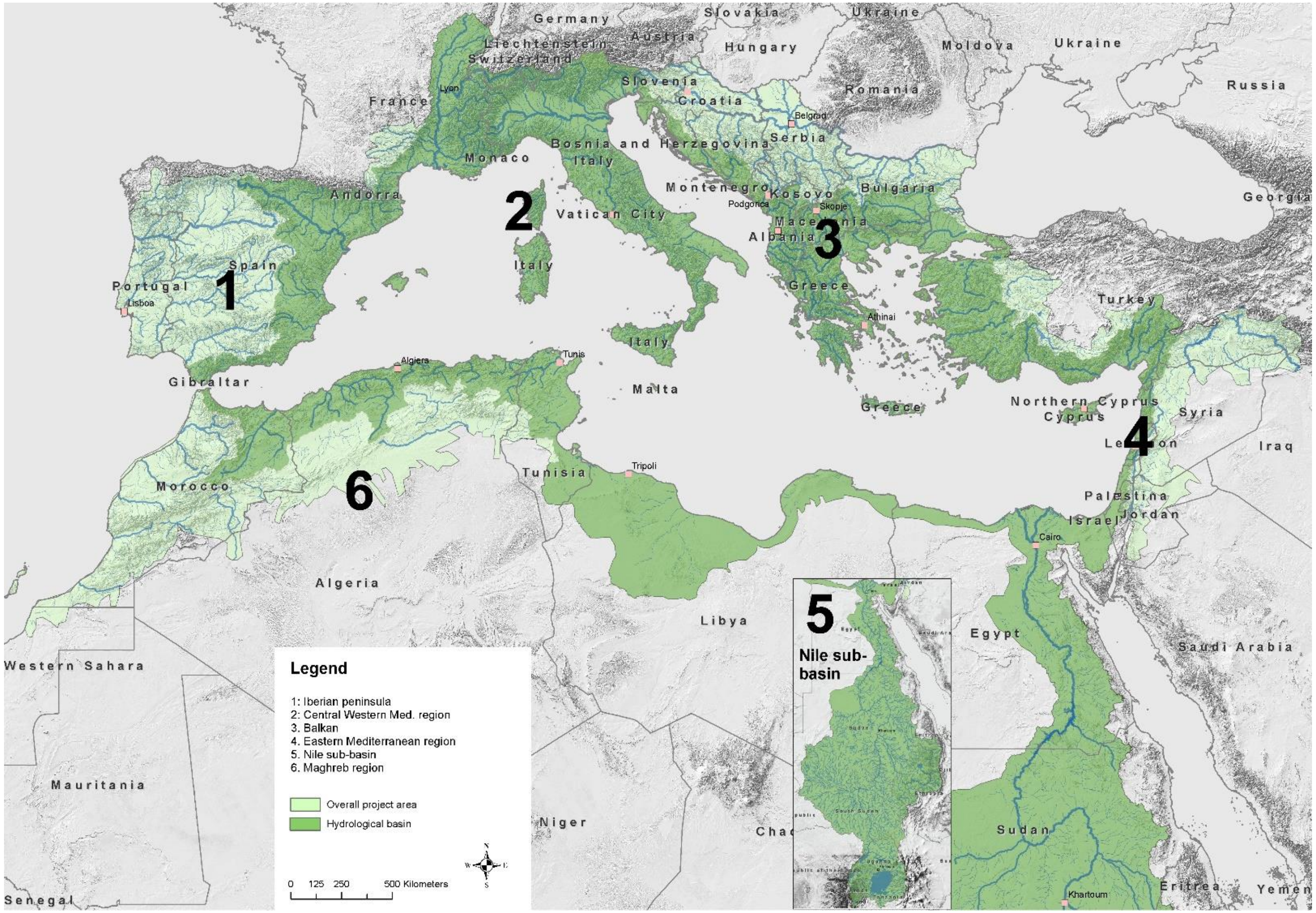


Figure 1: Study area, including the Mediterranean hydrologic basin

Chapter 2 outlines the methodology used in this study. In addition to providing an overview and hydromorphological assessment of the surveyed rivers, Chapter 3 presents the results. Chapter 4 concludes this study by addressing the on-going hydropower development in regards to protected areas and key biodiversity areas and providing recommendations to land managers.

2. Methodology and Assessment

The methodology used to collect data on hydropower plants (HPP) and assess the hydromorphological status is based on the first Balkan river assessment (Schwarz 2012) and the Balkan Eco masterplan (RiverWatch & EuroNatur 2018). All HPPs with > 0.1 MW installed capacity were collected and categorized as existing, under construction or planned.

The hydromorphological assessment follows the European CEN Standards (2004, 2010) and considers some tenants of the new preCEN standard (2018). The hydromorphological assessment classifies rivers into five alteration classes ranging from near-natural (blue) to severely modified (red). The assessment is based on remote sensing and publicly available data. The 25 years of experience were key to the success of this extensive study and its rapid turnaround time.

National and international datasets were used to identify the boundaries of protected. Nature 2000 and WDPA were used to identify protected areas in three classes: first national parks, Ramsar, World heritage sites, biosphere reserves; second, Natura2000, Emerald, and nature reserves; third, all other protected areas such as landscape protection. Key Biodiversity Areas (KBAs) identified by IUCN were used to identify where HPP development is taking place within KBAs.

The final results are visualised in maps with locations of the HPPs and coloured river stretches. The colours indicate the hydromorphological intactness. The regions can be compared by rkm of hydromorphological intactness. The boundaries of the protected areas and KBAs are included.

The results can be used to identify the “No Go Areas” for future HPP developments and to propose new and better protection status for those stretches with the highest conservation value.

Publicly available data sets such as the European rivers and catchment data was complemented by the Hydrosheds planform of USGS and WWF[4]. As the scale of the inventory reached beyond Europe, global dam databases were reviewed and organizations and research groups were contacted regarding existing data sets on dams. The Global Dam Watch[5], which collects dam and reservoir data worldwide at a high resolution, was utilized. GRanD[6] was used for a few planned dams and related projects.

[4] https://hydrosheds.cr.usgs.gov/dataavail.php
[5] http://globaldamwatch.org/
[6] https://www.researchgate.net/publication/266172562_Global_Reservoir_and_Dam_GRanD_database

2.1 Inventory of hydropower plants and projects

Hydropower dams were categorized in three groups: Existing, Under implementation and Planned. Many of the planned projects were already ratified by national and regional parliaments or have ongoing planning work and Environmental Impact Assessments. However, the “planned” category also includes proposed HPPs based on licensing lists or studies made public. In case of renovation and extension of existing HPPs, the environmental aspects must be considered (e.g., increased water levels in impoundments, increased water abstraction from the catchment or river stretches included in the planned HPP).

Five size classes were distinguished: 0.1-<1 MW, 1-<10 MW, 10 -<50 MW, 50-<100 and >100 MW. The attributes collected include: the name of HPP, Code (Country plus 4-digit number), name of the river, MW class and status (existing, under construction, planned). The type of HPPs varies from water abstraction HPPs with residual “old” river channels, over the most frequent run-of-the river HPPs to pumping storage HPPs, which makes the comparing the impacts more complex. In the Mediterranean region, many reservoirs’ primary role is water storage for irrigation and secondary role is energy production if that. Such reservoirs were not included in this inventory.

Verification of the maps was difficult in the initial inventory as for many small HPPs, the lists did not exist or the HPPs were out of operation. The restart of such operations could have adverse effects and therefore those small HPPs and mills were included where potential effects could be expected, namely in longer free-flowing stretches. The total number of small mills in Europe are expected to be greater than 50,000. The number of weirs, ramps with potential for small scale hydropower generation, are more than 100,000. The main target of the study is to localise the main impacts. If a small HPP is constructed together with a Fish pass, as is often the case in Switzerland, or if the energy of high-altitude differences in the mountains is generated, only one location (i.e. point) was recorded. In some cases, the installed MW was summarised. When such HPP consists of several dams, weirs, abstraction canals and powerhouses, the inventory located the main impact on the river, which was not always the powerhouse. This compromise is necessary not to overstate the number of impacts or focus on the inventory on obstacles (i.e. barriers).
Hydropower dams have a significant impact on the longitudinal as well as transversal river continuum for biota and sediments. Impacts can reduce ecological integrity, by way of lower biodiversity (e.g. migratory species) and species abundance, and serious river degradation downstream of the dam (channel incision, compare Hauer 2019). Impacts can be assessed according to the size and location (upper or lower course) and the number of dams in catchments and sub-catchments.

The study cannot predict the detailed impacts of specific dam projects. Rather, the downstream impacts of dams are hypothesized, and the hydromorphological assessment estimates the impact. The evidence of damage by hydropeaking and altered hydrologic regimes, such as the elimination of ecologically important smaller floods and bed incision, can be measured along large rivers. The assessment relies on qualitative experience and expert judgement. Existing dams impact always all major rivers' hydrologic and sediment regimes. National experts review the dam inventory and hydromorphological assessment results.

2.2 Hydromorphological assessment of rivers

According to the Water Framework Directive, hydromorphology should be monitored every six years and are used to support assessments with weak biological quality elements. The hydrological regime (i.e. quantity and dynamics of water flow), river continuity, and morphological conditions (i.e. river depth and width, structure and substrate of the river bed, structure of the riparian zone) are fundamental to the Water Framework Directive.

Since 2004, European Committee for Standardisation's framework for the survey of hydromorphological features (CEN 2004, 2010, 2018) has been in use. The framework is based on the long-time experience and method developments in the United Kingdom, France, Germany, Italy and Austria. The CEN framework standard outlines the assessment of river channels, banks and floodplains. Floodplain assessments are not required by the Water Framework Directive, but are an integral part of hydromorphological assessments of the river-floodplain-system. The five classes of the CEN assessment schema are similar but not equal to the five class systems of the Water Framework Directive:

Class 1 = Pristine and near-natural
Class 2 = Slightly altered
Class 3 = Moderately altered
Class 4 = Strongly altered
Class 5 = Totally altered

From the previous assessment of Balkan rivers, only large rivers (> 200 km length and > 500 km² catchment) were included in the assessment (Schwartz 2012). For this study, a hydromorphological assessment was applied to free-flowing river stretches, based mostly on the visible (satellite images and ground observations) hydromorphological intactness supplemented by various technical and local information on dams, river regulation, water abstraction and land use (compare Schwarz (2007 and 2008). The evaluation is based mostly on the visual interpretation of available high-resolution satellite and field images of channels with platform, in-channel features such as bars and islands, floodplain (land use) characteristics. Banks could not be easily assessed based due to inadequate resolution and coverage by tree canopies.

The following classifications were used for the hydromorphological assessment:

Class 1: “Near-natural” characteristics imply limited human disturbances to sediment or hydrologic regimes.

Class 2: “Slightly modified” river reaches are disturbed only by a few ground sill, short bank reinforcements and floodplain is cut only along small sections.

Class 3: “Moderately modified” river reaches disturbed by human activities such as longitudinal continuum interruptions, bank reinforcements, and riparian zone reductions by flood protection dikes on both sides. any Class 3 stretches have good restoration potential and are the first to be subject to Water Framework Directive measures.

Class 4: “Extensively modified” river stretches most often in towns or between large scale developments/dams with strong channel rectification, entirely reinforced banks and disconnected floodplains or significant changes of the hydrological conditions.

Class 5: “Severely modified” rivers stretches. Main disturbances include impoundments and artificial canals.

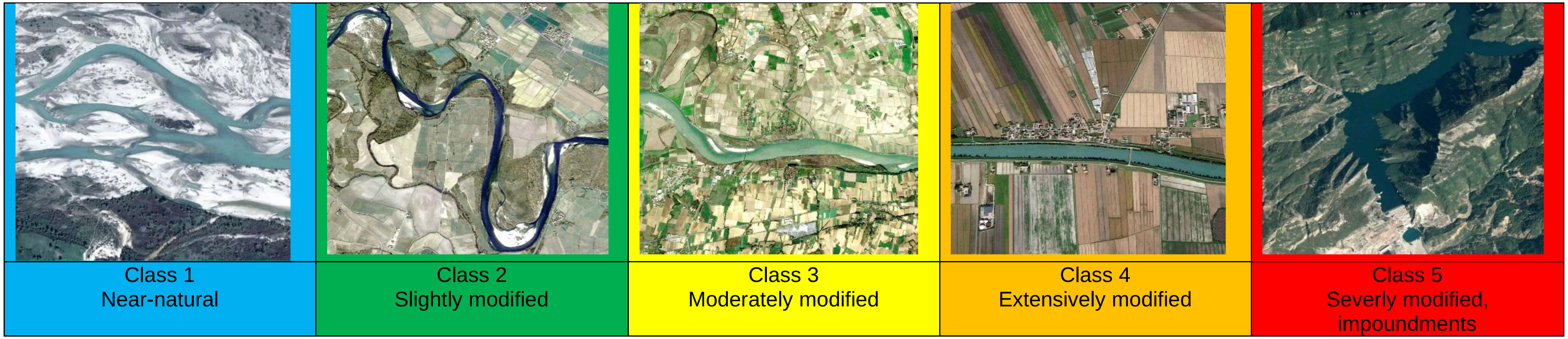


Figure 2: Hydromorphological assessment classes (source: GoogleEarth, Digital Globe 2019).

Rivers were subdivided into assessment stretches based on the overall geomorphology, slope and catchment characteristics as well as existing pressures. The minimum length criteria was 10 rkm. The assessments began in the headwaters and proceeded to the mouth of the river to understand the hydrological regime and alteration(s) by reservoirs and dams. This process increased mapping accuracy of stretches impacted by water abstraction HPP.

2.3 Overview of protected areas

The HPP inventory incorporates protected areas spatial data as well as the following basic attributes:

- Name,
- Size, and
- Type (Natura 2000, national park, biosphere reserve, Ramsar site, Emerald area, nature conservation, landscape protection).

For the purpose of this study, three main protected areas datasets were used: the EU Natura 2000, the WDPA (Global inventory of protected area) and the EIONET data on Emerald sites. For this study, protected areas were categorised into the three following classes:

1. National parks, Ramsar sites, World heritage sites, biosphere reserves,
2. Natura2000, Emerald areas for Eastern Europe, nature reserves, and
3. All other categories, including landscape protection.

2.4 Overlay with IUCN Key Biodiversity Areas

Key Biodiversity Areas (KBAs) are hotspots of biodiversity. However, hydropower has altered and will continue to alter such habitats as HPP are developed within KBAs.

The IUCN KBAs represents distinctive areas with a high and specific biodiversity (IUCN 2014; IUCN 2016). Various overlays were possible, and the core task of this study was to overlay the hydromorphological assessment and HPP inventory. The IUCN KBA's highlight areas with specific (endemic) and endangered habitat throughout the Mediterranean region, excluding the Nile basin. The KBA data (IUCN 2017) includes catchment information and the number of fish, macrozoobenthos and mollusc species. In parallel, several synaptic studies on threatened species for the Mediterranean area have been published under the umbrella of the WetMed project (Maitland et al. 2010). Studies on the distribution of key fish species in the Balkans have also been published (Weiß 2012). Hotspots for HPP planning have been identified in reference to endemic freshwater species (fish, caddisflies, molluscs) in Balkan Eco-Masterplan (RiverWatch & EuroNatur 2018).

3. Results

The results are sorted by the six regions (from west to east) with a final overall presentation for each topic.

1. Iberian Peninsula (PT, SP, AD)
2. Central Western Mediterranean region (FR, MC, CH, IT, SM, MT)
3. Balkan region (SI, HR, BA, ME, RS, KV, AL, MK, GR, BG)
4. Eastern Mediterranean region (TR, LB, SY, IQ, IL, JO)
5. Nile basin (EG, SD, SS, ER, ET, KE,UG, TZ, RW, BI, CD)
6. Maghreb region (LY, TN, DZ, MA)

3.1 Assessed rivers

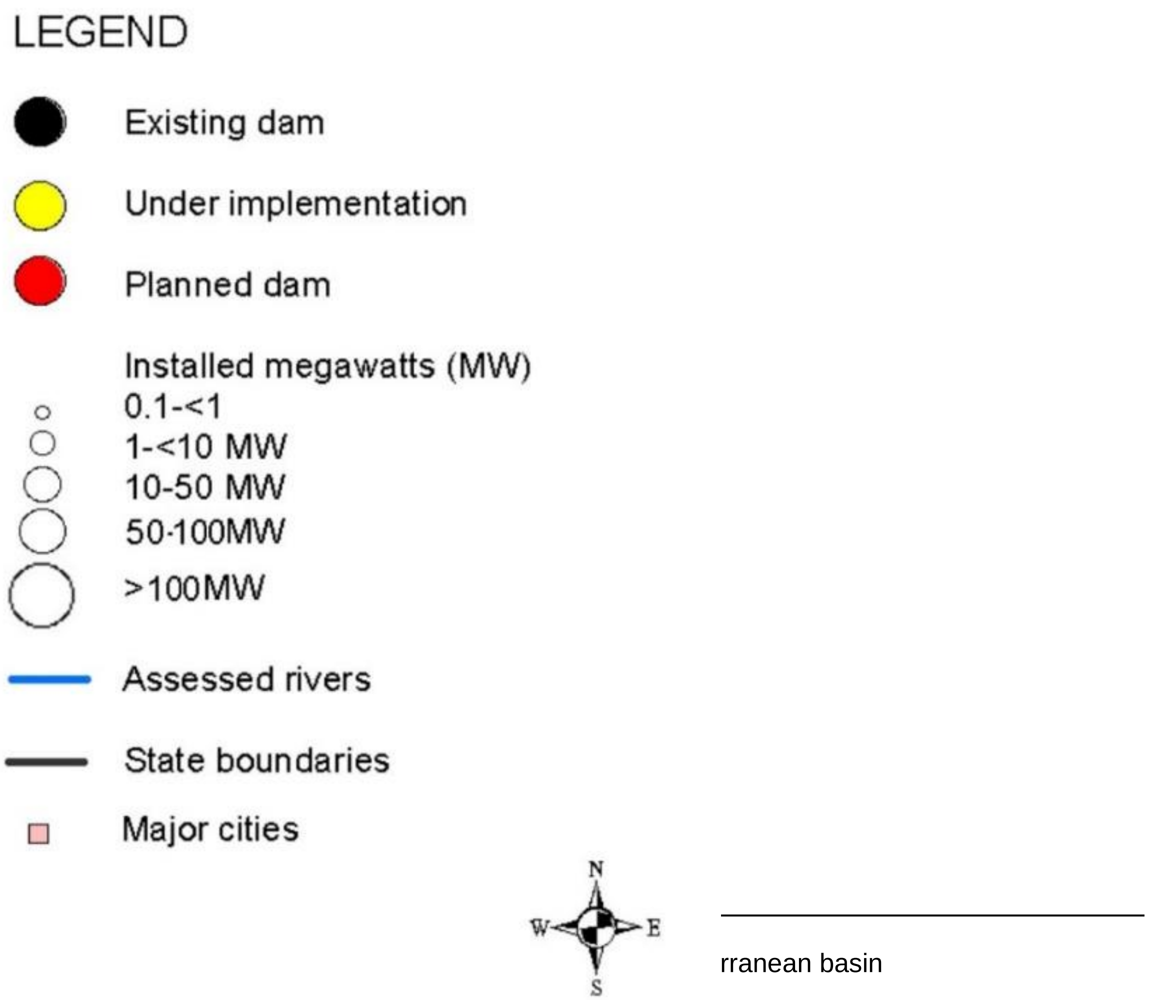
In the 6,157,728 km² study area (for comparison the Danube catchment has a size of roughly 800,000 km²), 66,800 rkm were assessed. The average length of river stretches, for which the hydromorphological assessment was completed, dependant on the size of the river, and averaged between 10 and 20 rkm. The length of river stretches did range from only a few km to several hundred km in the case of HPP cascades, along rivers such as those in Iberia, the Rhône in France, and the long pristine stretches in the Nile basin.

