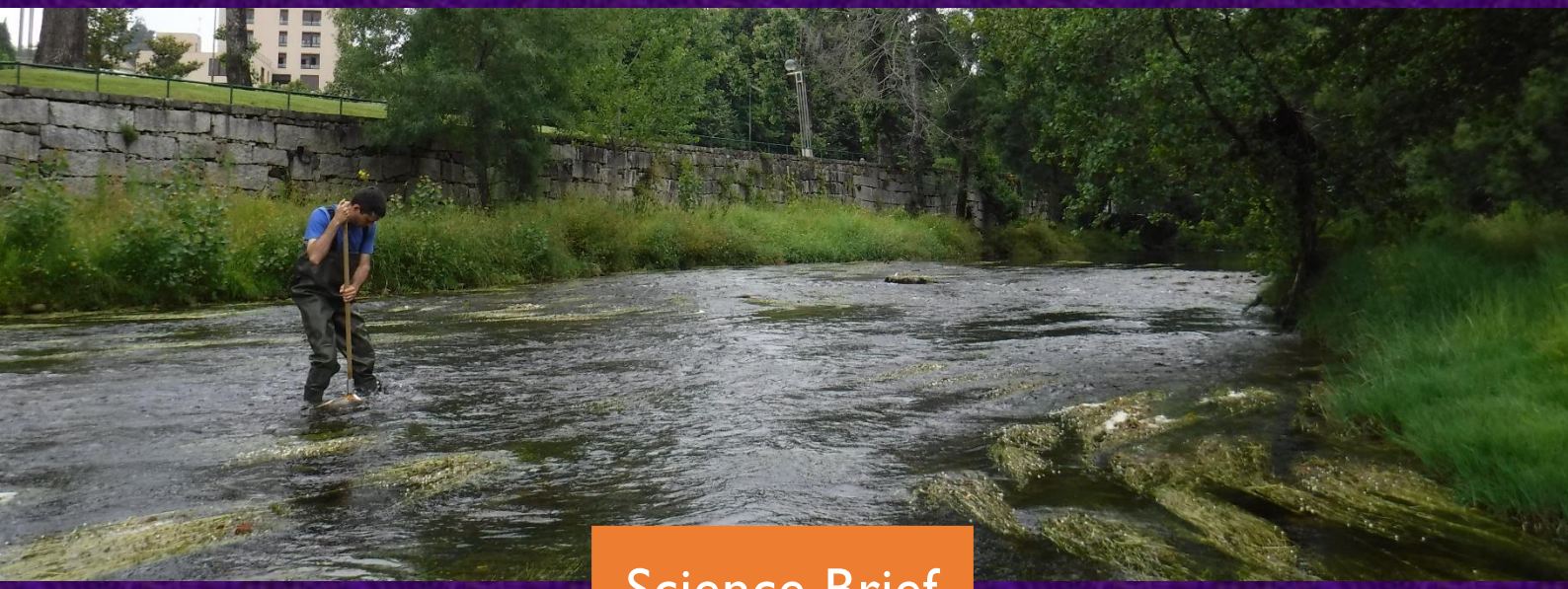
RIVEAL



Science Brief

How river regulation and climate change affect the fluvial ecosystems and its ecosystem services

FAST FACTS

- The natural flow regime
  - Regulates river's ecological processes;
  - Revitalizes the physical habitat;
  - Energizes communities, and maintains ecosystem productivity, biodiversity and water quality;
  - Links channel and floodplain, presenting increased opportunities for biotic interactions;
  - Establishes connectivity in the four river dimensions (longitudinal, transversal, vertical and temporal;
  - Drives river's ecological integrity according to its five main components: magnitude, frequency, duration, timing and rate of change.

The **natural flow regime** is the undisturbed streamflow variability of a river originated by the watershed drainage depending on the water cycle balance between rainfall and evapotranspiration.

- Ecosystem reliability on the natural flow regime
  - Habitat and biodiversity are molded by the flow regime;
  - Species life cycle events are triggered by flow regime components;
  - Interactions between riverine ecosystems endorsed by river dimensions;
  - Species persistence and coexistence ruled by the metastability of the natural flow regime.

