Assessment of the Ecological Status of an Intermittent river: water quality and ecosystem services

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Todas as correções determinadas pelo júri, e só essas, foram efetuadas.
O Presidente do Júri,

Porto, ______/______/_________

MSC

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Resumo

Rios e ribeiras intermitentes são ecossistemas aquáticos que perdem a conectividade hidrológica durante os períodos de seca. Pressões antrópicas, como mudanças no uso do solo e da água, aliadas às mudanças climáticas, aceleram a intermitência espacial e temporal desses ecossistemas, promovendo alterações na sua ecologia e nos serviços que prestam. A Ribeira de Silveirinhos, localizada nos concelhos de Valongo e Gondomar (norte de Portugal), foi o curso de água intermitente avaliado no presente estudo. O objetivo deste estudo pretendeu avaliar o estado ecológico da Ribeira de Silveirinhos, utilizando as métricas descritas pela DQA. Adicionalmente, avaliou-se a ocupação do solo e os serviços de ecossistema prestados em redor de cada local de amostragem. Para responder ao objetivo do estudo foram selecionados cinco locais de amostragem ao longo da Ribeira de Silveirinhos. Em cada local foram quantificados parâmetros físicos e químicos da água e caraterizada a comunidade de macroinvertebrados bentónicos. Os serviços de ecossistema na área envolvente e no ecossistema aquático foram avaliados através do levantamento fotográfico numa abrangência de 360° de cada local. A amostragem foi feita em três períodos distintos, primavera de 2019 e 2020 e outono de 2019. Os parâmetros físicos e químicos mostraram concentrações elevadas de fósforo nos locais mais a jusante da ribeira. A comunidade de macroinvertebrados revelou baixos valores de abundância e riqueza específica, especialmente durante o período seco. Pela análise dos resultados verificamos que a Ribeira de Silveirinhos é classificada entre "medíocre" e "razoável" quanto ao estado ecológico. Os serviços de ecossistema revelaram um elevado potencial de melhoria, principalmente devido à monocultura de eucalipto na área envolvente e à deterioração das margens fluviais. Os cursos de água intermitentes estão subvalorizados, consequentemente a sua proteção está em risco. Assim, é importante considerar o funcionamento ecológico específico desses ecossistemas e ajustar os modelos de planeamento e gestão de forma a garantir a qualidade ecológica e os processos de conservação.

Palavras-chave: Rios intermitentes, DQA, estado ecológico, monitoramento da qualidade da água, Ribeira de Silveirinhos.

Abstract

Intermittent rivers and streams are aquatic ecosystems that lose hydrological connectivity during drought periods. Anthropogenic pressures, such as changes in land and water use, combined with climate changes, accelerate the spatial and temporal intermittency of these ecosystems, promoting alterations in their ecology and in the services they provide. Ribeira de Silveirinhos, located in the municipalities of Valongo and Gondomar (north of Portugal), was the intermittent watercourse evaluated in the present study. The aim of this study was to assess the ecological status of Ribeira de Silveirinhos, using the metrics described by the WFD. Additionally, land occupation and ecosystem services provided around each sampling site were assessed. To answer the objective of the study, five sampling sites were selected along Ribeira de Silveirinhos. In each site, physical and chemical parameters of the water were measured, and the benthic macroinvertebrates community was characterized. Ecosystem services in the surrounding area and in the aquatic ecosystem were assessed through a photographic survey over 360º of each site. Sampling was done in three different periods, spring of 2019 and 2020 and autumn of 2019. Physical and chemical parameters showed high concentrations of phosphorus in the places further down the stream. The macroinvertebrate community revealed low values of specific abundance and richness, especially during the dry period. By analyzing the results, we found that Ribeira de Silveirinhos is classified between “poor” and “moderate” in terms of ecological status. Ecosystem services revealed a high improvement potential, mainly due to the eucalyptus monoculture in the surrounding area and the deterioration of the riverbanks. Intermittent streams are undervalued, so their protection is in risk. Thus, it is important to consider the specific ecological functioning of these ecosystems and to adjust the planning and management models in order to guarantee ecological quality and conservation processes.

Keywords: Intermittent rivers, WFD, ecological status, water quality monitoring, Ribeira de Silveirinhos.

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Abbreviations and Acronyms

AMP	Metropolitan area of Porto
APA	Agência Portuguesa do Ambiente
BMWP	Biological Monitoring Working Party
CICES	Common International Classification of Ecosystem Services
COS2018	Carta de Uso e Ocupação de Solo 2018
DGT	Direção Geral do Território
EQR	Ecological Quality Ratio
GIS	Geographic Information System
IBMWP	Iberian BMWP
INAG	Instituto Nacional da Água
$IPtI_N$	Índice Português de Invertebrados do Norte
IPtIs	Índice Português de Invertebrados do Sul
MEA	Millennium Ecosystem Assessment
PCA	Principal component analysis
PGRH	Douro Hydrographic Region Management Plan
PSeP	Parque das Serras do Porto
UN	United Nation
WFD	Water Framework Directive
WWC	World Water Council

1. Introduction

1.1 General considerations

Water is a key element for the evolution of societies. Throughout human history, mankind has always shown its dependence on this resource. When settling next to the rivers, man acquired access to water in abundance, allowing mankind to become sedentary (Yevjevich, 1992). It introduced a greater facility in obtaining drinking water, feeding itself using fishing and hunting, irrigating its lands, it reached transport routes, and many other services, such as a mild climate and leisure areas. Water, in particular freshwater, was the essential component for the evolution of countless civilizations (Feio & Ferreira, 2019).

Due to its unique characteristics makes freshwater an essential resource (Qadri & Bhat, 2020). The physical and chemical properties are the link for the biochemical metabolism for the biota, and all living organisms depend on it for their vital functions (Barban, 2009). Water is an irreplaceable natural resource of great importance, widely distributed throughout the planet Earth (Shiklomanov, 1998). The percentage of water in the Earth's surface occupancy reaches 70-72 %, however, the accessible freshwater resources for all direct human needs is < 1 %, including water located in lakes, reservoirs, rivers, and aquifers in which reach is low cost (Qadri & Bhat, 2020). Despite occupying a small part of the Earth's surface, surface waters such as rivers represent the main source of freshwater supply. These lotic systems, where water is in constant motion, portray the most accessible and cheapest water source to ensure domestic and industrial needs, the supply of drinking water, irrigation purposes, transport, and deposition of waste (Shiklomanov, 1998). In the same way that freshwater is essential for life, it also plays a supporting role in the different types of existing ecosystems (Barban, 2009). As open systems, they are closely connected to terrestrial ecosystems (Statzner, 1987), providing habitat, refuge, and food for several plants and animals. Rivers are also responsible for several biogeochemical processes, such as nutrient cycle, hydrological cycle, and material transport (Gallo, 2013). This link between aquatic and terrestrial environments is responsible for the dynamics of ecological cycles, which determines the biodiversity and productivity of the ecosystem (Albert et al., 2020). Lotic systems are characterized for being dynamic, with high variability and complexity at the abiotic and biotic levels (Statzner, 1987; Shiklomanov, 1998). Each watercourse presents specific characteristics, that change its ecology and consequently the productivity of the entire system (Ward, 1989). They are the result of a complex interaction between biological components and the physical and chemical environment, through different temporal and spatial scales (Feio & Ferreira, 2019). However, rivers are highly vulnerable, being affected by all types of anthropogenic activities developed in the hydrographic basin (Shiklomanov, 1998). So, the rivers' ecological status reflects the land use and occupation on the adjacent areas at the hydrographic basin. These activities, as well as some natural factors, contribute to the degradation of the quality of freshwater ecosystems, with consequences and changes in abiotic characteristics and their biotic communities (Jesus et al., 2020).

Aquatic systems are subject to high pressure due to disturbances of anthropic origin (Jesus et al., 2020). The population increase associated with technological and industrial advancement and intensive agriculture generated a considerable increase in the demand for water resources (Odum, 1990; Shiklomanov, 1998). Each year the water use has increased by 1 % since the 1980s, driven by socioeconomic development and a change in consumption patterns (WWAP (UNESCO World Water Assessment Programme), 2019). Moreover, the number of water resources, their spatial and temporal distributions are determined by natural climatic variations, but now also by economic activities. Indeed, water resource has become the main limiting factor for economic development and population growth (Shiklomanov, 1998). Currently, all ecosystems suffer from direct and / or indirect influences of humanity. The construction of dams and roads, the damming of rivers, the alteration of the surrounding landscape, the introduction of species, and the release of untreated waste into the environment are some examples of anthropogenic disturbances (Karr, 1991; Gallo, 2013). Smith & Schindler (2009) highlighted eutrophication as the primary problem of aquatic ecosystems, due to the enrichment in nutrients derived from human activities. Although eutrophication is a natural process, it is accelerated by anthropogenic activities, intensifying it through an abnormal concentration in nutrients, namely phosphorus (P) and nitrogen (N). Ecological instabilities are generated in the ecosystem (Smith & Schindler, 2009), qualitative and quantitative changes in physical and chemical conditions, in aquatic communities, and also in the level of production of the ecosystem (Jesus et al., 2020). The functioning of the entire ecosystem is affected by the increase in human disturbances, occurring changes and losses of habitat, changes in trophic networks, and loss of biodiversity (Feio & Ferreira, 2019). As a result, a decrease in availability and loss of quality of water has been observed (Odum, 1990).

Freshwater ecosystems provide numerous services that are irreplaceable to nature and society. They represent a resource of high economic, social, and environmental value (Albert et al., 2020). Therefore, they must be properly protected and managed sustainably, ensuring the preservation of their quality and ecosystem functioning. The study and understanding of these ecosystems is a key element to improve the knowledge of the communities that inhabit these aquatic ecosystems and to understand the relationships between them and the surrounding area (Feio & Ferreira, 2019). In this sense, Directive 2000/60/CE of the European Parliament and of the Council of 23 October 2000 was created, which establishes a framework for community action in the field of water policy and whose general objective is that European Union reaches the good ecological status of all water bodies (Europeia, 2000).

1.2 Water Framework Directive (WFD)

With the increasing pressure on the aquatic ecosystems due to anthropogenic activities, the main concerns focus on water quality. In the last decades, some awareness began to manifest as to the need to preserve the state of the water and the quality of services provided namely by the aquatic freshwater ecosystems (Blöch, 1999). The remarkable progress of civilization and economic development throughout the history of humanity shows that water is an important and very productive asset that requires special attention (Pinto-Coelho & Havens, 2016). In the second half of the twentieth century, several environmental movements took place intending to improve the situation of water resources (Blöch, 1999). One of the greatest developments obtained in the twentieth century was the appearance of national codes, laws, and acts on water policy and management (Hassan, 2011). The history of European water policy dates to the 1970s and can be divided into three distinct periods:

- From 1975 to 1988, the concern focused on public health and the establishment of standards for water quality (Hassan, 2011). In 1977, the United Nations held the first world water conference on water resources. It brought together only representatives of government entities and the objective focused on the unfavorable situation existing in freshwater systems in already one-third of the world. This conference resulted in the strengthening and international cooperation in the study and evaluation of water resources (Shiklomanov, 1998; Vargas, 2005). In the same year, the proposal to create a directive was presented, where it was considered an ecological quality. In 1980, the UN General Assembly proclaimed the Declaration of the International Decade for the Supply of Drinking Water and Sanitation (Hassan, 2011).