The rivers were classified by size, using a qualitative subdivision instead of catchment sizes or hydrological classification schemas. Also, the river length was not a precise indicator. For example, in karst areas, a short river can have huge water-rich catchments, while in a semi-arid or arid zone, long rivers can dry out over long distances. For practical reasons, but also for visualisation in the maps, only the largest rivers can be find in the first category (compare large rivers in the table 1 above) while in size category two all major rivers with at least 250 km length can be found. The third category comprises complementary rivers meaning some 200 km. Finally, small rivers are indicated only as background without hydromorphological assessment.

3.2 Hydropower plants and projects

In total 11,864 HPP have been recorded, including 5,269 existing HPP, 202 under construction HPP and 6,393 planned HPP.

HPP were firstly recorded by their status as “existing”, “under construction” or “planned”. The HPP were further divided into five size classes: 0.1-<1 MW, 1-<10 MW, 10-<50 MW, 50-<100 MW and > 100 MW.



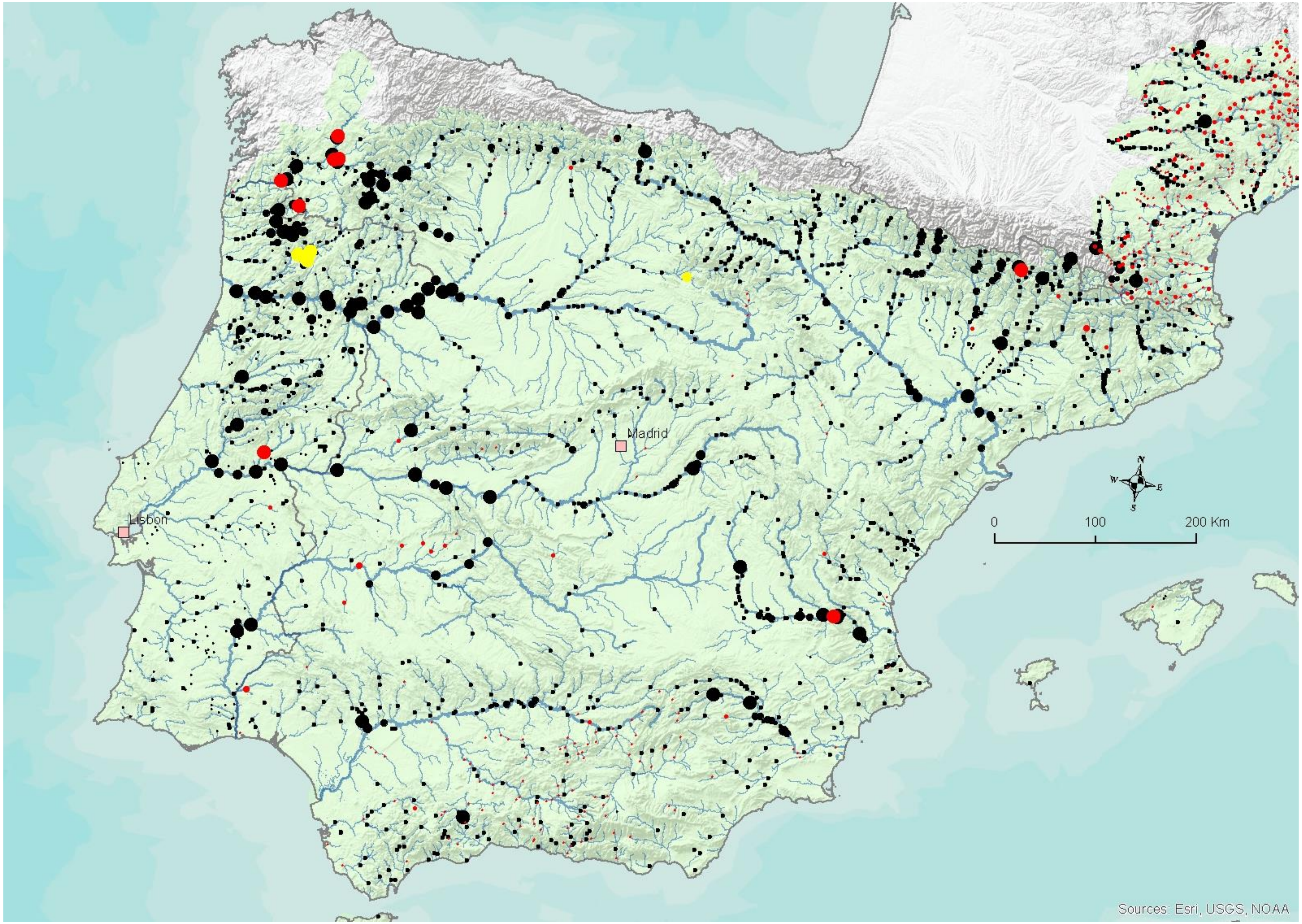


Figure 4: Hydropower plants on the Iberian Peninsula.

The major rivers of Portugal and Spain are intensively used for hydropower, namely lower and middle courses of Tagus and Duero and lower to the middle course of Ebro (on the upper Ebro many small mills with weirs exist). In contrast to countries saturated with hydropower development (focus on pumping storage and SHP), Portugal completing several large dams (Alto Tâmega projects).

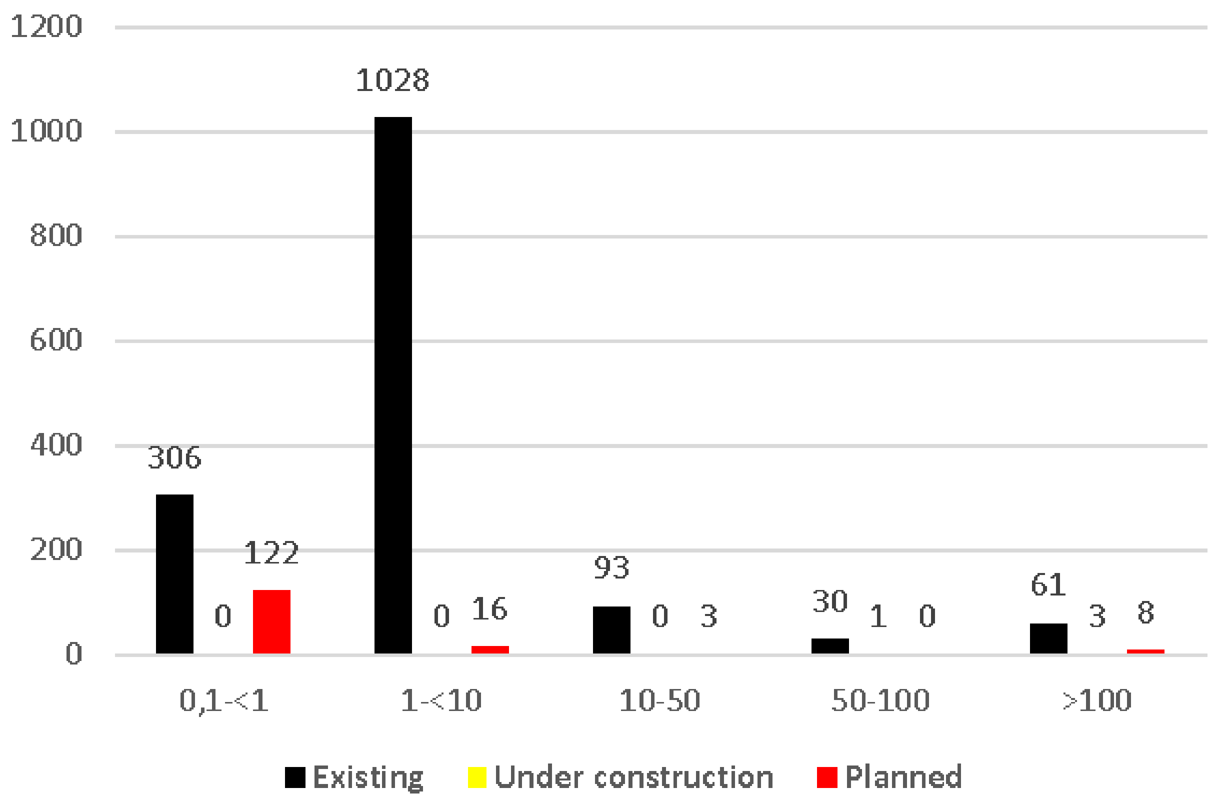


Figure 5: Distribution of hydropower plants on the Iberian Peninsula.

3.2.2 Central Western Mediterranean region (FR, MC, CH, IT, SM, MT)

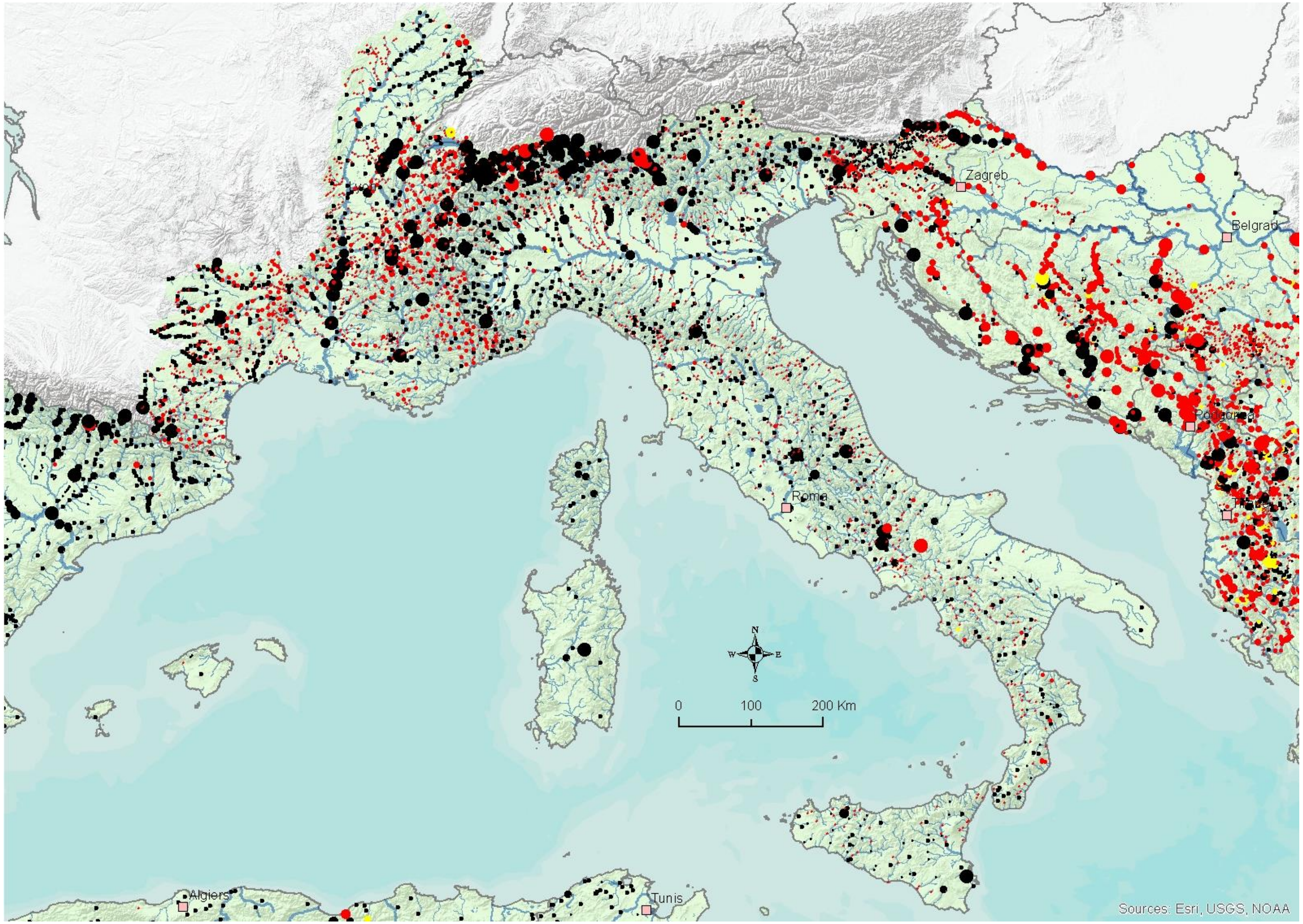


Figure 6: Hydropower plants in the Central Western Mediterranean region.

France, Italy and Switzerland are among the countries with the highest percentage of domestic hydropower usage (IHA 2018 list them with nearly 70% of used potentials). Most of their rivers serve hydropower production. In particular, the Alpine arc is densely covered with HPP. Pumping storage HPP exist or are under development (namely in CH) to take advantage of the substantial altitude differences in the mountains. In France, the potential for new HPP in the size class of 1-10 MW includes several still free-flowing reaches, but the development is very slow.

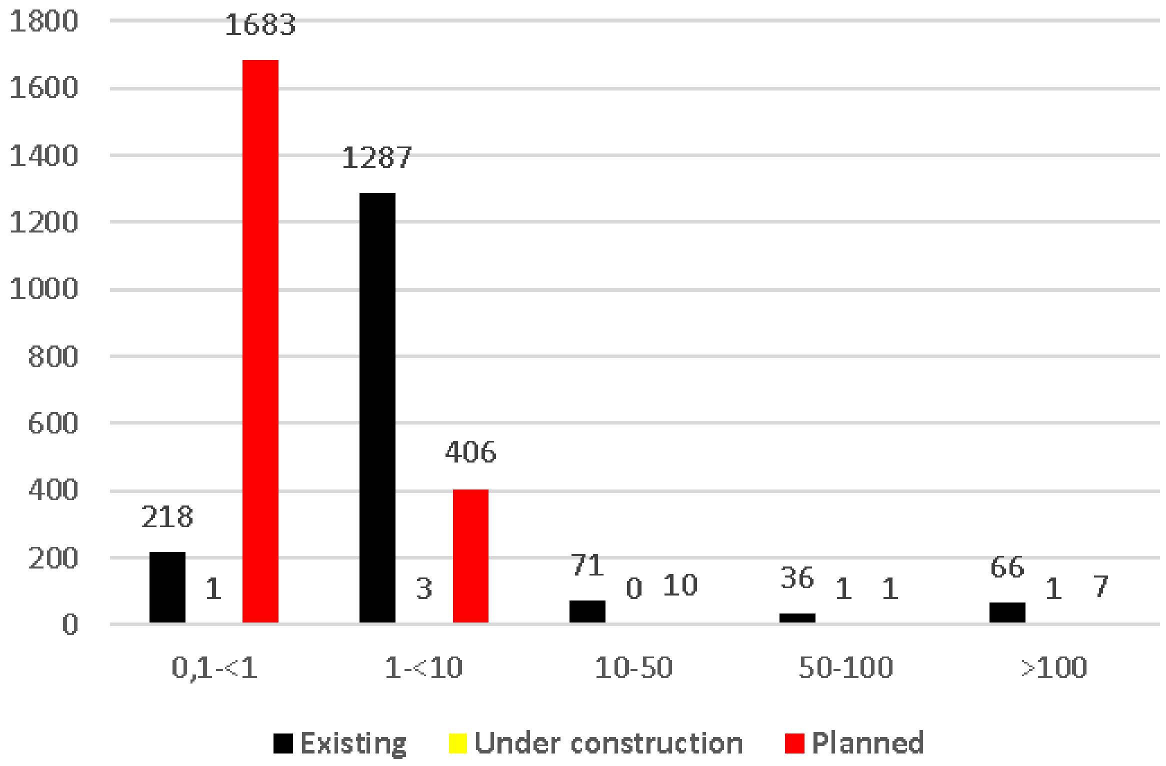


Figure 7: Distribution of hydropower plants in the Central Western Mediterranean region.

