Research Ideas and Outcomes 7: e77750
doi: 10.3897/rio.7.e77750

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Grant Proposal

Securing Biodiversity, Functional Integrity, and Ecosystem Services in Drying River Networks (DRYvER)

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Reviewable v 1

Received: 08 Nov 2021 | Published: 31 Dec 2021

Citation: Datry T, Allen D, Argelich R, Barquin J, Bonada N, Boulton A, Branger F, Cai Y, Cañedo-Argüelles M, Cid N, Csabai Z, Dallimer M, de Araújo JC, Declerck S, Dekker T, Döll P, Encalada A, Forcellini M, Foulquier A, Heino J, Jabot F, Keszler P, Kopperoinen L, Kralisch S, Künne A, Lamouroux N, Lauvernet C, Lehtoranta V, Loskotová B, Marcé R, Martin Ortega J, Matauschek C, Miliša M, Mogyorósi S, Moya N, Müller Schmied H, Munné A, Munoz F, Mykrä H, Pal I, Paloniemi R, Pařil P, Pengal P, Pernecker B, Polášek M, Rezende C, Sabater S, Sarremejane R, Schmidt G, Senerpont Domis L, Singer G, Suárez E, Talluto M, Teurlincx S, Trautmann T, Truchy A, Tyllianakis E, Väisänen S, Varumo L, Vidal J-P, Vilmi A, Vinyoles D (2021) Securing Biodiversity, Functional Integrity, and Ecosystem Services in Drying River Networks (DRYvER). Research Ideas and Outcomes 7: e77750. https://doi.org/10.3897/rio.7.e77750

Abstract

River networks are among Earth's most threatened hot-spots of biodiversity and provide key ecosystem services (e.g., supply drinking water and food, climate regulation) essential to sustaining human well-being. Climate change and increased human water use are causing more rivers and streams to dry, with devastating impacts on biodiversity and ecosystem services. Currently, more than a half of the global river networks consist of drying channels, and these are expanding dramatically. However, drying river networks (DRNs) have received little attention from scientists and policy makers, and the public is unaware of their importance. Consequently, there is no effective integrated biodiversity conservation or ecosystem management strategy of DRNs.

A multidisciplinary team of 25 experts from 11 countries in Europe, South America, China and the USA will build on EU efforts to assess the cascading effects of climate change on biodiversity, ecosystem functions and ecosystem services of DRNs through changes in flow regimes and water use. DRYvER (DRYing riVER networks) will gather and upscale empirical and modelling data from nine focal DRNs (case studies) in Europe (EU) and Community of Latin American and Caribbean States (CELAC) to develop a meta-system framework applicable to Europe and worldwide. It will also generate crucial knowledge-based strategies, tools and guidelines for economically-efficient adaptive management of DRNs. Working closely with stakeholders and end-users, DRYvER will co-develop strategies to mitigate and adapt to climate change impacts in DRNs, integrating hydrological, ecological (including nature-based solutions), socio-economic and policy perspectives. The end results of DRYvER will contribute to reaching the objectives of the Paris Agreement and placing Europe at the forefront of research on climate change.

Keywords

Adaptive Management; Biodiversity; Biogeochemical cycles; Climate Change; Drought; Ecosystem Functions and Services; Drying River Networks; Metaecosystems; Natural capital; Values; Socio-ecological systems; Water climate interactions; Droughts

1. Excellence

The 2015 Paris Agreement stresses the need to protect biodiversity and secure the functional integrity of ecosystems, while fighting against climate change and adapting to its impacts. River networks are among the most threatened hot spots of biodiversity (Reid et al. 2018). They act as ecological corridors for species and safeguard biodiversity at landscape and continental scales (Deiner et al. 2016). River networks contribute substantially to the carbon cycle, including the evasion of carbon dioxide into the atmosphere, linking terrestrial and aquatic ecosystems down to the sea (Battin et al. 2009). They provide key ecosystem services including provision of drinking water, regulating climate and food production which are essential to sustain human wellbeing (Thorp et al. 2010). In river networks, aquatic communities, ecosystem functions and services are organised through local environmental constraints (e.g., physical habitat) and regional fluxes of organisms (i.e., dispersal) and resources (e.g., organic matter transport). These fluxes are deeply modified by climate change and increased human water use, which cause rivers and streams to dry up worldwide, including in Europe. Over 50% of the global river networks include drying channels (Fig. 1), and this share is increasing worldwide (Döll and Schmied 2012, Acuña et al. 2014, Datry et al. 2018a). Because shifts from permanent to intermittent flow regimes represent major tipping points for rivers, with often irreversible environmental and societal consequences, including massive fish deaths and impaired water quality, we must urgently understand ecosystem processes and socio-ecological consequences of drying (Tonkin et al. 2019). Given that every river network dries at some point in time and space (Fig. 1) with cascading effects to adjacent terrestrial and marine ecosystems (Acuña et al. 2014, Datry et al. 2017), a fundamental breakthrough in our understanding of and approach to river networks is needed to better manage them in a climate change context.

Although drying river networks (DRNs) are expanding in time and space, they have received little attention from scientists and policymakers, and the public is seemingly unaware of the importance of DRNs in supporting human well-being (Acuña et al. 2014, Datry et al. 2018a). This lack of knowledge prevents us from predicting how climate change will alter riverine drying patterns and affect their biodiversity, ecosystem functions and services and the consequences of such alterations for both nature and humans. Currently, there is no effective integrated biodiversity conservation strategy or ecosystem management of DRNs facing climate change. DRNs are not only crucial in the European Union (EU) but also worldwide, including South America, harbouring 30% of Earth's freshwaters and several of the world's major biodiversity hotspots (IPBES 2018).

Capitalizing on the COST Action SMIRES, an international network-building project on DRNs, DRYvER will pioneer:

Figure 1. doi

Phases of flowing and drying alternate annually in the naturally intermittent Albarine River (France), a focal DRN of DRYvER. About half of EU's river channels now flow intermittently and this fraction is increasing. Photos: T. Datry.

- a knowledge-based dynamic meta-system framework of DRNs, integrating biodiversity, ecosystem functions and services and their values at multiple scales, and
- legislative and management tools (including nature-based solutions (NBSs)) for economically-efficient adaptive management of DRNs affected by climate change.

The meta-system thoery acknowledges that both local (i.e. niche selection and biotic interactions at a river reach) and regional (i.e. dispersal of organisms and spatial flows of material and energy across the river network) mechanisms interact to shape the spatial and temporal organization of populations and communities, and drive ecosystem processes and services. The meta-system framework is particularly relevant for DRNs due to their dendritic topology, their temporary fragmentation and the predominantly unidirectional flow of water, which simultaneously contribute to and constrain the exchange of matter and organisms at larger spatial scales.

1.1. Objectives

DRYvER will investigate how biodiversity, ecosystem functions, ecosystem services and their values in DRNs are directly and indirectly altered by climate change through empirical and modelling work at relevant spatial and temporal scales. Further, DRYvER will provide knowledge-based strategies and tools for cost-effective adaptive management of DRNs in the EU and worldwide.

With a broad geographic scope encompassing the EU and CELAC (Community of Latin American and Caribbean States), and a multi-scale approach that combines the continental (EU and South America) scale and network scales of 9 focal DRNs (representing 6 case studies in Europe and 3 in CELAC, see page 14 and box1), the specific objectives of DRYvER are:

Objective 1 (O1): Determine current and future patterns of DRNs in space and time with associated uncertainties under prospective climate change scenarios, through modelling of hydrological processes at both the continental (EU and South America) scale and network scales of 9 selected focal DRNs (Work Package (WP) 1).

Expected Result 1 (ER1): Predictive dynamic high-resolution maps of DRNs under different climate change scenarios to be used as a basis for the development of adaptation and mitigation measures to shifts in flow regimes.

Key Performance Indicator 1 (KPI 1): Number of focal DRNs for which changes in flow intermittence and associated uncertainties are modelled and projected. Target: 9 of 9 focal DRNs.

O2: Develop a dynamic meta-system framework to catalyse our understanding of the effects of drying on river network biodiversity and key ecosystem functions, allowing identification of tipping points at different spatial (EU and focal DRNs) and temporal scales (month, season, year, decade, century) (WP2 and WP3).

ER2: Definition of a safe operating space (i.e. drying thresholds in space and time that should not be transgressed to maintain biodiversity and functional integrity) for DRNs through reliable predictions of drying effects on river network biodiversity and functioning.

KPI2: Number of focal DRNs for which trends in biodiversity and ecosystem functioning are modelled. Target: 7 of 9 focal DRNs.

O3: Assess socio-economic impacts of changes in DRNs through the identification of ecosystem services of DRN and their values (WP4).

ER3: Identification and modelling of ecosystem services provided by DRNs and affected by climate change at the EU and focal DRN levels and assessment of their social values, along with their economic ones.

KPI3: Number of focal DRNs for which bundles of ecosystem services provided by DRNs are identified and modelled, and mechanisms for expanding this knowledge to the EU scale. Targets: bundle of ecosystem services modelled and valued at 6 focal DRNs; bundle of ecosystem services modelled at the EU level and value functions for wider EU valuation of ecosystem services.

O4: Identify options for environmental decision-making in DRNs by:

- exploring mitigation and adaptation measures including innovative NBSs in socio-ecological scenarios,
- economic appraisal, and
- identifying legislative barriers, opportunities and financing mechanisms (WP5).

ER4: A multi-criteria, scale-sensitive decision framework for adaptive DRN management under climate change, including a spatial planning tool for local stakeholders, as well as uncertainty-explicit co-designed model to guide biodiversity and ecosystem function conservation and ecosystem service management in DRNs at both focal DRN and EU scales.

KPI4: Number of focal DRNs with stakeholders implementing the decision framework. Target: 5 of 6 EU focal DRNs.

O5: Enable science-policy interfacing at local, national, regional and EU levels to embrace adaptive management strategies of DRNs through co-design processes (WP5).

ER5: Refinement of relevant EU Directives (e.g. Water Framework Directive) and their means of implementation (e.g. guidance documents, national implementation regulation and strategies), focusing on good practices, lessons learned, and nurturing of upcoming EU policy and policy reviews (e.g. EU Directive on Droughts) at different scales.

KPI5: Number of policy recommendations properly disseminated to and discussed with relevant policy decision-makers, including stakeholders from the focal DRNs. Target: 6-9 policy recommendations.

O6: Create shared value, capacity-building and public acceptance of the outcomes of the project through co-construction and participatory processes to:

- contribute to the understanding of interactions between climate change and biodiversity, ecosystem functions and services (WP1-WP4), and
- promote responsibility in protecting DRNs through active engagement in research, monitoring and management (WP5).

ER6: Adoption of sustainable river management practices in the focal DRNs and beyond through stakeholder activity, public acceptance and communication.

KPI6: Number of co-construction processes of adaptive management of river networks with local stakeholders; number of local citizens (‘citizen scientists’) monitoring activities on river drying and its ecological consequences. Target: 9 co-construction processes.

These objectives will be achieved in a 4-year timeframe, enabled by:

- complementary expertise of the consortium (including 21 EU partners, 3 CELAC partners to assess the applicability of the DRYvER framework in South America and US and China partners to maximise impact of the project) built on previous multi-and interdisciplinary national, EU and international research efforts on DRNs and,
- the originality of the novel hydrological, ecological and socio-economic modelling approaches.

The relevance of KPIs and realistic but ambitious targets that we defined will guide the achievement of objectives throughout the project.

1.2. Relation to the work programme

Table 1 below explains how DRYvER specifically and fully addresses the scope of topic *LC-CLA-06-2019 "Inter-relations between climate change, biodiversity and ecosystem services*".

Table 1.

How DRYvER specifically and fully addresses the scope of topic *LC-CLA-06-2019 "Inter-relations between climate change, biodiversity and ecosystem services*".

LC-CLA-06-2019 key points	How DRYvER will address these key points
Actions should investigate at all relevant spatial and temporal scales the way that ecological processes, biodiversity and ecosystem services are impacted, both directly and indirectly, by climate change.	DRYvER will explore at continental (EU, CELAC) and 9 strategically distributed focal DRN scales how aquatic biodiversity, ecosystem functions and services are directly and indirectly affected by increasing river drying under various climate change projections (WP1-WP4) at short- to long-term scales (month, season, year, decade, century). This will be possible through a compelling and multidisciplinary cyclic model presented in §1.3.1.
Actions should consider the interactions and feedbacks between climate change and biodiversity, ecosystem functions and services.	DRYvER will focus on interactions and feedback loops when drying alters various facets of biodiversity, ecosystem functions and services across DRNs, especially exploring mechanistic interactions and feedbacks in carbon cycling and greenhouse gas emissions linked to climate change (WP1-4).
The vulnerability of biodiversity and ecosystems functions and services to climate change should be investigated and modelled across a range of European (climatic and ecological regions; this includes human activities with relevance to climate change.	DRYvER will assess the vulnerability of riverine biodiversity, ecosystem functions and services to drying as a result of climate change and human activities across 6 biogeographical ecoregions in the EU (Alpine, Boreal, Continental, Pannonian, Balkanic and Mediterranean) and 3 in South America (Pacific Lowlands, Central High Andes, Caatinga) (WP1-4).
Actions should account for social, ecological and economic aspects and climate change relevant stressors and sources of uncertainty. These should include tipping points and safe operating spaces.	DRYvER will model ecosystem and socio-economic effects of increased river drying under various climate change scenarios, accounting for water uses and social changes. DRYvER will identify DRN tipping points in time and space and define safe operating spaces for stakeholders (river basin managers and citizens) (WP4, WP5).
The role of nature-based solutions in enhancing the efficiency and effectiveness of climate change adaptation and mitigation strategies should be assessed, and synergies with other pollution-reducing environmental policies be explored.	Through co-design with stakeholders, DRYvER will make an inventory and assess suitable NBSs for adapting DRNs to climate change, and derive mitigation strategies, including identifying societal, legal, economic and technical barriers. DRYvER will share knowledge from focal DRNs with the OPPLA community and the Think-Nature portals and explore financing mechanisms for relevant NBSs. DRYvER will seek synergies with other anthropogenic stressors and relevant EU policies (e.g. Water Framework Directive and Floods Directive) (WP5).

LC-CLA-06-2019 key points	How DRYvER will address these key points
Work should build, as appropriate, on existing knowledge and activities such as relevant FP7/Horizon 2020 and LIFE projects, European climate adaptation platforms and Copernicus Services and contribute to long-term monitoring initiatives. Actions should envisage clustering activities with other relevant selected projects for cross-projects co-operation, consultations and joint activities on cross-cutting issues and sharing of results as well as participating in joint meetings and communication events. To this end, proposals should foresee a dedicated work package and/or task, and earmark the appropriate resources accordingly.	DRYvER will gather the most renowned experts in the on-going and pioneering COST Action SMIRES and other EU and international research efforts (see § 1.3.1 for details). Copernicus Services will provide critical inputs to all WPs (e.g. land-use, satellite data). The European climate adaptation platform and Freshwater Information Platform will receive all relevant results, particularly data, scenarios and maps of river drying, riverine biodiversity and ecosystem functions. Some focal DRNs (e.g. the Albarine) are part of the eLTER network and will promote long-term monitoring initiatives as envisioned in the ESFRI roadmap on EU research infrastructures. DRYvER will seek synergies and develop cooperation through clustering activities (e.g. joint meetings and publications, training schools), with other relevant on-going (e.g. Euroflow, Aquacosm, SMIRES, AMBER) and future projects (WP6).
International cooperation is encouraged, in particular with CELAC countries.	DRYvER includes five international partners from China, USA, as well as CELAC countries (Bolivia, Ecuador and Brazil), where DRN research is growing, and climate change is severely altering DRNs. Three out of nine focal DRNs are located in CELAC. Chinese and US partners will strengthen capacity building and dissemination at the global level.
A contribution in the range of EUR 5 million to 7 million.	To achieve the challenging objectives of DRYvER, the budget of the project is 6,7 million EUR.

1.3. Concept and methodology

1.3.1. Concept

1.3.1.1. Overall concept of the project and main assumptions

Across a broad climatic and biogeographical scope (Fig. 2 WP1-4), DRYvER will assess how climate change, through changes in river flow regimes and modified water use, will have cascading effects on biodiversity, ecosystem functions and ecosystem services provided by DRNs. In turn, new knowledge combined with socio-economic, legislative and management analyses will guide adaptive management strategies of DRNs. Adaptive management is a flexible decision-making process for ongoing knowledge acquisition, monitoring, and evaluation leading to continuous improvements in management planning and implementation. To do so, DRYvER will embed the cascade model for ecosystem provisioning (Haines-Young and Potschin 2010) in a meta-system perspective (see 1.3.1.2.).