- From 1988 to 1996, the emphasis was directed to pollution control and environmental management, through the prevention of pollution that comes from urban wastewater and agricultural runoff (Hassan, 2011). It was in 1992, at the United Nations International Conference on Water and Environment, that water started to be declared a finite and vulnerable resource, to which an economic value must be applied (Vargas, 2005). This period was also marked by the attribution of a European competence for the common environmental policy, the creation of a World Water Council (WWC), which was founded in 1996 (Kallis & Butler, 2001).
- At the end of the 1990s, there was a visible need to strengthen legislation to further protect water resources (Hassan, 2011). The 1st World Water Forum took place in 1997, in Morocco, under the leadership of the WWC. This event takes place every three years and is an international political think tank that focuses on global concerns about the pressures to which freshwater resources across the planet are subjected (Barban, 2009). But the priority of this period was sustainable development and on December 22, 2000, the Council of Europe finally agreed and published the Water Framework Directive (WFD). Marking the beginning of a new season in the management and enhancement of water (Kallis & Butler, 2001). In the 2020 and 2030 Agenda, by the United Nations (UN), water quality and availability for all (Goal 6) is one of the several sustainable development goals to be achieved. However water policies are far from complete, they are constantly being updated (Desa, 2016).

The Water Framework Directive (Directive 2000/60/EC) establishes a framework for community action (transposed into Portuguese law by Lei nº 58/2005, of 29 December, with the wording of Decreto-Lei nº 245/2009, of September 22, and by Decreto-Lei nº 77/2006, of March 30, as amended by Decreto-Lei nº 103/2010, of September 24), to establish an adequate context for the protection of all water bodies. In order to promote sustainable consumption and contribute to the supply of water in the required quality and quantity (Kallis & Butler, 2001; Jesus et al., 2020). Water is now the sector with the most environmental regulation in the European Union, and the WFD has approaches to water management in 27 countries, establishing the principle of subsidiarity of the Member States and uniform standards (Kallis & Butler, 2001). To achieve the objectives, innovative principles were introduced in the legislation: 1) expansion of protection to all bodies of water: lotic and lentic surface waters, groundwater, transitional and coastal waters; 2) achieve “good conditions” in all water bodies, ensuring that it is achieved or maintained through monitoring systems; and 3) water management is carried out at the hydrographic basin level, maintaining cooperation and joint action by member states' objectives. The basin management plan contains a general description of its hydrographic characteristics, description of the significant impacts of human activity, identification of protected areas and economic analysis of water use, which must be updated every six years (INAG, 2006; Brito et al., 2009). Another principle now recognized is citizen involvement, encouraging public participation in the monitoring programs and awareness actions (Pahl-Wostl, Mostert, & Tabara, 2008). Concerning surface water, the WFD also establishes environmental objectives (Article 4) to prevent further deterioration of ecosystems, to protect and recover, and also to implement pollution control measures, to achieve “good water status” (Europeia, 2000; Kallis & Butler, 2001). The water status is stipulated by the global expression of the condition in which given surface water is found, defined according to the worst of its states, ecological (biological, hydromorphological) and chemical (physical and chemical). This introducing an ecological vision in the assessment of water quality (INAG, 2009).

This approach considers, in general, what occurs in the ecosystem, through the qualitative and quantitative evaluation of the various parameters measured (da Silva, 2013). The ecological status of surface waters is defined by the WFD as *"the expression of the structural and functional quality of aquatic ecosystems associated with surface waters"* (Europeia, 2000). The assessment of ecological status is carried out using three different types of quality parameters, described in Annex V of the WFD: biological parameters (e.g. benthic macroinvertebrates, fish fauna, aquatic flora), physical and chemical parameters (e.g. thermal conditions, oxygen conditions, salinity, acidification status, nutrient concentrations) and hydromorphological parameters (e.g. hydrographic regime, river continuity, morphological conditions). The main element is the biological parameters and the physical and chemical and hydromorphological parameters are analysed as supporting the elements of the biological communities, having a role in their composition and abundance (Europeia, 2000; INAG, 2006). The classification of ecological status is defined based on the deviation from the natural conditions, called reference conditions (Kallis & Butler, 2001). The water bodies are grouped based on their hydrological and geographical characteristics so that the reference conditions provide a comparable ecological status (INAG, 2009).

1.3 Macroinvertebrates as Bioindicators

Physical and chemical conditions do not fully reflect the various environmental factors and long-term sustainability, so biomonitoring is necessary for addition to traditional methodologies (Li, Zheng, & Liu, 2010). Biomonitoring is defined as the method of observing the biological responses of populations and communities, to assess the impact that external factors have on the quality of the aquatic ecosystem (Markert et al., 1999; Bae, Kil, & Bae, 2005). Bioindicators have been used in conjunction with physical and chemical analyses, to evaluate and monitor lotic systems. Benthic macroinvertebrates are the second largest group of organisms in aquatic ecosystems (Couceiro et al., 2007) and the most used in the freshwater assessment (Mondy et al., 2012). They are the most complete organisms of freshwater bioindicators (da Silva, 2013), as they present a series of characteristics:

- They are beings that inhabit the substrate of the river and with a sedentary nature, allowing a specific spatial analysis of the place they inhabit (Li et al., 2010);
- They present an omnipresent occurrence (Bae et al., 2005);
- Well-described taxonomic diversity, with varying sensitivity (Nuria Bonada et al., 2006);
- Relatively long life cycles, allowing for a temporal assessment (Li et al., 2010);
- The sampling equipment is low cost and easy to handle (Gresens et al., 2009).

Benthic macroinvertebrates are small-sized organisms, but visible to the naked eye, that colonizes the substrate of aquatic ecosystems in at least one stage of their life cycle. They are responsible for maintaining aquatic ecosystems, as they are a fundamental on the nutrient cycle and a key component of aquatic and terrestrial trophic networks (Couceiro et al., 2007; Li et al., 2010). Macroinvertebrates are composed of different species, which have a wide range of tolerances to changes in their environmental conditions (Gresens et al., 2009). The different environmental tolerances between species and their responses to disturbances can be used to infer environmental conditions in a specific location (Li et al., 2010).

Various indices have been developed to describe community responses and establish the ecological status of water bodies. The WFD recommends the use of multimetric approaches to detect possible disturbances (Sánchez-Montoya, Vidal-Abarca, & Suárez, 2010). For benthic macroinvertebrates, several indices are used, including the Biological Monitoring Working Party (BMWP) index. This was adapted for the Iberian Peninsula resulting in the IBMWP index (Iberian BMWP), where each family is assigned a value representative of its pollution tolerance (Li et al., 2010). Another index to assess water quality is the $IPtI_N$ or $IPtI_S$ (Índice Português de Invertebrados do Norte ou do Sul, respectively), applied according to the different types of rivers in Portugal. Its use makes it possible to respond to what is indicated by the WFD concerning biological parameters, the composition and abundance of aquatic communities. It also describes the gradients of degradation of water bodies and discriminates as a final value, quality classes expressed in (EQR) Ecological Quality Ratio (INAG, 2009).

1.4 Ecosystem services

An ecosystem is a functional unit in which a set of communities of living beings establish dynamic relationships among themselves and with their surroundings (Pereira et al., 2009). These relationships give rise to ecological processes responsible for ecosystem services (Dick, Smith, & Scott, 2011). According to Pereira et al. (2009), ecosystem services are the benefits that can be taken by humans from ecosystems. These services are divided into different categories, according to the type of benefit obtained, which may be provisioning services, regulating services, supporting services, and cultural services (Pereira et al., 2009). Provisioning services include sources of food, water, wood, and fibers; the regulating services contain important processes of climate regulation, control of soil erosion, hydrological regulation and mitigation of natural disasters; supporting services include the nutrient cycle, soil formation and flow mediation; and the cultural services provide recreational aesthetic, spiritual and other leisure activities (Millennium Ecosystem Assessment, 2005). This division was elaborated by the Millennium Ecosystem Assessment (MEA), to evaluate the consequences of changes in ecosystems on the human being's quality of life, and to develop methods for human development and the sustainability of ecosystems (Pereira et al., 2009; Grizzetti et al., 2016).

One tool for assessing the use and provision of ecosystem services is the Common International Classification of Ecosystem Services (CICES). Its main objective is to evaluate the different types of land use considering their availability. This methodology aims to standardize the assessment of ecosystems and verify the benefits available to humanity (Haines-Young & Potschin, 2018). The CICES classification, unlike the MEA, divides ecosystem services in three distinct categories. The provisioning services show the nutritional, material, and energy utilization of all living systems, the regulation and maintenance services encompass all activities that mediate or moderate the environment, such as the regulation of contaminants, mediation of flows, and maintenance of conditions physical and chemical and biological. Cultural services refer to products that affect men physically and mentally, covering non-material products (Haines-Young & Potschin, 2018).

To assist in the assessment of the ecosystem services provided, it is necessary to know the landscape occupations in the adjacent area. For this purpose, the Carta de Ocupação de Solo (COS), produced by Direção Geral do Território (DGT) since 1990, is used in Portugal. COS describes the land occupation present in Portugal and allows us to monitor its evolution over time. The most recent version produced and used in this work is that of 2018 (COS 2018). The existence of these data allows a good management of the territory considering the actions of man (Direção-Geral do Território, 2019).

Aquatic ecosystems, such as rivers, support the provision of ecosystem services in a variety of ways, from essential services such as fish production and water supply to recreational services. Many of the services provided can be directly assessed and quantified, but some, especially regulation and maintenance, are not so evident. The preservation of these ecosystems and their ecosystem services is extremely important. It is necessary to consider the resilience of the ecosystem and introduce the notion of sustainability in the assessment of obtaining ecosystem services (Grizzetti et al., 2016).