3.2.3 Balkan region (SI, HR, BA, ME, RS, KV, AL, MK, GR, BG)

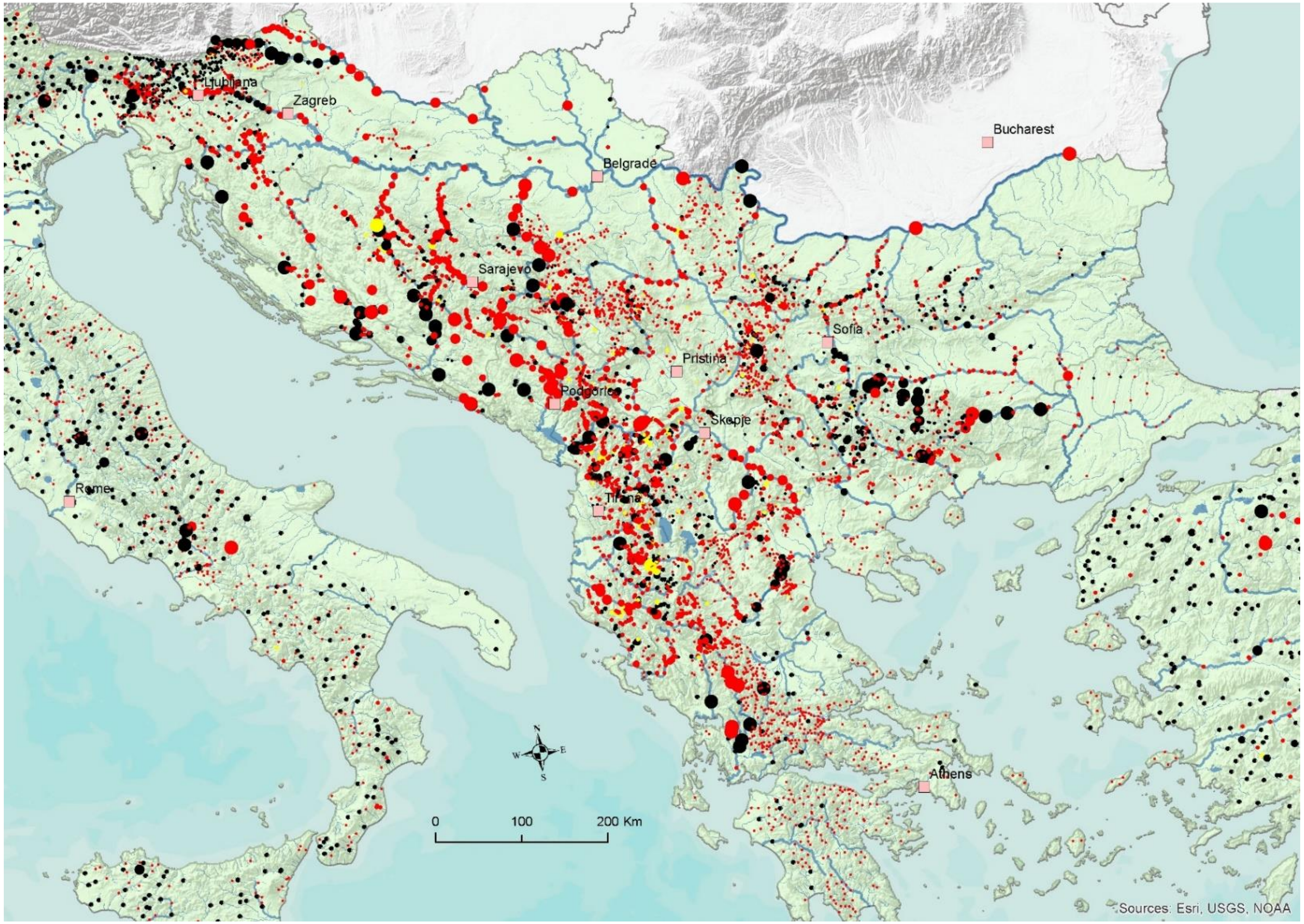


Figure 8: Hydropower plants in the Balkan region.

In the water-rich Neretva, Drin, and Drina river valleys, HPP were primarily developed in the 1970s. Many new dams are currently under construction in Albania and Bosnia & Herzegovina. Other HPPs are planned on most of the large rivers in Albania, Bosnia & Herzegovina, Montenegro and Serbia. The Iron Gate Dam 1 is the largest run of the river HPP in the European region with 1,100 MW installed power.

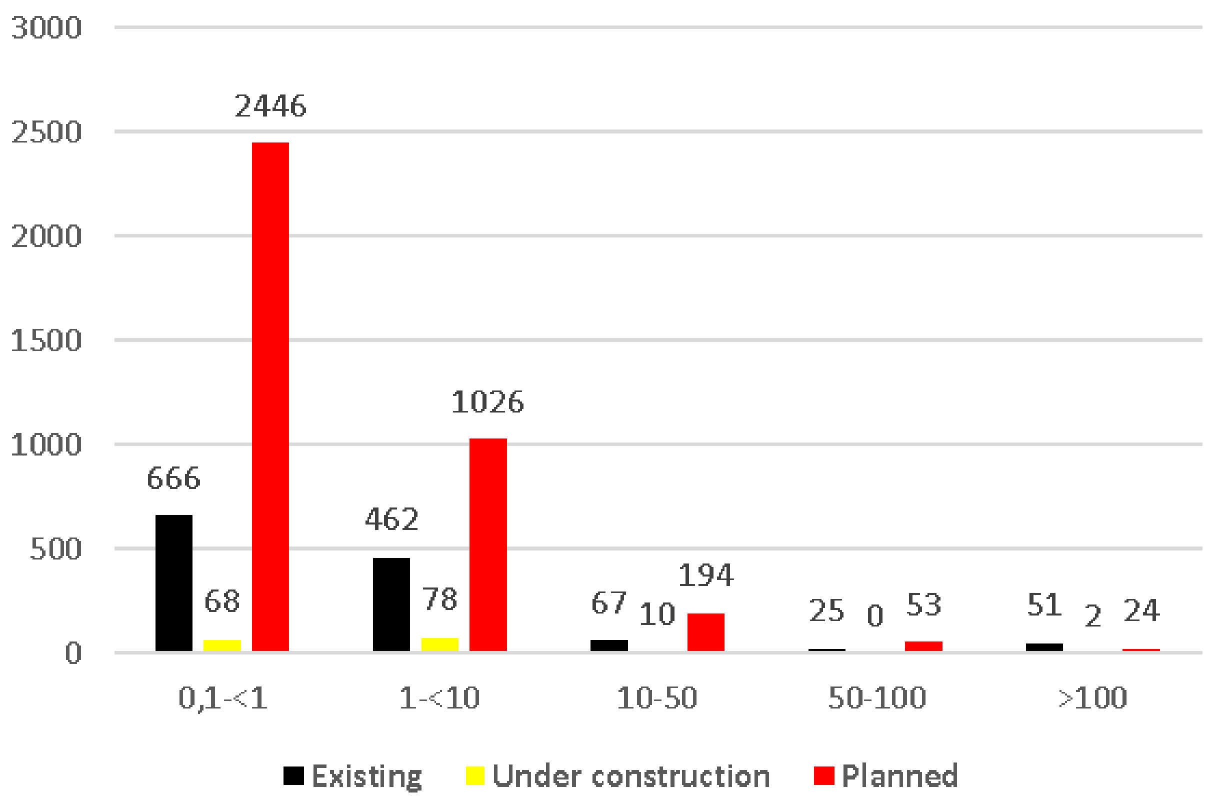


Figure 9: Distribution of hydropower plants in the Balkan region, including Greece (the baseline study: Schwarz 2012a).

3.2.4 Eastern Mediterranean region (TR, LB, SY, IQ,IL, JO)

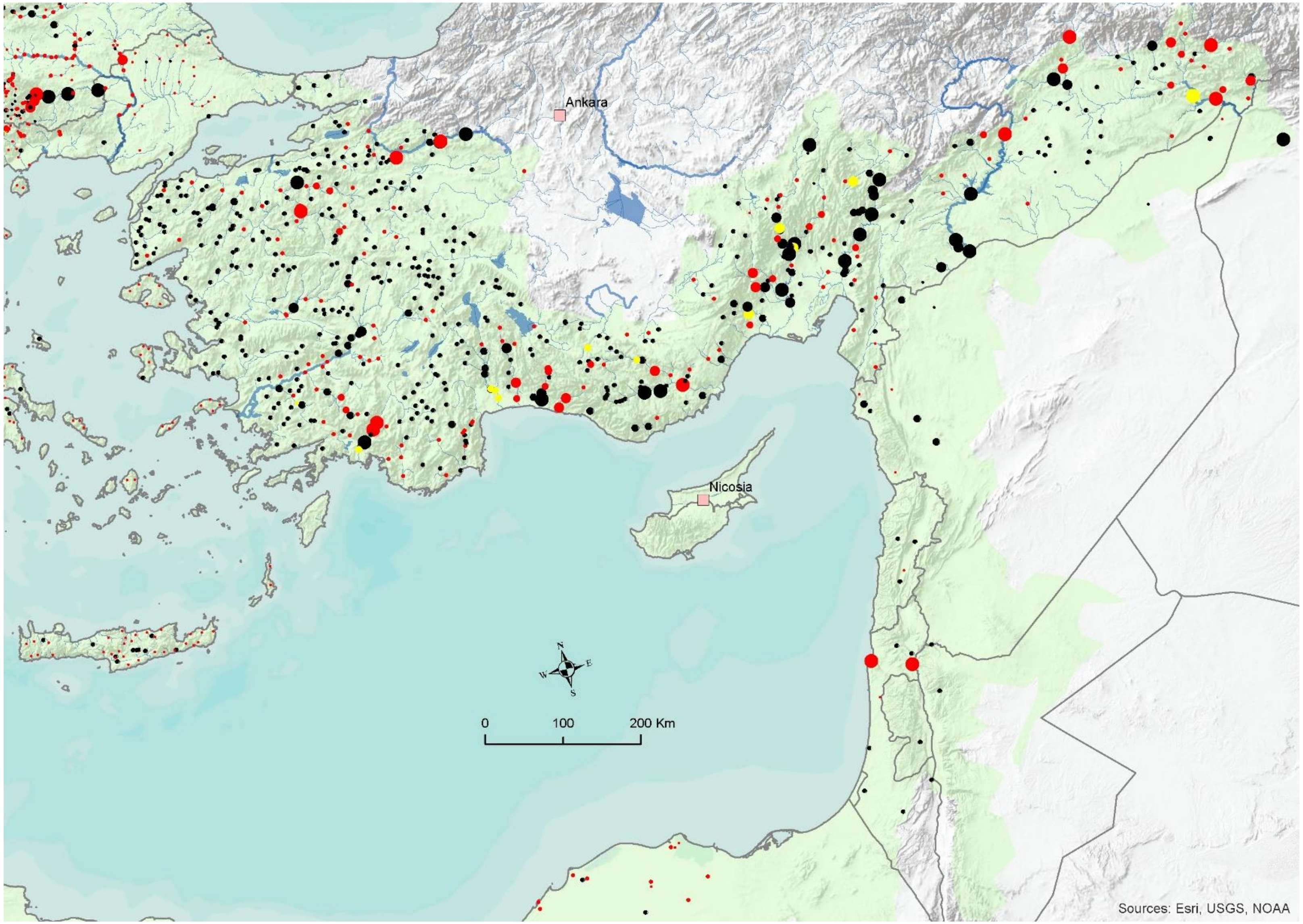


Figure 10: Hydropower plants in the Eastern Mediterranean region.

Turkey has one of the most ambitious plans to develop HPP until 2020 (plus 5,000 MW) and 2030. In the last 20 years, the usage of the hydro potential was raised from 15 to 50% and will be further developed up to 85% until 2030. The number of existing HPP, 490, will include another 534. While in western Europe the development of new run of the river plants on larger rivers has stalled or is completed, Turkey aims to increase its 50% to 80% (IHA 2018).

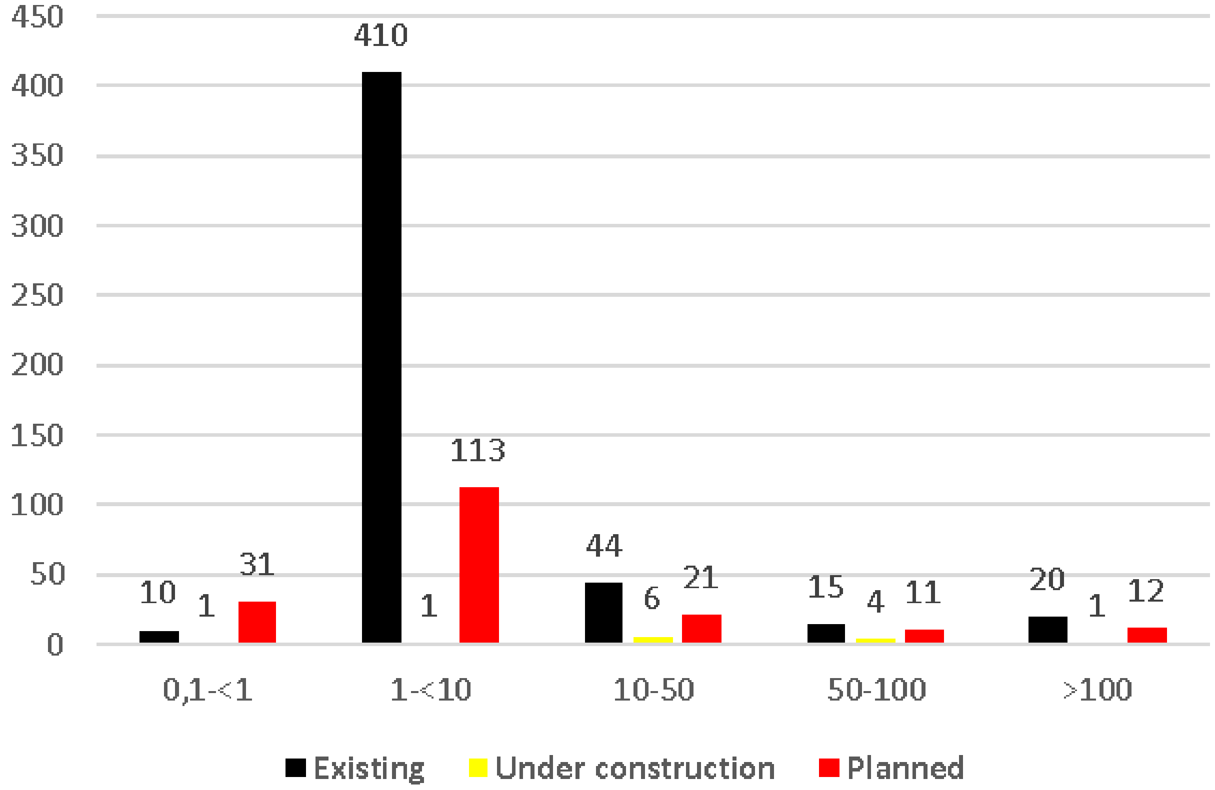


Figure 11: Distribution of hydropower plants in the Eastern Mediterranean region.

Figures 12 and 13: The impounding of Tigris in Turkey has started: downstream of the Ilisu dam a very little runlet remains (copyright RiverWatch); right the dam before impounding from space (GoogleEarth, Digital Globe 2019).

3.2.5 Nile basin (EG, SD, SS, ER, ET, KE,UG, TZ, RW, BI, CD)

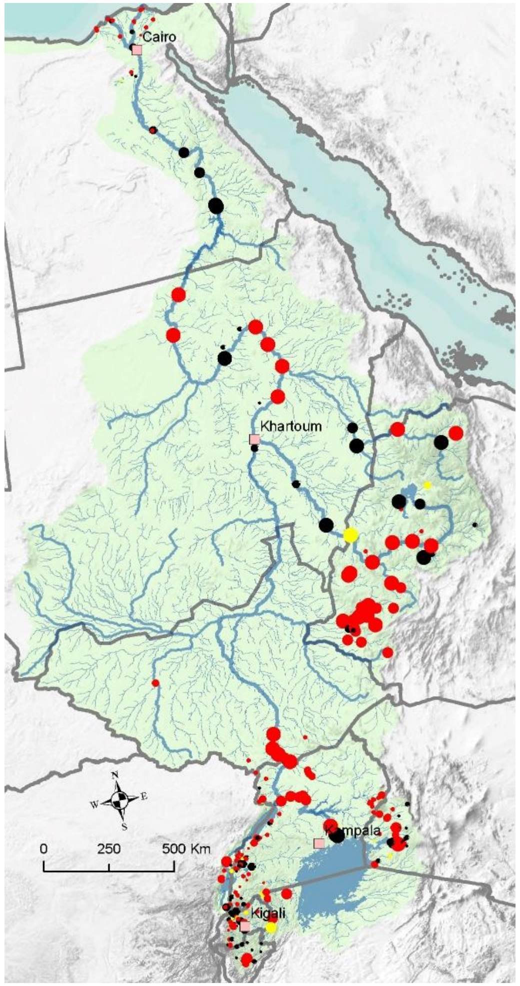


Figure 14 and 15: Hydropower in the Nile basin (left) and “GERD” dam construction site (one of the largest dams in the world), Blue Nile, Ethiopia (GoogleEarth, Digital Globe 2019) on the right.

Most of large dams of the Mediterranean basin are planned in the Nile catchment. One of the largest dams worldwide will be the Millennium dam (GERD, Grand Ethiopian Renaissance Dam) on the Blue Nile (6,000 MW) in Ethiopia when completed in 2022. The lower Nile includes three medium-sized dams, also used for water abstraction (irrigation). The huge Aswan dam, one of the largest worldwide, interrupts the lower to middle and upper Nile. In Ethiopia, several large dams are planned in the Blue Nile catchment, as well as on the upper “Mountain” Nile between the lakes in Uganda. Only the western water-poor catchment part is not affected. The Sudd swamps between Sudan and South Sudan are currently not the focus of large-scale water diversion projects as opposed to the 1970s.