1.3.1.2. A meta-system perspective

Meta-systems (i.e., meta-populations, meta-communities and meta-ecosystems) are networks of discrete populations, communities and ecosystems that are intermittently connected by gene flow, dispersal, and material and energy flows (Larned et al. 2010).

Spatial flows of energy, materials, and organisms are ubiquitous in nature. For example, organisms move within a landscape to forage for food, migrate, or disperse actively or passively. In turn, these flows, along with passive flows of inorganic nutrients and organic matter, connect ecosystems and influence local ecosystem dynamics (Gounand et al. 2018). The meta-community framework demonstrates how dispersal and environmental heterogeneity interact to determine species coexistence and biodiversity in a given landscape, both at local and regional scales (Heino 2012). Recent extensions of this framework allow taking into account non-stationarity in these spatially-extended systems (Jabot et al. 2020). Concomitantly, there has been a growing recognition that resources (i.e., inorganic nutrients, organic matter, organisms) are not stationary and that flows of resources within ecosystems can play a significant role in the dynamics of various types of biological communities (Massol et al. 2011). This fostered the recent development of the meta-system framework, which explicitly integrates dispersal of organisms and spatial movements of resources within meta-systems to include the feedbacks between community and resource dynamics across spatial scales (Gounand et al. 2018). By moving within and between ecosystems, organisms can modify the spatial distribution of resources and habitat suitability, through local resource consumption and biomass recycling. Conversely, the flow of resources links the dynamics of local communities through the production and export of these resources, which can generate trophic cascades in recipient ecosystems. Such mechanistic interactions between community and ecosystem functioning and spatial dynamics make the meta-system framework a powerful tool to investigate the dynamics of connected ecosystems and the interactions between biodiversity and ecosystem functions. Such a framework is particularly required in a climate change context, where extreme events are becoming more frequent, disrupting local processes and altering spatial flows of organisms and resources (Datry et al. 2016a).

In this framework, taking into account the hierarchical spatial organisation of river networks characterized by a tree-like topology is particularly important (Datry et al. 2016a). Fluxes within river networks are dominated by unidirectional downstream flows of water, solutes, material and organisms. Drying not only acts locally on communities and functions but also alters these fluxes by disrupting longitudinal, vertical and lateral connectivity and creating a shifting habitat-mosaic of aquatic and terrestrial conditions in the landscape affecting downstream deltas, estuaries and coastal waters (Acuña et al. 2014, Datry et al. 2018a). Such hydrological and ecological features call for a meta-system perspective at the river network scale to understand and predict how increasing drying alters biodiversity, ecosystem functions and services in entire river networks. However, drying is also highly dynamic in time and space, which:

1. challenges current conceptual and empirical developments of meta-system ecology (Datry et al. 2018a, Jabot et al. 2020) and
2. concurrently needs adaptive management strategies to protect these complex ecosystems that are of critical importance for supporting human well-being.

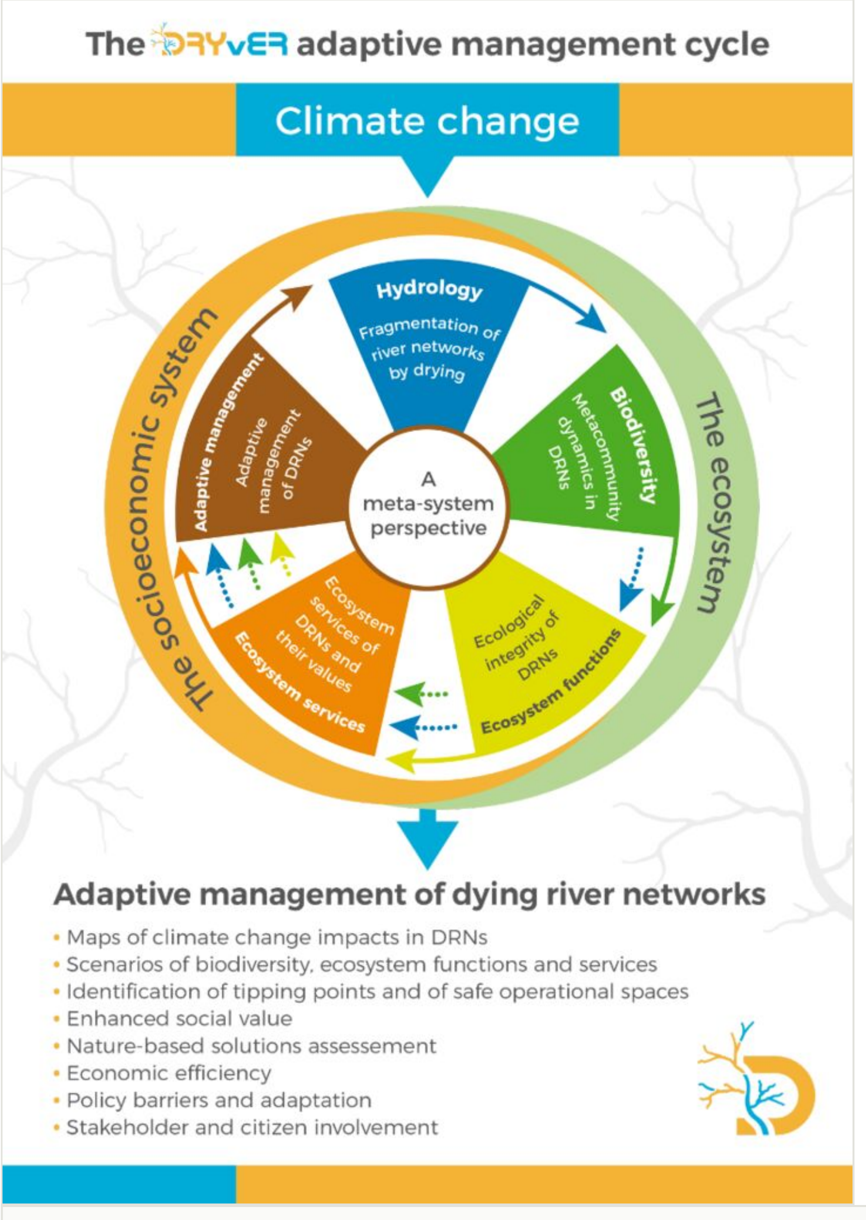

Figure 2. doi

It shows how DRYvER will use this **cyclic model** as a structured loop embedded in a **meta-system perspective** to guide adaptive management of DRNs. DRYvER will translate climate projections into changes in flow intermittence patterns at multiple scales, including that of the strategically-selected focal DRNs. This physical setting will then be used to implement a dynamic meta-system perspective to understand the cascading changes in biodiversity, ecosystem functions and ecosystem services. This knowledge will be integrated to develop a multi-criteria decision framework combining scientific, management, socio-economic, legislative barriers and leverages to promote an adaptive management of DRNs.

Building on outputs from recent EU projects (see §1.3.1.5) and the climatic, ecological, scientific and socio-economic contexts, DRYvER is based on the three premises that are needed to secure biodiversity, ecosystem functions and services in DRNs:

- a paradigm shift acknowledging that virtually all river networks are impacted by drying,
- a paradigm shift acknowledging that biodiversity and ecosystem functions are not static in river networks, but highly dynamic and non-stationary across multiple spatial and temporal scales, and
- a shift in the management of complex and dynamic ecosystems such as DRNs.

Such shifts require conceptual, methodological and empirical developments, which DRYvER aims to achieve in a meta-system framework to produce robust scenarios for facets of biodiversity (i.e.,genetic, taxonomic, phylogenetic and functional), carbon-related ecosystem functions, and ecosystem services in DRNs affected by climate change. The originality and innovative character of DRYvER is rooted in considering, within a meta-system perspective, variability over short (transient drying events) and long terms (non-stationary conditions related to climate change-induced trends in drying).

1.3.1.3. A wide climatic and biogeographic scope

Europe is impacted by increased extreme events but affected by climate change differently along north-south and west-east gradients: annual river flows are projected to decrease in Southern, Eastern and South-Eastern Europe and increase in northern and north-eastern Europe (Döll et al. 2018). Reductions of flow can be exacerbated by water abstractions, especially in summer when consumption is highest and input is typically low (Forzieri et al. 2014). Increasing drying has severe consequences for Europe's citizens and most economic sectors, including agriculture, energy production, industry and public water supply (Blauhut et al. 2015, Tonkin et al. 2019). Drying also has a significant impact on water quality by reducing the ability of a river to dilute pollution (Hoekstra 2014). The ecological and socio-economic consequences of increased river drying following climate change are already perceptible: many once-perennial rivers are now drying in central Europe, compromising water security (Zahrádková et al. 2015). Massive fish deaths are occurring in some DRNs due to a combination of repeated drought and inadequate management (Zahrádková et al. 2015). However, the responses to drying of the biota, the functions they contribute to and the ecosystem services river networks provide to societies are unexplored, particularly in areas where flow intermittence was rare (northern and central Europe). Contrasting responses to drying and different capacities of ecosystem resilience could be expected due to different biogeographic settings, as species from southern Europe have been exposed to fragmentation by drying for much longer (i.e. the Mediterranean climate has a Pliocene origin (Pons et al. 1995)). Such variability in ecological effects of drying and associated socio-ecological responses requires the involvement of several EU partners in charge of implementing the DRYvER cyclic model to a total of 6 focal DRNs covering a north-south gradient both on the western and eastern part of the EU.

South America is one of the most important regions in terms of biodiversity and unique ecosystems (Giuntoli et al. 2015). It hosts 30% of global freshwater resources but is highly vulnerable to climate change as 40% of the land is prone to desertification (Giuntoli et al. 2015). Moreover, 90% of the world's tropical glaciers are in South America, providing fresh water for humans and biodiversity. Climate change is likely to melt most of the glaciers by 2050 (IPBES 2018). Such vulnerability and the lack of understanding of the effects of drying on DRNs requires the involvement of 3 CELAC partners to test our approach in 3 focal DRNs located in biogeographically contrasting areas (Bolivia, Brazil and Ecuador) and in the long term to better understand and mitigate climate change impacts on biodiversity and ecosystem functions and services in South America. As climate change occurs globally, exploring the responses of DRNs across a variety of climatic and biogeographical contexts, along with various socio-ecological settings, is vital to assess the parallels and contrasts in the responses of communities, ecosystem functions and services to increased drying. This, together with the involvement of Chinese and USA partners, will allow for a robust and generic adaptive management of DRNs worldwide.

1.3.1.4. Interdisciplinary considerations and breakthroughs

The highly interdisciplinary effort in DRYvER creates multiple opportunities for scientific breakthroughs within and across a row of disciplines:

- From a hydrological perspective, DRYvER will, for the first time, model current and prospective high-resolution patterns of drying at the network and continental scales (EU and South America) under climate change scenarios.
- From a biodiversity perspective, DRYvER will produce a conceptual and empirical understanding of how drying cascades into biological community dynamics, species distributions and persistence in DRNs.
- From a biogeochemical perspective, DRYvER will assess how drying determines rates of key carbon-related ecosystem functions in DRNs by cascading into alterations of material fluxes and functional biodiversity.
- From a modelling perspective, two innovative downscaling methods will allow utilisation of existing global-scale hydrological multi-model ensembles for deriving high-resolution ensembles of streamflow intermittence in DRNs at network and continental scales. For the first time, a meta-system model integrating hydrological processes, material fluxes, and biological functions in DRNs at the network scale will be implemented in an adaptive modelling platform for a holistic assessment of biodiversity, ecological functioning and ecosystem services assessment.
- From a socio-economic perspective, DRYvER will overcome the epistemological limitations that have hampered valuing ecosystem services so far. This is to be done by placing the understanding of monetary and non-monetary benefits delivered by DRNs at the core of the process of establishing and depicting ecosystem services (a transdisciplinary process promoting stakeholder and citizen participation).
- From a policy perspective, DRYvER will identify barriers to adaptive management of DRNs, inform current EU Directive revisions and implementation on DRNs (e.g.

Water Framework Directive) and contribute to new policies (e.g. EU Directive on Droughts) with a DRN focus.

- From a management perspective, DRYvER will – together with stakeholders and citizens – co-construct a multi-criteria decision framework to allow for climate-robust adaptive management of DRNs.

1.3.1.5. Use of stakeholder's knowledge

One of DRYvER's features is its co-development with stakeholders. Two key stakeholders are involved as partners in the consortium and will assist in DRYvER's development to maximise management needs and gaps. ACA (Catalan Water Agency) from Spain, where DRNs are over-represented, has been involved for a long time in the science and management of DRNs and is part of several different EU projects (e.g. TRivers, SMIRES) and a member of the ECOSTAT group. The DDVIZIG water agency from Hungary faces management challenges of increased droughts and extending DRNs, so they will provide views and consideration from a EU13 perspective. Both will help with the implementation and animation of the Stakeholders Committee (WP5).

DRYvER will also rely on key stakeholders from different relevant scales. A Stakeholders Committee (SHC) will be formed, comprising local stakeholders of each EU focal DRN (see annex B letters of support), national stakeholders (to be identified through a stakeholder mapping in WP5) and the European Joint Research Center (JRC, also in our Advisory Board). The SHC will join our annual meetings and have internal meetings throughout the project, to:

- optimise the use of DRYvER's outputs at different scales,
- liaise with local citizens to promote the citizen-science network,
- maximise the uptake of DRYvER's outputs to the management spheres, and
- co-construct adaptive management of DRNs.

1.3.1.6. Measures taken for public/societal engagement on issues related to the project

DRYvER will raise public awareness on the prevalence and ecological significance of DRNs and engage society in protecting DRNs through (WP5):

1. co-construction processes of adaptive management of DRNs with local stakeholders (180 000 EUR are earmarked);
2. identifying links with relevant societal and policy issues such as flood and drought risks (120 000 EUR are earmarked); and
3. helping local citizens ('citizen scientists') monitor river drying and its ecological consequences (148 000 EUR are earmarked).

DRYvER will also work with citizens to create an EU-wide network of citizen-scientists to monitor and raise awareness about drying events in river networks. Building on the past efforts from several EU projects (e.g. SMIRES, AMBER), and using a fully open-access application for smartphones, DRYvER will first develop the network at the focal DRN scale (including for CELAC countries) and then upscale the network to the EU and South America levels. Information, training and capacity-building workshops are planned at each focal DRN to build momentum and involve as many citizens as possible in this effort.

DRYvER will liaise with several influential NGOs (WP6), such as WWF, Wetlands International, the European River Network, the Alliance of Freshwater Life (see annex A letters of support) to maximise dissemination and impact of the project.

1.3.1.7. Positioning of the project

DRYvER addresses several key socio-ecological challenges of climate change in river networks from a research perspective, while simultaneously producing knowledge-based end-user-oriented tools and guidelines to optimise adaptive management of rivers in the EU and globally. Outputs include open-source software spatial tools adapting systematic conservation planning approaches (e.g. Marxan), policy recommendations, a citizen-science network built on current EU initiatives (e.g. AMBER, Crowdwater) and an adaptive management framework. DRYvER is not a technology-driven project, however, the tools that are developed will be ready to use at the end of the project. Therefore, their Technology Readiness Level (TRL) can be considered as 5-6.

1.3.1.8. International research and innovation activities, which will be linked with DRYvER

DRYvER's consortium comprises the PIs and partners of major relevant EU efforts, international networks and will also build on national projects on DRNs across the participating countries (Tables 2, 3).

Table 2.

Link with other EU projects.

Name and type of project	Project aim	Synergies with and/or inputs to DRYvER
SMIRES: Science & Management of Intermittent Rivers and Ephemeral streams, (COST ACTION, 2016-2020)	Synthesise knowledge on the science and management of DRN and identify gaps.	The state of the art and knowledge accumulated during SMIRES will be used in DRYvER. Representatives of INRAE and UIBK were the Chair and Vice-Chair of SMIRES, and a large proportion of the partners are involved in SMIRES, ensuring good exchange of knowledge.
ALICE: Improving the management of Atlantic Landscapes: accounting for biodiversity and ecosystem services (Interreg Atlantic; 2017-2020)	Protecting biodiversity while assuring human activities through the implementation of Blue and Green Infrastructures to adapt to climate change.	The methods developed to model ecosystem services and to design green infrastructure networks will constitute a basis for DRYvER. Project coordinator (UC-IHC) is actively involved in DRYvER.
ThinkNature (H2020, 2017-2020)	The objective of the ThinkNature project is the development of a platform that supports the understanding and the promotion of Nature-Based Solutions (NBSs).	Dryver will capitalise on all the knowledge on NBSs established by ThinkNature, notably concerning the barriers and opportunities of NBSs, as well as the business cases for investing in them.