1.5 Intermittent rivers

A typology of fluvial ecosystem poorly understood but whose importance has already been recognized, are intermittent rivers (Kalogianni et al., 2017). Intermittent rivers are defined as watercourses that at some point in time and space, naturally cease their flow (Núria Bonada et al., 2007). Its regime alternates between wet and dry periods over an annual cycle and may leave some pools (Figure 1) between dry sections of the riverbed (Steward et al., 2012). They are frequent rivers in the Mediterranean region, where there is great seasonal variability in temperature and precipitation, as well as in arid and semi-arid regions (Núria Bonada et al., 2007). They represent a dynamic ecosystem, with a high spectrum of variations in terms of duration, predictability, and volume as well as the extent of interruption of the drought period (Arthington et al., 2014; Datry et al., 2018). They are endowed with a remarkable hydromorphological diversity since the river goes through periods of droughts and floods that alter the conditions of the ecosystem. Flow variability has been identified as an important factor affecting other abiotic and biotic factors that regulate processes in the ecosystem (Kalogianni et al., 2017; Nikolaos T. Skoulikidis et al., 2017). Several studies show that during the drought period, with the decrease of the water surface area, chain reactions are triggered in the physical and chemical parameters, such as the increase in temperature and hypoxia/anoxia that negatively affect the aquatic biota (Kalogianni et al., 2017).

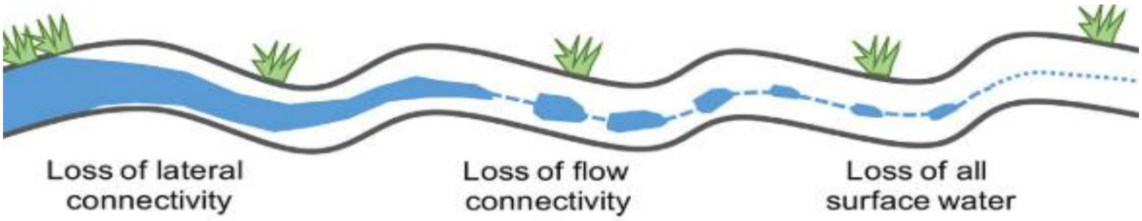

Figure 1 - Loss of water flow, with increased intermittency and the existence of isolated pools, changing the type of habitats and its availability (adapted from Stubbington et al., 2017)

The duration of the drought is crucial in determining the diversity in intermittent rivers (Núria Bonada et al., 2007). Studies by Sabater et al. (2016) concluded that the flow variation had a significant and more relevant influence on the macroinvertebrate community than pollutants. Other studies of communities in intermittent rivers show that they are characterized by a lower abundance and richness of species compared to a perennial river, which never ceases its water flow. Biotic communities vary across intermittent gradients, for example, richness decreases as the severity of intermittency increases (Datry, Larned, & Tockner, 2014). Drying the bed represents a loss of longitudinal connectivity, fragmentation into sections, and changes in the availability of habitat (Núria Bonada et al., 2007). However, despite the decrease in lotic species, the presence of pools between the dry sections allows the occupation of communities like those of lakes (lentic systems) and semi-aquatic communities. These two periods allow a unique combination of aquatic, amphibious, and terrestrial associations, with a succession of biota being observed during the transition of the two periods. The peculiar conditions of the intermittent rivers impose, however, a strong selective pressure for the evolution of characteristics of resistance and resilience of the biota (Steward et al., 2012).

The great variability that exists in intermittent rivers allows them to function as a biodiversity hotspot, throughout its annual cycle, with diverse and unique communities, as well as biogeochemical processes and ecosystem services (Arthington et al., 2014). The provision of services in these ecosystems is still poorly understood, the functioning of nutrient cycling, water purification, etc. These rivers are undervalued because they do not represent a reliable source of water (Datry et al., 2018). However, in various areas of the world and during the dry period, these places are used for leisure activities such as dry riverboat races (Australia's Northern Territory), some people fish for catfish aestivating in dry riverbeds, and the dry riverbeds can provide also fertile substrates for agriculture (Steward et al., 2012). Intermittent rivers are highly threatened ecosystems, due to their devaluation, lack of information, and protection legislation (Datry et al., 2014).

Overall, there is difficulty in interpreting biological communities to distinguish a natural disturbance from an anthropogenic one (Kalogianni et al., 2017). Despite naturally intermittent rivers, the anthropogenic impact and climate change have been increasing the global extent of this type of rivers (Datry et al., 2018). The construction of dams and weirs, the capture and diversion of water, as well as seasonal changes in precipitation and flow, changed the natural flow regimes, increasing the duration of the drought periods and converting perennial rivers into intermittent rivers (Datry et al., 2014). Therefore, efforts must be made to understand the ecology behind these ecosystems as well as adjust the ecological classification to better conserve them.

1.6 Objectives

This study intends to characterize and evaluate the ecological conditions along the Ribeira de Silveirinhos incorporated in the Parque das Serras do Porto (PSeP), following the guidelines of the WFD for lotic systems and complementing with an analysis of ecosystem services and riverside ecosystem. With the results obtained it will be possible to create intervention proposals that can be implemented by the municipalities of Valongo and Gondomar, to improve the ecological status of Ribeira de Silveirinhos.
The specific objectives defined for the here-presented study were:

- Evaluate the water quality of Ribeira de Silveirinhos through the evaluation of physical and chemical parameters and the benthic macroinvertebrate community.
- Assess the landscape basin and ecosystem services in the area surrounding Ribeira de Silveirinhos.
- Classify the ecological quality of the Ribeira de Silveirinhos waterbody: WFD vs Ecosystem Services.

2. Materials and Methods

2.1 Study area

The watercourse evaluated was Ribeira de Silveirinhos, a small stream with a 4 km length, located in the north of Portugal. It is within the limits of Parque das Serras do Porto (PSeP), inserted in the municipalities of Valongo and Gondomar (Figure 2). This aquatic ecosystem is a small intermittent mountain brook in slate and quartzite terrains. It flows into Rio Ferreira, in Gondomar, being its main effluent. It belongs to the Hydrographic Region 3, which is under the Douro Hydrographic Region Management Plan (PGRH) and it is part of an area covered by Natura 2000 network classified as PTCON0024 (“Valongo”) (Viterbo, Bessa, & Nunes, 2015; Associação de Municípios do Parque das Serras do Porto, 2017). This region, with protected landscape status, highlights the landscape and heritage values present. The occurrence of significant natural ecosystems associating a vast floristic and fauna biodiversity, a relevant geological and cultural heritage as well its location in the Metropolitan area of Porto (AMP) are some of the factors that recognize this area with high environmental development potential (Associação de Municípios do Parque das Serras do Porto, 2017; Andresen et al., 2018).

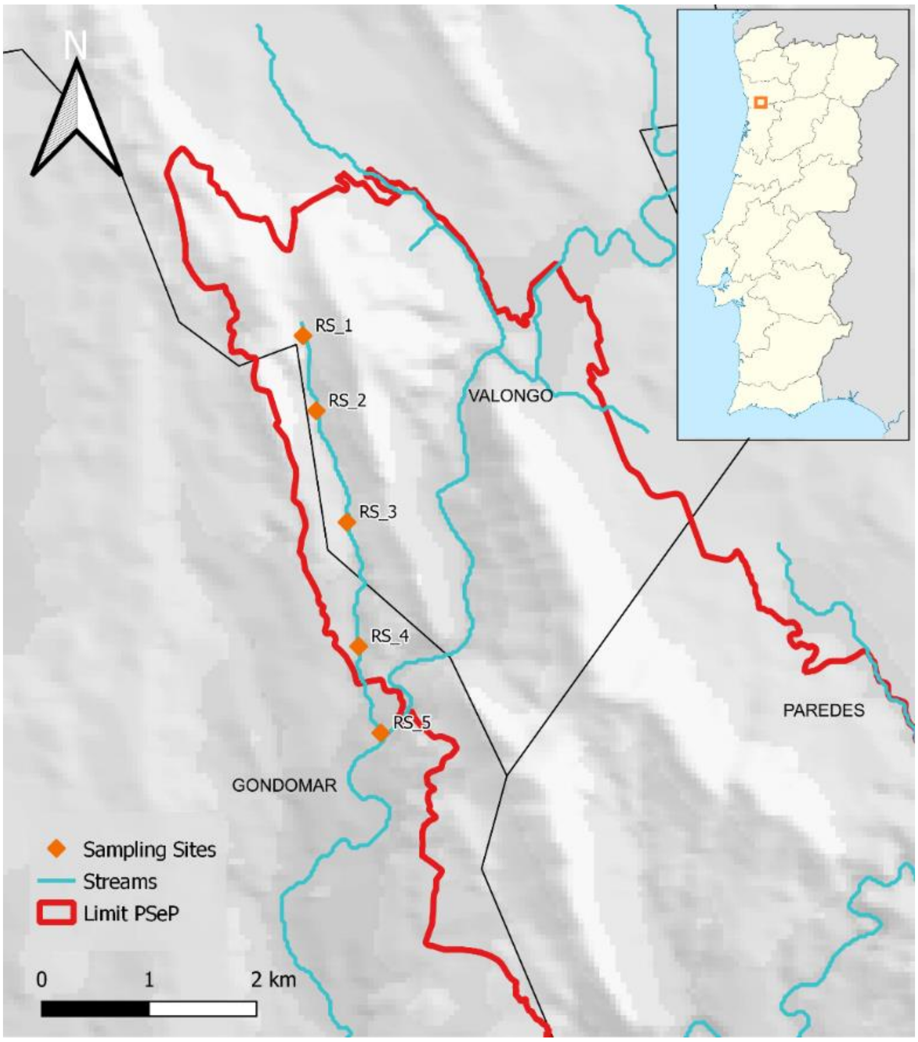

Figure 2 - Location of Ribeira de Silveirinhos in PSeP, and the five sampling sites selected for this study (Table 1).

Ribeira de Silveirinhos is located in an area with a very mild climate, with a moderate thermal amplitude, which is expected given the proximity of the coast. Inserted in a north western Portuguese region, it is subject to the influence of the Atlantic regime, so there are relatively frequent rains (Associação de Municípios do Parque das Serras do Porto, 2017; Andresen et al., 2018). However, an absence of precipitation during the summer period causes water stress on aquatic and terrestrial ecosystems. Therefore, the Ribeira de Silveirinhos has a temporary drought in its flow, being designated as an intermittent river (Datry et al., 2018). Another characteristic of the place to be considered is the diversified extractive activity that dates to the Roman era, with the extraction of gold (Au) and iron (Fe) observed in the area surrounding this watercourse. This activity left significant marks on the landscape, which persist over time, one of them is the presence of very iron waters with brownish-yellow hue (Figure 3) (Santos, 2013; Andresen et al., 2018).

Figure 3 - Landscape of the RS_3 site showing the brownish-yellow hue, characteristic of this river by the presence of old iron mines.

At the fauna level, in this region (PSeP) several species are listed in the Annexes to the Habitats Directive, highlighting the importance for the conservation of the Portuguese salamander (*Chioglossa lusitanica*), endemic to the Iberian Peninsula. In PSeP is described as the most abundant population of this species in the entire Portuguese territory. This species uses the mines resulting from Roman exploitation to reproduce and remain during its metamorphosis period. The fauna richness of the area is however very vast with several important examples from all classes of vertebrates and invertebrates (Associação de Municípios do Parque das Serras do Porto, 2017; Andresen et al., 2018).