In the middle of 2019, the website of Africa-energy.com[7] gave a representative overview, but did not include all projects for Africa. It listed 62 projects as under construction (over 16,109 MW) and 621 planned projects with a total of 76,786 MW. Some planned HPP will be for tea farms in Kenya the potential for SHP <10 MW is estimated with at least 3,000 MW. This gives a magnitude of current planning of hydropower and can be compared with the development in South-America and Asia.

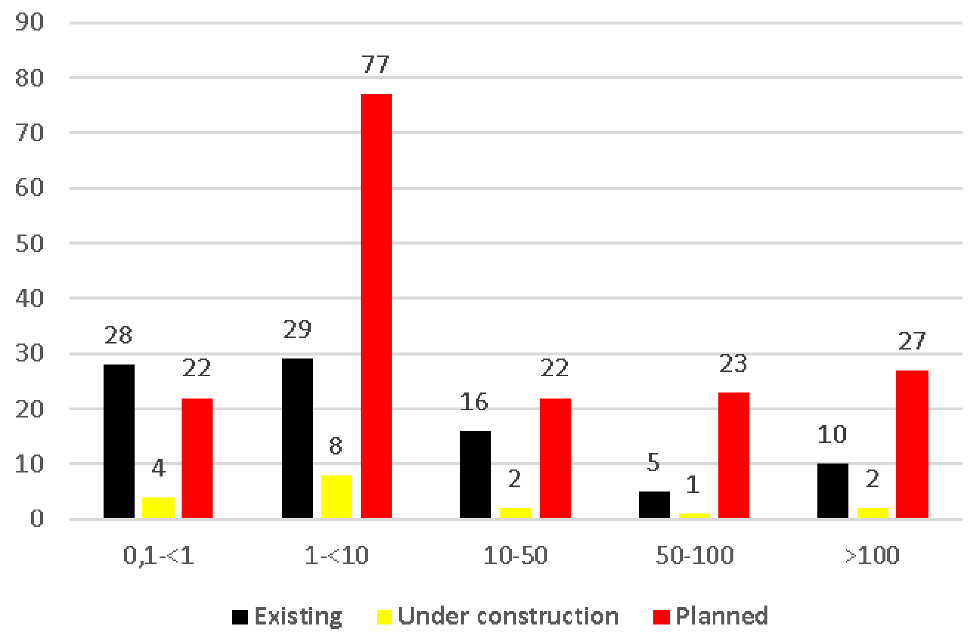


Figure 12: Distribution of hydropower in the Nile basin.

[7] https://www.africa-energy.com/database

3.2.6 Maghreb region (LY, TN, DZ, MA)

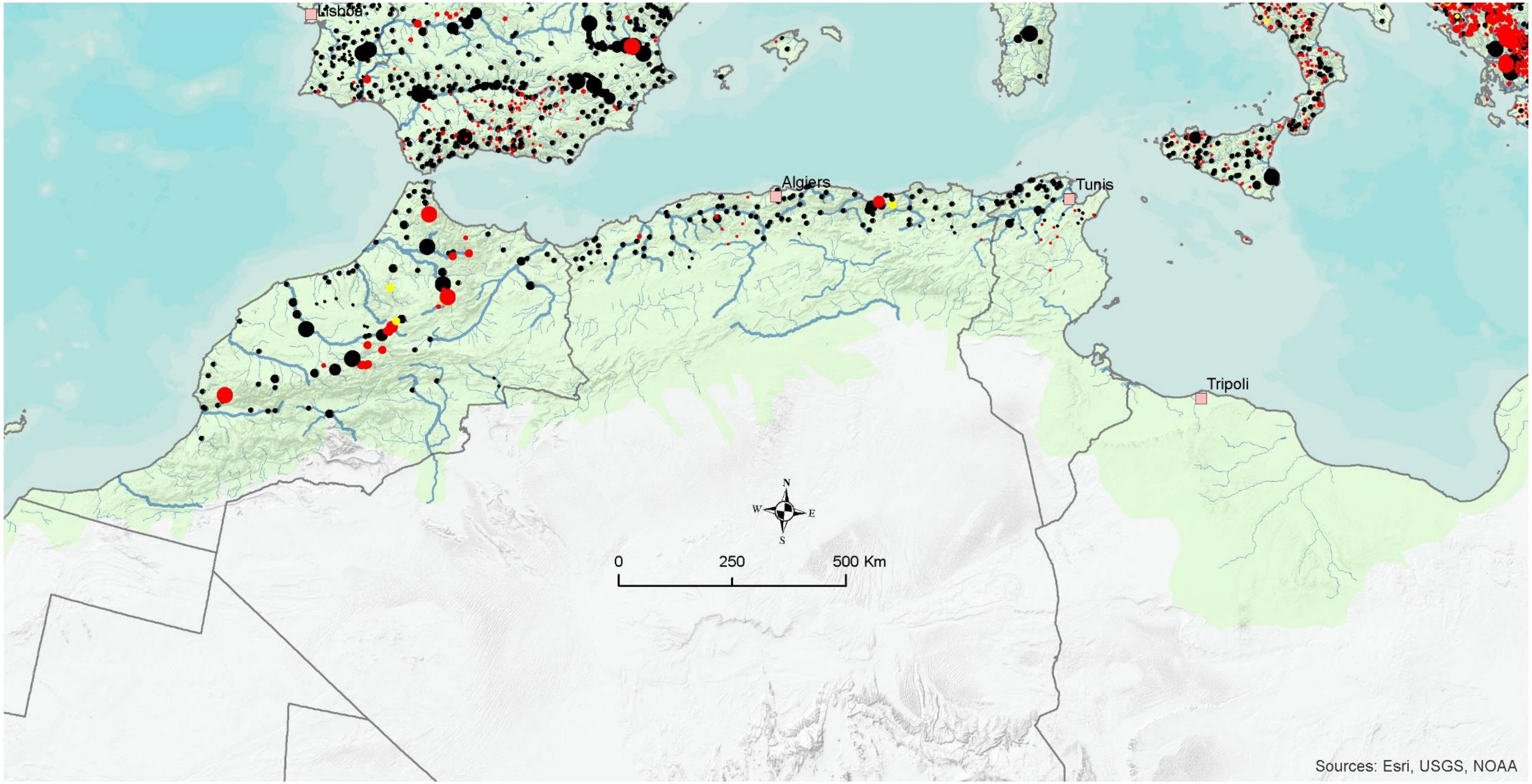


Figure 17: Hydropower in the Maghreb region.

In general, the hydropower development in the Maghreb region is focusing on the few water-rich mountain rivers, where a significant part of the regional potential is already used, namely in Morocco within the Atlas Mountains.

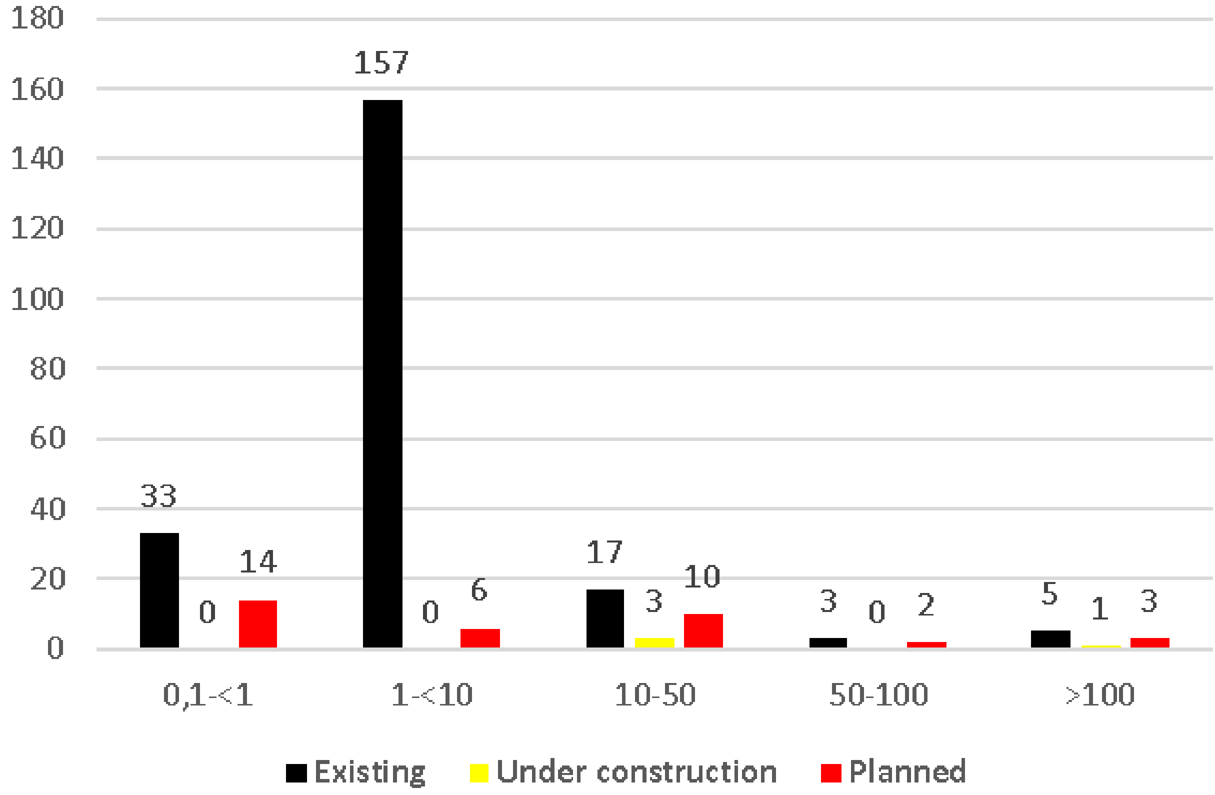


Figure 18: Distribution of hydropower in the Maghreb region.

3.2.7 Entire Mediterranean basin and region

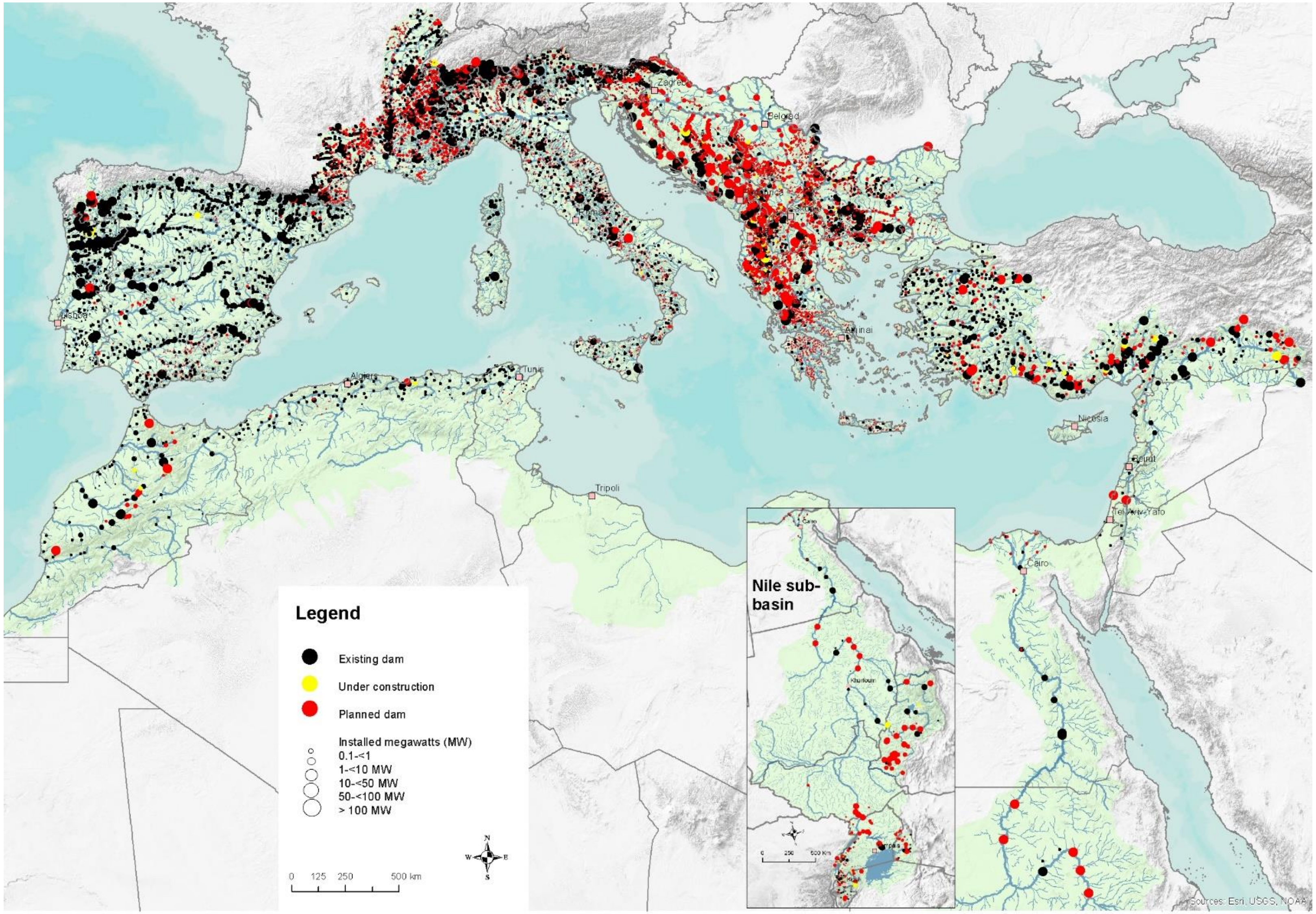


Figure 19: Comprehensive hydropower in the Mediterranean basin

In total 11,864 HPP have been recorded, including 5,269 existing HPP, 202 HPP under construction and 6,393 planned HPP.

On the overview map (see Figure 19), there are clear regional differences regarding the further hydropower development across the study area. In Europe, the pressure is most considerable in the Balkans and Turkey. In Africa, Ethiopia is amongst the top hydropower developers, largely funded by Chinese investment, and in the Nile basin the single projects are by far the largest by MW.

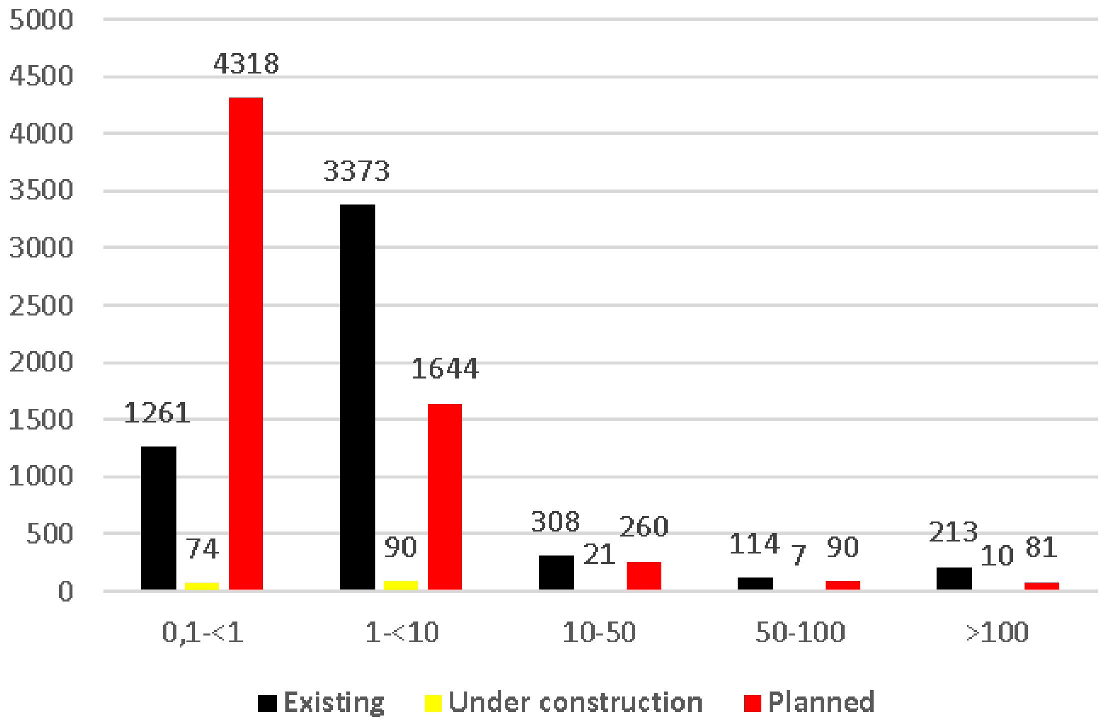


Figure 20: Distribution of hydropower plants in the Mediterranean region.