Name and type of project	Project aim	Synergies with and/or inputs to DRYvER
Globaqua (H2020, 2014-2019)	Explores the effects of multiple stressors on freshwater ecosystems under water scarcity.	ICRA is responsible for the relevance of water scarcity on the biodiversity and functioning of river ecosystems. Knowledge will be shared with DRYvER.
MANTEL - Management of Climatic Extreme Events in Lakes & Reservoirs for the Protection of Ecosystem Services (Horizon 2020, EJD ITN, 2017-2020)	Train a cohort of Early Stage Researchers to investigate the effects on water quality of the most extreme events while at the same time providing training in state-of-the-art technology, data analysis and modelling, and linking to the water management sector.	DRYvER will capitalise on the management frameworks being developed under MANTEL. NIOO is WP leader on Informing stakeholders to ensure ecosystem services protection in the face of extreme events.
Euroflow, A EUROpean training and research network for environmental FLOW management in river basins (Horizon 2020, ITN-ETN, 2019-2023)	Understanding how (managed environmental) flow dynamics, shape biodiversity, functioning and service provisioning of streams and rivers and how policy/management need to be adjusted.	UC-IHC is WP leader in Euroflow, and UIBK and UoL are involved in Euroflow as PhD-supervisors, ensuring a good exchange of knowledge.
FLUFLUX, Fluvial Meta-Ecosystem Functioning: Unravelling Regional Ecological Controls Behind Fluvial Carbon Fluxes (H2020, ERC-STG, 2019-2021)	Understand spatial constraints on biodiversity-ecosystem functioning relationships behind carbon dynamics in fluvial networks.	Relevant developed field techniques and modelling knowledge will be made available to DRYvER before publication. UIBK is the PI of FLUFLUX and WP-leader of DRYvER.
MetaCene, From meta-system theory to the sustainable, adaptive management of rivers in the Anthropocene (AlterNet AHIA 2019-2021)	Transfer the most recent knowledge in meta-system theory into policy and management recommendations for the management of the rivers of the Anthropocene.	INRAE coordinates and UIBK, SYKE, and UB are key members of this network, which will ensure optimal flows of knowledge to DRYvER.
GlobeDrought (German BMBF project) (2017-2020)	Global-scale analysis of drought hazards and risks and development of a web-based drought information system, together with international stakeholders	Experience with quantifying meaningful drought indicators in GlobeDrought will enhance the development of intermittence indicators in DRYvER, while GlobeDrought will benefit from an improved understanding of intermittence.

Table 3.

Link with international networks: DRYvER will liaise with five international networks on DRNs (WP6) to broaden its geographic scope and place the EU at the forefront of climate change adaptation and mitigation.

Network	Objective of the network	Synergies or gaps with DRYvER
“Drought in the Anthropocene” working group of the International Association of Hydrological Sciences (IAHS)	This working group of the Panta Rhei scientific decade focuses on the anthropogenic influences in streamflow drought under global change.	DRYvER WP1 leader (INRAE) is an active member of this working group and will make the project benefit from the recent advances in modelling anthropogenic influences on low-flows and intermittent rivers.

Network	Objective of the network	Synergies or gaps with DRYvER
UNESCO EURO FRIEND-Water “Low flow and drought” group	Coordinating and fostering research on drought and low-flows across Europe	DRYvER WP1 leader (INRAE) is an active member of the group and will promote links between groups.
ISIMIP: The Inter-Sectoral Impact Model Intercomparison Project	ISIMIP offers a framework for consistently projecting the impacts of climate change across affected sectors and spatial scales. An international network of climate-impact modellers contributes to a comprehensive and consistent picture of the world under different climate-change scenarios.	DRYver will make the best use and exploit ISIMIP products, i.e. an ensemble of projections of future runoff/streamflow derived by a large of global hydrological modelling groups in a consistent manner, providing new information on DRN-related futures.
The 1000 Intermittent River Project (1000IRP)	An international network fostering the use of coordinated experiments to unravel the role of DRN on C fluxes	INRAE and UGA are members of the core group leading this network. This will facilitate the clustering with international activities on DRN and data compiled will be made available.
water@leeds	water@leeds is one of the largest interdisciplinary networks for water research in any university in the world. The water@leeds team comprises over 160 professionals from across the different departments and faculties of the UoL, ensuring a cross-section of expertise and different disciplinary backgrounds. water@leeds has over 1000 partners across 143 countries.	water@leeds encompasses expertise from across the physical, biological, chemical, social and economic sciences and engineering as well as the arts. This will allow DRYvER to benefit from this wide-ranging expertise, but also it will be used as a platform for the international dissemination of new knowledge generated by DRYvER.
StreamCLIMES	StreamCLIMES is the first coordinated study of DRNs in the United States. The StreamCLIMES team will coordinate extensive sampling efforts (hydrological and biological), and spatial ecological models will be used to explore how future climate-change-driven drying patterns could alter stream biodiversity patterns.	The conceptual ideas and research approaches of StreamCLIMES bear many similarities to those of DRYvER. UO is the lead investigator of StreamCLIMES. His role will be to synergise linkages with DRYvER and the data and work products produced by StreamCLIMES.

DRYvER will integrate data on DRNs compiled in these various efforts. For example, all hydrological and biological data collected in the SMIRES COST Action are openly available, along with those collected in the 1000 Intermittent River Project. Moreover, the PIs of the projects and networks listed above will actively promote synergies through co-organisation of conference special sessions or publication of special issues. In addition, several partners (eg. INRAE, UIBK, SYKE) are members of European networks, such as EurAqua which organised working groups on the Water Framework Directives, and ALTER-Net which manages the EKLIPSE Mechanism to better support policy decision with respect to Biodiversity and Ecosystem Services. Through its contribution to these EU policies, DRYvER will also meet the challenges of the 2030 Agenda and the achievement of the 17 Sustainable Development Goals. Its action, while transversal, will contribute particularly to the achievement of the SDGs related to climate change, biodiversity and underwater life (SDGs 13, 14, 15). Lastly, national initiatives will be identified to seek synergies and increase the geographical scope of DRYvER. A budget of 180 000 EUR (WP6) is earmarked for clustering with ongoing (see above) and relevant selected projects (e.g.

funded under LC-CLA-06-2019 topic, such as Ponderful), short-term scientific missions of Early Career Investigators in the involved institutions, workshops (e.g. protocol development, modelling), knowledge and data flow among projects and joint meetings and/or communication events.

1.3.2. Methodology

1.3.2.1. DRYvER overall methodology

DRYvER will follow a three-steps workflow with a consistent approach throughout each scientific WP (Fig. 3). In addition to this research methodology, WP6 will ensure that all outputs of DRYvER are appropriately communicated, disseminated and exploited to maximise the impact of the project. WP7 will ensure the proper management of the project and flow of information to deliver all outputs as planned.

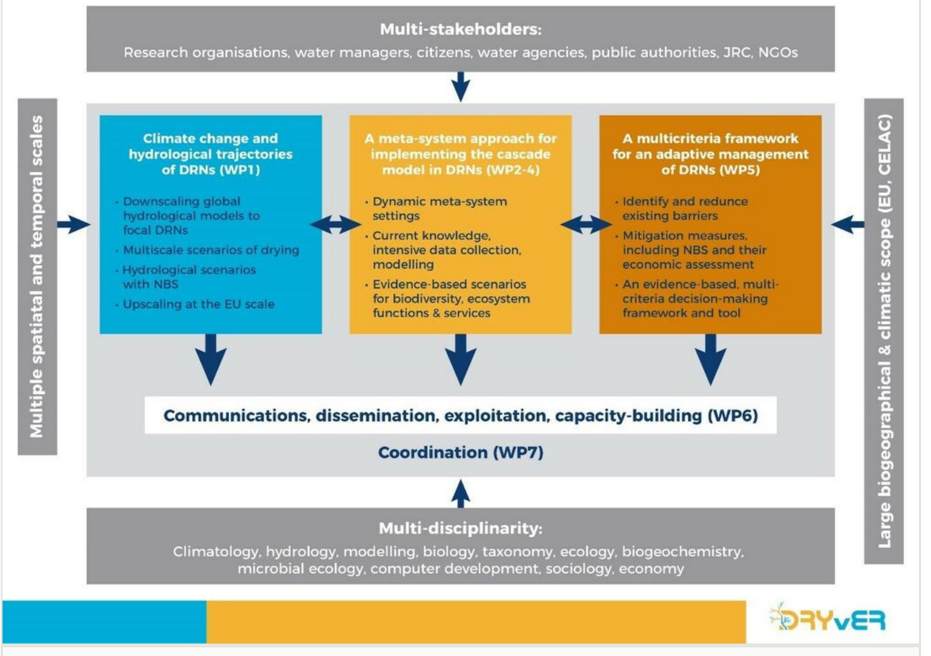

Figure 3. doi

The DRYvER three-step workflow embedded within 7 Work Packages (WP) and the four main attributes of the DRYvER consortium (red ovals).

DRYvER's three-steps approach

Step 1. Hydrological trajectories of DRNs under climate change (WP1): WP1 will downscale ensembles of coarse-level projections of global hydrological models and local focal DRN hydrological process-based models to derive trajectories of drying for the focal DRNs in EU and CELAC. For the very first time, the future (10-80 years) development of DRNs will be explored under contrasting climate change scenarios and mapped dynamically (on a daily time scale and for each river section of the focal DRNs). In addition, WP1 will combine runoff projections, field observations and focal DRN results through statistical models to propose dynamic maps of drying at the EU scale and the CELAC region. The combination of statistical and process-based numerical approaches will ensure an overall assessment of DRNs' future trajectories and associated uncertainties.

Step 2. A dynamic meta-system approach to understand and predict the effects of drying (WP2-4) on:

1. biodiversity and structure of the DRN meta-community containing organisms with contrasting dispersal modes and resistance strategies to drying (WP2),
2. ecosystem functions related to carbon cycling (WP3), and
3. key ecosystem services provided by DRNs and their values (WP4).

Here, maps and trajectories produced by WP1 will serve as spatially explicit physical templates. Current knowledge and field campaigns will be integrated into dynamic, spatially-explicit meta-system models to produce prospective scenarios of biodiversity, ecosystem functions and services under changing climates. Scenarios and trajectories at the focal DRN scale will be upscaled to the EU scale through statistical modelling using river catchment information from EU databases. Socio-economic impacts will be assessed by evaluating changes in the provision of ecosystem services using a combination of valuation methods, including state-of-the-art survey-based techniques (e.g. stated preference choice experiments) and alternative methods, such as deliberative valuation and field experiments, investigating shared and social values (WP4).

Step 3. A multi-criteria decision framework for adaptive management of DRNs (WP5): The resulting data and information from Steps 1 and 2 will be used to develop a participatory process with stakeholders in which NBSs, technological mitigation and adaptation measures will be identified and their societal, legal and technical barriers assessed, as well as their economic appraisal and financing mechanisms (WP4, WP5). The multi-criteria decision framework for adaptive management of DRNs applied to each focal DRN (WP5) will incorporate different aspects of decision-making such as public acceptance, development of innovative NBSs and technological mitigation measures, economic appraisal and identification of legislative and financial barriers. DRYvER will allow for uncertainty-explicit decision-making at the focal DRN- and the EU-scales, by coupling the model outputs from WP1-4 to Bayesian Belief Networks to derive a generic multi-criteria decision framework. In addition, a spatially explicit prioritization mapping tool for stakeholders to optimize the implementation of NBSs and technological measures at the network scale will be developed. To overcome the scarcity of hydrological data, validate hydrological models, raise awareness of the abundance of DRNs in EU and promote societal actions, an EU-wide citizen science network will be created to monitor river drying and its ecological consequences, building on current long-term initiatives in EU (e.g. AMBER, Crowdwater) and generating a fully open-access smartphone application (WP5).

DRYvER consistent workflow

For WP1-4, a consistent workflow will be implemented to put the cyclical adaptive management model embedded in a meta-system perspective to work:

- First, conceptual models (models representing a conceptualisation or generalisation of one or several processes based on current knowledge) will be developed to serve the aims of each WP.
- Second, various versions of process-based models (models that simulate the functioning of an ecosystem, including mathematical representations of several hydrological, community assembly and ecosystem-scale processes) will be developed in parallel in each WP, including equation-based linkages to other disciplines, and deriving knowledge from past and on-going related research efforts (clustering).
- Third, extensive empirical data will be collected within WPs on each focal DRN in a coordinated manner using shared protocols, curated, stored and supplied to other WPs relying on them to calibrate and heuristically refine the process-based models. To this end, each focal DRN is associated with a contact partner in charge of coordinating the data collection and fieldwork efforts and ensuring the links with local stakeholders and citizen-scientists. Technical meetings are planned to train partners for this effort.
- Lastly, based on refined models, disciplinary outputs will be created within each WP: scenario exploration for focal DRN and EU-upscaled assessments (based on focal DRN efforts and existing EU databases) and predictions, along with a framework for multidisciplinary, adaptive management of DRNs.

CELAC partners are involved in all WPs, with dedicated task/subtask in WP1-WP3, so that specific research questions can be asked with respect to the contracting climatic and biogeographical contexts. For example, in WP1, hydrological modelling approaches will be adapted to the specific conditions of each CELAC focal DRNs: use of pre-existing hydrological models (e.g. WASA) in Brazil; set up of J2000 model as for the EU focal DRNs in Ecuador; simple statistical estimates due to the lack of available data in Bolivia. In WP2, DRYvER will look for generalities in meta-community responses to drying by testing for the transferability and congruence of patterns obtained for EU focal DRNs to CELAC river networks. In WP3, CELAC partners will run a leaf decomposition experiment in parallel with the EU focal DRNs, allowing tests of the generality of patterns in ecosystem functioning. For WP4 and WP5, capacity-building activities and knowledge exchange processes on the valuation of ecosystem services and water governance are planned. This will include remote exchange and two workshops taking place in the UK and Brazil. CELAC partners will also contribute to the dissemination of DRYvER (WP6) and the management of the project (WP7). USA and China partners will contribute to DRYvER dissemination and capacity-building activities (WP6) to maximise the impact of the project.

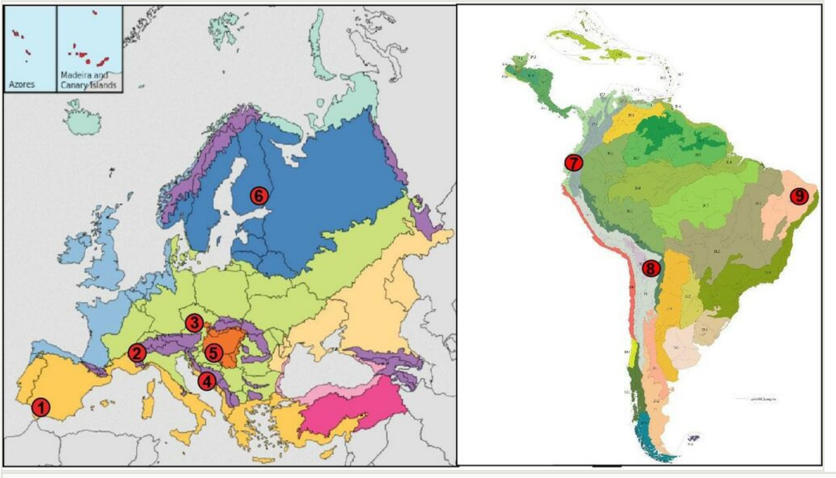

Figure 4. doi

DRYvER focal DRNs located in highly contrasted EU and CELAC biogeographic and climatic settings (red points), chosen to span the expected natural variability of drying processes and associated DRN responses.