The use of the landscape is an important pressure factor on the aquatic ecosystem. Through the visualization of COS2018, we were able to identify the different types of soil that occur in the surrounding area and their occupational size. The dominant occupation, which covers more than half of the area, is the eucalyptus forest, well-marked in the upstream regions. In the downstream direction, patches of other occupations are visible, such as bushes of *Ulex* and heathers (e.g. *Erica* sp.), present in areas without tree cover well adapted to poor and dry soils (Andresen et al., 2018). Eucalyptus monoculture as well as the presence of invasive species such as *Acacia* sp. and *Hakea* sp. (Arntzen, 2015), condition the floristic development of the area which, due to natural occurrence, should be occupied by species such as common oak (*Quercus robur*), cork oak (*Quercus suber*) and maritime pine (*Pinus pinaster*) (Viterbo et al., 2015; Andresen et al., 2018). The majority of the riverside flora has been replaced, and only representative populations, such as patches of endemic ferns, are visible in some downstream places, for example *Dryopteris guanchica* (Associação de Municípios do Parque das Serras do Porto, 2017; Koch, 2018). The local agriculture recorded in COS2018, is entirely for subsistence and is always associated with artificial territories, such as houses, roads and bridges (Andresen et al., 2018).

2.2 Sampling sites and fieldwork

This study was carried out in spring and autumn of 2019 (Sp19; Au19) and spring of 2020 (Sp20). Five sampling sites were selected along Ribeira de Silveirinhos (RS_1, RS_2, RS_3) being part of the municipality of Valongo and the (RS_4, RS_5) belonging to the municipality of Gondomar (Figure 2 and Table 1). The selection of the five sampling sites considered the various human activities practiced in the surrounding areas, along the watercourse, to understand its impacts on the quality of the aquatic system.

Table 1 - Geographical location of the sampling sites of Ribeira de Silveirinhos.

Sampling sites	Latitude	Longitude
RS_1	41°10'22.58"N	8°30'2.29"W
RS_2	41° 9'59.97"N	8°29'56.85"W
RS_3	41° 9'26.40"N	8°29'44.41"W
RS_4	41° 8'48.97"N	8°29'39.50"W
RS_5	41° 8'22.86"N	8°29'30.55"W

At each sampling site, physical and chemical parameters of general water support were measured *in situ*, such as thermal conditions (ºC), acidification status (pH), conductivity (µS/cm), oxygenation conditions (% saturation and mg/L), and total dissolved solids (TDS) (INAG, 2009). The *in situ* parameters were measured on the water surface, with a multi-parameter WTW probe, model Multi 350i. An additional water sample was collected in a 1.5 L plastic bottle to quantify other parameters such as the 5-day Biochemical Oxygen Demand (BOD_5) and nutrient concentrations (nitrates, ammoniacal nitrogen, phosphorus) in the laboratory.

The sampling of the benthic macroinvertebrate community was carried out according to the INAG 2008 protocol (INAG, 2008). A hand net with a mesh of 0.5 mm and 25 cm in width was used. A composite sample was collected with the guarantee that all the habitats recorded in each sampling site were sampling. The benthic macroinvertebrates samples were preserved in 4 % formaldehyde (INAG, 2008) and properly labeled and packaged in plastic bottles. However, in the autumn of 2019 sampling, the stream was dry at points RS_1, RS_2, and RS_3 and therefore no water samples were collected, or macroinvertebrate communities surveyed.

To achieve the ecosystem services provided in each sampling site a survey of hydromorphological observations and a photographic around 360º of the area was carried out. In the dry season, ecosystem services in the surrounding area were also assessed. Standard field cards were applied to assess and characterize Ribeira de Silveirinhos (Table 2 and 3).

2.3 Laboratory procedures

In the laboratory, on the day of the harvest, the collected water samples were used to determine the 5-day Biochemical Oxygen Demand. Water samples from each site were placed in 250 mL amber glass bottles and the dissolved oxygen concentration (mg /L) was measured. Subsequently, a drop of nitrification inhibitor (Allylthiourea 98 %) was placed in each bottle and then these were filled and closed, ensuring the absence of air bubbles inside. The samples were incubated at 20ºC in the dark, for five days. At the end of this period, the dissolved oxygen concentration (mg /L) was again measured with a multiparametric probe and BOD_5 was calculated considering the difference between the dissolved oxygen concentration at the beginning and after 5 days of incubation. For the quantification of nutrients, the concentration of nitrates (NO_3), ammoniacal nitrogen (NH_4), and total phosphorus (P-total) were determined on a Spectroquant Multy Colimeter bench photometer using standardized procedures (method 321; method 383; method 33, respectively).

Regarding the samples of benthic macroinvertebrates community, they were washed with a 0.5 mm mesh sieve in order to remove all the fine sediment present in the sample. The material retained in the sieve was placed in trays and sorted, to separate the macroinvertebrates from the remaining debris. The harvested organisms were preserved in small bottles properly labeled in 70 % alcohol, for later identification. The identification was performed using a binocular magnifying glass, up to the family level in almost all *taxa*, and the class level for Oligochaetas, using specific dichotomous keys (Tachet, 2000).

2.4 Data analysis

2.4.1 Physical and chemical parameters

To carry out a multivariate analysis, a data matrix was built with the values of the environmental variables measured *in situ* and the laboratory, for each sampling site. The values were previously normalized using the equation $x' = (x-\mu)/\sigma$. A principal component analysis (PCA), calculated using CANOCO for Windows version 4.0, was used to summarize the physical and chemical parameters in a small number of components. Allowing to analyse their relationship between the different sampling sites and to identify the existence of gradients (Antunes, Pereira, Sousa, Santos, & Gonçalves, 2008).

2.4.2 Biological quality parameters

The index used for the aquatic ecosystem quality regarding macroinvertebrates community was the Portuguese Northern Invertebrate Index ($IPtI_N$). The values of composition and abundance of benthic macroinvertebrates were analysed to describe gradients of general degradation and to discriminate quality classes, using a set of metrics (INAG, 2009).

$$\mathbf{IPtI_N = N^o\ Taxa \times 0{,}25 + EPT \times 0{,}15 + Evenness \times 0{,}1 + (IASPT - 2) \times 0{,}3 + Log\ (Sel.\ ETD+1) \times 0{,}2}$$

- EPT – Nº of families belonging to the orders Ephemeroptera, Plecoptera, Trichoptera;
- Evenness - Also called the Pielou Index or Equitability, it is calculated as:

  $E = H / \ln S$

where H is Shannon-Wiener diversity, S = the number of taxa present, ln = natural or Neperian logarithm

The Shannon-Wiener index is calculated using the expression:

$$H = - \Sigma\, p_i \ln p_i$$

where $p_i = n_i / N$, that is, the number of individuals of each taxon i (n_i) divided by the total number of individuals (N) present in the sample

- IASPT - ASPT Iberic, which corresponds to the BMWP Iberic (Alba-Tercedor & Sanchez-Ortega, 1988) divided by the number of families included in the calculation of the BMWP Iberic;
- Log (Sel. ETD + 1) - Log10 of 1 + sum of the abundances of individuals belonging to the families Heptageniidae, Ephemeridae, Brachycentridae, Goeridae, Odontoceridae, Limnephilidae, Polycentropodidae, Athericidae, Dixidae, Dolichopodidae, Empididae, Strididae;

The value is the result of the sum of the weighted metrics. Two normalization steps are performed, before the multiplication of the metrics by the weighting factor and after the sum of the weighted metrics, reaching the final value expressed in the Ecological Quality Ratio (EQR). The normalizations are computed through the quotient between the obtained value and the reference value for that type of river. The Ribeira de Silveirinhos falls within the categorization of small rivers in the North, less of 100 km^2 (INAG, 2009; APA - Agência Portuguesa do Ambiente, 2016).

The water ecological classification system (by EQR) is divided into five quality classes, referred to in Annex V of the WFD, according to a scale of values between 0 and 1. The range of values for each class differs according to the type of river. For small northern rivers, the five classes are divided on the following scale: High [0.87 - 1], Good [0.68 – 0.87[, Moderate [0.44 – 0.68[, Poor [0.22 – 0.44[, and Bad [0 – 0.22[(APA - Agência Portuguesa do Ambiente, 2016). The class reached will represent the degree of change in the ecosystem, due to the anthropogenic pressures to which the surface water is subjected. A body that is classified as having a good ecological status, presents biological communities with only a slight deviation from the reference conditions, and its values of physical and chemical parameters and hydromorphological parameters are compatible with the values described in the legislation (INAG, 2006).

2.4.3 Assessment of ecosystem services

For each sampling site, methodologies for assessing ecosystem services were used, namely the Common International Classification of Ecosystem Services - CICES V5.1 and the Carta de Uso e Ocupação do Solo (version 2018) - COS2018 (level 1). The Ribeira de Silveirinhos, according to information from COS2018 and using the Geographic Information System (GIS) - QGIS, has four landscape elements: Agriculture; Forests; Bushes and Surface water bodies. The application of CICES aims to classify and quantify the ecosystem services provided, for each landscape element present in each sampling site. The characterization and evaluation of the sampling sites were simplified with the compilation of these two methodologies, resulting in only one field form (Table 2). The photographic survey carried out in the field was analysed, always in line with COS2018, to respond to the various requirements of the form. The improvement potential ecosystem services were calculated, and the value is obtained through the difference between the evaluation performed and the maximum values possible to obtain, at each site. The assessment is made on a scale of 1 to 5, where 1 corresponds to Bad and 5 to Excellent.

Table 2 - Standard field card for assessing ecosystem services provided at each sampling site.

Ecosystem services provided CICES V5.1		Types of landscape elements COS2018 (Level 1)			
Provisioning Bad 1 - 2 - 3 - 4 - 5 Excellent		Agriculture	Forests	Bushes	Surface water bodies
Biotic	Biomass	**5**	**5**	**5**	**5**
	Genetic material from all biota	**5**	**5**	**5**	**5**
Abiotic	Water				
	Non-aqueous natural abiotic ecosystem outputs				
Regulation and Maintenance Bad 1 - 2 - 3 - 4 - 5 Excellent					
Biotic	Transformation of biochemical or physical inputs to ecosystems	**5**	**5**	**5**	**5**
	Regulation of physical, chemical, biological conditions	**5**	**5**	**5**	**5**
	Other types of regulation and maintenance service by living processes				
Abiotic	Transformation of biochemical or physical inputs to ecosystems	**5**	**5**	**5**	**5**
	Regulation of physical, chemical, biological conditions	**5**	**5**	**5**	**5**
	Other type of regulation and maintenance service by abiotic processes				
Cultural Bad 1 - 2 - 3 - 4 - 5 Excellent					
Biotic	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	**5**	**5**	**5**	**5**
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	**5**	**5**	**5**	**5**
	Other characteristics of living systems that have cultural significance				
Abiotic	Direct, *in situ* and outdoor interactions with natural physical systems that depend on presence in the environmental setting	**5**	**5**	**5**	**5**
	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	**5**	**5**	**5**	**5**
	Other abiotic characteristics of nature that have cultural significance				
Maximum evaluation (optimal)		**50**	**50**	**50**	**50**
Evaluation performed		**0**	**0**	**0**	**0**
Improvement potential (%)		**0**	**0**	**0**	**0**

The methodology for assessing the river ecosystem and the riverside area is based on direct observation and photographic record. The focus is on assessing the conditions of the waterline and respective margins. As a result of several authors a specific field form was developed (Table 3; Koch, 2018) and the same approach was used for the evaluation of each sampling site in this study. The evaluation is made on a scale of 1 to 5, where 1 corresponds to Bad and 5 to Excellent.