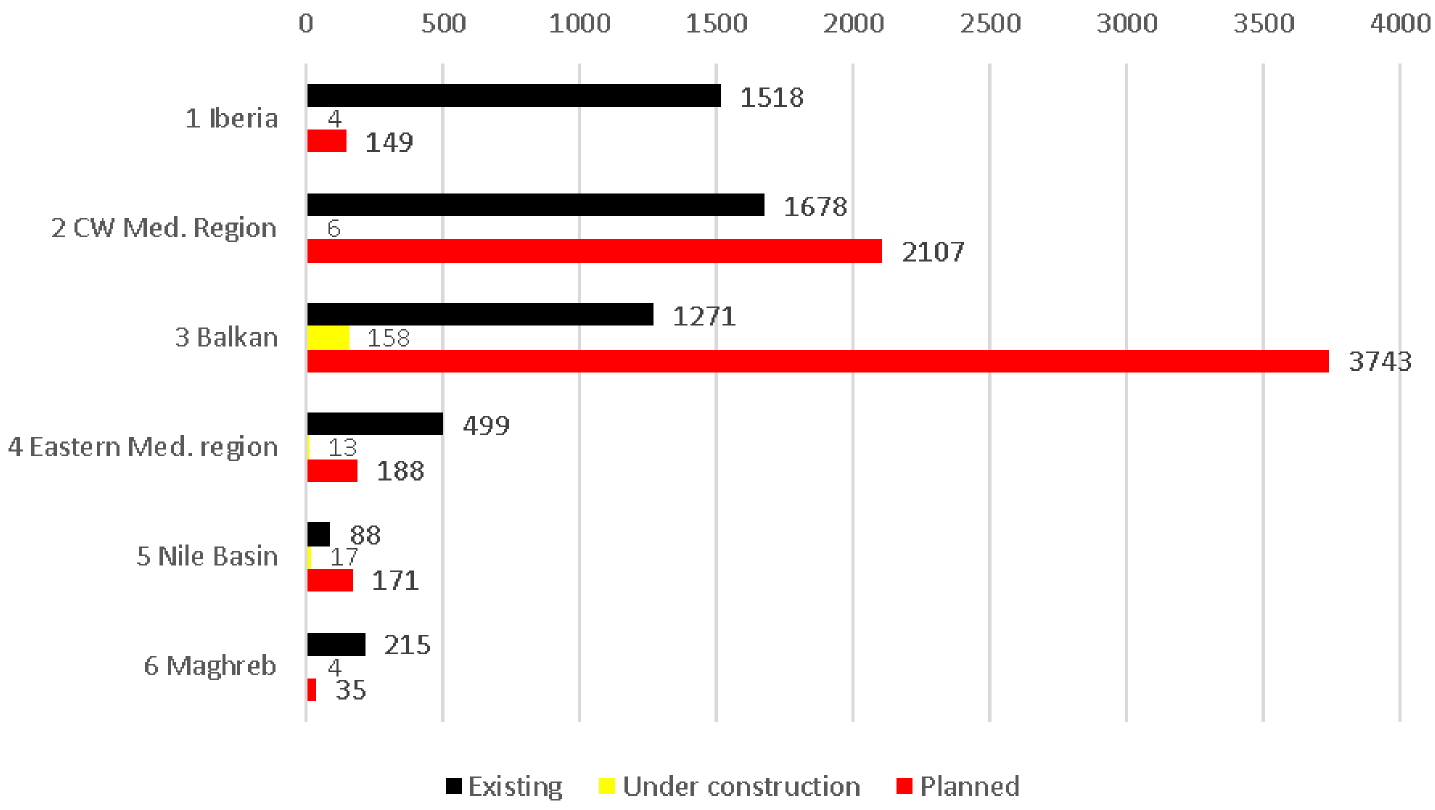


Figure 21: Regional distribution of hydropower plants in the study area.

Looking at the regional distribution, together with the SHP, the Balkan region faces the most aggressive development. However, the HPP in Turkey and North African are larger in size.

3.3 Hydromorphological intactness of rivers

Five classes were used to characterize the different levels of hydromorphological intactness: Class 1 stands for high intactness (near-natural) and bears the blue colour code (lakes and rivers outside of the project areas are in light grey-blue). Class 2 is characterised by slightly modified status, indicated in green. Class 3 shows the moderately altered stretches in yellow. Class 4 for river stretches which are extensively altered are orange and class 5 (red) indicates stretches with severe modifications, in particular impoundments.
Only main rivers with length over app. 200 km or basins with app. 500 km^2 are considered, which sums up to 66,791 rkm in total for assessed rivers.

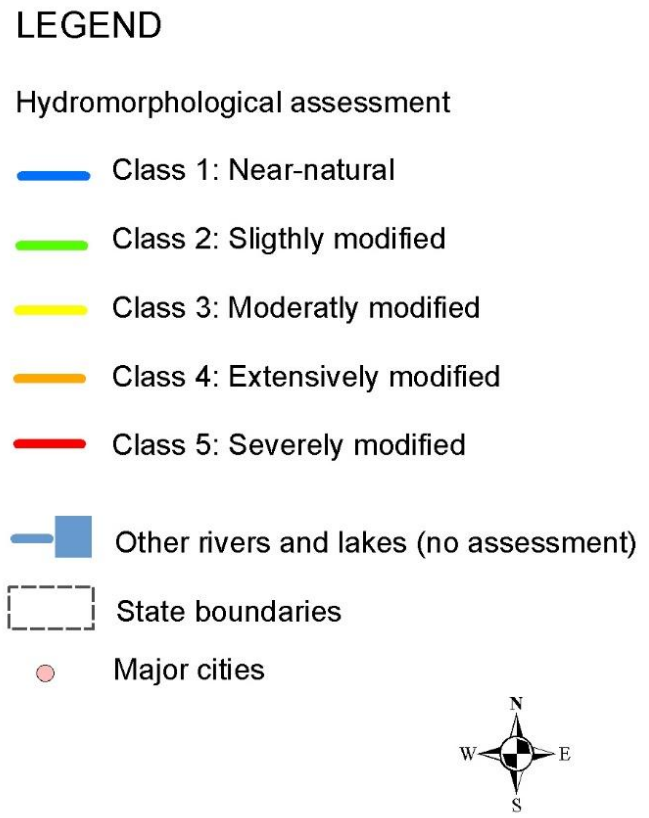


Figure 22: Legend of the maps in Chapter 3.3.

Figure 23: The Devoll river in Albania exemplifies a worst-case scenario: hydropower dam development on a previously free-flowing river with intact hydrological regime and sediment continuum. Now the large impoundment degrades the river from the braided section downstream start (compare also Hauer 2019). The HYMO assessment drop not only for the impounded reach considerably, but also downstream (source: Google Earth, Digital Globe 2019).

3.3.1 Iberian Peninsula (PT, SP, AD)

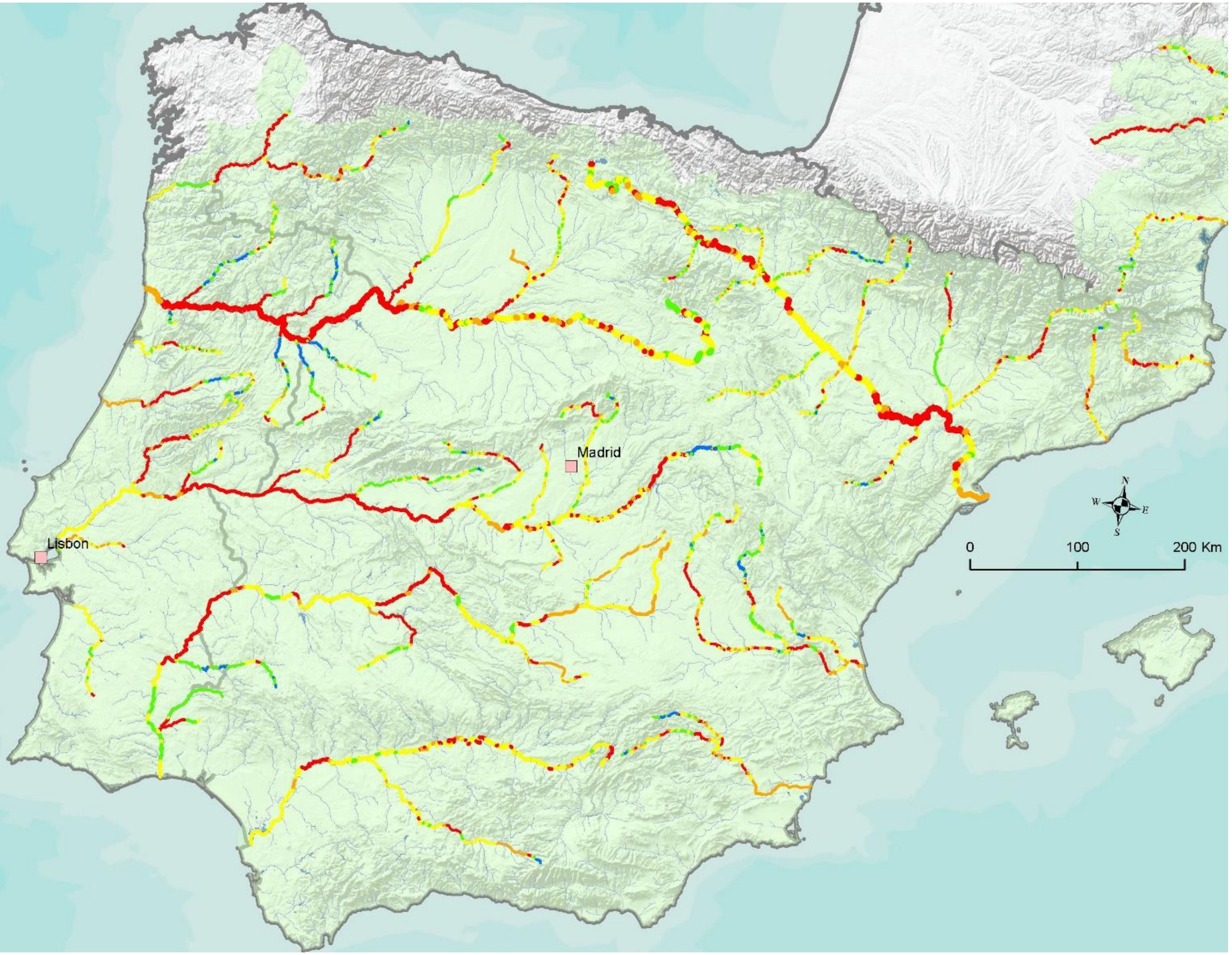


Figure 24: Hydromorphological assessment for the Iberian Peninsula.

The largest rivers in Portugal and Spain are almost entirely altered and only a very few short gorges remain in the headwaters. Rivers like the Ebro and the Guadalquivir are mostly affected by water abstractions for irrigation and SHP facilities/mills. The cascades of hydropower "lakes" on Duero and Tagus are among the longest in Europe, leading to a total loss of 81% of near-natural and slightly modified large rivers. The hydromorphological assessment covered 12,383 km of the Iberian Peninsula. Only 19% remain in the first two classes, which indicates the high alteration of rivers in this region.

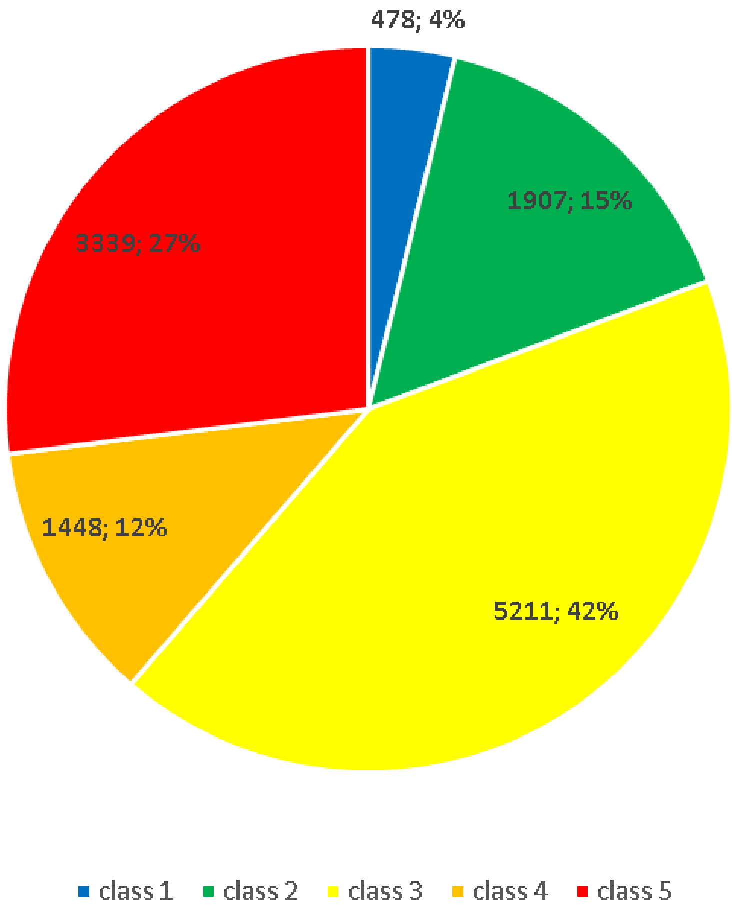


Figure 25: Hydromorphological assessment results for the Iberian Peninsula, by rkm and percentage.

3.3.2 Central Western European region (FR, MC, CH, IT, SM, MT)

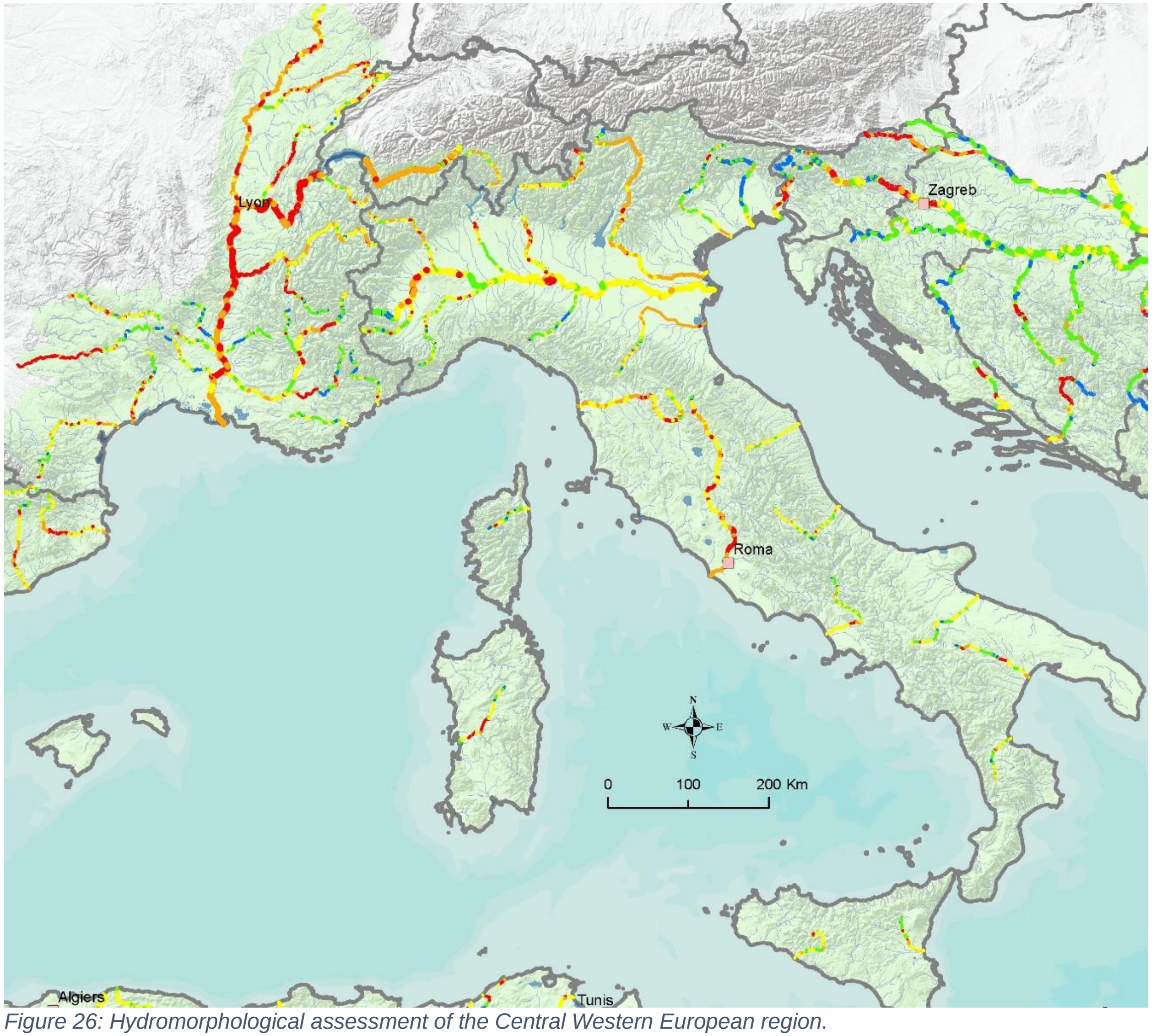


Figure 26: Hydromorphological assessment of the Central Western European region.

In general, rivers in France and Italy are strongly altered by various pressures. In France, the Rhône river provides hydropower production for navigation, but many other rivers are also strongly regulated for flood protection (only a few smaller river jewels like Ardèche remains within the projects area). While Italy builds larger HPP at higher elevations in the mountains (e.g., Alps, Abruzzo) several larger rivers were not entirely developed for hydropower as such as the Po or the famous Tagliamento, which is the best, mostly preserved braided Alpine river. A total of 8,971 km was assessed.

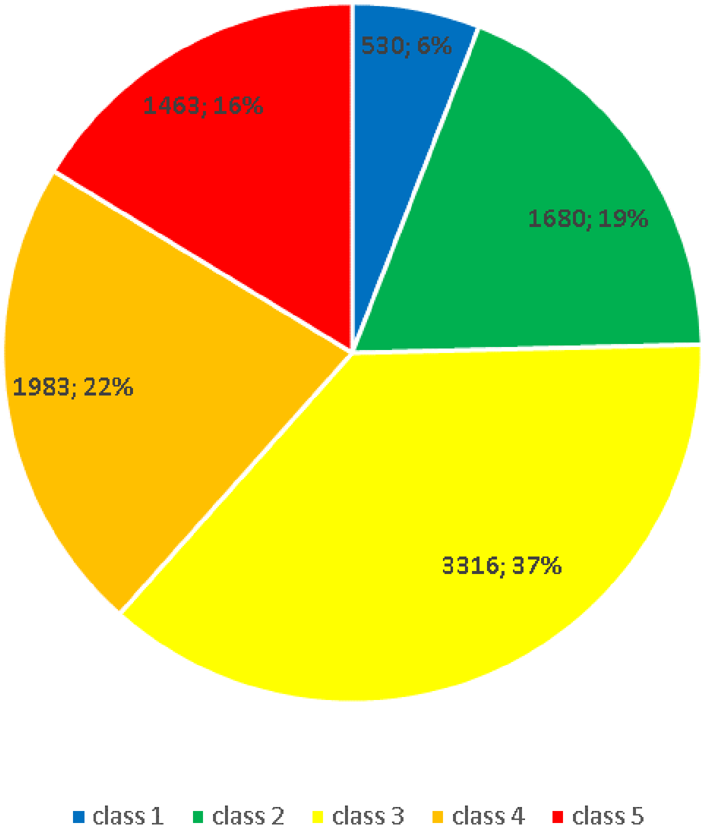


Figure 27: Hydromorphological assessment results for the Central Western European region, by rkm and percentage.