River regulation is the human interference with the river's natural flow patterns, modifying the natural riverine environment and destroying the ecological requirements of the inhabiting communities beyond their adaptation limits.

- River regulation
  - Resulting from human environmental manipulation through river damming, channelization, water diversion, groundwater pumping of watershed land use changes;
  - Affects roughly two thirds of the rivers worldwide;
  - Disturbs both aquatic and riparian habitats;
  - Interferes with river processes and ecosystems services;
  - Induces the loss of habitat and biodiversity;

- Climate change
  - Global mean surface warming by the end of this century due to anthropic CO_2 emissions;
  - Will affect temperature and rainfall patterns around the globe, therefore standing as a crucial factor influencing river flow regimes worldwide;
  - Disturbed river flows result in ecological impacts on freshwater ecosystems.

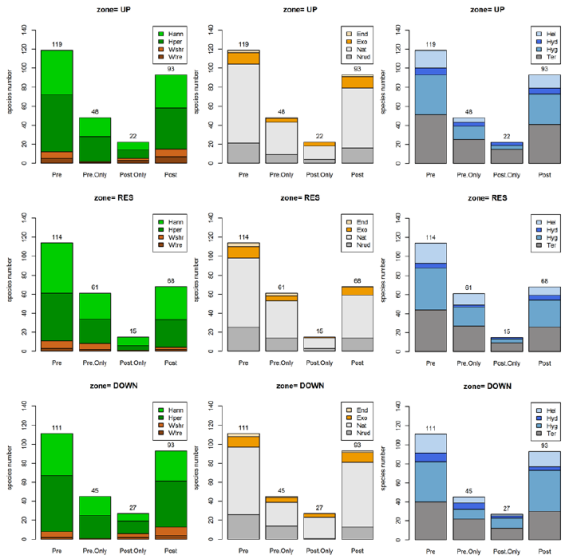
Ecosystem Services are the goods and benefits provided by the ecosystems to mankind. These can be provisioning, regulating, supporting and cultural services, and are made available as a proportion of the ecosystems' healthiness.

EFFECTS OF RESERVOIRS ON AQUATIC AND RIPARIAN PLANTS

Know more at:
Aguiar et al., 2019.
DOI: 10.3390/w11112379

River damming modifies the river hydrology in quality, quantity and timing, interrupting the longitudinal connection of habitat patches, and consequently affecting fluvial plant species distribution and biodiversity. This modification of the natural flow regime depends on the technical characteristics of dams and their operation rules, thus affecting aquatic and riparian ecosystems differently in composition and spatial distribution.

- Observed effects of river damming:
  - The post-dam aquatic and riparian zones are floristically different from the pre-dam landscapes, characterized by a generalized loss of native plant species against a gain of exotic and ruderal species;
  - Biodiversity and ecosystem processes in fragmented riverine landscapes are exposed to novel geomorphological settings and to habitat loss, with expected variation in species communities;
  - The reservoir area is the most divergent zone from the pre-dam landscape, with a high number of local native and endemic species losses, great decline in riparian woodlands, and relatively higher number and cover of exotic species;
  - Alongside the native species declines, shifts of congener species can also be found;
  - Fragmentation effects on expansion obstruction of riparian herbs due to the interruption of hydrochoric dispersal, impediment of the flow of seeds, and clonal fragments downstream of the dam.



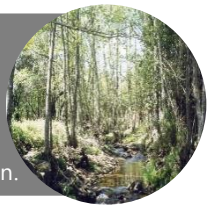
Number of species per functional group observed upstream of dam (UP), reservoir (RES), and downstream of dam (DOWN) during pre-dam surveys, observed on pre-dam but not post-dam (Pre.Only), observed in post-dam and not pre-dam (Post.Only), and in post-dam surveys *(from Aguiar et al., 2019. DOI: 10.3390/w11112379).*

CARBON STOCKS OF MEDITERRANEAN RIPARIAN FORESTS

Know more at:
Fernandes et al., 2020.
DOI: 10.3390/f11040376

Riparian forests and floodplain areas are important carbon sinks, thus crucial to mitigate the effects of climate change and provide a regulation ecosystem service.