Table 3 - Standard field card for the characterization and assessment of the river ecosystem and riparian zone at each sampling site.

River Ecosystem				Bad 1 - 2 - 3 - 4 - 5 Excellent
Riverbanks	Left	Riparian	Continuity	
			Composition	
			Width	
		Erosion zone		
		Artifilization of the riverbank		
		Point sources of pollution		
		Maximum evaluation (optimal)		
		Evaluation performed		
		Improvement potential (%)		
	Right	Riparian	Continuity	
			Composition	
			Width	
		Erosion zone		
		Artifilization of the riverbank		
		Point sources of pollution		
		Maximum evaluation (optimal)		
		Evaluation performed		
		Improvement potential (%)		
Riverbed		Heterogeneity of the substrate		
		Heterogeneity of water flow		
		Debris		
		Transversal obstacles		
		Maximum evaluation (optimal)		
		Evaluation performed		
		Improvement potential (%)		
Water		Turbidity		
		Eutrophication		
		Smell		
		Exotic vegetation		
		Colour		
		Maximum evaluation (optimal)		
		Evaluation performed		
		Improvement potential (%)		
Maximum evaluation (optimal)				
Evaluation performed				
Improvement potential (%)				

3. Results and Discussion

3.1 Physical and chemical parameters

Table 4 shows the results of the physical and chemical parameters evaluated during the three sampling periods (Sp19, Au19, and Sp20). Temperature, conductivity, and the Total Dissolved Solids do not present a limit value for rivers according to WFD. However, the results of the autumn sampling (Au19) show higher values of conductivity and TDS when compared to the spring (Sp19 and Sp20) sampling period.

The remaining physical and chemical parameters evaluated show a reference limit for establishing the good ecological status, in this study for rivers of the northern type (APA - Agência Portuguesa do Ambiente, 2016) (Table 4). It should be noted that for the parameters dissolved oxygen, nitrates (NO_3), ammoniacal nitrogen (NH_4), and also the BOD_5, all sampling sites in the three sampling periods presented values within the reference limits. Regarding the pH values in RS_1 at Sp19 and Sp20 as well as the site RS_2 at Sp20, low pH values were observed, below the limits defined by WFD (≥6 and ≤9). In natural waters, the pH depends on the geology of the place, the absorption of atmospheric gases, and the oxidation of organic matter, but its value can be changed by anthropogenic factors such as the dumping of domestic and industrial waste (Pinheiro, 2017). The low pH values obtained here can be explained by the existence of a reduced flow upstream, it is visible that in general, the pH values increase in the downstream direction in the same direction as the flow rate increases. Also due to the existence of a reducing environment, characteristic of the occurrence of iron waters (Alfaia, 2009; Alberto et al., n.d.).

The evaluation of total phosphorus (P) also exceeded the WFD reference limit of ≤ 0.10 mg/ L (INAG, 2009), in some sites. Phosphorus can come from the wear and tear of rocks, domestic and industrial sewers, detergents and fertilizers, and pesticides used in the agricultural activity (Pinheiro, 2017). This element is relevant in biological systems due to its participation in fundamental processes in the metabolism of living beings, such as energy storage and the structuring of the cell membrane. It can be found in waters in organic and inorganic form, dissolved or suspended (Cortes, R. M., Carvalho, L. H., & Carvalho, 1997). In Table 4, we found that the sites with the highest concentrations were the RS_3 and RS_5 in Sp19, and still RS_4 in all sampling periods, having reached a value of 0.25 mg/L in the Sp20 sampling. These sites are located in an area downstream of the stream, which suggests that these values may be related to the proximity of anthropogenic activity recorded there. They can be explained by the flow of agricultural products used in agriculture located on the banks of the river or by the discharge of domestic sewage.

Table 4 - Results of physical and chemical parameters determined *in situ* and in the laboratory, for each sampling site for the three sampling periods. Limit values indicated by the WFD to achieve "Good ecological status" in northern rivers were also included. The values indicated in red exceed the limits of the reference values stipulated for the respective parameter.

Sampling sites	**Season**	**T (°C)**	**Cond. (µS/cm)**	**TDS (mg/L)**	**pH**	**O_2 (mg/L)**	**O_2 (%)**	**NO_3 (mg/L)**	**NH_4 (mg/L)**	**P (mg/L)**	**BOD_5 (mg/L)**
Limit values (INAG, 2009)					**≥6 and ≤9**	**≥5**	**≥60 and ≤120**	**≤25**	**≤1**	**≤0.10**	**≤6**
RS_1	Sp19	15.4	52.6	53	**5.56**	8.44	85.7	ϕ	0.02	ϕ	0.27
	Au19	No water									
	Sp20	16.1	55.9	56	**5.17**	6.35	74.7	ϕ	ϕ	ϕ	0.47
RS_2	Sp19	14.7	53.3	53	6.05	9.72	96.8	ϕ	0.02	ϕ	0.20
	Au19	No water									
	Sp20	17.9	55.6	56	**5.91**	7.69	82.2	ϕ	ϕ	ϕ	0.57
RS_3	Sp19	15.1	75.7	76	6.41	9.41	93.4	ϕ	0.02	**0.15**	0.47
	Au19	No water									
	Sp20	17.6	107.7	108	6.60	7.05	74.6	ϕ	ϕ	ϕ	0.98
RS_4	Sp19	16.5	391.0	392	6.77	9.15	93.5	ϕ	ϕ	**0.16**	1.46
	Au19	17.7	1091.0	1091	6.77	6.81	70.8	ϕ	0.42	**0.23**	3.34
	Sp20	18.8	910.0	854	6.93	8.11	87.5	ϕ	0.03	**0.25**	3.54
RS_5	Sp19	17.3	449.0	449	7.17	9.45	97.5	ϕ	0.05	**0.16**	0.49
	Au19	15.6	950.0	950	7.72	9.70	96.7	ϕ	0.20	ϕ	2.06
	Sp20	20.1	774.0	774	7.35	8.41	93.0	0.50	ϕ	0.02	0.67

ϕ - Below the detection limit of the equipment used in the quantification – concentration of nitrates (NO_3) <0.5 mg/L; concentration of ammoniacal nitrogen (NH_4) <0.03 mg/L and concentration of total phosphorus (P) <0.01 mg/L.

From the physical and chemical parameters of general water support, the results do not demonstrate the influence of negative impacts, although some variations in some parameters have been detected. The occurrence of river intermittency during the dry period must have been considered when observing these results. Flow variability has been identified as an important factor affecting abiotic factors (Pires, Cowx, & Coelho, 2000). Boulton & Lake (1990) carried out studies on the temporal changes in environmental characteristics in intermittent rivers and demonstrated that the amplitudes in physical and chemical conditions far exceed when compared to perennial rivers. They observed that in rivers that dried completely, the tendency was for an increase in conductivity and temperature, with a decrease in pH and dissolved oxygen when the flow decreased. Few studies provide a direct comparison to the assessment of physical and chemical parameters in intermittent rivers. However, its greater sensitivity to nutrients and other pollutants increases the risk of eutrophication, especially in low flow conditions. On the other hand, low concentrations of nutrients can have high impacts on water quality and biota of intermittent rivers (Chiu et al., 2017).

In order to perceive if a natural gradient occurs in Ribeira de Silveirinhos, an analysis of the main components, Principal Component Analysis (PCA) was carried out between the physical and chemical parameters (*in situ* and in the laboratory) and the sampling sites (Figure 4). In Sp19 and Sp20, sampling sites, an association with high values of oxygen concentration was observed. This gradient increases towards the downstream and in the Sp19 sampling revealed higher values than the Sp20 sampling sites. On the other hand, a relationship with the high pH and conductivity values were recorded, where a gradient of the Sp20 sampling sites is associated with an increase in the pH values, more evident downstream. This phenomenon is justified by the presence of iron waters that manifest themselves more strongly in the same direction. No association with any of the studied parameters was recorded in the autumn sampling (Au19), however in this sampling period, only 2 sites out of 5 were sampled.

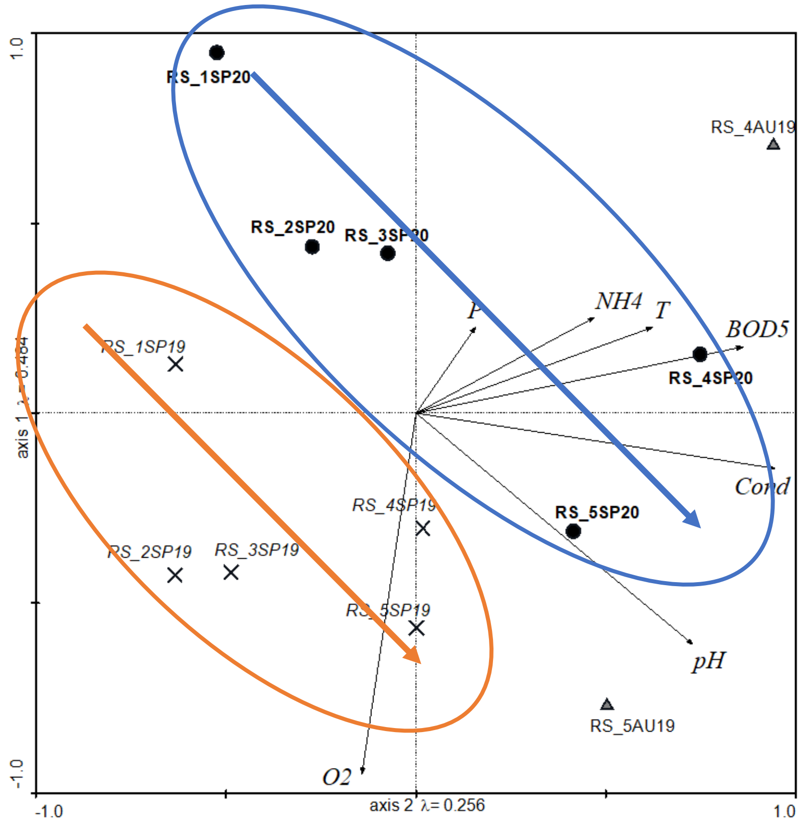

Figure 4 - PCA biplot of sampling sites and environmental variables analyses. The variables are represented by arrows (T – temperature; pH; Cond – conductivity; O_2 – oxygenation; NH_4 – ammoniacal nitrogen; P – total phosphorus). The sampling site codes correspond to each of the five points (Figure 2) in each data collection.