3.3.3 Balkan region (SI, HR, BA, ME, KV, AL, MK, GR, BG)

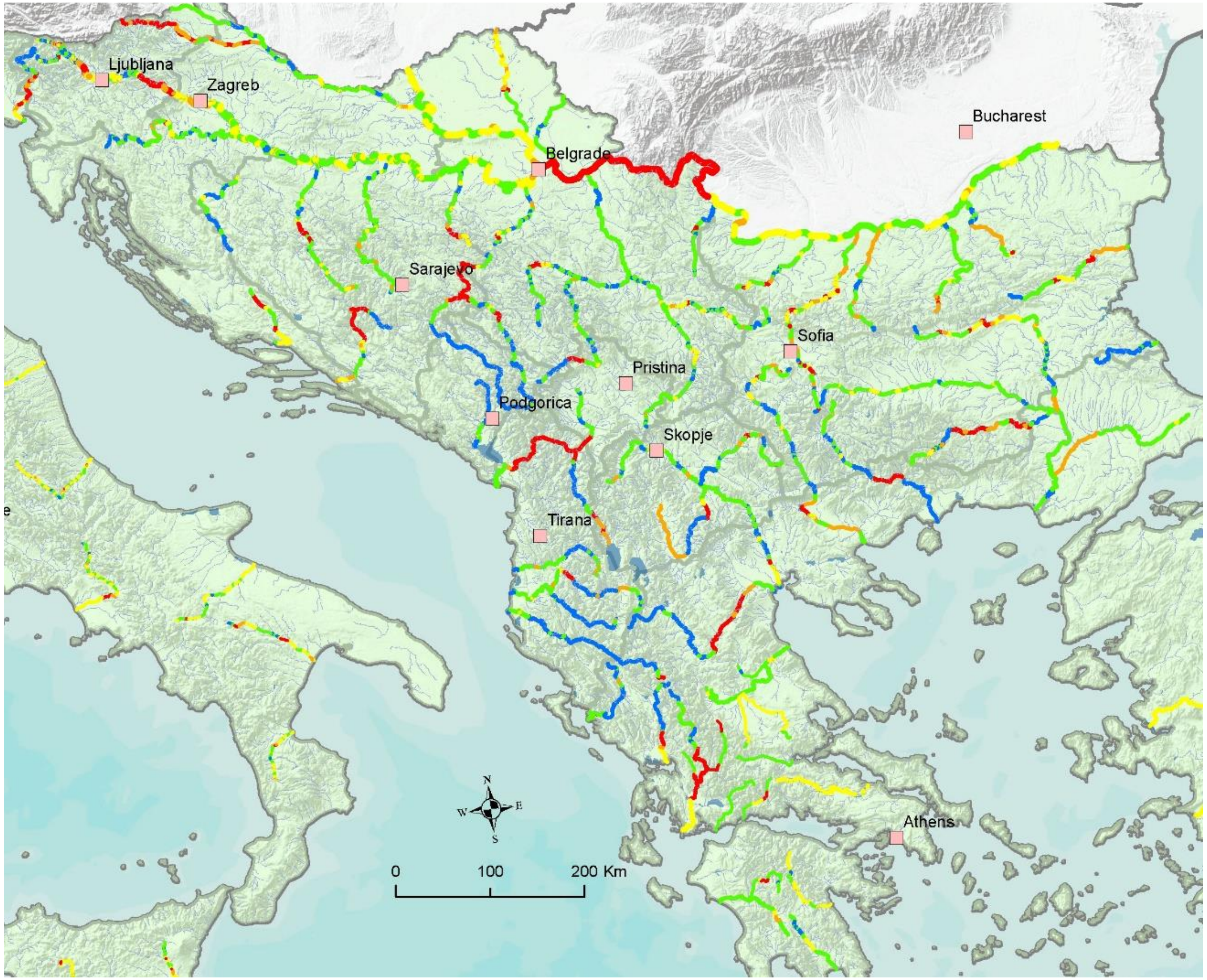


Figure 28: Hydromorphological assessment for the Balkan region.

In Slovenia and Croatia, rivers are already intensively used for hydropower, which is the core pressure on all main rivers in the Balkan region. The Vjosa river in Albania, the longest free-flowing mountain river (250 km) of western, southern and central Europe, remains almost intact. All other similar rivers are under HPP development pressure. As the data for the hydromorphological assessment is coming from before 2015 it is most likely to assume a slight reduction of blue and green classes in the meanwhile. For the Balkan region, smaller rivers improve the general assessment towards the better classes 1-3. In total, 66% of the 13,352 km assessed were in the first two classes. The Balkan rivers remain the most intact in the European section of the Mediterranean basin. However, this region currently faces the highest number of dam projects in the assessment area.

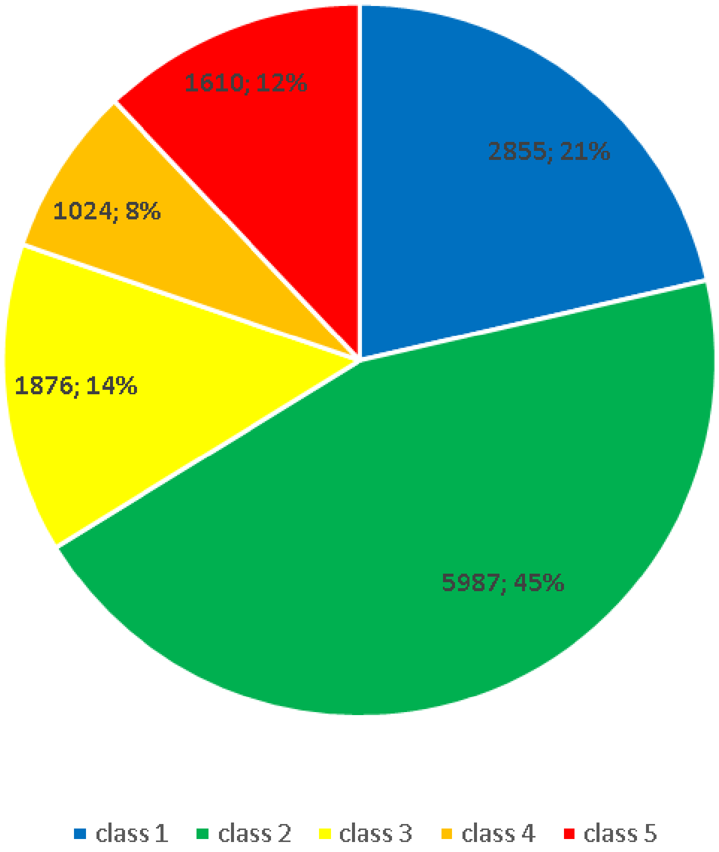


Figure 29: Hydromorphological assessment results for the Balkan region, by rkm and percentage.

3.3.4 Eastern Mediterranean region (TR, LB, SY, IQ, IL, JO)

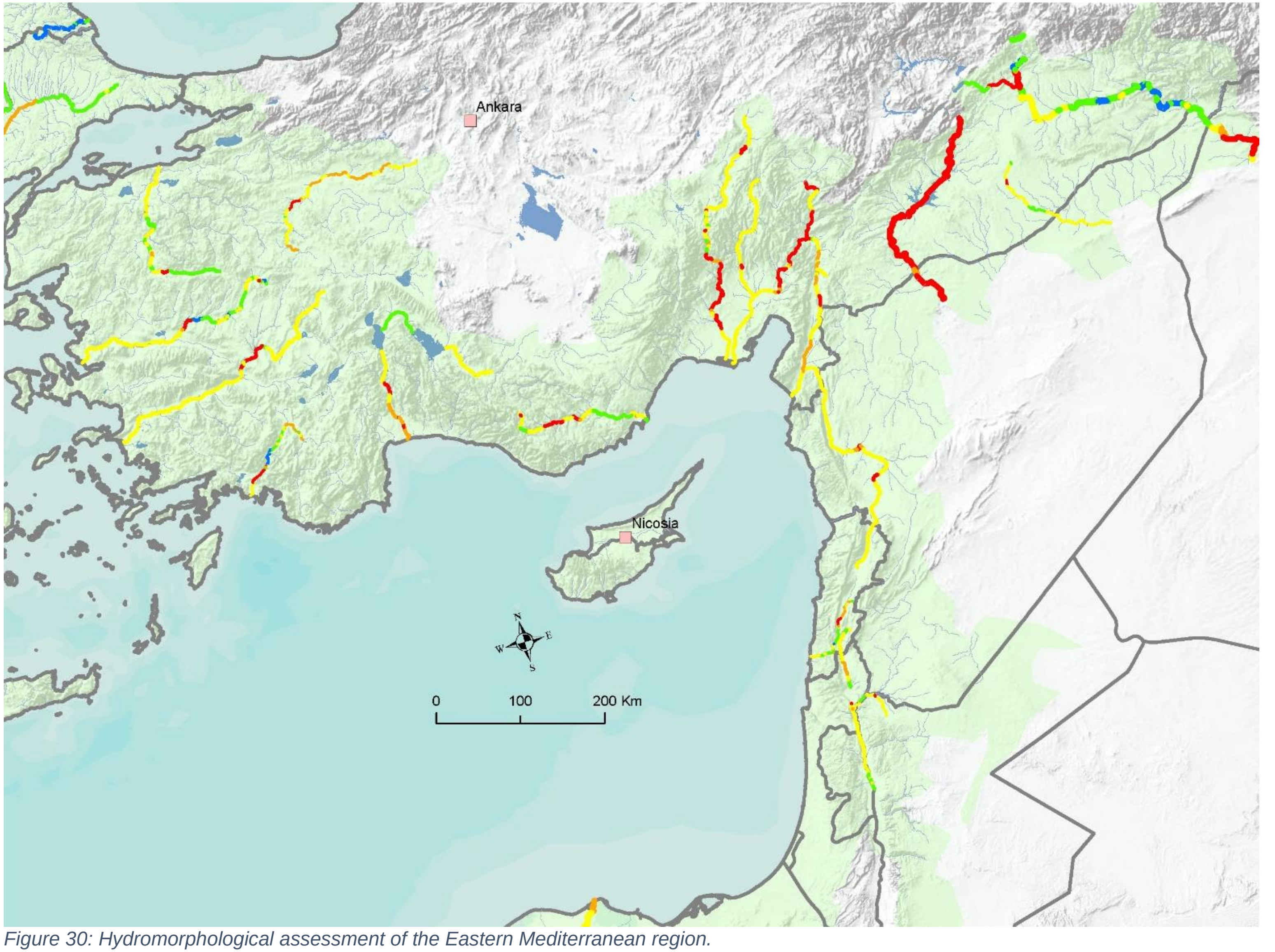


Figure 30: Hydromorphological assessment of the Eastern Mediterranean region.

The big rivers in the Eastern Mediterranean region are already altered or water serves for irrigation and hydropower. Aside from the barrages and some long chains of hydropower cascades also the upper and lower river stretches are at least moderately altered. Only a very few larger near-natural rivers remain, but some smaller still exist in Turkey. However, the upper Euphrates river in Turkey exceeds with 600 km length of continuous impoundment even the Aswan dam (500 km) in Egypt (for comparison, the Iron Gate dam impoundments on the middle and lower Danube reach up to 250 km in total). Of the 5,965 km assessed rivers, half were in the third class, showing the general high degree of deterioration also caused by hydropower and the changed hydrological conditions downstream of dams.

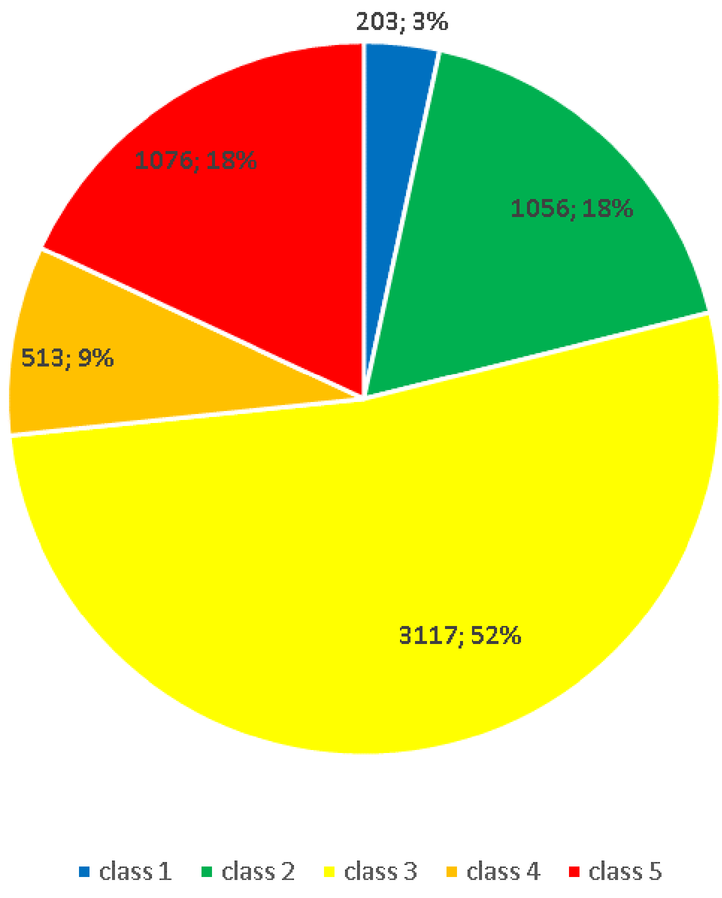


Figure 31: Hydromorphological assessment results for the Eastern Mediterranean region, by rkm and percentage.

3.3.5 Nile basin (EG, SD, SS, ER, ET, KE, UG, TZ, RW, BI, CD)

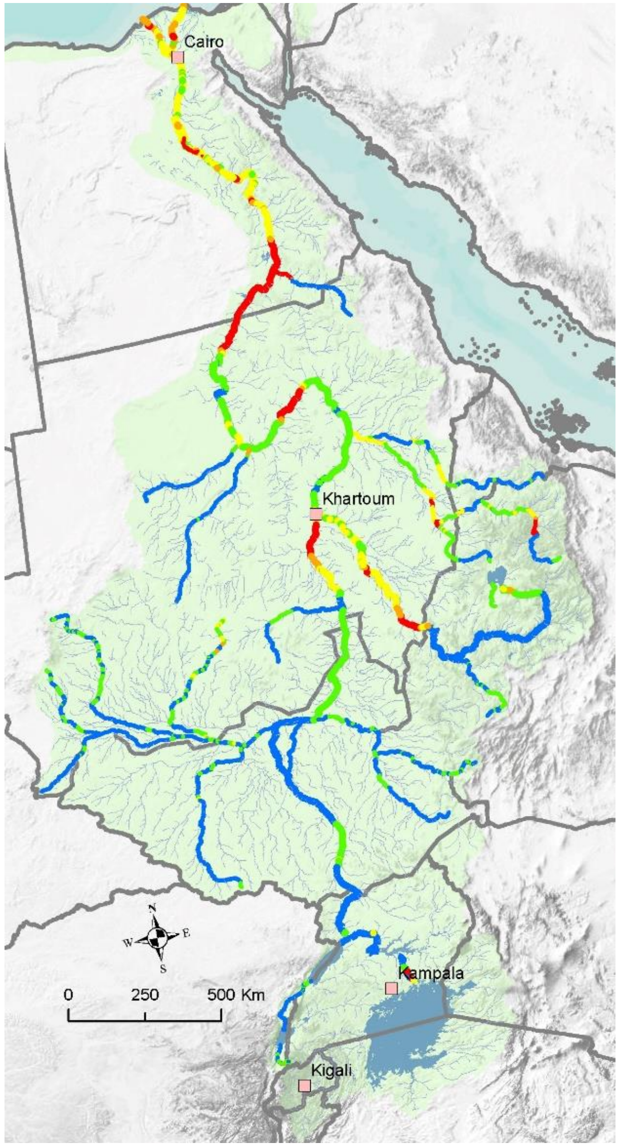


Figure 32: Hydromorphological assessment of the Nile basin region.

The first time, a raw assessment of major rivers in the Nile basin was performed, indicating apparent differences in the various parts of the catchment and the Nile. Coming from Europe and beginning from the lower course and Delta the alterations are obviously visible and being driven to a significant part by hydropower, but also by irrigation. The Nile is the only major River worldwide crossing the arid climatic zone entirely, but losing a lot of discharge on this long way: While average discharge summing up to 3 800 m³/s at the confluence of White and Blue Nile feeding into the Aswan barrage, in Cairo Egypt's capital only some 1,500 m³/s arrive after the long way through the Eastern Sahara. Due to intensive irrigation within the delta the final discharge of major branches into the Mediterranean Sea summing up to only 200 m³/s (compare also figure 2 where Nile is far behind of major European rivers such as the Rhône in France or the Po in Italy).

A large number of pristine rivers untouched by hydropower are the partially drying out western bound Sahel tributaries and still parts of Blue Nile and southeastern tributaries being all under pressure by large scale hydropower projects. Of the 18,899 km assessed, the largest share of class one and two rivers was found in the central and southern catchment.