1. Mediterranean ecoregion: the Genal network, in Andalucía (Spain, Mediterranean climate), a dry region heavily impacted by climate change, where most rivers are already affected by drying (contact partner: UB);
2. Alpine ecoregion: the Albarine network, in the Southern Jura (France, temperate climate), a region mildly impacted by climate change (the Albarine network is part of a national LTER project and monitored since 2006) (contact partner: INRAE);
3. Continental ecoregion: the Velička network, in Morava (Czech Republic, continental climate), a region heavily impacted by climate change where many perennial rivers are shifting towards intermittent flow (contact partner: MU);
4. Balkanic ecoregion: the Krka network, in the Dinaric Karst (Croatia, Mediterranean climate), a region where most rivers are already drying and heavily impacted by climate change (contact partner: UZ);
5. Pannonian ecoregion: the Bükkösdi-víz network, in the Mecsek (Hungary, continental climate), a region moderately impacted by climate change, where DRNs are becoming common (contact partner: UP);
6. Boreal ecoregion: the Vantaanjoki network, Helsinki-Uusimaa Region (Finland, boreal climate), region moderately impacted by climate change, where flow intermittence is currently rare (contact partner: SYKE);
7. Pacific Lowlands: the Cube network, in the Andean-Choco region (Ecuador, tropical climate), a region where drying is very seasonal and increasing in duration and frequency (contact partner: USFQ);
8. Central High Andes ecoregion: the Rio Chico network in the Sucre region (Bolivia, semi-arid climate), a dry area prone to desertification where political conflicts emerge due to water scarcity (contact partner: USFX);
9. Caatinga ecoregion: the Jaguaribe network, in the Northeast Semiarid region (Brazil, semi-arid climate), the driest region in Brazil, already heavily impacted by climate change (contact partner: UFC).

1.3.2.2. DRYvER focal DRNs

The DRYvER cyclical adaptive management model will be applied both in EU and CELAC countries through 9 strategically distributed focal DRNs (Fig. 4).

Each focal DRN consists of a drying river network of 100-300 km^2, comprising sections prone to drying and others with perennial flow and with fairly pristine conditions allowing disentanglement of the responses to water quantity and quality. With respect to water quality, several past and on-going EU projects (e.g. Globaqua) have produced substantial knowledge which will be integrated into DRYvER through clustering, including an assessment of whether the safe operating spaces identified in DRYvER could promote the resilience of river networks to other stressors. The focal DRNs have been selected to encompass six climate zones (semiarid, Mediterranean, continental, tropical, temperate and boreal) and nine biogeographical ecoregions (Mediterranean, Alpine, Continental, Balkanic, Pannonian and Boreal, and Pacific Lowlands, Central High Andes and Caatinga for CELAC). First, these regions are affected differently by climate change (Döll and Schmied 2012, Giuntoli et al. 2015), allowing DRYvER to produce a wide and regionally relevant range of scenarios. Second, the biotas of these regions have evolved very differently, which could lead to contrasting responses to current and projected river drying. For example, in the southern part of the EU, aquatic populations have been facing fragmentation for millennia, while those of central or northern EU are only starting to face this pressure (Pons et al. 1995). Third, the functions and services provided in these different focal DRNs vary substantially along the gradients covered, which will allow us to broaden the socio-economic scope of DRYvER.

1.3.2.3. DRYvER methodological activities

DRYvER will combine different methodological activities so that results are supported by multiple lines of evidence to be stronger and more compelling:

- Literature search, database exploration and synergies with past and on-going research efforts: DRYvER will build up a meta-community database for freshwater biodiversity in Europe (WP2) by collating meta-community data on bacteria, fungi, diatoms, macroinvertebrates and fish. Data sources include several biodiversity platforms (e.g. Freshwater Biodiversity Platform, Biodiversity Information System for Europe, IRBAS), partners' databases, and published and grey literature datasets. WP5 will also use existing knowledge from past EU projects to generate a catalogue of mitigation measures, including NBSs (OPPLA community and the Think-Nature). DRYvER will also liaise with other past (e.g. BioFresh, LIFE+ TRivers) and on-going (e.g. SMIRES, Euroflow) EU efforts, including current national research efforts on DRNs.
- Conceptual, numerical and statistical modelling: DRYvER will develop conceptual models to predict the cascading responses of biodiversity, ecosystem functions and ecosystem services to increased river network drying caused by climate change. These models will be based on the most up-to-date knowledge in meta-system theory. DRYvER will use numerical and process-based models, for example, to

translate changes in hydrological signals into spatio-temporal patterns of flow intermittence in the focal DRNs (WP1), or to model associated changes in biodiversity assembly processes (WP2). Meta-system models of spatialized flows of water, resources, organisms and functions will be developed in WP3 (Gounand et al. 2018). DRYvER will also use statistical models to explore the temporal dynamics of biodiversity in DRNs and identify responsible processes at work (WP2 (Jabot et al. 2020)) and to upscale focal DRN knowledge to the EU scale (WP1-4 (Snelder et al. 2013)). Bayesian Belief Networks will be used to integrate all model outputs from WP1-WP4 into a multi-criteria decision framework.

- Downscaling large-scale hydrology to reach-scale flow intermittence: DRYvER will produce innovative methods to generate reach-scale streamflow from large-scale gridded streamflow projections of global hydrological models such as WaterGAP (Hunger and Döll 2008). Ultimately, this will create spatially-distributed streamflow projections for the focal DRNs. More specifically, this involves developing innovative ensemble particle filter assimilation techniques to assimilate global streamflow time series into modelled streamflow time series at the outlet of each focal DRN.
- Field data collection: DRYvER will collect substantial biodiversity data from each focal DRN, including sediment-bound and epilithic microbes (i.e. bacteria, fungi and diatoms), macroinvertebrates and fish (WP2). The rates of the targeted ecological functions (i.e. ecosystem respiration, gross primary production, leaf decomposition and GHG emissions, WP3) will also be measured *in-situ* across the focal DRNs through an intense array of loggers and point measures.
- Biodiversity quantification: Samples collected in WP2 will be analysed through different ways of quantifying biodiversity, using morphological identification (fish) and molecular identification through metabarcoding (microbes). Different biodiversity facets (i.e. genetic, taxonomic, phylogenetic or functional diversity) and components (i.e. alpha, beta or gamma diversity) will be considered.
- Ecosystem functions: DRYvER will create an unprecedented database on ecosystem functions at the network scale through state-of-the-art distributed-sensor networks and in-situ measurement instruments (e.g. gas monitors), sophisticated analysis techniques including ultra-high resolution mass spectrometry and infrared spectroscopy to characterize organic matter resources, and modelling techniques to close the scale gap between localized point measurements of functions and river network-wide functioning. State-of-the-art spatial modelling methods will further be used to link biodiversity with ecosystem functions. An experiment will explicitly test this link to compensate for potential confounding factors and the spatial complexity inherent to the focal DRNs datasets. WP3 will quantify the relative contributions of abiotic drivers (climate, hydrology, resources availability) and multi-trophic biodiversity to the rates and stability of key ecosystem functions related to the carbon cycle.
- Ecosystem service valuation: Ecosystem services will be listed in each focal DRN and their values quantified through intensive interactions with local stakeholders and the public in the field through multiple valuation techniques (WP4; WP5). DRYvER will employ a range of primary valuation techniques, including state-of-

the-art survey-based techniques (e.g. stated-preference choice experiments), and alternative techniques such as deliberative valuation and field experiments, which will allow incorporation of shared and social values and a better representation of cultural ecosystem services. This will be complemented with the development of value transfer functions. This combined use of primary data collection and benefit transfer will not only allow estimation of the value of ecosystem services at the focal DRN level, but will also inform the development of principles and criteria for their wider valuation across the EU.

- Co-construction with stakeholders and citizens: Different methods for co-learning, co-creation and knowledge sharing with diverse stakeholders and citizens will be applied to create shared values, ownership and public acceptance for the outcomes of DRYvER and suggested policy changes. In addition to workshops and interviews with stakeholders for expert inputs, surveys, focus groups and capacity building, and the benefits of citizen science for research and monitoring will be explored and harnessed at the focal DRN level. Uptake of DRYvER results will be facilitated through collaboration with SME and NGO partners (Z5P, FT, REVIVO) with stakeholders (ACA, DDVIZIG) and the stakeholders committee, along with international partners.

1.3.2.4. Gender balance

Regarding research activities, we will specifically assess how the expected changes in the supply of ecosystem services will affect genders in different ways, and identify specific management strategies to address these. We will ensure that female (and minority voices) are actively sought when engaging with stakeholders in the participatory process throughout the project.

Regarding project management, DRYvER promotes gender equality and participation of women at all levels of the project. Achieving equitable gender and other social balances is paramount in DRYvER, which comprises 41% females, with 3 WPs being led by female scientists. DRYvER promotes diversity and inclusiveness at all levels of the project, through the establishment of diverse scientific advisory boards, the stakeholder committee, and through close monitoring of compliance with inclusiveness and diversity strategies in the recruitment process. The coordinator of the project, INRAE, has endorsed the European Charter and Code of Researchers, committing itself to the principles of non-discrimination and, ethics.

1.4. Ambition

The overall ambition of DRYvER is to:

1. develop a dynamic spatio-temporal and multidisciplinary framework to understand and predict the interrelations between climate change, biodiversity, ecosystem functions and services in DRNs, and
2. derive generic and transferable, evidence-based, and cost-effective adaptive management strategies for DRNs in the EU and worldwide.

From an applied perspective, DRYvER will produce a holistic framework for biodiversity conservation planning and ecosystem service management, and generate a network of citizens mapping and monitoring DRNs. The concept, approach and framework demonstrated in DRNs will be relevant for many other freshwaters (e.g. water ponds, glacial streams), marine (e.g. coral reefs, intertidal zones), or terrestrial (e.g. forest, alpine grasslands) ecosystems experiencing climate change and increased extreme events. DRYvER will thus have an impact far beyond DRNs to other types of complex socio-ecological systems and will help prevent such stressed systems from exceeding their tipping points.

1.4.1 DRYvER's progress beyond the state of the art

DRYvER will bring progress beyond the state of the art in several domains:

Climate change and drying patterns (WP1): Drying river channels represent over half of the river network globally and are expanding while drying for longer - every river network is now prone to drying. Yet, the effects of these increasing drying patterns have received scant attention from scientists and managers compared to low flows (Giuntoli et al. 2015). Hydrologically, DRNs are unexplored at the EU scale, although evidence is accumulating from national initiatives that they are prevalent; for example, 25-45% of the river network length in France includes dry channels (Snelder et al. 2013), as well as 50% of Czech streams (Zahrádková et al. 2015). The situation in CELAC is not different as DRNs have been largely overlooked (Datry et al. 2016b). DRYvER will map DRNs for the very first time at the EU and CELAC scales and will model their future development under contrasting climate change scenarios at different spatial and temporal scales. DRYvER will produce dynamic maps of flowing and drying conditions for the focal DRNs, using a downscaling approach validated through citizen-science observations of drying events in the focal DRNs. Such maps will serve as the physical basis to implement the dynamic meta-ecosystem approach (O1). Lastly, DRYvER will also consider how such scenarios could be modified by adaptive management of DRNs and the implementation of NBSs enhancing resilience to drying.

DRNs and biodiversity (WP2): The effects of drying on freshwater taxonomic biodiversity are well-known at the local scale (Datry et al. 2017). Yet, virtually nothing is known on how drying alters the spatio-temporal organisation of biodiversity at the river network scale by dynamically disrupting hydrological connectivity (Datry et al. 2016a). Moreover, information remains scarce on how drying impacts the genetic (i.e. the intraspecific variability at the molecular scale), phylogenetic (i.e. the interspecific diversity at the molecular scale) and functional (i.e. the role played by each species in an ecosystem) facets of biodiversity. DRYvER will explore how different biodiversity facets are organised in dynamic ecosystems, overcoming the current lack of an appropriate conceptual framework for biodiversity in DRNs. DRYvER will produce scenarios for different facets of biodiversity in DRNs (O2, WP2) at focal DRN and EU scales, and will identify tipping points (e.g. drying thresholds in space and time) that should not be transgressed to maintain biodiversity in these systems – this is equivalent to the definition of safe operating spaces in DRNs.

DRYvER will also look for the generality of meta-community responses to drying by comparing models developed for EU focal DRNs to those in CELAC.

DRNs and ecosystem functions (WP3): River networks play pivotal roles in processing terrestrial carbon (Battin et al. 2009, Raymond et al. 2013), yet how drying alters ecosystem functions related to carbon cycling in rivers is poorly known at the local scale and unexplored at the network scale (Datry et al. 2016a). Recent studies suggest drying impairs many carbon-related ecosystem functions, and there is also evidence for modulation of ongoing ecosystem functions during dry phases with implications for subsequent wet-phase processes (Arce et al. 2018). It is also clear that cycles of alternating dry and wet conditions can drive substantial greenhouse gas emissions (Datry et al. 2018b, Marcé et al. 2019). DRYvER will explore the impact of drying on carbon-related ecosystem functions in DRNs, namely decomposition of terrestrially derived dissolved and particulate organic carbon, ecosystem respiration and gross primary production, and associated greenhouse gas emissions. These functions are mediated by biotic communities and their biodiversity, and have strong cascading effects on various provisioning and regulating services (e.g. self-purification, climate regulation). To achieve a mechanistic description of ecosystem functioning in DRNs with predictive capacity, DRYvER will exploit a dynamic meta-system framework that accounts for the dynamics of organic carbon sources and transport by flowing water as well as the dependence of ecosystem functions on biodiversity and particular key species (O2, WP3). Inclusion of biodiversity in an adequate way will be guided by an innovative experiment assessing the importance of dispersal-mediated biodiversity gradients for all ecosystem functions considered in the focal DRN investigations.

DRNs and ecosystem services (WP4): Socio-economic costs of river drying have not been investigated to date (Tonkin et al. 2019), although several examples indicate major economic impacts could occur. Conceptually, a meta-system approach to model the provision of ecosystem services in river networks is a real challenge, probably explaining why these approaches have been restricted to population and community dynamics. **DRYvER will assess the impact of drying on DRN ecosystem services and their values** (O3, WP4). Innovative conceptual ecosystem service provision and valuation frameworks will be developed. Conceptually, a meta-system approach to model the provision of ecosystem services in river networks is a real challenge, probably explaining why these approaches have been restricted to population and community dynamics. Our Also, our valuation framework will focus on:

1. understanding how ecosystem service valuations are subject to change in the presence of short-term dynamics, climate change and possible tipping points, and
2. the aggregation of individual ecosystem services at relevant scales to obtain the overall socio-economic costs and benefits of DRNs and their ecosystem services.

DRYvER aims to break through some of the epistemological limitations that have hampered ecosystem services-based valuation approaches so far. This will be done by **placing the understanding of the socially relevant outcomes at the core of the process of establishing and depicting ecosystem services**. Key to achieving this is a transdisciplinary process that will integrate the biophysical underpinning of ecosystem functions and services (WP1-4) with stakeholder views and knowledge and the wider public's values (WP4-WP5). This will be applied to each EU focal DRN while providing principles and criteria for wider EU application.

Adaptive management of DRNs (WP5): Current management of DRNs is hindered by:

1. lack of predictive capacity based on sound mechanistic understanding of biodiversity, ecosystem functions and services (Stubbington et al. 2018), and
2. barriers to social acceptance and policy implementation (Tonkin et al. 2019).

These knowledge gaps also challenge many EU Directives and management practices developed for permanent water bodies (Stubbington et al. 2018). In the CELAC region, DRNs are also devoid of appropriate management. DRYvER will breach these barriers by implementing new insights in socio-ecological and economic processes, through integrating several aspects of decision making, including impact assessment of diminishing flows, identification of mitigation and adaptation measures, cost-benefit evaluation, and identification of legislative, public acceptance and administrative barriers. As public acceptance is key to the successful implementation of adaptive management strategies, DRYvER will foster co-design principles in the development of all WP5 deliverables. Ultimately, DRYvER will lead to more evidence-based adaptive management strategies by developing two complementary approaches that guide decision-making at the focal DRN and EU scales. This includes a spatially explicit statistical approach allowing decision-making at the focal DRN scale (both for EU and CELAC), when high-resolution spatial data are available, as well as an uncertainty-explicit approach that will allow decision-making at the focal DRN and EU scales using a combination of model outputs, empirical data and expert knowledge (O4, WP5). Additionally, for the CELAC, due to limited local resources and expertise, capacity-building and knowledge-transfer workshops will be organised to share ecosystem service valuation approach and DRN adaptive management approaches.