3.2 Biological parameters – Benthic macroinvertebrates

Table 5 presents the results of the individual metrics for the calculation of the Portuguese Northern Invertebrate Index ($IPtI_N$) and the value of the EQR for the three sampling periods performed. In the spring of 2019 (Sp19), the richness (nº of families, S) recorded the highest value at site RS_2 (17) and the lowest value at site RS_1 (7) and the evenness values varied between 0.23 in RS_1 and 0.72 obtained in RS_5, gradually increasing in the downstream direction. The EPT value stands for the number of families belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera more sensitive to water pollution. The highest values were observed at Sp19, EPT in RS_2 with a value of 5 and the lowest values at site RS_5 0 value of EPT, indicating a total absence of the mentioned families. The log (Sel.ETD+1) presented lower values (0) at sites RS_3 and RS_5 and the highest values at RS_2 (0.60). IASPT-2 varied between 3.25 registered at site RS_2 and 1.54 at point RS_5. The result of $IPtI_N$ and EQR registered the highest value in RS_2 (0.50 and 0.49, respectively) and the lowest in RS_1 (0.27 and 0.27).

Regarding the autumn sampling (Au19) and due to the intermittency occurring in Ribeira de Silveirinhos, the three upstream sites were dry, which allowed only the collection of biological material at RS_4 and RS_5. The recorded richness was higher in RS_5 (16) while in RS_4 only 7 different families were observed, well below the reference value (30). However, site RS_4 presented a higher evenness value of 0.89 and RS_5 a value of 0.42, it should be noted that the reference value for this metric is 0.71, a value that RS_4 exceeds. The range of EPT values varied between 0 (RS_4) and 2 (RS_5) and log (Sel.ETD+1) between 0.30 and 0.70 (RS_4 and RS_5, respectively). The IASPT-2 values recorded were in RS_4 of 3.29 and RS_5 of 2.44, with the reference value being 4.52. In this sample, the $IPtI_N$ and EQR values were similar at the two sites, registering values of 0.43 and 0.42 respectively at site RS_4 and 0.44 and 0.44 at RS_5.

As for the spring 2020 sampling (Sp20), richness was lower upstream (RS_1 and RS_2) with a value of 7 and higher at site RS_3, registering a value of 12 and, even so, well below the indicated reference of 30. Evenness remained higher at RS_3 with a value of 0.63 and lower at 0.25 at site RS_4. The EPT was low compared to the reference value 16, a value of 3 was recorded in RS_3 and the lowest value was 1 presented in sites RS_1, RS_4, and RS_5. The log (Sel.ETD+1) varied between 0 at sites RS_1 and RS_2 and 0.30 at the other sites sampled. The RS_2 site presented the highest IASTP-2 (3.71), as seen in the Sp19 sampling. On the other hand, the site RS_1 registered the lowest value (1.57). Regarding the final value of $IPtI_N$ and EQR, site RS_1 presented the lowest values (0.23 and 0.22), being the worst classification in the set of the three samples. As would be expected given the values recorded in the metrics that make up this assessment, site RS_4 recorded the highest values of $IPtI_N$ and EQR (0.47 and 0.46, respectively).

In general, was observed that most of the results are below the stipulated reference value for this river typology (small rivers in the North; INAG, 2009). Sánchez-Motoya et al. (2009) showed that intermittent rivers obtained the metric values in the lowest reference conditions when compared to other types of rivers, which must be attributed to the natural differences in macroinvertebrate communities.

Table 5 - Values obtained and reference values of WFD stipulated for small rivers in the North that make up the $IPtI_N$ and the respective EQR in the three moments of data collection.

Sampling sites	Season	Abundance	Diversity	Richness	Evenness	EPT	log (Sel. ETD+1)	IASTP - 2	$IPtI_N$	EQR
Reference values (INAG, 2009)				**30**	**0.71**	**16**	**1.95**	**4.52**	**1.02**	
RS_1	Sp19	412	0.45	7	0.23	2	0.30	2	0.27	0.27
	Au19	No water								
	Sp20	191	0.78	7	0.40	1	0.00	1.57	0.23	0.22
RS_2	Sp19	875	0.69	17	0.24	5	0.60	3.25	0.50	0.49
	Au19	No water								
	Sp20	430	0.59	7	0.30	2	0.00	3.71	0.37	0.36
RS_3	Sp19	193	1.32	11	0.55	2	0.00	2.55	0.36	0.35
	Au19	No water								
	Sp20	59	1.56	12	0.63	3	0.30	3.33	0.47	0.46
RS_4	Sp19	99	1.68	16	0.61	1	0.30	3	0.46	0.45
	Au19	14	1.73	7	0.89	0	0.30	3.29	0.43	0.42
	Sp20	115	0.52	8	0.25	1	0.30	3.50	0.37	0.37
RS_5	Sp19	105	1.84	13	0.72	0	0.00	1.54	0.31	0.31
	Au19	217	1.16	16	0.42	2	0.70	2.44	0.44	0.44
	Sp20	39	1.12	8	0.54	1	0.30	2.25	0.33	0.33

EQR classification (APA - Agência Portuguesa do Ambiente, 2016)	High	Good	Moderate	Poor	Bad
	[0.87 - 1]	[0.68 - 0.87[	[0.44 - 0.68[	[0.22 - 0.44[	[0 - 0.22[

Also presented in table 5 are the results of abundance and diversity that provide relevant information but are not necessarily directly for the calculation of $IPtI_N$. Regarding the abundance values, a higher abundance was observed in the Sp19 sampling, with a maximum of 875 individuals found in the RS_2 site. The lowest abundance record occurred in the Au19 sampling, at the site RS_4 with a value of 14 individuals. It should be noted that in the Sp20 sampling the stream had a lower flow than that found in Sp19 sampling, which may be responsible for the decrease in the parameters described above. Regarding diversity, this gradually increases towards the downstream in the Sp19 sampling, recorded a value of 1.84 in RS_5. In the Au19 sample, the diversity was 1.73 at RS_4 and 1.16 at RS_5. In the Sp20 sample, diversity showed a higher value in RS_3 (1.56) and a lower value in RS_4 (0.52). When we look at the values obtained and compare them with the results of the physical and chemical parameters, we identify some possible relationships. The low record in richness (7) in the Sp19 sampling in RS_1 may be due to the interference of the low pH levels. As in RS_1 and RS_2 in Sp20, which obtained low pH values and similar levels of richness were found (7). The influence of the high concentrations of phosphorus, registered in Sp19 in the RS_3 and RS_5 sites and also in RS_4 in all the sampling periods, did not have a visible interference in the species richness. In RS_4 there is a great variation in richness between the sampling periods, with Sp19 registering the highest value of 16, Au19 and Sp20 with a lower value of 7 and 8 respectively.

As stated by Datry et al. (2014) intermittent rivers are characterized by less abundance and species richness, due to the low existing connectivity, which is in agreement with the results here-obtained. However, there are a few exceptions to this pattern, Núria Bonada et al. (2007) recorded comparable values of richness in perennial and intermittent locations in a network of Mediterranean rivers. It is verified the disappearance of *taxa* sensitive to desiccation progressively, but the temporal variation in habitats promotes occupation by different *taxa* at different times (Stubbington et al. , 2017; Datry et al., 2018;).

Figure 5 presents the proportion of some of the families found in the different sampling periods. There is a clear dominance of the family Chironomidae in the three sampling periods, showing that it is less affected by environmental changes. Indeed, this family is characterized by tolerant to high pollution and environmental impacts (Li et al., 2010; Stubbington et al., 2017). The EPT *taxa* was associated with the occurrence of flow, and the family Leptophlebiidae (Ephemroptera) and Leuctridae (Plecoptera) were only found in spring samples. Oligochaeta were found at all times of sampling, since they are considered a generalist group that adapts to different conditions. During the drought period, an increase in individuals of Gastropoda was observed, which may indicate a greater resilience of these *taxa* to these environmental conditions. One of the families that was only found one time was Planorbidae, in the Au19 sampling in RS_4. This family, unlike most mollusks, has hemoglobin in their blood instead of hemocyanin. As a result, Planorbidae individuals can breathe oxygen more efficiently. This adaptation allows the storage of oxygen and therefore the occupation of habitats with variations in oxygen concentration and temperature (Lieb et al., 2006).