Regulation Ecosystem Service is the benefit provided by the ecosystem processes that moderate the natural phenomena. Such services in river systems include flood control, thermal regulation, carbon storage and climate mitigation.



- Carbon stocks *in situ*:
  - Field surveys revealed that the woody tree layer brings the highest contribution to the total carbon stock in the riparian forest;
  - Average estimation of total carbon stocks ranged from 122.4 to 201.2 tC ha^{-1};
  - Carbon stocks are driven by both large- (e.g. climate, geology) and local-scale factors (e.g. channel complexity, soil type);
  - Human disturbance influence carbon storage dynamics in riparian ecosystems.

Follow a field trip day to collect C storage data.

- Allometric model for total aboveground biomass quantification in riparian systems:

$$AGB = 0.1758 \times DBH^{2.1314}$$

Aboveground biomass (AGB) as a function of the diameter at breast height (DBH) of riparian vegetation (coefficient of determination R^2=0.94) *(from Fernandes et al., 2020. DOI: 10.3390/f11040376).*

- Remote sensing approach:
  - Provides a finer-grained spatial distribution of tree aboveground biomass (AGB);
  - Direct ability of multispectral UAV imagery data to classify riparian species and to indirectly estimate tree AGB.

EFFECTS OF RIVER REGULATION ON CARBON STORAGE

- Carbon storage increases following river regulation with high variability along the river.
- Different hydrological disturbances lead to distinct contributions to carbon stock changes in riverine areas.
- Differences in species composition and land-uses have an effect on riparian carbon stocks.

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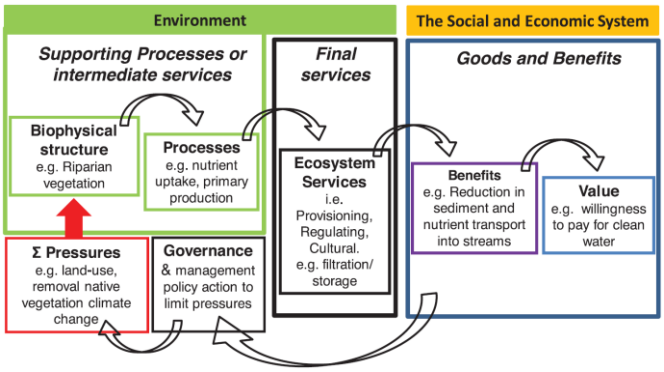
ECOSYSTEM SERVICES PROVIDED BY RIPARIAN VEGETATION

Riparian vegetation offers a variety of ecosystem services (ES), whether they be provisioning or cultural ES with direct benefits to people, or supporting and intermediate ES with little or no direct benefits to people.

Know more at:
Riis et al., 2020. DOI: 10.1093/biosci/biaa041



The ecosystems cascade model. Note the role of supporting processes and intermediate services in the supply of benefits to people (from Ris et al., 2020. DOI: 10.1093/biosci/biaa041).

- Examples of riparian ES:
  - Provisioning: biomass or genetic resources;
  - Regulating and maintenance: filtration of pollutants and chemical conditions of freshwaters, carbon sequestration, erosion control and flow regulation, pollination and seed dispersal, pest control, microclimate regulation, or fire effects mitigation.
  - Cultural: outdoor interactions with living systems, cultural heritage, aesthetics, or sacred, religious or symbolic values.

- Floodplain restoration represent an important action to mitigate river degradation but actual paradigm focus mainly on habitat and water quality, disregarding other important ES.

- ES-based decision-making should include riparian vegetation to maximize the benefits of restoration investments.

KNOWLEDGE GAPS

- Deficient knowledge on how vegetation types and species traits support different ecosystem services.

- ES provided by seed and propagule dispersal, gene resources and fire protection highly understudied.

- Insufficient information regarding the economic value of riparian ES.

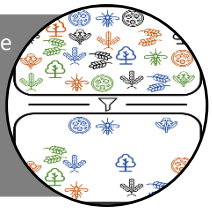
- Need for advances in ES mapping.

MEDITERRANEAN VS TEMPERATE RIVERS

River regulation works has an environmental filter with subsequent reduced functional diversity. However, there is still little empirical evidence about such decline magnitude in different regions.