1.4.2. Innovation potential of DRYvER

In addition to highly ambitious objectives and progress beyond the state of the art, DRYvER will generate highly innovative concepts, strategies, guidelines and tools such as:

- an iteratively applicable cycle model to guide adaptive management of DRNs;
- a dynamic meta-system perspective and model to quantify how drying affects aquatic biodiversity, ecosystem functions and services, shifting from the current equilibrium-dominated paradigm of their organisation in the landscape;
- an innovative valuation framework for DRNs that accounts for changing temporal and spatial dynamics (also useful for other dynamic complex ecosystems) and applying it to a combination of valuation techniques for the assessment of monetary, shared and social values;
- a co-designed approach with stakeholders to assess and manage ecosystem services in DRNs and implement mitigation measures such as NBSs, overcoming

some of the epistemological limitations that have hampered ecosystem services-based approaches so far;

- the very first maps of current and future DRNs across the EU and CELAC;
- a combination of global and local models and tools in hydrology to translate climate change projections and water uses into flow patterns in DRNs;
- a robust, evidenced-based multi-criteria framework consisting of two complementary approaches to guide adaptive management of DRNs at the focal DRN and EU scales;
- a citizen-science network to monitor drying in EU (and CELAC) river networks and raise awareness of the prevalence and values of DRNs; and
- advice for revision and refinement of policy guidelines and legislation to improve DRN management.
- DRYvER will innovate beyond the project's lifespan and exert a pivotal role in stimulating research in the EU and beyond in the next decade as it will push the knowledge frontiers on:
- the prevalence and ecological significance of river network fragmentation by drying due to climate change;
- the dynamic organisation of species and their traits in ecosystems prone to climate change;
- the interactions between biodiversity and resources flows in explaining the rates of key ecosystem functions; and
- how to adjust valuation strategies and techniques to variation and spatial-temporal dynamics in ecosystem services.

The lessons and high-level model from DRYvER will be applicable to other complex socio-ecosystems prone to strong climate interactions: the concepts, approach (i.e. the adaptive management cycle) and frameworks demonstrated in DRNs will be relevant for many other freshwater, marine and terrestrial ecosystems experiencing climate change and increased extreme events. DRYvER will thus have an impact far beyond DRNs to other types of complex socio-ecological systems and will help prevent such stressed systems from exceeding their tipping points.

2. Impact

2.1. Expected impacts

2.1.1. Contribution to the expected impacts described in the call for proposals

DRYvER will contribute substantially to each of the expected impacts described in the call, and take necessary measures so that these impacts continue beyond the end of the project.

2.1.1.1. More effective, integrated and evidence-based biodiversity conservation strategies and ecosystem management in the face of climate change

Freshwater biodiversity and the associated ecosystem services are collapsing on our watch. As this crisis deepens, we must understand and manage DRNs more effectively. Currently, there are neither frameworks nor efforts to translate climate change projections onto drying patterns in river networks. Moreover, the effects of drying are being studied mostly on a few aspects of biodiversity (e.g. local taxonomic diversity), whereas a broader approach incorporating beta and gamma diversity, but also genetic, phylogenetic and functional metrics of diversity, is crucially needed (Datry et al. 2017). It is not known how changes in biodiversity alter ecosystem functions and services, and no framework has been developed to produce process-based models linking climate change to such change, even though there have been recent calls to do so (Tonkin et al. 2019). The values of the ecosystem services provided by DRNs are overlooked, and consequently these prevalent ecosystems are either poorly managed or not managed at all (Datry et al. 2018a). Combining empirical and modelling efforts, DRYvER will develop an evidence-based multi-criteria decision framework, scenarios and strategies for adaptive management of biodiversity and ecosystem functions and services in DRNs. It will integrate dynamic connectivity into existing decision-support, open-source software for systematic conservation planning (e.g. Marxan), calibrated and tested on different focal DRNs. Thanks to our high-level approach, such a framework will be largely based on the robust evidence collected within WP1-WP4. For example, scenarios of biodiversity patterns and ecosystem function rates under climate change will be produced using process-based models conceived, calibrated and validated in a wide range of current conditions across the different focal DRNs. Bundles of ecosystem services will be identified and modelled, and their social values will be estimated and used to inform the economic assessment of adaptation and mitigation strategies. The close collaborations among multiple disciplines will maximise the integrative aspects of the multi-criteria decision framework. Benefiting from the active involvement of the stakeholders in DRYvER, such a framework will be co-constructed to be useful and widely used for climate change mitigation and adaptation strategies. Some of the stakeholders involved in DRYvER are working in other European groups (e.g. ECOSTAT), which will ensure the wider uptake of our multi-criteria decision framework. The participation of citizens in this co-construction process will also promote public acceptance of mitigation measures as well as raising awareness of the prevalence of drying events in river networks. DRYvER will have an unequivocal positive environmental impact through actions helping to preserve biodiversity, maintain ecosystem functional integrity and secure ecosystem services, implement NBSs and guide management decisions within safe operating spaces.

Furthermore, DRYvER will lead to more effective, integrated and evidence-based biodiversity conservation strategies and ecosystem management of DRNs in the 6 EU focal DRNs covered by the project (and at least for 2 of the CELAC focal DRNs) through direct implementation of the framework (e.g. local stakeholders will use the results of DRYvER to adapt their management programmes). DRYvER will also contribute to the implementation of more effective management strategies by other stakeholders in other river networks in Europe through the targeted dissemination strategy described in §2.2. Finally, as the effects of climate change unfold, it is expected that all ecosystems (not just DRNs) will be subject to increased variation and unpredictability of their patterns of ecosystem service delivery. Therefore, DRYvER will push the knowledge frontier on how to adjust valuation strategies and techniques to variation and spatial-temporal dynamics in ES more broadly and the lessons from DRYvER will be applicable to other complex ecosystems with strong climate interactions.

Indicator/Target: The number of stakeholders integrating the recommendations of DRYvER/at least 9; the size of the citizen-science network at the EU scale/at least 1500 annual observations through mobile app.

Main objectives of DRYvER related to this impact: O4, O6

2.1.1.2. Pushing the EU to the forefront in climate-change predictive capacity through models better accounting for interactions and feedbacks between biodiversity, ecosystems and climate systems

DRYvER will produce, for the first time, models and scenarios of how increasing drying as a result of climate change will alter different components of biodiversity, ecosystem functions and services in river networks. By simulating for the first time the high-resolution impacts of climate change on the drying patterns of rivers, using a state-of-the-art multi-model ensemble approach, DRYvER is at the forefront of linking the climatic system first with the hydrological system and then with freshwater biodiversity and ecosystems. While the EU is gradually being recognised as a hot-spot for freshwater biodiversity thanks to past EU efforts (e.g. BioFresh, the Freshwater Information Platform) and NBS research through the OPPLA community and other platforms, DRYvER will place the EU at the forefront in climate-change predictive capacity through our multidisciplinary cyclic cascading model integrating physical and biological responses to climate change in river networks and through the statistical and process-based models developed in WP1-5.

In the USA, an emergent group of scientists from different disciplines is set out to explore DRNs (https://www.dryriversrcn.org/), and the DRYvER coordinator has recently been invited as an EU Principal Investigator to transfer knowledge and efforts made in EU to the USA and *vice versa*. The USA PI (OU) of this network is a DRYvER partner to promote this dissemination and enhance synergies. Our Chinese colleagues from NIGLAS also follow closely the efforts developed in the EU on DRNs - being partners in DRYvER (without EU funding) will promote the dissemination of our methodologies and knowledge to China's internal research. Several members of the consortium (e.g. Datry, Bonada, Marce, Lamouroux, Cid, Barquin) already benefit from strong international visibility on DRNs and having them collaborate will undoubtedly enhance such visibility, along with increasing that of the remaining partners. These partners are joined by others with internationally recognised expertise in critical complementary knowledge (e.g. Martin-Ortega on the valuation of ecosystem services, Singer and Foulquier on meta-system ecology, Vidal, Döll and Lamouroux on hydrological and statistical modelling, Mykrä, Jabot and Heino on meta-community dynamics (See section 4.1. for more details). Therefore, DRYvER will promote EU predictive capacity in climate change and its environmental and socio-economic impacts through collaboration and dissemination across EU and international levels by involving key international and CELAC partners, as well as vital synergies with relevant projects.

Indicator/Target: The number of publications related to the predictive capacity submitted, and their citations, in the Web Of Science/at least 15 publications with a total of 3000 citations in the next 5 years; the number of special sessions at international conferences promoting the outputs of DRYvER; a special issue on DRNs by DRYvER PIs in a high-level international journal (e.g. Global Change Biology, Nature Climate Change).

Main objectives of DRYvER related to this impact: O1, O2

2.1.1.3. More effective ecosystem-based adaptation and mitigation, through evidence-based design and implementation of systemic NBSs

DRYvER will develop optimised management scenarios for 6 EU focal DRNs, based on NBSs and other mitigation strategies, including their socio-economic analysis. DRYvER will also organise a workshop on these aspects in Brazil to promote the adoption of adaptive management of DRNs in the participating countries. DRYvER will provide a robust and evidence-based understanding of the impacts of changing dynamics (including climate change effects) of DRNs on the ecosystem services they deliver (and their values). To this end, a substantial amount of the work in WP1-WP4 will be based on a coordinated and substantial data collection effort across the focal DRNs (and beyond). In turn, these data will be integrated and modelled to produce scenarios including NBS implementation for more effective evidence- and ecosystem-based adaptation and mitigation accounting for:

- economic appraisal (cost-benefit analysis) of the strategies to mitigate negative effects and to secure biodiversity, ecological functioning integrity and the delivery of services by DRNs;
- whether the implementation of such strategies and scenarios will increase the overall social welfare (i.e. whether they are economically efficient);
- financing mechanisms for implementing NBSs (i.e. the value they generate needs to be understood so that the case for investment can be made);
- legislative and policy opportunities and barriers to identify, exploit opportunities for change; and
- public acceptance and bottom-up support of policy change through co-creation with end-users and identification of public perceptions of DRNs.

In addition to promoting NBSs in the focal DRNs, DRYvER will contribute to more effective ecosystem-based adaptation and mitigation in Europe through the production of a catalogue of mitigation measures and the development of a multi-criteria decision framework, whose aim could be adapted to any ecosystem facing severe dynamic impacts due to climate change in Europe and beyond. DRYvER will establish principles and criteria for the valuation of ecosystem services provided by DRNs across the EU and more broadly, beyond the 6 focal DRNs and as part of its legacy. The DRYvER cyclic model will offer an integrated framework to European stakeholders to identify, evaluate and implement NBSs. For instance, to promote flow permanence at some target river sections as being pivotal refugia for organisms or key sites for leaf litter decomposition, NBSs could be implemented to increase water storage or residence time in the river network (i.e. natural water retention measure, http://nwrm.eu, NBSs of Type 2 or 3). The DRYvER framework will allow modelling how such implementation promotes flow permanence under different climate scenarios and explore ecological gains for biodiversity, ecosystem functions and services, along with identifying financial and legislative barriers and opportunities. Similarly, to conserve meta-community dynamics within safe operational spaces (i.e. potential ability of freshwater biodiversity in a river network to support drying) and prevent river networks reaching tipping points, pivotal river reaches acting as biological reservoirs (natural reserves) and associated connectivity among them will be identified and conserved or restored through NBSs of Type 1 (e.g. protected area or river restoration). In this way, the ecological benefit will be modelled and the financial and legislative aspects fully integrated. This framework will be operationalised by WP5 and transferred to stakeholders in focal DRNs and beyond through the stakeholders' committee and other dissemination actions described below.

Indicator/Target: The number of adaptation and mitigation measures included in management scenarios produced for each focal DRN and total (potential) monetary value of adaptation and mitigation measures (if adopted) /at least three measures for each focal DRN.

Main objectives of DRYvER related to this impact: O3, O4.

2.1.1.4. Enhanced ecosystem integrity, functionality, resilience and delivery of services

DRYvER will quantify the functional integrity of DRNs, their resilience and their ecosystem service delivery in a context of climate change. By using coordinated and intensive data collection across focal DRNs to link biodiversity to ecological functions related to carbon cycling across river networks, DRYvER will determine the functional integrity of DRNs and the resilience of ecosystem service delivery, identify tipping points of functioning, and specify safe operational spaces. DRYvER will also identify protected areas in each focal DRN, review management plans accordingly and propose suitable NBS implementation as measures to improve adaptation and enhance functional integrity. This effort will be done at higher scales too, thanks to the consistent and coordinated upscaling efforts across WP1-4. By identifying tipping points and defining safe operational spaces at the focal DRNs based on hydrological and ecological functional dynamics and trajectories (rather than on static states as usually done), DRYvER will promote novel approaches and solution for adaptive management of ecosystems altered by climate change. Consequently, this will enhance ecosystem integrity, functionality and resilience, and the delivery of services will be maintained or increased.

Indicator/Target: The identification of tipping points and safe operational spaces for each focal DRN/provide an acceptable range of drying in space and time for each focal DRN.

Main objective of DRYvER related to this impact: O2.

2.1.1.5. Inform and support increased investment in NBSs, and ecosystem conservation, restoration and management, to support climate change adaptation and mitigation strategies:

In addition to ecological analyses, socio-economic analyses undertaken in DRYvER will inform future business cases for the investment in NBSs. They will inform ecosystem management fostering climate change adaptation and mitigation strategies to secure the provision of key ecosystem services in DRNs. For example, the annual amount of revenue collected from the different water services in the EU concerning drinking water (for domestic use) exceeds 25 billion EUR. Thanks to a comprehensive analysis of adaptation and mitigation measures including NBSs, DRYvER will inform and support the investment in NBSs by assessing their economic appraisal (cost-benefit analysis), exploring the financing mechanisms for implementing NBSs, identifying legislative and policy barriers and exploiting opportunities for change, and promoting social acceptance through co-construction of scenarios. DRYvER will advise stakeholders on future water management plans and share knowledge and experiences from the focal DRNs with the OPPLA community, a new EU knowledge marketplace and community where the latest thinking on ecosystem services, natural capital and NBSs is brought together. Wider dissemination towards European, national, regional and local authorities, private environmental consultants and NGOs is planned through a comprehensive stakeholder mapping effort (WP5). This will identify key personnel who will be invited to our final meeting to maximise dissemination and impact beyond the stakeholders involved in DRYvER. Moreover, policy and management briefs will be produced (see §2.2.1.).

Indicator/Target: The number of occasions on which supporting information for the implementation of NBSs is provided by DRYvER at the focal DRN level / at least one for each focal DRN.

Main objective of DRYvER related to this impact: O4.

2.1.1.6. Providing evidence on the impacts of biodiversity on climate mitigation and adaptation, including indicators/quantitative data:

Biodiversity can mitigate climate change impacts on biodiversity itself because more diverse systems could be more resilient to climate change impacts, but also on ecosystem functioning thanks to the positive interactions and relationships between biodiversity and ecosystem functioning. DRYvER will undertake substantial data collection, analyses and modelling to provide evidence on the effects of DRN biodiversity (WP2) and ecological functions (WP3) on climate mitigation and adaptation, including the development of quantitative scenarios and associated tipping point indicators and their socio-economic effects (WP5). Evidence of the impacts of biodiversity on climate mitigation and adaptation will be spearheaded by an innovative experiment assessing the importance of dispersal-mediated biodiversity gradients for all ecosystem functions considered in the focal DRN investigations (WP3).

Indicator/Target: The influence of key taxonomic groups on the ecosystem functions considered in DRYvER / Identify thresholds in biodiversity loss below which functional integrity is at risk.

Main objective of DRYvER related to this impact: O2.

2.1.1.7. Underpinning the EU Nature Directives, EU Biodiversity Strategy, 7th Environment Action Programme, and the EU Strategy on adaptation to climate change:

DRNs are not included in most EU policies because they have so far received little attention from scientists and policymakers, and the public is unaware of their importance in promoting well-being. DRYvER will make a step-change contribution to introduce DRNs into relevant EU policies and directives (i.e. Birds, Habitats, Water Framework, Floods Directives, Biodiversity Strategy to 2020, 7th Environmental Action Plan, Water–Environment interaction, Common Agriculture Policy, Strategy on Green Infrastructure, Strategy on Adaptation to Climate change, etc). This will be achieved thanks to policy experts involved in DRYvER (e.g. SYKE, FT) and to the active stakeholder involvement (WP5).