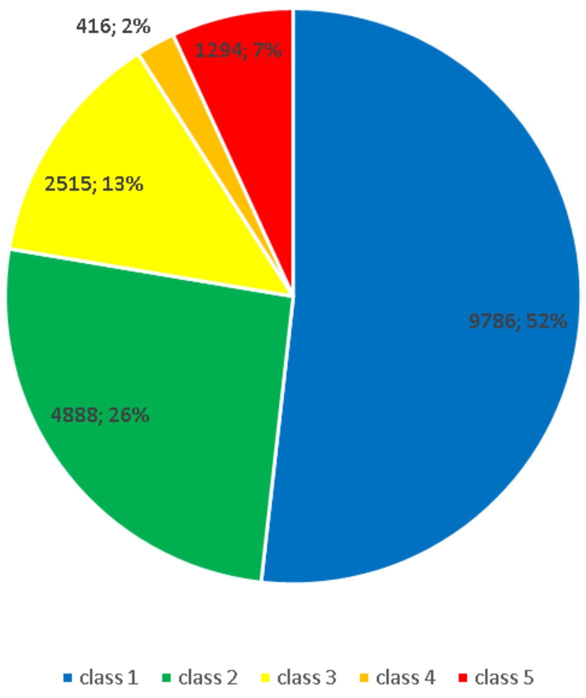


Figure 33: Hydromorphological assessment results for the Nile basin region, by rkm and percentage.

3.3.6 Maghreb region (LY, TN, DZ, MA)

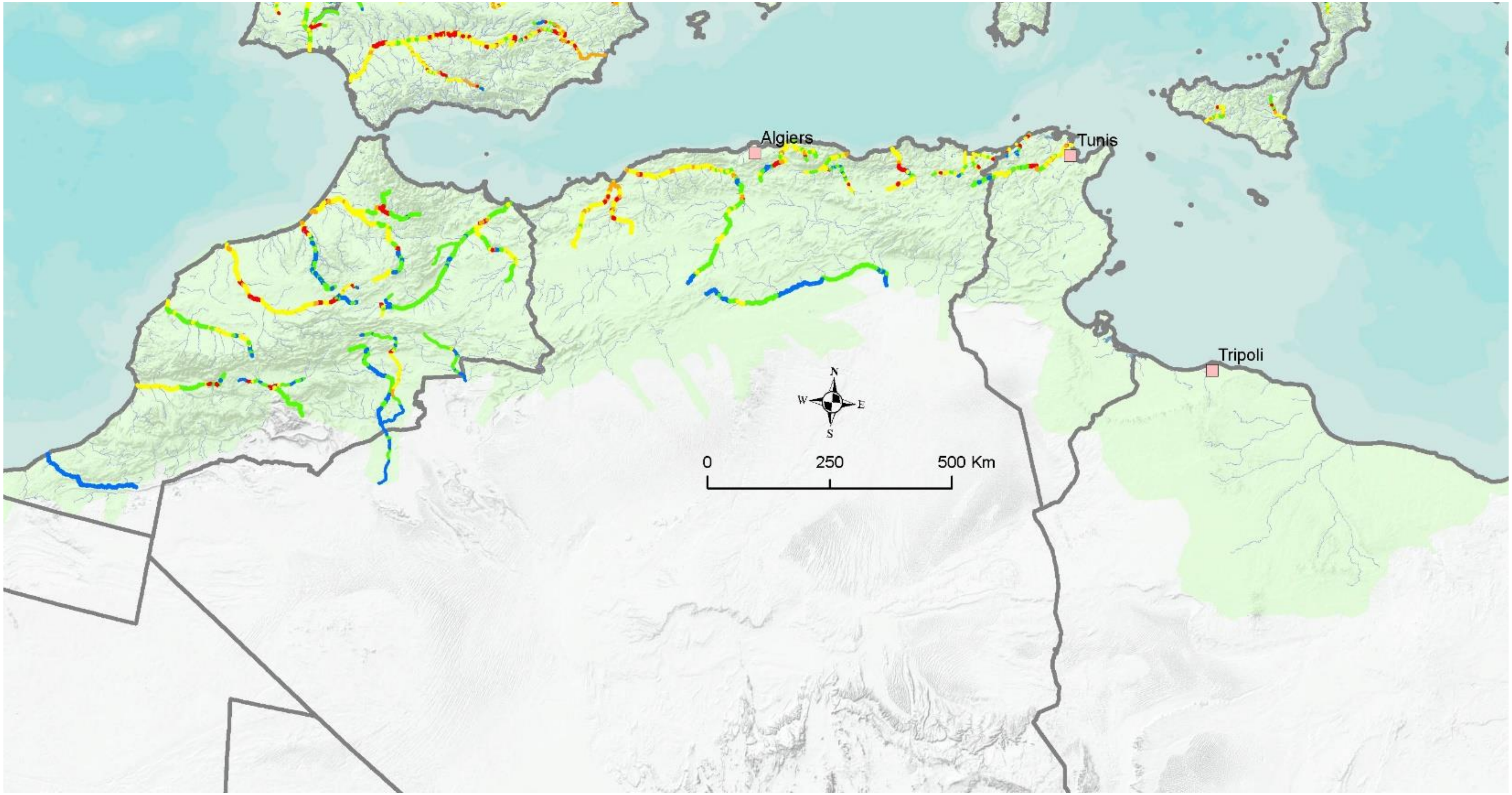


Figure 34: Hydromorphological assessment for Maghreb region.

Many rivers are already altered by hydropower and irrigation storage, but in between many river stretches are reaching moderate to good conditions. Rivers which are not interesting for hydropower are the temporal flowing Wadis in the Sahara catchments still reach high assessments. 7,221 km were assessed.

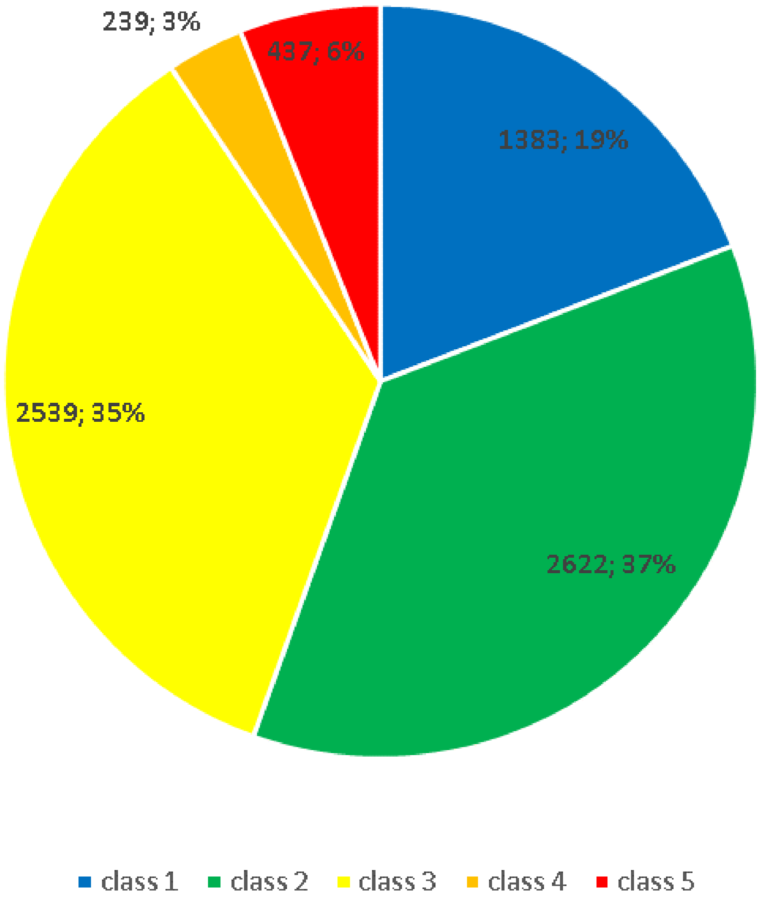
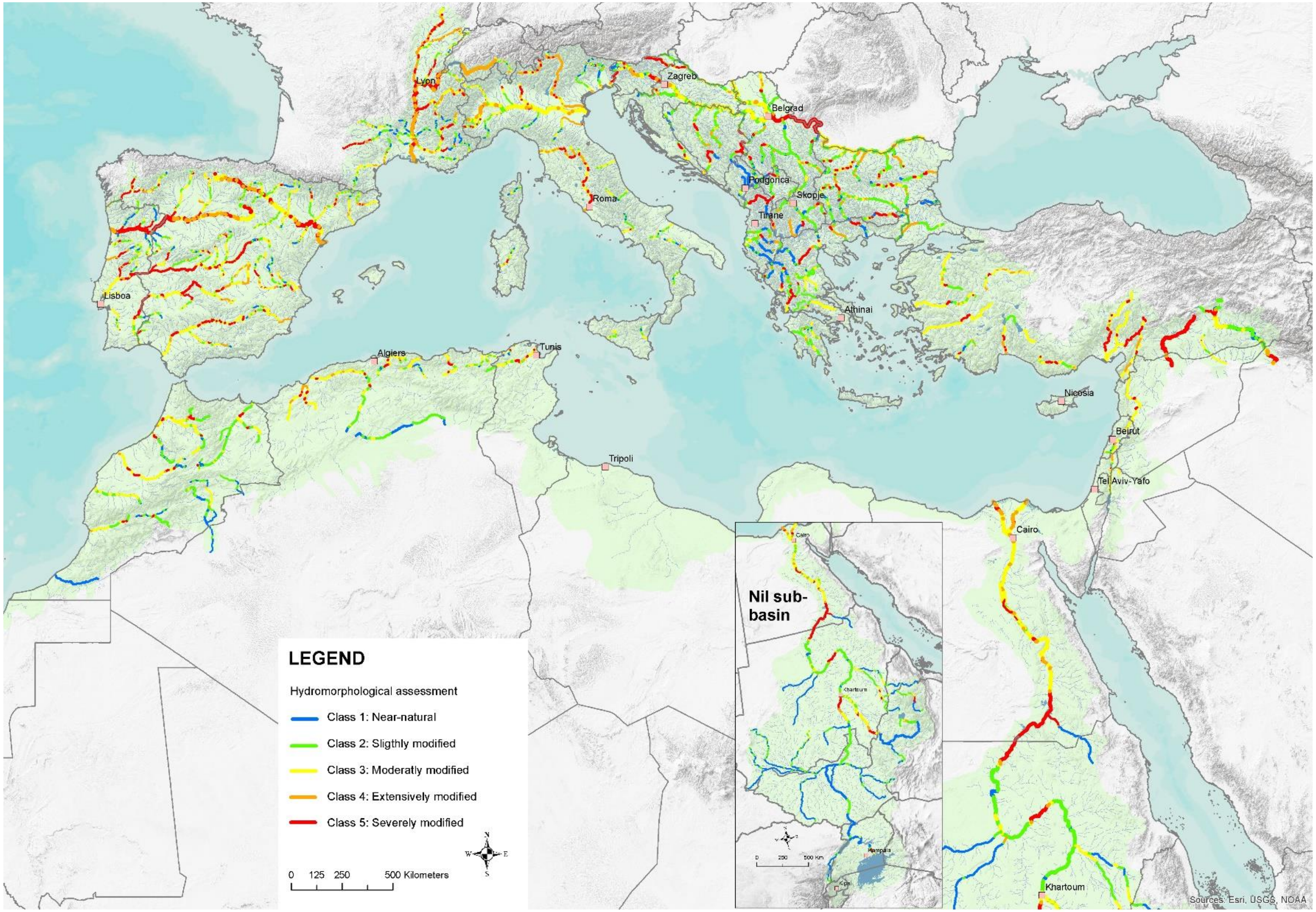


Figure 35: Hydromorphological assessment in rkm and percentage for the Maghreb region

3.3.7 Entire Mediterranean basin



Hydropower inventory and river assessment for the wider Mediterranean basin

Figure 36: Hydromorphological assessment of the study area.

The general picture underlines the intensive usage of rivers in Europe, Western Asia and Northern Africa. The picture is improved by remote rivers in the arid zone as such as the western Nile tributaries and Wadis, but also still by rivers in the Balkans, namely Albania, Montenegro or Bosnia & Herzegovina.

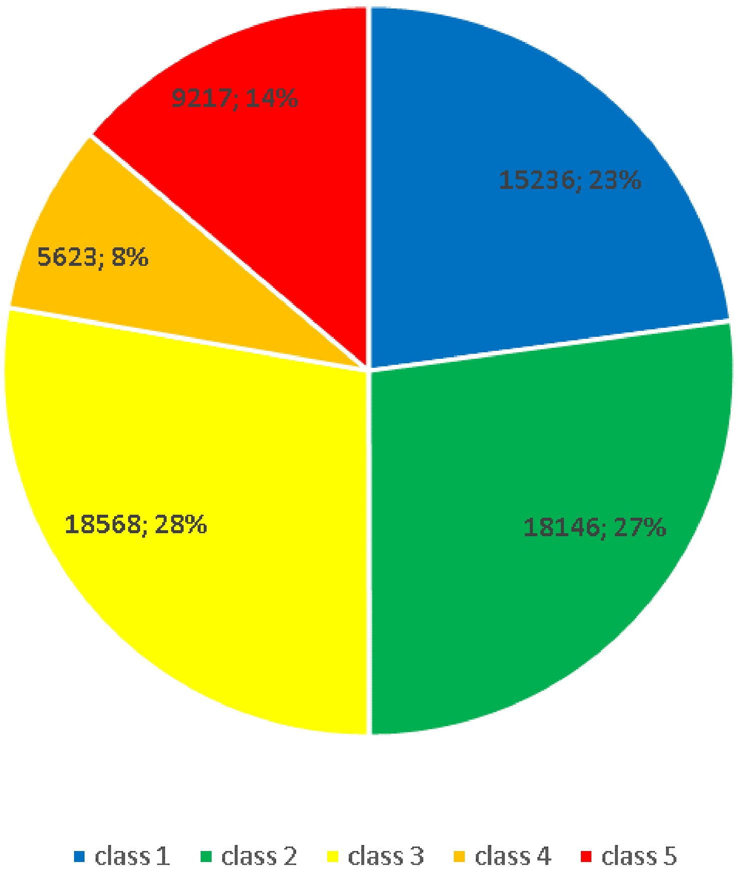


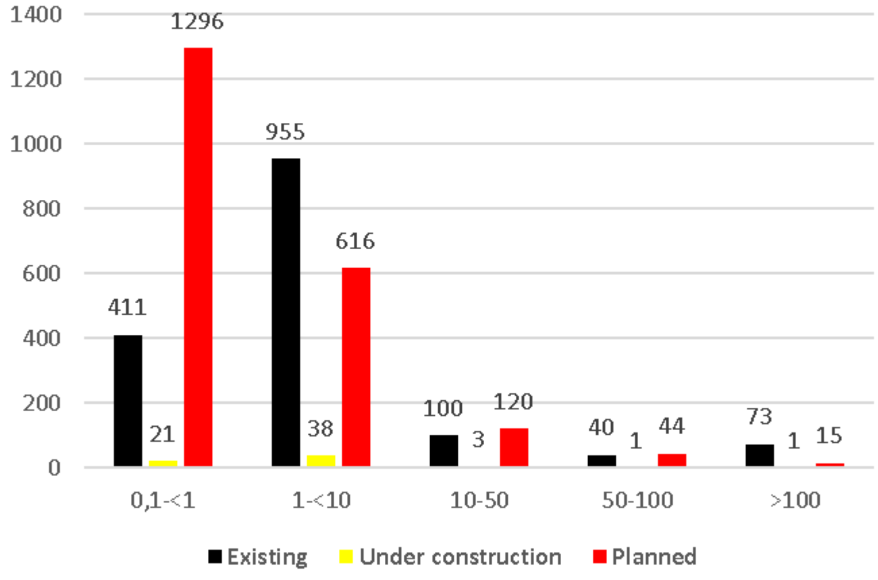
Figure 37: Hydromorphological assessment of the study area in rkm and percentages.

3.4 Dams in protected areas

Protected areas are mapped and grouped into three groups, as described in the Methodology section.

In Europe, the Natura2000 network includes many rivers and its valleys. However, it includes also impoundments and the protection purpose lays not always on the rivers. In the non-EU south-eastern countries, several important river valleys are not protected so far while in Turkey and several African countries protected areas in river valleys are missing to a wide range. In the Balkan region with its enormous development of accession to EU many planned HPP would also fall in (partially planned) nature reserves within all categories.

For protected areas the overall analysis indicates up to one third (31% or 3,734) of all HPP being inside a protected area (2,091 planned, 64 under construction and 1,579 existing HPP). 503 new HPP are planned in the highest category.



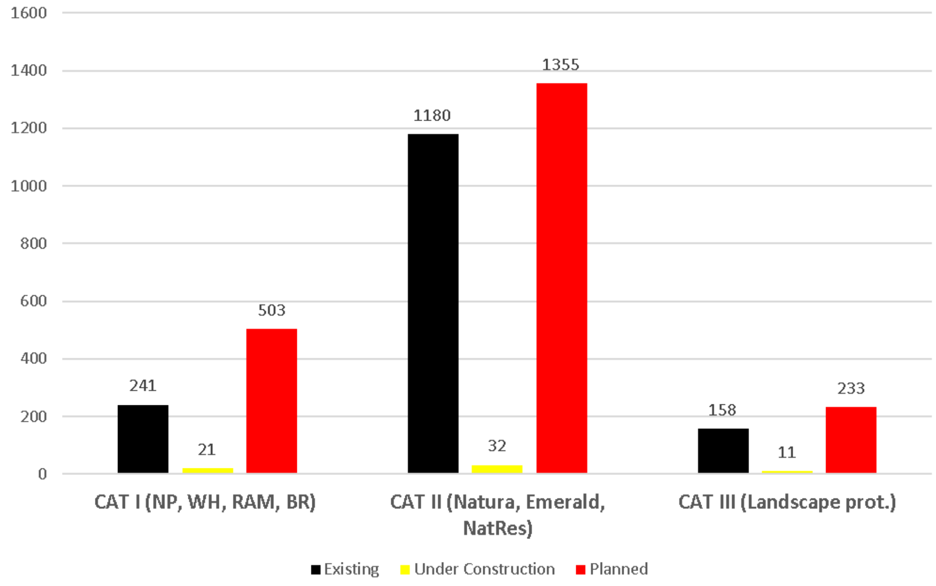


Figure 38 and 39: HPP in protected areas (left) and categories of protected areas and HPP on the right side.