Know more at:
Lozanovska et al., 2020. DOI: 10.3389/fpls.2020.00857

Environmental filtering is a selection of suitable features performed by the environment, which leads to changes in community composition. **Functional diversity** is the range of organisms' functions in their communities and ecosystems.



DIFFERENCES FOUND BETWEEN RIVER SYSTEMS

- The effect or regulation can differ among biomes, likely due to species' natural adaptations to flow-related disturbances and to the extent of the hydrological change.

- There are differences in species traits between regions because the distinct environmental conditions determined disparate evolutionary trends.

- Functional traits:
  - Significant differences exist in the characteristics of plant species between free-flowing and regulated sites in temperate rivers;
  - No significant differences in the trait values of plant species between free-flowing and regulated sites in Mediterranean rivers.

- Functional diversity:
  - Significant reduction of functional richness (FRic) and redundancy (FRed) with regulation in temperate rivers;
  - Non-significant variation in Med rivers.
  - Effects of environmental filtering in temperate rivers but not in Mediterranean rivers.

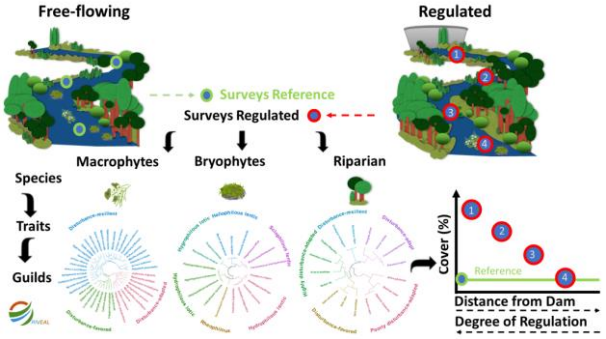
- Hydrological changes:
  - The magnitude of the hydrological alterations and the number of hydrological variables affected was smaller in Med rivers than in temperate;
  - The "Duration of annual extreme water events" and "Rate of changes" were key for both FRic and FRed in temperate rivers;

- River regulation in temperate rivers may have more severe consequences for riparian vegetation than in Mediterranean rivers, possibly because hydric stress is already typical for Mediterranean regions under natural, free-flowing conditions, and over evolutionary scales, it has shaped communities by exposing them to rapid shifts between droughts and floods.

EFECTS OF RIVER REGULATION ON VEGETATION

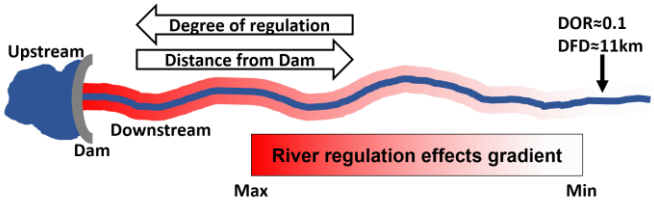
Know more at:
Lozanovska et al., 2020. DOI: 10.1016/j.scitotenv.2020.141616

The question about how distinct plant groups and their adaptive strategies can mediate the river regulation effects is largely unexplored yet. Understanding how the degree of regulation (DOR) and distance from dam (DFD) become sufficient to stop affecting significantly plant communities is of great importance for water management.



Vegetation cover differences between regulated and free-flowing rivers, and in regulated rivers along the gradients of DOR and DFD. Species inventory is converted into guilds with equal traits to perform a functional diversity level assessment (from Lozanovska et al, 2020. DOI: 10.1016/j.scitotenv.2020.141616).

- Vegetation response to regulation is plant group-reliant and guild-specific, expressed by changes in cover.
- Macrophytes increase the guild cover while bryophytes decrease with increasing regulation gradient.
- Riparian guilds present diverse responses to such gradient and according to the river regulation type.
- Different trends downstream dams according to river regulation type: encroachment of riparian vegetation downstream of storage reservoirs whereas expansion outwards the floodplain downstream of run-of-river dams.
- Higher amount of significant alterations for storage reservoirs.
- Specific DOR and DFD, for particular guilds, from which guild covers became significantly indistinct from respective guild cover in unregulated circumstances.