Through its contribution to theses European policies, DRYvER will also meet the challenges of the 2030 Agenda and the achievement of the 17 Sustainable Development Goals. Its action, while transversal, will contribute particularly to the achievement of the SDGs related to climate change, biodiversity and underwater life (SDGs 13, 14, 15). ACA is currently contributing to review and implement the Water Framework Directive (WFD-CIS) in DRNs. For example, DRYvER's ecosystem service valuation work will break through some of the epistemological limitations that have hampered valuation approaches so far. This will be done by placing the understanding of the socially relevant outcomes at the core of the process of establishing and depicting ecosystem services, through a transdisciplinary process that will integrate the biophysical underpinning of ecosystem functions with stakeholder views and knowledge. DRYvER will primarily target implementation and policy gaps/conflicts and provide input to technical processes (e.g. working groups on ECOSTAT, expert exchanges, workshops) in terms of good practice, lessons learned and modelling. New policies (e.g. EU Directive on Droughts or other policies to tackle water scarcity and its effects) will be informed and nurtured by DRYvER. Our team will follow the discussions happening at policy level (e.g. in CIRCABC, LinkedIn groups and by direct participation in such events) and prepare for upcoming events with proper briefs, applied recommendations and focal DRN illustrations.

Indicator/Target: Number of contributions to working groups; Number of policy uptakes of DRYvER recommendations, e.g. by including in guidelines or other policy documents / 6-9 regional, national or international policies informed.

Main objective of DRYvER related to this impact: O5.

2.1.1.8. Informing major international scientific assessments such as the IPCC reports and the IPBES / The protection, restoration and enhancement of natural capital in line with the work of the CBD, IPBES, IPCC and further relevant global processes and organisations

DRYvER's international Advisory Board includes key IPBES, IPCC, ISIMIP, IWMI, WMO-UN and JRC members, as well as high-level international scientists (K Tockner, S Bunn, CN Dahm, AJ Boulton) and key NGOs (e.g., WWF, Wetlands International, Europe River Network, Alliance of Freshwater Life). The Advisory Board will be continuously informed (three meetings are planned) on the results of the project, and their feedback will be integrated into DRYvER. This flow of information and the confirmed interest of these organisations for DRYvER will ensure that DRYvER will inform major scientific assessments in Europe as well as internationally. Several members of DRYvER are already contributing to key national (e.g. Iberian Limnological Society – UB, Center of Expertise on Water of the Scottish Government – UoL, Dutch platform ecological restoration – NIOO) and international advisory groups (e.g. ACA in ECOSTAT group on intermittent rivers, NIOO in ESF and IPCC review group, MU in International Association for Danube Research, GU in International Hydrological Programme of UNESCO and Hydrology and Water Resources Programme of WMO World Meteorological Organization.). DRYvER will also publish opinion papers on the ecology and management of DRNs under climate change and produce press releases whenever relevant. DRYvER provides inputs to CBD Target 11 (conservation of at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures), Target 14 (restoration and safeguarding of ecosystems that provide essential services, including services related to water), Target 15 (enhanced ecosystem resilience and contribution of biodiversity to carbon stocks, through conservation and restoration) and Target 17 (improvement of knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends). DRYvER will expand previous IPBES assessment reports (methodological assessment report on scenarios and models of biodiversity and ecosystem services; thematic assessment on land degradation and restoration; EU and Central Asia regional assessment) by including river networks facing climate change. DRYvER will also provide inputs to the more recent thematic assessment on sustainable use and conservation of biodiversity, and the upcoming thematic assessment on invasive alien species and their control. DRYvER will help achieve some of the objectives of the EU Biodiversity Strategy to 2020, especially Target 2 (maintain and restore ecosystems and their services), the SDG 15.9.1 (Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011-2020) and Goal 13 "Climate Action" of the UN Sustainable Development goals. Through the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) to whom GU is contributing along with a member of our International Advisory Board, DRYvER will inform the IPCC about how climate will increase drying events within river networks.

Indicator/Target: Number of contributions to working groups of the relevant international scientific assessment groups; Number of recommendations provided by our advisory board and adopted/integrate five recommendations from the AB.

Main objectives of DRYvER related to this impact: O1-O6.

2.1.2. Other expected impacts

Beyond the many impacts mentioned in the work programmes, DRYvER will have significant environmental, economic, scientific, social and policy impacts:

- Impact on EU scientific collaboration: DRYvER will involve the participation of 19 research organisations and universities (among a total of 25 partners), including entities from all over Europe. These partners will benefit from increased visibility and reputation and strengthen their international and interdisciplinary network. They will broaden their scientific experience with direct contacts with end-users and stakeholders. While DRYvER is partly based on an existing partnership developed in the COST Action SMIRES, new members (e.g. water@leeds, Döll, de Senerpont Domis, Vidal, Lamouroux, Jabot, Barquin, Munoz) now join the network providing key complementary knowledge as well as access to new networks in which DRN knowledge will be further spread; notably including 3 CELAC partners (Brazil, Ecuador and Bolivia).
- Training of early-stage researchers: Through proactive training of early-career investigators, Short Term Scientific Missions, training schools and a Forum of Young Researchers (WP6), DRYvER will train the next generation of EU and CELAC freshwater scientists about the prevalence of drying events in river networks. DRYvER will also include co-supervision of PhD students (e.g. 1 PhD co-supervision by UZ/MU in WP2, 1 PhD co-supervision by USFQ/INRAE in WP2) and postdocs (e.g. 3 in WP1, 3 in WP2, 6 in WP3, 1 in WP4, 2 in WP5) and exchange students (e.g. between UoL, UB and INRAE);
- International collaboration is a major strength of DRYvER thanks to the active involvement of 5 international partners, including three from CELAC countries in the project, along with the International Scientific Advisory Board. CELAC is one of the most important global regions in terms of biodiversity and ecosystems and is highly vulnerable to climate change. Fostering collaborations will help to build up a new generation of scientists in South America where climate change is dramatically altering some of Earth's most diverse ecosystems (e.g. Amazon basin, the high-Andes, the Caatinga). DRYvER includes non-EU partners to broaden our geographical scope and foster synergies with active research groups on DRNs in the USA and support the development of DRN research in China, where DRNs are prevalent but not yet considered in research and management. These countries are the highest contributors to ecosystem services studies in recent years, and we foresee very active exchanges of knowledge, data, methods and best practices. In addition, water scarcity and e-flows are relevant topics for some of the European Strategic Partnerships, including with India and Iran, as well as Brazil. Lastly, the coordinator of DRYvER is hosting for two years one of the very few "Make Our Planet Great Again" postdoc researchers (N. Cid) supported by the French government to help adapt to climate change. Her research project is to identify novel strategies to improve the assessment of the ecological status of DRNs, which complements DRYvER;

- DRYvER will empower citizens (social impact) to adaptively manage DRNs by establishing a citizen-science network gathering hundreds of people across the EU thanks to synergies with existing initiatives (e.g. SMIRES, AMBER, Crowdwater). This network, a long-term initiative, will monitor drying events within river networks of EU through an open-access mobile application, overcoming the lack of regional hydrological data while raising environmental literacy and public awareness of water scarcity as well as the risks of flash floods, a key feature in many intermittent river reaches which is a growing societal issue;
- DRYvER will have a beneficial economic impact on SMEs participating in the project, who can use the results of DRYvER to reinforce their position and revenues. For instance, FT (consultancy specialised in support to public administration related to the management of environmental-related issues) expects a 10-20% increase in quantifiable aspects such as employment, contract volume and number. Z5P, who will develop the web and the mobile application, expects a 20% revenue growth in this field thanks to DRYvER. They will recruit two new employees to their current web development and programming team (one full time and one part-time employee). Also, in the long-term, the implementation of technological mitigation and adaptation measures (including NBS) suggested by DRYvER to stakeholders at different scales (focal DRN to EU) will have economic impacts on SMEs.

2.1.3. Barriers and obstacles to DRYvER

Barriers and obstacles that may limit DRYvER impact include:

- Negative perception of stream drying and lack of public acceptance of NBSs. The perception of drying might vary among regions in different ways and often might not be seen as a problem by the public in some areas. For example, in Northern Europe (e.g. Finland), droughts are not currently seen as a major problem, where water is usually abundant, so it is critical to get people to take this matter seriously. However, extreme weather events are starting to change this public view and particularly, the 2018 and 2019 EU heat waves and drought conditions will favour this shift;
- Lack of interest and funding of stakeholders to implement DRYvER recommendations: water management agencies may be reluctant to use a novel approach based on NBSs. Public authorities might also lack resources to deal with DRN appropriately. Our co-construction approach (WP5) will undoubtedly help, along with looking for financial mechanisms to implement mitigation measures;
- The review/fitness-check of several relevant EU Directives (WFD, UWWTD, FD) and policies is almost achieved and the conclusions of DRYvER could arrive too late to inform this process (which can include a lag of 5-10 years until they could be effectively implemented at the EU level). However, we consider that the regulatory EU framework allows for sufficient flexibility to adapt management properly. We will focus on implementation and raise technical aspects (e.g. in the Common

Implementation Strategy of the WFD) which should promote good practice, adaptive implementation and inform next evaluation and review processes;
- The post2020 EU Biodiversity strategy is being discussed now, so the conclusions of DRYvER could arrive too late to strongly influence the follow-up strategy. However, DRYvER will still have an impact by focussing on implementation and technical issues and with strong interactions with JRC and EEA about modelling and use of indicators to support policy objectives, especially as JRC is part of our Advisory Board and could ensure fast uptake of DRYvER outputs.

2.2. Measures to maximise impact

2.2.1. Dissemination and exploitation of results

2.2.1.1. Draft Plan for the dissemination and exploitation of the project's results

Specific objectives, target groups and means for the exploitation and/or dissemination of each project result will be defined in the Plan for the Exploitation and Dissemination of Results (PEDR) to be established in M6 of the project by UP with contribution from all partners. The PEDR will constitute an essential tool to guide the activities of the consortium throughout the lifetime of the project and beyond. It will be updated at the end of each period taking into consideration additional needs and integrating the project results to ensure a continuous coherence with the final project's impacts. Advice on the dissemination and exploitation of results will be obtained from the Advisory Board and Stakeholders Committee. We have established a preliminary plan defining the high-impact project results, target end-users and measures to disseminate the results and support their exploitation and their uptake by these target groups.

The plan will target DRYvER end-users:

- Policymakers managing water resources (e.g. water authorities, biodiversity managers, environmental agencies) at the national and international level; although they are increasingly concerned about the relevance of drying watercourses, they often lack the knowledge to manage freshwater ecosystems appropriately;
- Private sector (e.g. insurance agencies and consultancies) interested in NBSs and companies in charge of water management;
- Academia (e.g. hydrologists, biologists, socio-economists, professors, teachers); and
- Citizens and civil society organisations (NGOs), who benefit from the services provided by DRNs.

Dissemination of the project results will be through channels tailored to each target group

Dissemination to academia will be ensured through:

- Scientific publications in key journals and as open access. We already foresee publications on key deliverables from WP1-WP5 indicated as "confidential" in

§3.1.5. KPI: Number of accepted papers in scientific journals and international conferences (target: at least 1 per academic partner); Number of citations (target: at least 50 within four years post-publication date); special issue on DRNs in at least one high-level international journal;

- Presentations in major international conferences in the field of water sciences. KPI: Number of accepted presentations in technical workshops (target: at least 1 per academic partner).

Dissemination of DRYvER results will be complemented by the following training and/or knowledge transfer activities, open to researchers from entities outside of the consortium:

Organisation of 2 workshops (one in the UK and one in Brazil - WP4 and WP5 - to transfer knowledge to CELAC scientists and stakeholders) [KPI: 25 participants]

- Organisation of short-term scientific missions (STSMs) to train young researchers [KPI: 6-8 STSMs];
- Forum for Young Researchers (FYR) to stimulate communication among new generation scientists via social media groups and mailing list [KPI: 25 participants to the Forum for Young Researchers];
- Organisation of 2 training schools on field techniques and development of analytical skills [KPI: 10-12 participants for each training school]
- Webinars [KPI: 1 per year] and teaching materials for master courses on freshwater ecology, climate change, biodiversity conservation, etc

Dissemination to the stakeholders and policy-makers will be ensured through:

- Continuous engagement with stakeholders at the DRN level (and beyond);
- Advisory Board and Stakeholders Committee meetings;
- Organisation of 6 workshops with stakeholders to co-design the framework developed in WP5 [KPI: 15 participants]

Finally, the following media will be used to reach all target groups:

- Website and social media accounts, and disseminating DRYvER’s output on existing platforms Press releases and policy recommendations [KPI: 6-9 policy recommendations]
- Organisation of a final dissemination workshop (if possible, attached to a big event to reach a wider audience), at the end of the project open to scientific, end-users and stakeholders beyond the focal DRNs [KPI: 80 participants]

In addition to these measures, DRYvER will promote a proactive approach in dissemination by making use of the connections of the partners to key stakeholders and seizing every window of opportunity which may arise during the project (e.g. policy consultations, policy reviews). Several DRYvER partners will attend major international conferences, such as the next COP Biodiversity (CDB) in 2020 and 2022, the COP climate every year and the Water Global Forum every 3 years (next Dakar in 2021).

Exploitation plans

All partners are aware of, and committed to, the exploitation of the project's results. It is a paramount practice in exploitation activities to make immediate and timely use of the results of the project to create value within the participating organisations and thus to improve their competitive advantages.

We have already identified several high-impact results which will be generated by DRYvER and which will be of interest for the end-users identified above (Table 4).

Table 4.

Examples of high-impact results which will be generated by DRYvER.

Main expected results	Potential users	Means to reach these end-users
Open-source software tools for the mathematical simulation of hydrological processes (WP1)	Scientists, consultants, NGO	Publication and presentation in international conferences Open-Source availability
Dynamic maps at each focal DRN for hydrology, biodiversity, ecological functions, and ecosystem services (W1-WP4)	Water management entities at focal DRN level, NGO	Participation in the project, co-design approach, Stakeholders Committee
Open-source software tools for the simulation of biodiversity dynamics in DRNs (WP2)	Scientists, consultants, NGO	Publication and presentation in international conferences Open-Source availability
Predictive models for biodiversity at local and European scales (WP2)	NGO, policy-makers, scientists,	Stakeholders Committee
Open-source software tools for the simulation of ecosystem function dynamics in DRNs (WP3)	Scientists, consultants, NGO	Publication and presentation in international conferences Open-Source availability
Open-source software tools for the simulation of ecosystem service provision in DRNs (WP4)	Scientists, consultants, NGO	Publication and presentation in international conferences Open-Source availability
Evidence-based decision support framework (incl. Bayesian belief networks, Marxan optimisation algorithm) (WP5)	Water agencies, policy-makers (at focal DRN level and beyond)	Stakeholders Committee, final dissemination workshop (incl. training on Marxan software) Use of Marxan open-access software
Value functions for the estimation of the value of ecosystem services across the EU (and potentially worldwide)	Scientists, consultants, NGO, Water agencies, policy-makers (at focal DRN level and beyond)	The value functions will be publicly available and ready to use, with guidance on how to apply them. Dissemination workshop
Recommendations to adapt legislation	National and European policy-makers	Participation in advisory groups Website, Advisory Board
Assessment of NBSs and other measures	Policy-makers, investors	Publications, CELAC Workshop, Stakeholders Committee
Citizen science smartphone application and networks	Hydrologists, citizens, NGO, Water management entities at focal DRN level, JRC	Open Access App, Website, Social media

Policy-makers and water management agencies will use the results of DRYvER to adapt their management policies for DRNs. At the focal DRN level, the involvement of stakeholders in the Stakeholders Committee and co-design of the adaptive management framework will ensure that the project results are implemented locally. For instance, ACA plans to include the results of DRYvER in the next River Basin Management Plan. At the European level, other stakeholders beyond the project will be invited to the final dissemination workshop. They will be identified by FT in WP5, and the methodology used at the focal DRN level will be made available so that it can be applied to their river networks.

Academic partners will exploit breakthroughs of DRYvER under existing activities and for educational and training purposes. They will use DRYvER results in future research projects by applying for funding either at local (e.g. ERDF, EAFRD, Water Agencies), national (e.g., National Science Foundations) or European (e.g. Interreg, LIFE, PRIMA, BiodivERsA) level. In countries where there is no permanent research unit on DRNs (e.g. Croatia, Finland, Germany, Hungary, China), DRYvER partners will apply for funding to ensure the continuity of the project.

NGO partners will use DRYvER results in their ongoing projects and activities, transferring the knowledge to the regional, national and local levels to raise awareness and develop capacity-building. The experience gained in DRyVER will be used to develop new projects and offer new solutions in future activities.

SME partners will exploit Research & Development efforts in individual business strategies and build new partnerships/projects on the results of DRYvER.