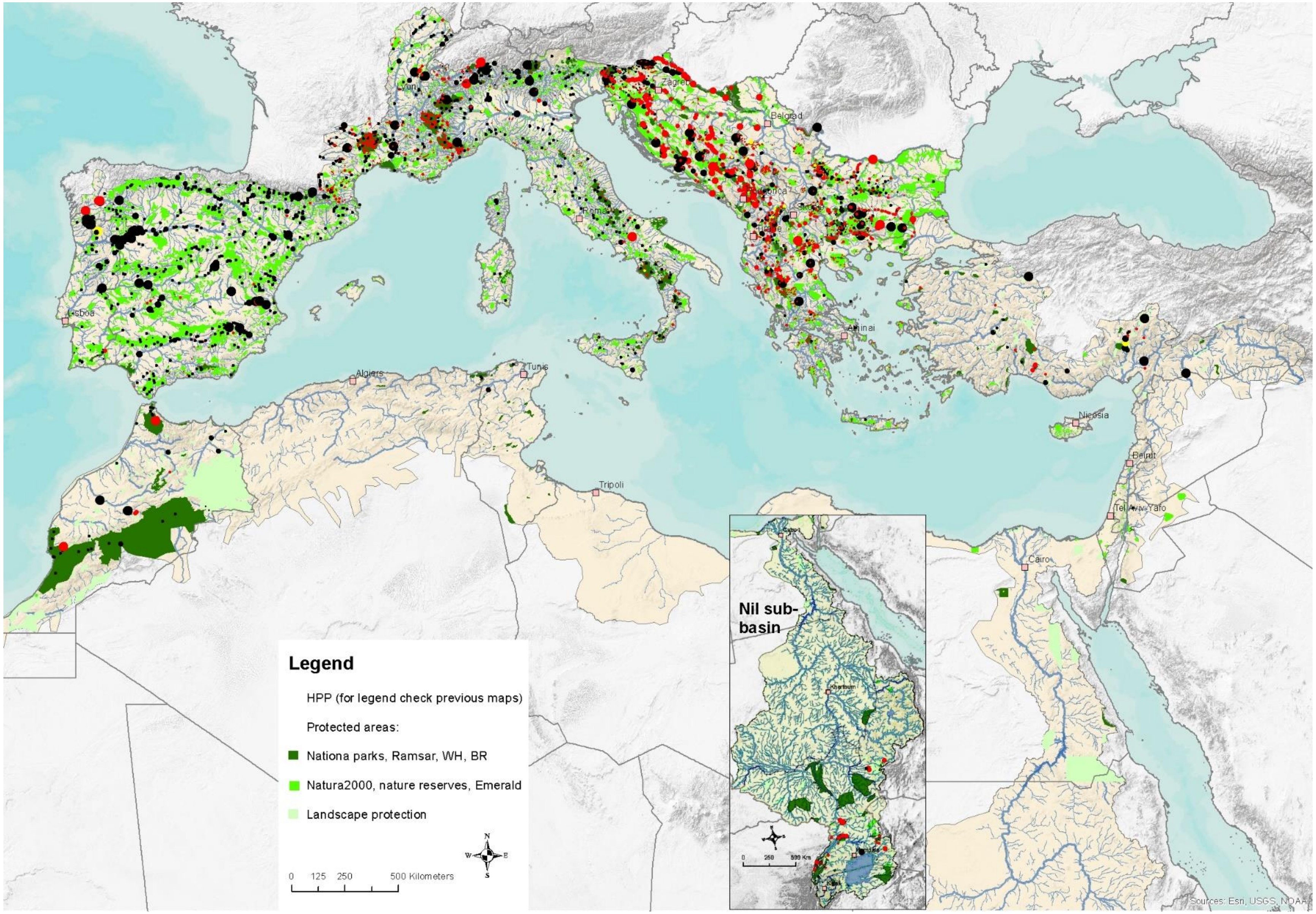


Figure 40: Protected areas within the project area and hydropower plants.

3.5 Dams in IUCN Key Biodiversity Areas

Inside of freshwater key biodiversity areas (KBAs), there are 1,394 HPP - 557 exist, 12 are under construction and 825 are planned. Due to the dispersal distribution of KBAs only general regions and conclusions can be formulated, but several spots in Dalmatia, north-eastern Greece or Turkey seems to be seriously affected by existing and particular planned HPP projects including endemic species.

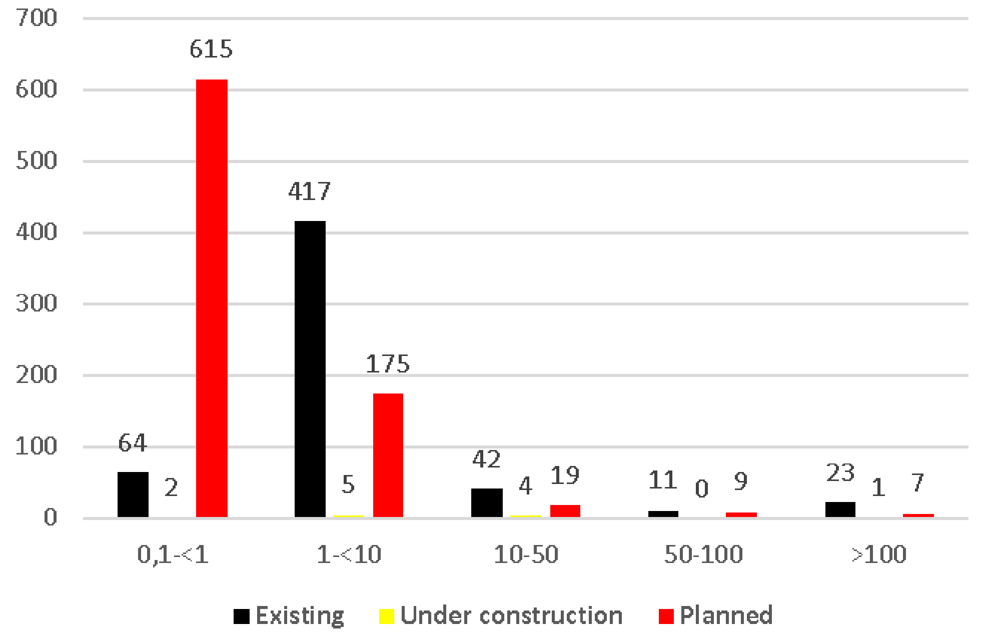


Figure 41: Distribution of hydropower plants in key biodiversity areas.

Figure 42 on next page indicates the thread by SHP, namely in Greece for HPP below 1 MW, but also the size of 1-10 MW is considerable, e.g. for Balkan region. However, even a few large-scale projects > 50 MW are planned in KBA.

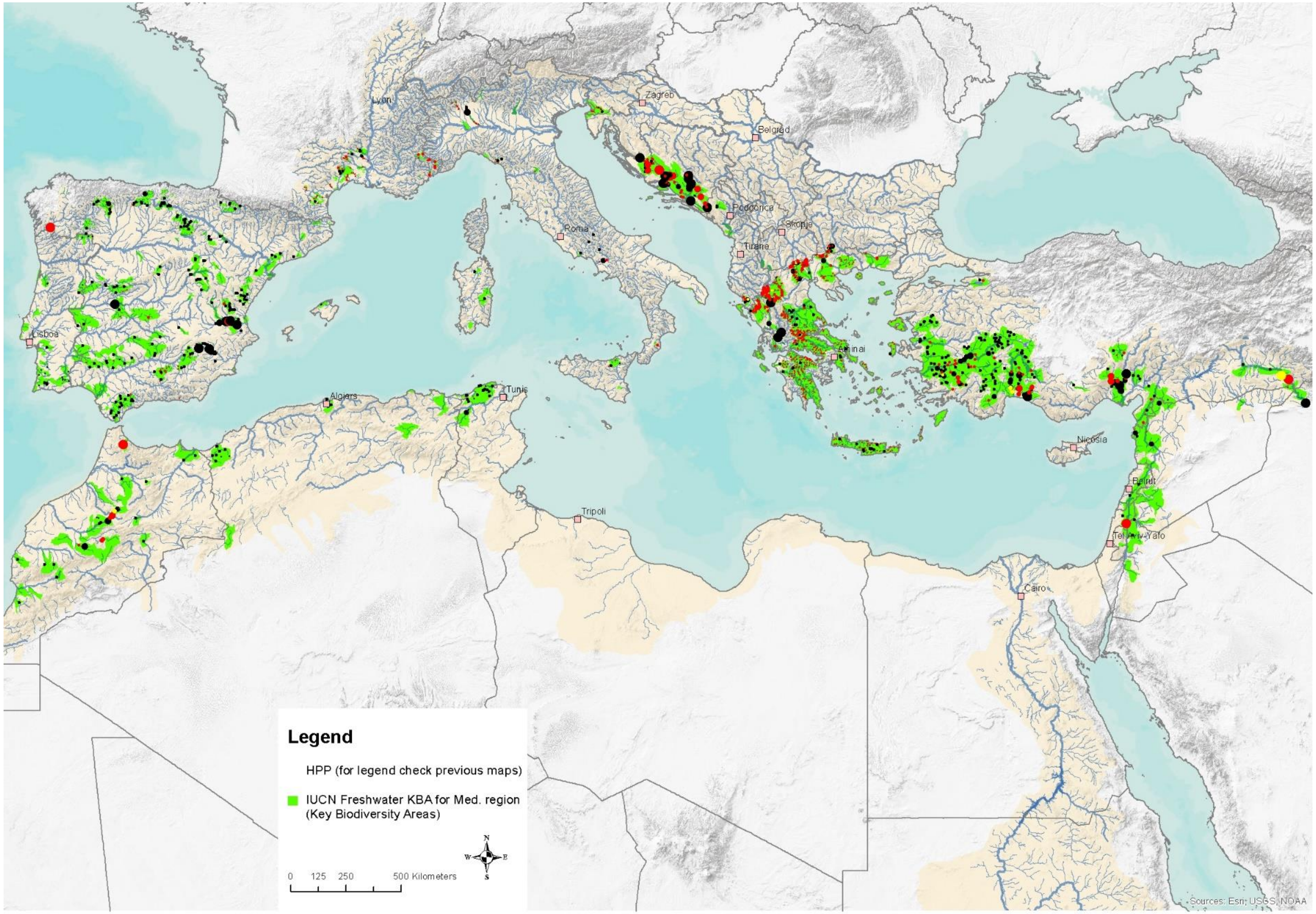


Figure 42: Key biodiversity areas in the study area. Hydropower plants are also included.

3.6 Overview by country

The following table summarizes the distribution of hydropower plants by country. in alphabetical order and colour for the six regions.

	Existing					Planned					Under construction					Total
Countries	0,1-<1	1-<10	10-50	50-100	>100	0,1-<1	1-<10	10-50	50-100	>100	0,1-<1	1-<10	10-50	50-100	>100	
Albania	57	103	11	3	4	177	241	25	9	1	22	30	7		1	**691**
Algeria	10	81	3	1		6	2		1				1			**105**
Bosnia and Herzegovina	41	45	3	3	9	84	158	53	12	5	5	6	1		1	**426**
Bulgaria	159	102	15	5	9	217	115	3	3	3		5				**636**
Burundi	5	3					1	2	1							**12**
Croatia	12	26	9	3	7	46	63	29	9	2	1	1				**208**
Democratic Republic of the Congo	1		1				4	2	1							**9**
Egypt	3	3	2	2	2	7	13				2					**34**
Ethiopia		2	2	1	3		3		11	15			1		1	**39**
France	5	469	13	7	23	793	313	2								**1625**
Greece	14	65	4	2	10	896	150	8		5	3	5	1			**1163**
Iraq					1											**1**
Israel		7				1				2						**10**
Italy	143	715	24	6	20	780	54	1	1	2		3				**1749**
Jordan		2														**2**
Kenya	5	5	1	1			10	5	1	1	1	1				**31**
Kosovo	2	8	2			12	58	4	1	2	1	15				**105**
Lebanon		3				1										**4**
North Macedonia	47	38	5	1	2	118	52	14	4	1	9	5				**296**
Malta						1										**1**
Montenegro	3	13			2	14	56	11	9	2	2	1				**113**
Morocco	8	53	11	2	5		4	10	1	3			2		1	**100**

	Existing					Planned					Under construction					Total
Countries	0,1-<1	1-<10	10-50	50-100	>100	0,1-<1	1-<10	10-50	50-100	>100	0,1-<1	1-<10	10-50	50-100	>100	
Palestine		1														**1**
Portugal[8]	162	175	21	7	23		1			1					3	**393**
Rwanda	8	7	5			4	9	2	2		1	3		1		**42**
Serbia	43	32	3	2	5	698	107	17	5	3	21	9	1			**946**
Slovenia	288	30	15	6	3	184	26	30	1		4	1				**588**
South Sudan							2	1	1	4						**8**
Spain	144	853	72	23	38	122	15	3		7				1		**1278**
Sudan	1	2	2	1	3					6						**15**
Switzerland	70	103	34	23	23	109	39	7		5	1			1	1	**416**
Syria	2	3	4			4										**13**
Tanzania								2	1				1			**4**
Tunisia	15	23	3			8										**49**
Turkey	8	394	40	15	19	25	113	21	11	10	1	1	6	4	1	**669**
Uganda	5	7	3		2	11	35	8	5	1		4			1	**82**
Total	**1261**	**3373**	**308**	**114**	**213**	**4318**	**1644**	**260**	**90**	**81**	**74**	**90**	**21**	**7**	**10**	**11864**

Table 2: HPP distribution by country (colours indicate the 6 regions), status and size.

Even though many rivers are already affected by HPP, an increasing number will be affected by the 6,414 planned HPP. 2,092 of the planned HPP are expected to be inside of existing PAs.

[8] For Portugal only two HPP projects are considered as decided by project partner.

4. Conclusion and recommendations

This study compiled an inventory of HPP of the entire Mediterranean region, assessed the hydromorphological status of rivers, and the intersection with protected areas. This study highlights the HPP projects that should be considered for international and national planning. Water sources, but in particular perennial and temporal river ecosystems in the semi-arid and arid regions of the Mediterranean basin must be better protected and a long-term usage strategy of this resource is very important.

As expected, the density of hydropower plants in western Europe is exceptionally high. The Balkan region, in particular Albania, still hosts many hydromorphologically intact rivers and the development of dams is rapid. The cascades of impoundments over hundreds of rkm can be found in Portugal, Spain and France, some in Italy and more in Turkey (the Euphrates river, the cradle of the prehistoric Mesopotamia downstream is impounded for almost 90%). In general, the hydro potential is more or less exhausted in the western European countries while in the Balkans and Turkey there are ambitious plans to increase the exploitation of hydro resources. Such exploitation will further interrupt major and medium-sized rivers throughout all countries. Many of those rivers fall in existing or planned protected areas and in the IUCN key biodiversity areas.

The protection of river valleys is a paradox. In western European countries, many heavily altered rivers exist within the boundaries of protected areas while in many other countries important rivers are still unprotected.

The development of hydropower in the Nile basin is a development hotspot of the so-called second and third world countries. The 6,000 MW Millennium Dam (Grand Ethiopian Renaissance Dam) in Ethiopia will impound and alter roughly 500 km of intact blue Nile and will flood 1,874 km² (more than one third of Aswan dam).

The protected areas analysis found that those areas are generally not protected in regards to new hydropower projects. In the Balkans, even national parks are not excluded from HPP planning.

The study recommends

- A moratorium on all major HPP planning along free-flowing rivers.
- A reduction of the number of small HPP, which are significant to the ongoing ecological destruction. 90% of the planned HPPs are smaller than 10 MW, and a subsidy system mostly drives those small HPP, that is not economically viable.
- Due to the ongoing deterioration and interruption of river continuum, the impoundments over long distances and altered hydromorphological regime downstream, existing HPP must go into strong restoration of river continuums but also into further morphological improvements up to the decommissioning of dams.
- Protected areas and KBAs should be completely free of hydropower planning and rivers must be restored, catchment approaches (continuity) are necessary to assess the landscape impacts of disturbances such as dams further.
- The large impacts by dams, such as the continuity interruptions to biota and sediment and the strong changes of hydrological regimes, should be mitigated or prevented entirely.
- The hydromorphological alterations to European rivers restrict rivers from reaching good ecological status (WFD) in EU countries and can be addressed to a large extent to hydropower (among others such as navigation, flood protection, land reclamation or irrigation). Only long-term strategies of mitigation or even removal of dams and replacement of close dykes will lead to real improvements. Therefore, it is necessary to protect those few remaining near-natural or only slightly modified rivers across the entire project area.
- The Balkan Eco Masterplan recognizes the dangerous situation and designates large parts of the drainage system as “no go” for further HPP development. We recommend that this approach is applied in other regions in the Mediterranean basin.
- Further evaluation of the overall impacts of dams on terrestrial fauna, namely large carnivorous and effects on the food chain, genetic viability of ecosystems and biodiversity.
- Further evaluation of the impacts of dams on the sediment balance and coastal erosion in the Mediterranean and Atlantic coast is necessary.
- Use of ecosystem services and natural based solutions for flood risk and coastal erosion complementing or even substituting “grey” infrastructure (dams and dykes).
- Increased recognition of the cultural benefit of free-flowing rivers.

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