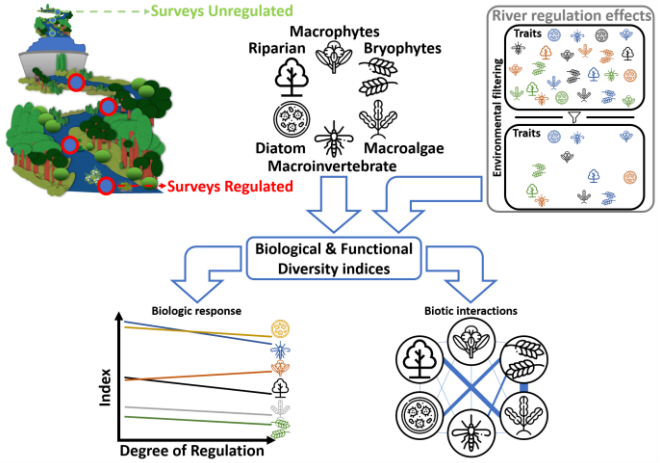


Example of the river regulation fading effects on fluvial vegetation downstream dams. Note the possibility of determining a particular DOR and DFD from which the effects are not significant for vegetation communities.

EFFECTS OF RIVER REGULATION ON BIOLOGICAL COMMUNITIES

Know more at:
Rivaes et al., 2020. DOI: 10.1016/j.scitotenv.2020.144327

River damming is one of the most aggressive processes in freshwater ecosystems, as well as one of the greatest contributors to the degradation of freshwaters and endangered species threatening. There is scarce research on determining accurately the relationships between biota and modified flow regimes, particularly the relationships amid communities and processes.



River regulation affects biological communities by means of an environmental filtering of its functional traits, with consequent changes in the interactions between biological elements. Responses of the biological communities and proportional to the river regulation intensity (Rivaes et al., 2020. DOI: 10.1016/j.scitotenv.2020.144327).

- River regulation promotes an artificial environmental filtering of species assemblages, acting as a selective force towards the prominence of particular phenotypic similarities reflecting regulation tolerance.
- Biological communities exhibit particular traits significantly correlated with environmental variables.
- Riparian vegetation and macroinvertebrates show the greatest number of significant correlations between environment and traits, being the most responsive to river regulation and its gradient.
- Richness responds better to regulation for the biological communities in general and appears to be the most interesting single measure for general fluvial ecological quality facing river regulation.
- There are high correlations between the biological and functional diversity of different biological groups, which emphasizes the habitat cascade effect promoted by anthropic disturbances, and stresses the necessary holistic perspective when assessing the effects of river regulation on fluvial ecosystems.

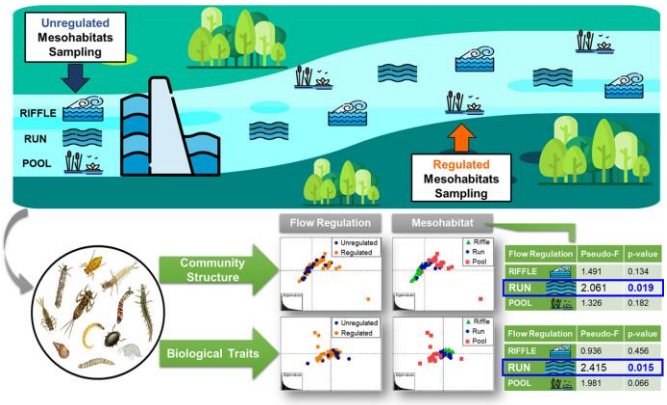
EFECTS OF RIVER REGULATION AND HABITAT ON INVERTEBRATE ASSEMBLAGE

Know more at:
Calapez et al., 2021. DOI:
10.1016/j.scitotenv.2021.148696

Dams modify geomorphology, water quantity, quality and timing of stream flows, affecting ecosystem functioning and aquatic biota, disturbing species distribution, abundance and ultimately their functional response.

Aquatic macroinvertebrates are creatures big enough to be observed without a microscope, lacking a backbone, living at least a part of their lifecycle in aquatic systems and acknowledged players in these fluvial ecosystem functioning.