<u>SME and Protection, Exploitation and Dissemination policy and rules</u>

The policy and rules for protection, exploitation and dissemination activities have been developed based on the basic principles set out in H2020 Annotated Grant Agreement (GA) and will comply with the Consortium Agreement (CA) to be signed based on the DESCA model by all consortium partners before the signature of the GA. Main issues that will be tackled in the CA will be confidentiality, ownership of results, joint ownership, background, access rights, dissemination and use of results.

To ensure continued participation of all partners to the strategy and implementation of these activities as well as an efficient follow-up, we will organise Dissemination and Exploitation Reviews (DER) throughout the project, every year. These reviews will take place as a session of the General Assembly meetings. This review will allow close monitoring of the generated results and associated dissemination and exploitation activities and measurement of the impact of the project based on previously defined success criteria and KPIs defined above. UP, WP6 leader, will chair these reviews, monitor the implementation of the activities, and update and adapt the PEDR accordingly during the whole duration of the project.

<u>Contribution of the PEDR to achieve the expected impact of DRYvER</u>

The PEDR will contribute to achieve the expected impacts through the following pathways:

- The consortium has been shaped to ensure a critical mass of experts gathering the wide set of required expertise to ensure the effectiveness of tools, methods and proposed solutions. All measures mentioned above will be undertaken and managed by dedicated experts (Communication Manager from Z5P, Data Manager from INRAE, and Dissemination, Exploitation & Intellectual Property (DEIP) Manager from UP);
- All partners are aware of the importance and impact of these measures, and all necessary resources have been allocated to the implementation of these activities (see WP6 in §3.4);
- Several partners have a consolidated and consistent track record of high-impact research (e.g. Datry, Martin-Ortega, Bonada, Singer, Vidal), dedicated Research Impact Offices (e.g. UoL) and are involved in international networks;
- The active participation of the International Advisory Board and Stakeholders Committee, as well as the mapping of stakeholders performed by FT in WP5, will support the dissemination and exploitation strategy;
- The overall strategy, established at the beginning of the project and dealing with all these aspects (exploitation, IP, dissemination) comprehensively, will avoid fragmentation or implementation of individual actions that do not contribute to the identified objectives; and
- Specific communication actions will take into account individual positions and expectations of the target groups, ensuring that relevant information is communicated in a timely way.

2.2.1.2. Management of research data

DRYvER will participate in the Open Research Data Pilot. The standards for data storage, access and management will be detailed in the Data Management Plan (DMP) prepared by INRAE, which will be delivered at M6 in WP6. We have prepared a preliminary DMP:

<u>Type of data to be collected during the project:</u>

- Hydrological data (e.g. time series from gauging stations, observations of flow states);
- Biological data (e.g. biodiversity data, ecological function rates); and
- Socio-economic data (e.g. monetary and non-monetary values of ES provided by DRN, costs and benefits of NBSs and mitigation strategies).

<u>Standards to be used:</u>

- In-project Data Management Approach: WP leaders will act as WP data managers overseeing data management and data quality assurance for their respective WPs. At the project level, INRAE will be responsible for quality assurance and control as described below. As part of the start-up phase of the project, all project staff will be made aware of their responsibilities to data quality assurance, data management, metadata standards, code versioning and ethical requirements as described below.

The consortium members will receive full training on these issues, as well as ongoing guidance and oversight from their respective WP leaders. IT staff from INRAE, UP, UB and UL will provide additional support concerning data-sharing between researchers, data storage and backup services.

- Data Storage, Management and Sharing: All project team members will follow a strict storage/back-up procedure using agreed file-name conventions to ensure all updates are recorded and auditable. During the lifetime of the project, all electronic data will be shared among project staff using a central repository, password-protected and with security features hosted by INRAE. This will allow real-time access from all project partners, ensure that data are continually backed up and that versioning of documents can be maintained. The number of copies of data containing personal information will be kept to a minimum, and all data involving human participants (WP4, 5 and 6) will be digitised and anonymised, in full compliance with GDPR. This includes archiving and sharing audio-recordings of qualitative data as well as transcribed textual files and digital versions of secondary sources (e.g., documents). The participants' own procedures will govern back-ups of local data. In all cases, original data files will be kept on a password-protected PC and will be backed-up regularly online to the secure network, and offline to an encrypted removable hard drive. Non-electronic data (e.g., hard copies of documents not available electronically) will be stored securely in a locked filing cabinet. Where possible, these data will also be digitised to the level of scanned images so that they can be analysed using qualitative analysis software and archived.

How will these data be exploited and/or shared/made accessible for verification and re-use?

A central repository, password-protected and with security features, will be used to exchange relevant documents among project partners, to store relevant documentation for up to two years after the project end, to exchange confidential commercial data and to support collaborative e-work. The use of personal data collected for workshops and trials will be managed according to GDPR and applicable laws and regulations. Data will also be shared on open-access, online databases such as the Freshwater Biodiversity Platform, IRBAS, PANGAEA, GBIF, DRYAD, OPPLA, EVRI (environmental valuation reference inventory). We will comply with the FAIR standards for data collection. The citizen-science network data will be hosted for the duration of DRYvER onto the DRYvER website, with real-time, on-line visualisation and then transferred to INRAE for at least 10 years to ensure the continuity of the effort.

Data curation: WP leaders will be in charge of curating the data collected in their WP, which will then be transferred by INRAE onto a central repository.

2.2.1.3. Strategy for knowledge management and protection

IP, exploitation and dissemination activities will be managed by appointed managers (Data Manager, DEIP Manager) with clearly defined roles within the WP6.

Open access policy and measures

The DRYvER consortium will ensure compliance with Horizon 2020 rules regarding Open Access to scientific publications by making freely accessible any scientific publication that is produced under the project. Each beneficiary will choose the most suitable approach (either “green” or “gold” OA) for each publication concerned. The publisher will be chosen among those who respect the authors’ interests and accept open access publication (with an embargo period).

Knowledge management

Our consortium is aware that results that can be generated under the project could be any output, not limited to industrial and intellectual property assets. Therefore, we will identify all project outcomes (new knowledge, new technology, and any data or business information) from the beginning until the end of the project. For the avoidance of doubt, access to or dissemination of a Party’s Results or Background will be subject to prior written approval from the owning Party. If the owning Party grants access or permission to disseminate the Results or Background concerned, the owning Party may identify specific limitations or restrictions on its use. Our strategy for knowledge management and protection is closely linked to dissemination and exploitation management. It is proactive and consists of:

- Identifying all relevant outputs of the project during Dissemination and Exploitation Reviews but also continuously during the implementation of the tasks;
- Establishing, with the partner(s) having generated the result, the most appropriate strategy to protect (e.g. IP, nondisclosure), to exploit (e.g. further research project as background, commercial agreements) or to disseminate (e.g. open access publications, international conferences, website, etc.) the result; and
- Once the strategy is adopted by the partner with the help of managers, taking necessary measures, following up the activity, and updating the PEDR.

Intellectual Property Rights (IPR) management

IPR issues are a part of the knowledge management, but require specific attention and a well-defined strategy and action plan. In line with the Model Grant Agreement, our strategy is to protect the project’s results whenever they are expected to be commercially exploitable and whenever protection is feasible, reasonable and justified.

For any protectable IP that may arise during the project, the following steps are to be carried out:

- The partner notifies the DEIP Manager about the technical contents to be protected and related ownership rights (including in case of joint ownership);
- The DEIP Manager brings the IP protection intention to the attention of the Steering Committee;
- In the case of jointly owned new IP, the procedures for IP protection, use and licensing will comply with the rules set in the GA and also described in the CA;

- Filing of the related IP protection application is followed directly by the relevant partner(s).

When results are not protected, we will promote open access in all forms (e.g. publications, tools, R packages).

2.2.2. Communication activities

Communication activities will be designed to maximise the impacts of the project to the most diverse audience possible. The PEDR will include a clear and efficient communication strategy, related objectives, target audiences, tools and channels. Thanks to the in-house capacity of Z5P, a professional Communication Manager will ensure the efficient management of these activities. Partners will also contribute to the communication activities based on well-defined strategies, objectives and target groups throughout the project implementation. UP will support the Communication Manager by supervising the content of the information communicated.

For each audience, we will set up a distinct communication strategy and use targeted messages and appropriate means and language.

The objectives of the communication activities will mainly be to translate the scientific results of the project into non-expert-friendly communication material in order to:

- inform relevant stakeholders about the project results and show how the outcomes of our project have positive direct and indirect impacts on the European society and economy and beyond (CELAC, USA, China);
- demonstrate how our EU-scaled collaboration can achieve more than what would have been possible without this collaboration.

With these objectives in mind, target audiences will be international researchers, citizens, and students, and EU and national stakeholders involved in water and environment management strategies. To reach these target groups, we will develop dedicated communication tools:

- Project website [targeting the public and DRYvER end-users]: Z5P will design and build the website of the project where all the relevant information will be published (e.g. objectives, main results, leaflets and dissemination materials, news, events). The website will be continuously updated with project information and deliverables and other results that may interest the public, scientific community or end-users [KPI: number of visitors on the website per month];
- Z5Plus will develop visual identity materials such as a logo and slide templates to transfer a recognisable and coherent image of the project [KPI: a logo];
- Other Online engagement and digital communication tools: press, brochures, social media accounts, a final workshop and events (e.g. open doors) [KPI: number of subscribers/participants]; and
- European Commission Communication channels: We will also use European Commission services to communicate our project’s results and events. This will be

done in close coordination with our project officer and allow us to reach a Europe-wide "qualified" audience.

Project partners will also contribute to promoting the project and its results by sharing information on their website, in local media and via mailing lists. The PEDR will detail all specific communication activities to be performed by each of the partners with their associated schedule (Table 5).

Table 5.

Communication activities schedule.

Actions	Year 1	Year 2	Year 3	Year 4
Website	Set-up M3	Follow-up and updates		
Visual entity	Set-up M3	-	-	
Social media	Set-up M3	Information shared monthly		
Infographics		Visualisation of DRYvER results		
Press releases	-	When results are available		
Brochures	M6	-	M36	
e-newsletters	M6, M12	M18, M24	M30, M36	M42, M48
Final Workshop		-		M48

3. Organisation structure and decision-making in DRYvER

3.1. DRYvER management structure

The DRYvER Consortium is based on the collaboration of 25 partners coming from 16 different countries. The project will be implemented with a proper, simple and efficient management structure, including specific teams and procedures. The roles and responsibilities of each partner are clearly defined, avoiding any confusion and minimising complexity in decision-making and all other procedures. The organisational structure of the consortium will comprise the following Bodies: Coordinator, Steering Committee (SC), General Assembly (GA), Management Support Team (MST), Advisory Board (AB) and Stakeholder Committee (SCH) (see Fig. 5).

Project Coordinator (PC) - Thibault Datry (INRAE)

Thibault Datry and INRAE have extensive experience in coordinating collaborative programmes, and a strong scientific background (see part 4 for details). He will act as the intermediary between the partners and the EC and his roles will include:

- Ensuring that all WPs maintain the overall project vision with a common approach for technical decisions;
- Collecting, reviewing and submitting reports and other deliverables to the EC;

- Preparing and chairing meetings and monitoring the implementation of the decisions taken;
- Ensuring the flow of project information and documents between the partners; and
- Administering the EC financial contributions in accordance with the Grant Agreement.

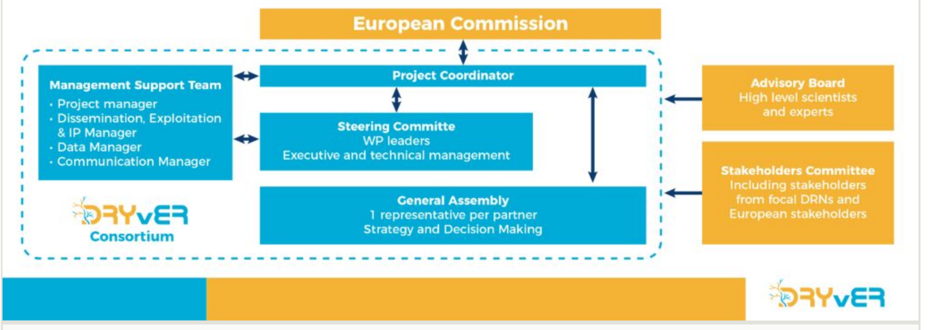

Figure 5. doi

DRYvER management structure.

General Assembly (GA) - PC + 1 representative per partner

The GA is the highest level of authority in the project and is responsible for the high-level decision making on all issues that can have an impact on the project. The GA takes any major decision affecting the execution of the project (termination, creation, or reallocation of activities, amendments to the Grant Agreement), such as a change in the consortium composition, a transfer of resources between partners or between WPs, or a change in the planning or the technological choices.

Steering Committee (SC) - PC, WP leaders, Project Manager

The SC will be in charge of the technical implementation of the project by:

- Managing deliverables in accordance with the schedule and requirements of the Grant Agreement;
- Detecting potential issues and deviation from the work plan and identifying, proposing and implement corrective actions;
- Deciding on specific technical (re)orientations of the project whenever the need arises;
- Ensuring the application of standard quality assurance practices and performing risk management;
- Establishing and developing relationships with the Advisory Board and Stakeholder Committee;
- Managing and controlling the data required and generated by the project;
- Securing appropriate dissemination and exploitation of project results;
- Supporting the PC in preparing meetings with the European Commission.

WP Leaders - WP1: Jean-Philippe Vidal (INRAE), WP2: Nuria Bonada (UB), WP3: Gabriel Singer (UIBK), WP4: Julia Martin-Ortega (UOL), WP5: Lisette de Senerpont Domis (NIOO), WP6: Zoltan Csabai (UP), WP7: Thibault Datry (INRAE)

WP leaders are responsible for the production of WPs deliverables and their anticipated submission to the SC; they report on the progress of their WPs and present detailed and updated work plans to contribute to the maintenance of the quality assurance plan. They contribute to management decisions within the SC scope and implement the decisions that impact their WPs. WP leaders will organise specific meetings bringing together partners involved in their WP as often as necessary to follow WP progress or discuss any technical issue within their WP. These may be physical meetings or virtual meetings.

Management support team (MST) - Project Manager, Dissemination, Exploitation & Intellectual Property Manager, Data Manager, Communication Manager.

MST will assist and facilitate the work of the PC in executing the decisions of the SC and GA and carrying out day-to-day management of the project.

Project Manager (ERDYN) will support the PC in project management. ERDYN will be in charge of the daily management of the project, monitoring of the progress, support to periodic reports preparation, preparation of project meetings and conference calls, advice on financial issues and budget follow-up.

Dissemination, Exploitation & IP (DEIP) Manager (UP) will establish and update dissemination strategy, provide guidance and best practices to partners while dealing with open access journals, ensure the compliance with the dissemination rules from Grant Agreement, Consortium Agreement and PEDR and support dissemination activities undertaken by the partners.

Data Manager (INRAE) will set up the data management plan and take measures to ensure open access to the research data generated by DRYvER.

Communication Manager (Z5P) will plan, establish and update communication strategy and raise target groups awareness about project results.

Advisory Board (AB) - High-Level experts and scientists

AB will include high-level experts in the field of freshwater sciences (e.g. Tockner, Boulton, Bunn), climate change (e.g., Niamir, Friler, Langan) and adaptive management of water resources and biodiversity (e.g. Dahm, Van de Bund,). It includes the coordinator of the *Inter-Sectoral Impact Model Intercomparison* (ISIMIP, Friler), key experts from the IPCC (Bernauer, Kabat) and IPBES (Niamir), along with members from the International Water Management Institute (Langan), the World Meteorological Organisation (Kabat) and the European Joint Research Center (Van de Bund). AB will be set up at the beginning of the project.

Stakeholders Committee (SHC) - European and focal DRN Stakeholders

SHC will include stakeholders from the focal DRNs considered in DRYvER, the two stakeholders involved as partners (ACA, DDVIZIG), and will be extended to other European stakeholders during the project (e.g. JRC). The SHC will be set up and managed by ACA (WP5).

3.2. Methods for Governance and Control

Our management structure, appropriate for the scale of the project (large consortium, highly-interdependent WPs), will allow us to discuss the right questions and take the right decisions in the right places with appropriate participants.