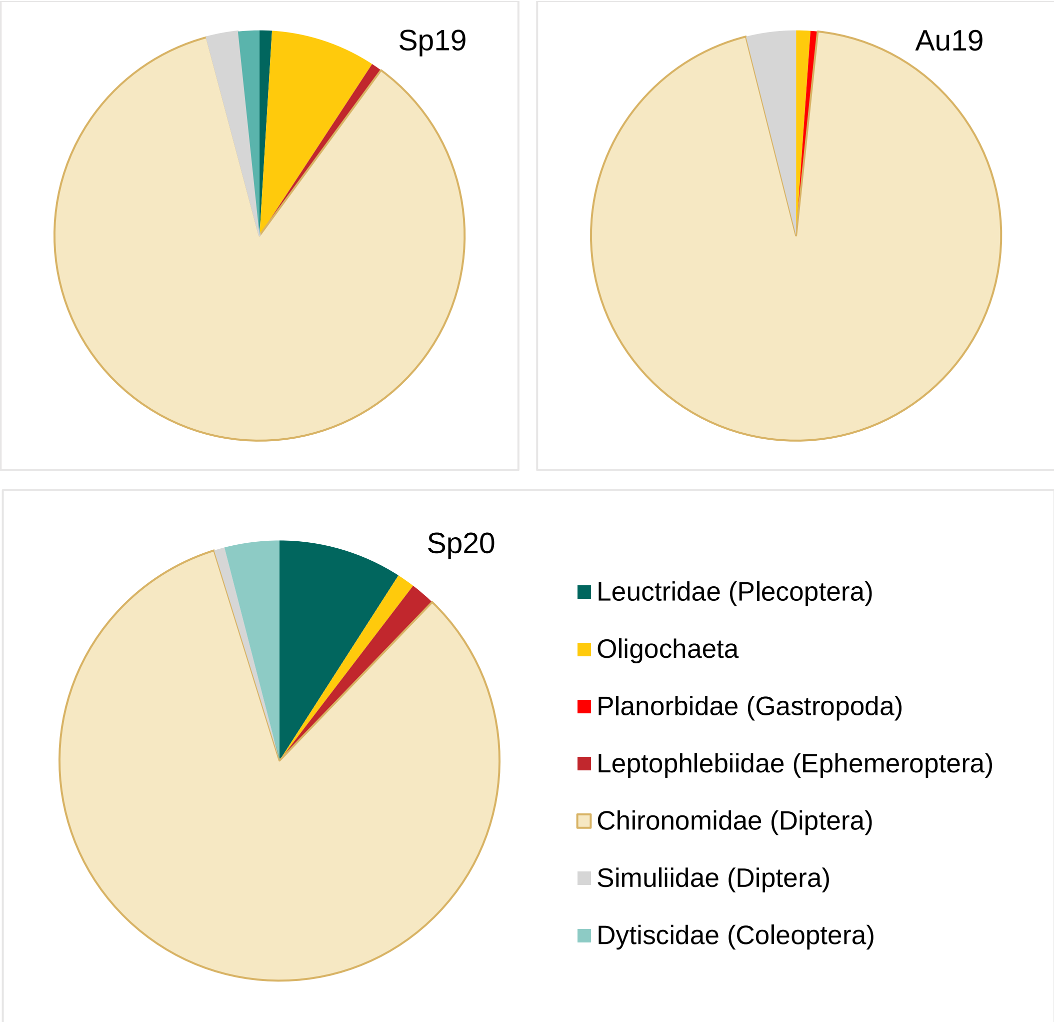

Figure 5 - Proportion of some of the families sampled in each of the sampling periods (Sp19, Au19, Sp20).

Some studies showed no significant differences in the communities affected only with hydric stress, which indicated a high resilience (Nikolaos Th Skoulikidis et al., 2011; Kalogianni et al., 2017). However, there were changes in the structure and composition of these communities. In the dry phase, the Plecoptera organisms decreased while an increase of Diptera is recorded (Kalogianni et al., 2017). On the other hand, Stubbington et al. (2017) demonstrated that as flow velocities fall, rheophilic *taxa* (flow-loving) lose their habitat and most disappear after the flow ceases, including many species of EPT (Figure 6 - Group B). These are replaced by macroinvertebrates characteristic of lentic habitats such as Odonata nymphs, diving beetles (Dysticidae family), Heteroptera, and Gastropoda (Figure 6 - Group D). Other *taxa* such as fly larvae (Diptera) and Oligochaeta are generalists and can persist in lotic and lentic conditions (Figure 6 - Group E). The first organisms to reappear when the flow returns, are larvae of Simuliidae, filtering organisms that require the flow to feed and nymphs of Plecoptera are also early colonizers.

Figure 6, adapted from Stubbington et al. (2017), shows the principal families that occur in the different phases in an intermittent river. Highlighted in green are the families that were found in the spring samples (Sp19 and Sp20) and orange the families recorded in autumn samples (Au19). An agreement in the results obtained was observed, with the occurrence of the family Planorbidae in the dry phase and the families Leptophlebiidae and Simulidae in the wet phase (Figure 5). Chironomidae and Oligochaeta were always families that occurred (Figure 5) and that are found in both phases. However, Dytiscidae marked as a family that belongs to the dry phase, in the present study it was sampled in Sp19 and Sp20. The permanence of pools allows resilient beings to persist in refuges until the flow returns. However, if the pools dry, there is an elimination of *taxa* sensitive to desiccation, which causes marked reductions in the richness of the ecosystem (Stubbington et al., 2017).

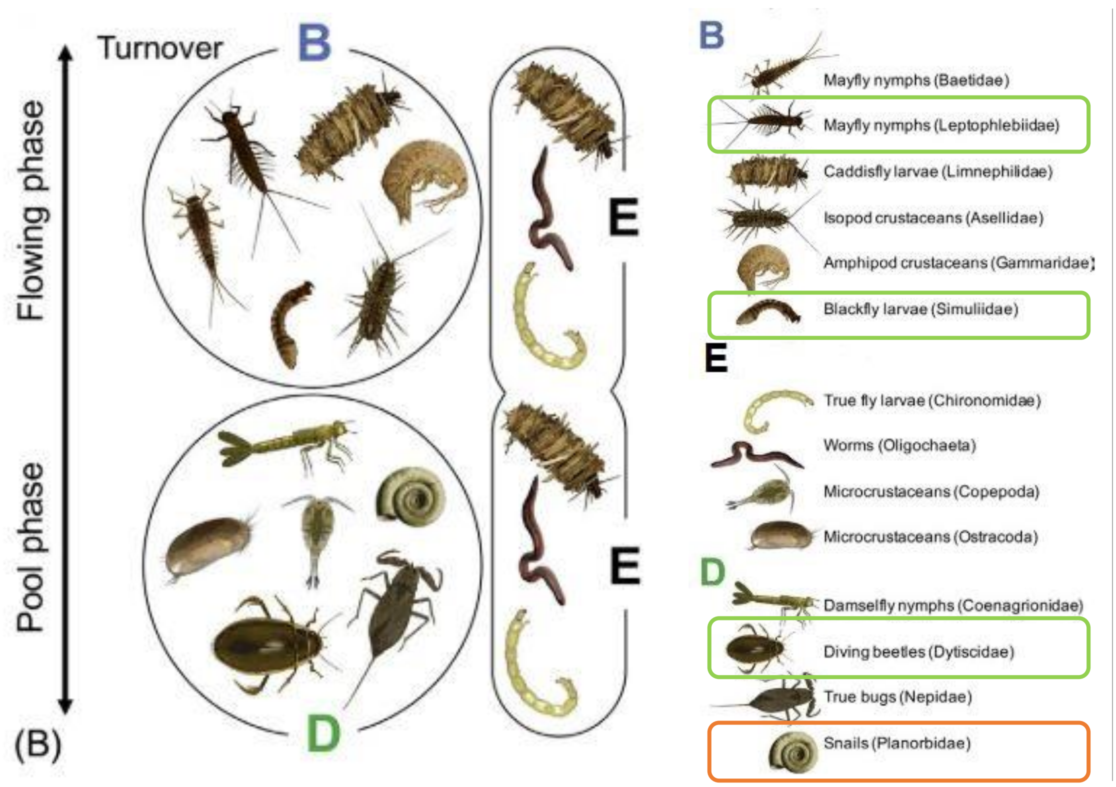

Figure 6 - Macroinvertebrate communities exhibit turnover as transition conditions between the flow (B) and pool (D) phases. Group E represents generalist bodies that adapt to the various conditions (adapted from Stubbington *et al.*

2017). Green are indicated for families found in wet period sampling (Sp19 and Sp20) and orange in dry period (Au19) in the present study.

3.3 Ecological Status

Table 6 shows the ecological status of each site sampled along Ribeira de Silveirinhos, for the three sampling periods (Sp19, Au19, Sp20). Ecological status is the result of the combination of the worst-rated parameter between physical and chemical parameters and biological parameters. Thus, it was found that the biological parameters, namely the benthic macroinvertebrates community, being the parameter with the worst classification and, therefore, the ecological status shows this classification.

A moderate ecological status was observed only in 3 situations while 9 samples showed a poor ecological status. Degradation of the waterline at RS_2 and RS_4 has been visible since spring 2019 with the assessment of a moderate ecological status (Sp19) to a poor ecological status (Au19 and Sp20). The low diversity and abundance recorded (Table 5) already demonstrated that ecological states would be of low quality.

Table 6 - Classification of physical and chemical parameters, classification of biological quality parameters and determination of the ecological status of each sampling point in the three moments of data collection, according to the WFD classes. The ecological status is determined based on the parameter with the worst classification between the parameters of general physical and chemical quality and the parameters of biological quality.

Sampling sites	Season	Physical and chemical parameters	Biological parameters	Ecological Status
RS_1	Sp19	Good	Poor	Poor
	Au19	No water		-
	Sp20	Good	Poor	Poor
RS_2	Sp19	Good	Moderate	Moderate
	Au19	No water		-
	Sp20	Good	Poor	Poor
RS_3	Sp19	Moderate	Poor	Poor
	Au19	No water		-
	Sp20	Good	Moderate	Moderate
RS_4	Sp19	Moderate	Moderate	Moderate
	Au19	Moderate	Poor	Poor
	Sp20	Moderate	Poor	Poor
RS_5	Sp19	Moderate	Poor	Poor
	Au19	Good	Poor	Poor
	Sp20	Good	Poor	Poor

3.4 Ecosystem services

After analyzing and treating the collected data, the improvement potentials corresponding to the landscape elements of each sampling site and an assessment of the river ecosystem were calculated. Both evaluations are the result of the CICES and COS2018 methodology applied in the three sampling periods (Sp19, Au19, Sp20). It should be noted that in the autumn sampling (Au19) the three sites upstream RS_1, RS_2 and RS_3 area absence of water flow, so it was not possible to assess the fluvial ecosystem in this period.

3.4.1 RS_1

Table 7 present the results of the ecosystem services evaluation for site RS_1. It shows that land use is characterized by landscape elements such as forests and surface water bodies, recorded in COS2018. The improvement potential for the forest is 26% and was recorded in the three sampling periods since no relevant changes in the structure and land use were recorded. The forest is dominated by eucalyptus, a fast growing species (Figure 7). Taking into account the biomass present in the area, the eucalyptus forest obtained a good evaluation regarding the provision services. However, the lack of floristic diversity leads to a deterioration of the regulation and maintenance services. Eucalyptus trees capture more resources than native trees, causing the decrease and quality of habitats and the ecosystem (Arntzen, 2015). The water bodies showed a low improvement potential, having been higher in Sp20 due to a lower flow and the presence of high turbidity. These characteristics disturbed the provision of regulation and maintenance services. In Au19 sampling, only the provision of services by the forests was evaluated due to the lack of water flow in this period. The total improvement potential is overvalued in the Au19 sampling compared to Sp19 and Sp20 by just considering a landscape element.

Table 7 - Assessment of ecosystem services provided in site RS_1.

Ecosystem services (CICES V5.1)		Types of landscape elements COS2018 (Level 1)						Total		
		Forests			Surface water bodies					
		Sp19	Au19	Sp20	Sp19	Au19	Sp20	Sp19	Au19	Sp20
Provisioning, Regulation and Maintenance and Cultural	Maximum evaluation	50	50	50	50	-	50	100	50	100
	Evaluation performed	37	37	37	47	-	45	84	37	82
	Improvement potential (%)	26	26	26	6	-	10	**16**	**26**	**18**

Figure 7 - Sampling site RS_1 merged by the monoculture of eucalyptus in Sp19, and Au19 with no water flow.