- There are significant alterations in both macroinvertebrate assemblage structure and biological traits composition between regulated and unregulated sites, but also between instream mesohabitats (riffles, runs and pools).



Methodology to assess the effects of river regulation and habitat changes on benthic macroinvertebrates based on taxonomic and trait composition analysis (from Calapez et al., 2021. DOI: 10.1016/j.scitotenv.2021.148696).

- Riffles present higher proportions of organisms closely associated with turbulent and fast waters while pools are represented by higher proportions of organisms related to lentic conditions.

- Run-type mesohabitats are characterized as intermediate habitats where communities and biological trait composition comprise a mixture of both riffles and pools.

- Significant differences between regulated and unregulated sites were found only in runs, supporting communities more sensible in detecting changes induced by river regulation.

- This evidence points out the need to establish suitable methods focused on run habitats only, for an improved river assessment and efficiency evaluation of ecological flows.

ADDITIONAL EFFECTS OF CLIMATE CHANGE IN REGULATED RIVERS

Know more at:
Rivaes et al., 2022. DOI:
10.1016/j.scitotenv.2021.151857

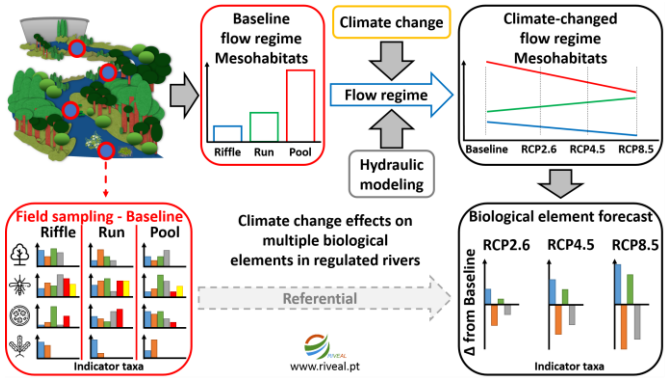
Habitat degradation is another major threat of freshwater systems and a result of river damming, which can be further amplified by climate change, other key driver of biodiversity loss. All of these pressures can conjugate and potentially magnify the menace to freshwater ecosystems.

River habitat degradation is the human-driven degeneration process of the physicochemical conditions of the natural environment where living beings inhabit and are adapted to, turning it less suitable or available for these.

- River hydraulics is the main factor for mesohabitats discrimination, enabling its differentiation according to flow velocity, water depth and river width.

- Climate change will affect the hydrological cycle of river basins influencing the water availability for dam operation.

- The expected climate change and the projected alterations in human energetic demand will entail a reoperation of hydropower dams and causing further modifications on the flow regimes of regulated rivers.



Modified river flow regimes result in biota assemblage alterations based on habitat availability. Hydraulic modeling of the projected flow regimes further modified by expected shifts from climate change and human energetic demands are used to determine the resulting habitat modifications, forecast biota response to further pressures, and compare it to the current baseline condition (from Rivaes et al., 2022. DOI: 10.1016/j.scitotenv.2021.151857).

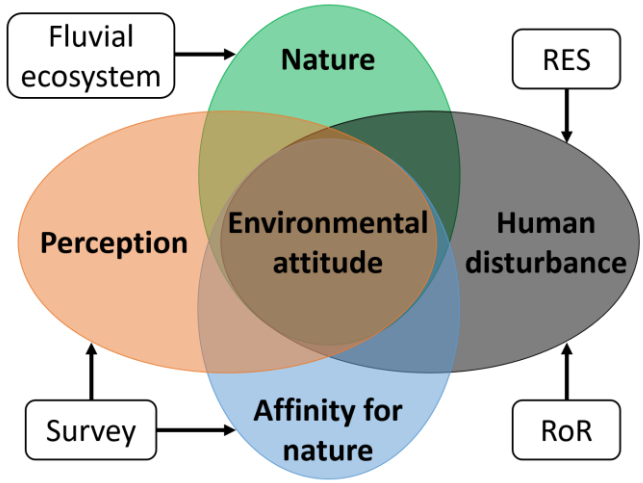
- Climate change-driven flow regimes will influence river hydraulics towards less disparate flow conditions, modifying mesohabitat proportionality in the direction of run prevalence over riffles and pools.