Management tools

DRYvER will have dedicated management tools which will ensure an efficient implementation of the project and facilitate contact and information exchanges between partners. In order to ensure the maximum level of transparency, awareness, responsiveness and integration of activities, all partners will be kept informed of the project status and relevant issues. A correctly empowered governance and control for the overall project management will be guaranteed by the following means:

- *Grant Agreement and Consortium Agreement*, define the rules of collaboration among partners within the project (roles, responsibilities and mutual obligations for the project life), the roles of each partner, formal rules of participation, IPR protection (see dedicated section), rules for budget re-allocation…;
- *Project Quality Assurance Plan* will highlight quality assurance and management procedures, templates for the documents, internal review processes to ensure the quality of deliverables and any other publication;
- A secured *Documents Repository* will be implemented to assist in the management of documents and will contain information about the project status, the planning, meetings, minutes and deliverables.

Project meetings

Project Meetings will be organised by the project manager or WP Leaders, according to the needs of the project. The meetings dates and locations will be selected in order to minimise the number of travels; the use of teleconferences will be maximised to limit costly face-to-face meetings. Project meetings are presented in Table 6.

3.3. Decision Process

As a general rule, all decisions will be taken by consensus at the management level at which the need for a decision arises. In the case of no consensus, a decision will be taken by vote: each EU and CELAC partner shall have one vote. Non-funded international partners (OU, NIGLAS) will be invited to consortium meetings but will not have a vote.

Ultimate decision level is the GA, which will vote according to the majority of 51%. Proxy voting is allowed. Detailed procedures will be provided in the CA.

Table 6.
DRYvER Project Meeting Schedule.

Meeting	When	Who	Objective	How
General Assembly Meeting	M1, M12, M24, M36, M48	GA	To discuss the project's objectives, work in progress, budgets; to promote creativity and cooperation	Face-to-face
Steering Committee Meeting	Every three months	SC	To ensure continuous monitoring of the project's tasks and activities, and to identify any risk that can occur and related mitigation measures	Face to Face; Conference calls
WP meetings	When necessary	WP members	To monitor the progress of the tasks within each WP	Face to face: Conference calls
Dissemination and Exploitation Review	M12, M24, M36, M48	SC	To review and update the Dissemination and Exploitation Plan	Face to face
Advisory Board and SHC meetings	M12, M24, M48	AB, SHC, GA	To gather feedback on the project results, redirect the work of DRYvER and maximise impact	Face to Face; Conference calls

3.4. Project Reporting and monitoring

The procedure for the preparation of formal Periodic and Final Reporting will be coordinated by ERDYN and will be explained to the partners to ensure that the procedure is clear for each partner and respected by them. The procedure is built on the collaboration and collection of the input from each partner orchestrated at different levels. WP leaders will coordinate the reporting for their WP, consolidate and complete the information they collect from partners and send the report to ERDYN within the planned schedule. Based on the inputs of the partners, ERDYN will consolidate and complete the report with the PC before submitting to the EC. Continuous monitoring and reporting will also be ensured through key milestones that have already been identified for the project implementation. They will be carefully monitored by the corresponding WP leaders and at the project level by the PC. When the date of each milestone's review is achieved, the results' verification will be conducted against set objectives, and a short explanation will be issued regarding the milestones' assessment. If a milestone is delayed or is not achieved, the impact on project and WPs will be assessed, and the concerned WP leaders will propose a back-up plan.

3.5. Addressing effective innovation management

Innovation management is a process which requires an understanding of both market and technical problems and aims at successfully implementing appropriate creative ideas. In

DRYvER, project management structure and work plans have been designed to foster innovation through:

- The co-design approach with stakeholders and citizens to ensure that the framework developed by DRYvER is adapted to the needs of society at large;
- The identification of project results during Dissemination and Exploitation reviews (WP6) and the participation of a DEIP manager in the management support team. These measures will ensure that project results are identified and exploitation strategy is decided and implemented rapidly; and
- The participation of high-level experts in the Advisory Board to the integration of their recommendations in the project.

All these measures will allow us to manage the innovations developed in the project efficiently.

3.6 Risk Management

DRYvER risk management will consist of the following processes:

- Identification of the potential risks of the project (see Table 5). During the project, the PC, with the support of WP leaders, will identify further risks that can occur. ERDYN will maintain a risk register;
- Assessment and prioritisation of the identified risks by the SC;
- Monitoring by the PC, WP leaders and project manager. In each project management meeting, a risk management session will be organised, the list of the risks will be updated, each risk will be reviewed, and new mitigation measures and partners responsible for implementing mitigation measures will be defined;
- Mitigation of the identified risks by the identified partners;
- Evaluation of results and integration of lessons learned to risk management (Table 7).

Table 7.

Critical risks for implementation.

Description of risk	L & I*[1]	WP	Proposed risk-mitigation measures
Risks related to focal DRNs			
Frictions emerging from cultural and political differences at the focal DRN level (e.g. a small part of one focal DRN is located at the border between Croatia and Bosnia-Hercegovina and the sampling to be done on the few locations there could be sensitive)	Low x Low	1-5	Cultural/political differences are not expected to be of major concern, and the researchers have vast international experience in collaborating across countries. Local focal DRN partners will act as facilitators of this process, including translation to the local language, introduction to local stakeholders, etc.
Not getting the Nagoya protocol permissions to share genetic resources among EU countries (as no material from CELAC will be sent to EU).	Low x Low	2-3	Local EU focal DRN partners already requested permissions to their focal point (see annex 3 Ethics Supporting Documents) and we do not expect any problems to get the permissions.

Description of risk	L & I*[1]	WP	Proposed risk-mitigation measures
Risks related to models and collected data			
Impossibility to create hydrological models at the focal DRN scale due to lack of input/ validation data	Low x High	1	Apply a simplified modelling approach, use other data (e.g. from stations close to the focal DRN or neighbouring basins)
Mismatch between field data and predictions of the dynamical meta-community model/meta-ecosystem model	Medium x Low	2, 3	Identify the cause of model-data mismatch and modify the model. Rely on static statistical models to project biodiversity/ecological functions scenarios
Lack of compatibility between meta-community and meta-ecosystem models	Low x Low	3	Ensure strong interactions within INRAE to promote coherence and compatibility of the models.
Meta-ecosystem model too complex for focal DRN or EU scale application/ Difficulties associated with adjusting ecosystem service modelling and valuation scenarios to local conditions at the focal DRN level while keeping sufficient commonalities for upscaling and to draw broader lessons	High x Medium	3,4	T3.4 will modify the concepts/formulations of the model to relax data requirements in focal DRNs or at the EU scale. Overarching conceptual models will be created for the whole project ensuring enough higher-level commonalities, while these will be locally adjusted at the focal DRN level through specific activities built-in as part of the WP design.
Risks related to management, impact and stakeholders' engagement			
Difficulties in stakeholder and general public engagement involvement (e.g. stakeholder conflicts; lack of interest from the public)/Difficulty to involve citizens in the citizen science network	Low x Medium	4,5	It is expected that any conflicts can be resolved through facilitation. In the case of the general public, individual 'protests' can be replaced by engagement with other individuals of similar socio-economic characteristics. In the case of stakeholders, early engagement and continued interaction will be used. We will build on existing citizen scientist networks (e.g. SMIRES, AMBER).

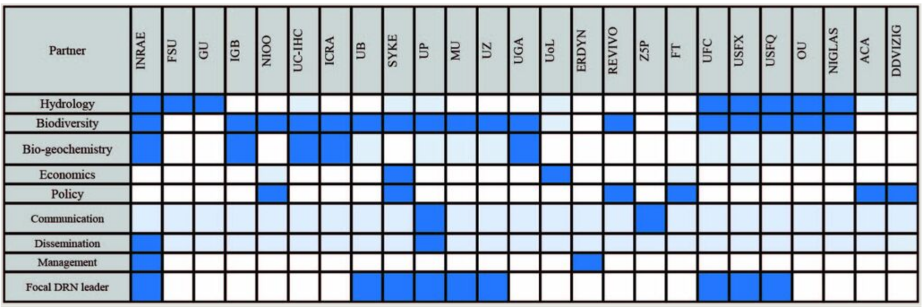

Figure 6. doi

DRYvER partners' complementarity.

3.7. Consortium as a whole

DRYvER is an interdisciplinary consortium of 25 partners, including scientific leaders in DRN sciences, end-user stakeholders, SMEs, and international partners including CELAC (i.e. fully in line with the Responsible Research & Innovation principles, a cross-cutting issue of Horizon 2020). Their high complementarity (Fig. 6) will ensure the successful implementation of DRYvER.

DRYvER academic partners have highly complementary expertise which will ensure the achievement of the project's objectives:

- INRAE, the coordinator, has a strong expertise in climate change impacts on river hydrology and fragmentation by drying, along with an international leadership role on DRN ecology and management. INRAE will model the fragmentation of river networks by drying and associated biodiversity responses at multiple scales;
- FSU and GU are leaders in regional and global hydrological models, and predictions of climate change impacts on water use and river flows and will project river network fragmentation by drying at different scales;
- UB, SYKE, UP, MU and UZ are EU leaders in freshwater ecology and biodiversity conservation. They will explore the cascading effects of river fragmentation on meta-community dynamics at the focal DRN and EU scales;
- UIBK, UC-IHC, UGA and ICRA are international leaders on river meta-ecosystems, with extensive expertise in biodiversity, ecological functions and restoration ecology, including NBS implementation. They will translate projected changes in river fragmentation and meta-community dynamics onto the associated ecological functions linked to the carbon cycle in DRNs.
- INRAE, UC-IHC and UoL have experts in ecosystem services in DRNs and will integrate projected changes in DRN hydrology, biodiversity and ecological function onto expected changes in the provision of ecosystem services;
- UoL has experts in environmental economics, with particular expertise in freshwater systems and hosts water@leeds, one of the largest interdisciplinary research hubs of any university in the world, including connections across policy and businesses. They will quantify the different values of changes in ecosystem services provision and assess the economic efficiency of NBS implementation;
- NIOO and SYKE are international leaders on adaptive management of ecosystems, biodiversity conservation, policies and management and will integrate the knowledge gained in DRYvER into a multi-criteria decision framework to promote the adaptive management of DRNs.

The participation of private partners will contribute to maximising the impact of the project:

- Z5P is a leading SME in science communication and dissemination and will develop effective communication tools for DRYvER;
- REVIVO is deeply involved in biodiversity conservation and NBS implementation and will generate a catalogue of mitigation measures in DRNs, including NBSs;
- FT is a forward-thinking policy consultancy based in the EU, providing expertise, novel ideas and resources to support decision-making and implementation of environmental policies. They will explore the impact of DRYvER in terms of policy at national and EU levels;
- ERDYN is a high-level innovative consulting SME managing various H2020 projects and will ensure the smooth implementation of DRYvER.

Key stakeholders are fully engaged among consortium partners:

- ACA, which is now leading an ECOSTAT subgroup to improve the implementation of the EU Water Framework Directive in DRNs, will be in charge of fostering the participation of stakeholders in the project via the SHC;
- DDVIZIG represents public administration and water management actors and will support the work of the SHC.

DRYvER partners are based in 16 countries (Fig. 7). This wide geographical coverage will ensure the relevance of the DRYvER's results for DRNs in Europe and worldwide and maximise the impact of the project. DRYvER includes international partners to broaden our geographical scope and foster synergies with active research groups on DRNs:

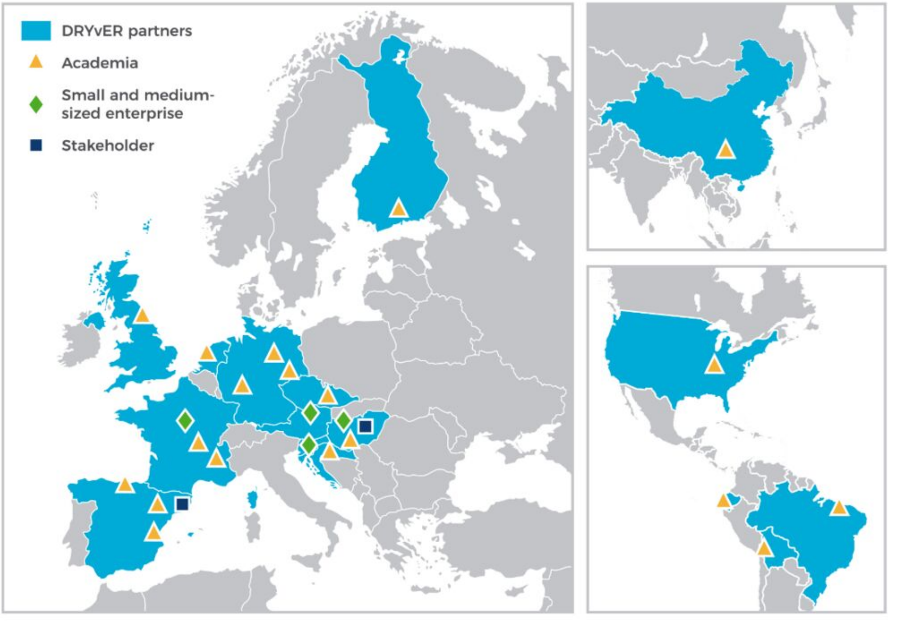

Figure 7. doi

DRYvER geographical coverage.

- To explore the impact of climate change on key biodiversity hotspots of South America, UFC, USFX and USCQ will bring their expertise on the 3 CELAC focal DRNs considered in DRYvER.
- The participation of two non-funded partners (OU – USA, and NIGLAS - China) will contribute to the capacity building of DRYvER in Europe and abroad.

Furthermore, beyond the partners involved in the project, DRYvER will actively liaise with key actors:

- Stakeholders in charge of managing the focal DRNs will form a Stakeholders Committee (interest and participation already confirmed), with continuous interaction during the project and beyond. Specific stakeholder engagement processes will include workshops and surveys. DRYvER will engage a broader scope of stakeholders ranging from scientists and policy makers to practitioners and local communities. A dedicated task and budget (180 000 EUR) is secured to liaise with local, national and EU stakeholders and ensure their acceptance of innovative climate change adaptation and mitigation measures and management strategies and identify the phases of the management process in which stakeholders are most influential and effective.
- An International Scientific Advisory Board will comprise strategic members of IPBES, IPCC, ISIMIP, WMO, IWMI, JRC, and four senior international leaders in the field (C Dahm, AJ Boulton S Bunn, K Tockner) to guide and monitor DRYvER and optimise its impacts (interest and participation already confirmed).

3.8. Resources to be committed

The total cost of DRYvER is 6 732 608,75 EUR. DRYvER has a balanced budget distribution between participating countries, in line with their role in the project (see Fig. 8) and 8% of the total budget is dedicated to SMEs. The main part of the budget (85%) is dedicated to R&D activities (WP1-WP5). Because of the large number of partners, 10% of the budget is dedicated to management (including travel costs). A significant part of the budget (7%) is dedicated to communication, dissemination, exploitation and capacity-building. For instance, a budget of 180 000 EUR is earmarked for clustering, short-term scientific missions of Early Career Scientists, workshops (e.g. protocol development, modelling), and knowledge and data flow among projects. In addition to that, a part of WP5 budget is dedicated to stakeholder engagement: 180 000 EUR for co-construction processes, and 148 000 EUR for citizen science networks.

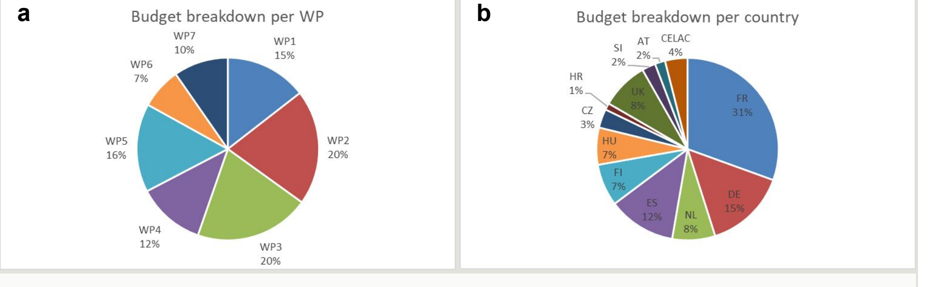

Figure 8.

Budget Breakdown per WP, and Budget Breakdown per country.

a: Budget Breakdown per WP. doi

b: Budget Breakdown per country doi

Acknowledgements

We warmly thank the French National Agency for Research (ANR), which funded the two workshops that allowed developing this proposal (ANR MRSEI 2018, MetaServ). This proposal has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 869226. More: www.dryver.eu.

Funding program

Horizon 2020 Research & Innovation Action N°869226

Grant title

Securing Biodiversity, Functional Integrity, and Ecosystem Services in Drying River Networks (DRYvER).

Author contributions

authors should be in alphabetical order, with T Datry as the first author

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Endnotes

*1 Likelihood & Impact