- All the assessed biological groups disclose potential drastic changes facing such flow modifications, exposing an ecosystem risk that cannot be ignored and call for the establishment of more sustainable river flows in regulated rivers facing climate change.

EFECTS OF RIVER REGULATION ON RIVERINE SOCIETIES

Know more at:
Rivaes et al., 2022. DOI: 10.1016/j.envman.2022.115992

Rivers are powerful systems supporting human civilization and establishing strong river flow-human relationships. River degradation prompts health and non-tangible problems for humans, such as changes in the affinity for nature and the perception of humans regarding the regulation effects on river systems.



Humans disturb nature (surrogated by the fluvial ecosystem) with their activities (e.g. river regulation imposed by different dam operation typology, namely RES – storage reservoirs and RoR – run-of-river dams). This coexistence feedback on how riverine societies perceive and relate with nature (assessed by field surveys) thus influencing their environmental attitude (Rivaes et al., 2022. DOI: 10.1016/j.envman.2022.115992).

- River regulation imposes modifications that vary according to the operation scheme, influencing the perspective of local communities concerning its effects on the fluvial system, as well as their affinity for the naturalness of rivers.
- The affinity for nature responds firstly to river ecology aspects and then to river hydraulics but present significant differences regarding gender, educational attainment, age and type of river regulation.
- The human perception of the river regulation effects on the ecosystems is influenced by gender differences and regulation type and not by educational attainment of age.
- Human perception of the river regulation effects is generally in accordance with scientific knowledge, despite some gender disagreement, revealing a gender difference that works as a barrier to the perception of the regulation effects on river systems.
- There is a need for effective planning to promote emotive connection with nature in communities towards a more sustainable management of river systems.

THE RIVEAL PROJECT

Know more at:
www.riveal.pt

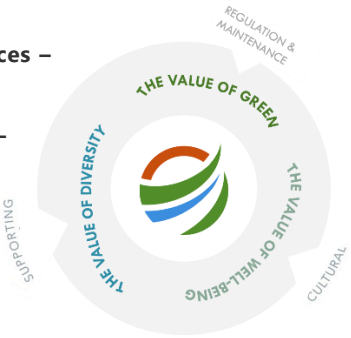
The RIVEAL project aimed to quantify key ecosystem services (ES) of riparian forests, and predict the balance of ES under diverse climatic, land use and water management scenarios in Portuguese fluvial landscapes. In particular, the case studies were regulated rivers downstream of dams, namely, Alva River downstream of Fronhas Dam, and Lima River downstream of Touvedo Dam.

The project focused in three ES:

Intermediate Ecosystem Services – Fluvial Ecological Integrity

Regulating and Maintenance – Carbon Stocks and Carbon Sequestration

Cultural services – direct and indirect socio-cultural values



- Throughout its duration, the RIVEAL project:
  - Provided relevant ES assessment concerning C sequestration and ecological integrity;
  - Determined trade-offs and synergies of land-use conversion on ES of riparian forests;
  - Provided understanding of land-water-riparian linkages across spatial and temporal scales;
  - Enlarged understanding of the effects of hydrologic alterations by different dam operations;
  - Developed an innovative framework for fluvial ecological integrity based in the concept of ES and functional interactions between aquatic biota and riparian vegetation;
  - Assessed socio-cultural values of rivers and riparian forests and people's affinity for nature;
  - Delivered products useful to wide-research community and stakeholders supporting management, conservation, monitoring and planning;
  - Mapped, characterized, and assessed the riparian zones in its multifaceted dimensions.
- Total funding: 239 810.90€
- Performance evaluation:
  - Scientific publications WoS: 10
  - Scientific communications: 23
  - Factsheets: 16 (pt/en)
  - Advanced training: 3
  - Seminars, workshops and sessions organization: 4
  - Models, software, web pages: 4

This science brief should be cited as: Rivaes R., Aguiar F. (2022) Science Brief of the RIVEAL Project – How river regulation and climate change affects the fluvial ecosystems and its ecosystem services. DOI: 10.5281/zenodo.7319204