Regarding the evaluation of the river ecosystem, a higher improvement potential was observed, with an increase of the evaluation Sp19 (25.7%) to Sp20 (30.5%) (Table 8). In the Sp20 sampling, the riverbed and the water presented worse conditions, due to the high turbidity and the presence of the amount of debris. The dominance of eucalyptus monoculture means that it is not possible to establish and develop a healthy riparian corridor (Figure 7), an area of the stream with the greatest improvement potential.

In this sampling site and adjacent area, the effort must be applied in the introduction of native trees. This addition must be complemented by different species in order to guarantee variability and allow recovery of the riverbanks since there is not present a true riparian corridor.

Table 8 - Assessment of the river ecosystem at site RS_1.

River Ecosystem		Riverbanks Left	Riverbanks Right	Riverbed	Water	Total
Season	Maximum evaluation	30	30	20	25	105
Spring 2019	Evaluation performed	18	18	18	24	78
	Improvement potential (%)	40	40	10	4	**25.7**
Autumn 2019	Evaluation performed	-	-	-	-	-
	Improvement potential (%)	-	-	-	-	**-**
Spring 2020	Evaluation performed	18	18	17	20	73
	Improvement potential (%)	40	40	15	20	**30.5**

3.4.2 RS_2

At this sampling site, the land occupation was recorded as forest and surface water bodies. Table 9 and Figure 8 show that the site RS_2 is very similar to the one described above (RS_1). The difference recorded was, no deterioration in water body condition between the sampling periods. As for the services provided by the body of water, the lack of aquatic plants leads to poorer provision services. The forest remained the worst-rated landscape element, with an improvement potential of 26%. The forest biomass leads to provision services in better condition than those registered by the regulation and maintenance services, as described for the site RS_1. The total improvement potential recorded was 16% in the spring and 26% in the autumn.

Table 9 - Assessment of ecosystem services provided in site RS_2.

Ecosystem services (CICES V5.1)		**Types of landscape elements COS2018 (Level 1)**						Total		
		Forests			Surface water bodies					
		Sp19	Au19	Sp20	Sp19	Au19	Sp20	Sp19	Au19	Sp20
Provisioning, Regulation and Maintenance and Cultural	Maximum evaluation	50	50	50	50	-	50	100	50	100
	Evaluation performed	37	37	37	47	-	47	84	37	84
	Improvement potential (%)	26	26	26	6	**-**	6	**16**	**26**	**16**

Figure 8 - Sampling site RS_2 merged by the monoculture of eucalyptus in Sp19, and Au19 with no water flow.

Regarding the river ecosystem, an improvement potential of 29.5% in Sp19 and 30.5% in Sp20 was calculated (Table 10). In Sp20, the riverbed had some debris, responsible for the worst assessment. This evaluation was also reflected due to the lack of continuity in the riparian corridor and to a poor composition in riparian species (Figure 8), with an improvement potential of 43.3% for the riverbanks.

This site is dominated by a forest of eucalyptus and invasive species that makes it impossible to fix and develop a healthy riparian corridor. The recommendations on this site are similar to those on the upstream site, introducing native tree species and alternating with different species. It is also advisable to control invasive species (e.g. Acacias), which will contribute positively to the improvement of the site.

Table 10 - Assessment of the river ecosystem at site RS_2.

River Ecosystem		Riverbanks Left	Riverbanks Right	Riverbed	Water	Total
Season	Maximum evaluation	30	30	20	25	105
Spring 2019	Evaluation performed	17	17	16	24	74
	Improvement potential (%)	43.3	43.3	20	4	**29.5**
Autumn 2019	Evaluation performed	-	-	-	-	-
	Improvement potential (%)	-	-	-	-	**-**
Spring 2020	Evaluation performed	17	17	15	24	73
	Improvement potential (%)	43.3	43.3	25	4	**30.5**

3.4.3 RS_3

Table 11 shows the evaluation of the ecosystem services provided in site RS_3, where there are only two distinct landscape elements, forest, and surface water bodies. The type of land occupation with the highest improvement potential was the forest with a value of 24%. Eucalyptus monoculture was the predominant flora, but in this place, some species of ferns were already visible, in scattered spots (Figure 9). The water body recorded an improvement potential of 6% in Sp19 and of 8% in Sp20, due to the presence of a lower flow rate in this last sampling. These lead to less efficiency in the regulation and maintenance of the system. In the overall landscape, provision services are in a better state than regulation and maintenance services.

Table 11 - Assessment of ecosystem services provided in site RS_3.

Ecosystem services (CICES V5.1)		**Types of landscape elements COS2018 (Level 1)**						Total		
		Forests			Surface water bodies					
		Sp19	Au19	Sp20	Sp19	Au19	Sp20	Sp19	Au19	Sp20
Provisioning, Regulation and Maintenance and Cultural	Maximum evaluation	50	50	50	50	-	50	100	50	100
	Evaluation performed	38	38	38	47	-	46	85	38	84
	Improvement potential (%)	24	24	24	6	**-**	8	**15**	**24**	**16**

Figure 9 - Sampling site RS_3 in Sp19 and in Au19 with the existence of small pools of flow.

The assessment of the river ecosystem at this site was the same in the different sampling periods with a total improvement potential of 27.6% (Table 12). Once again, the potential of the riverbanks (40%) portrays the low quality, lack of diversity, and connectivity. From this site on, a brownish-yellow hue of water began to be noticed, coming from the runoff of iron water from the old mining operations. The hue and the presence of some turbidity are reflected in the recorded values.

As mitigation actions, it is proposed to introduce native trees, with larger species and a deeper root system introduced further away from the stream to stabilize the land, for example, poplar and common oak. In the area closest to the riverbed, preferably a mixture of riparian species, such as alders, willows, and elderberries in order to stabilize the margins and serve as a buffer zone for the runoff from the surrounding area.

Table 12 - Assessment of the river ecosystem at site RS_3.

River Ecosystem		Riverbanks Left	Riverbanks Right	Riverbed	Water	Total
Season	Maximum evaluation	30	30	20	25	105
Spring 2019	Evaluation performed	18	18	17	23	76
	Improvement potential (%)	40	40	15	8	**27.6**
Autumn 2019	Evaluation performed	-	-	-	-	-
	Improvement potential (%)	-	-	-	-	**-**
Spring 2020	Evaluation performed	18	18	17	23	76
	Improvement potential (%)	40	40	15	8	**27.6**

3.4.4 RS_4

In the fourth sampling site of Ribeira de Silveirinhos, three distinct elements are predominated of the landscape, forests, surface water bodies, and bushes (Figure 10). Among the three samplings, no relevant changes in the structure and occupation of the soil were observed, and the calculated improvement potential was 13% for all sampling periods (Table 13). The worst assessment was the eucalyptus forest (16%), an evaluation inferior to those recorded up to this point, which is justified by an increase of diversity of plant species around the stream. However, the regulation and maintenance services remain in a worse condition than the provision services. The surface water bodies have a brownish-yellow hue, characteristic of the area, which reduces the quality of the regulation and maintenance services at the site.

Table 13 - Assessment of ecosystem services provided in site RS_4.

Ecosystem services (CICES V5.1)		**Types of landscape elements COS2018 (Level 1)**									Total		
		Forests			Surface water bodies			Bushes					
		Sp 19	Au 19	Sp 20	Sp 19	Au 19	Sp 20	Sp 19	Au 19	Sp 20	Sp 19	Au 19	Sp 20
Provisioning, Regulation and Maintenance and Cultural	Maximum evaluation	50	50	50	50	50	50	50	50	50	150	150	150
	Evaluation performed	42	42	42	45	45	44	44	44	44	131	131	130
	Improvement potential (%)	16	16	16	10	10	12	12	12	12	**13**	**13**	**13**

Figure 10 - Sampling site RS_4 in Sp19 and Au19 showing the brownish-yellow hue.

Regarding the assessment of the river ecosystem, significant degradation was observed. In the Sp19 samples, the improvement potential was 33.3%, for Au19 it was 35.2% and for Sp20 it reached 39.1% (Table 14). The explanation lies in the artificialization of the banks that make a healthy riparian ecosystem impossible, with the right bank in worse condition compared to the left bank at the beginning of the sampling. In the Sp20 sampling, the left bank was more disturbed, reaching an equivalent improvement potential (43.3%). The riverbed had debris with an increase in the Sp20 sampling and the water in this site has a strong brownish-yellow hue and high turbidity values.

At this site, measures must be taken to promote biodiversity on the artificial margins. First, the exotic vegetation present must be cleaned and then rehabilitate the margins using natural materials and techniques such as live cuttings of native riparian species and with nutrient rolls (Wlodarczyk & Mascarenhas, 2016). The implementation of improvement measures on the riverbanks will be an asset, namely with the introduction of native tree and shrub vegetation, thus increasing the biodiversity of the place, and enabling it to regulate the chemical, physical and biological processes of the aquatic ecosystem more effectively.

Table 14 - Assessment of the river ecosystem at site RS_4.

River Ecosystem		Riverbanks Left	Riverbanks Right	Riverbed	Water	Total
Season	Maximum evaluation	30	30	20	25	105
Spring 2019	Evaluation performed	19	17	14	20	70
	Improvement potential (%)	36.7	43.3	30	20	**33.3**
Autumn 2019	Evaluation performed	19	17	14	18	68
	Improvement potential (%)	36.7	43.3	30	28	**35.2**
Spring 2020	Evaluation performed	17	17	12	18	64
	Improvement potential (%)	43.3	43.3	40	28	**39.1**

3.4.5 RS_5

Table 15 shows the results of ecosystem services provided by the elements of the landscape surrounding the site RS_5, namely forest, surface water bodies, and agriculture. The total improvement potential was 16%, with agriculture showing the highest improvement potential (20%) in the regulation and maintenance services. The agriculture observed in this site is entirely subsistence, so intervention is more difficult. The provision services are in a better condition than the regulation and maintenance services, as the surface water bodies in RS_5 show a brownish-yellow hue, and signs of anthropic pollution are visible (Figure 11). The deposition of residues is related to the presence of artificial territories in the place, such as houses, a bridge, and a road representing easier access to contamination by liquid and solid residues. The forest patch in this place is not very representative, and agriculture has the highest potential for improvement, accompanied by the assessment of surface waters concerning support and regulation services.

Table 15 - Assessment of ecosystem services provided in site RS_5.

Ecosystem services (CICES V5.1)		Types of landscape elements COS2018 (Level 1)									Total		
		Forests			Surface water bodies			Agriculture					
		Sp 19	Au 19	Sp 20	Sp 19	Au 19	Sp 20	Sp 19	Au 19	Sp 20	Sp 19	Au 19	Sp 20
Provisioning, Regulation and Maintenance and Cultural	Maximum evaluation	50	50	50	50	50	50	50	50	50	150	150	150
	Evaluation performed	44	44	44	42	42	42	40	40	40	126	126	126
	Improvement potential (%)	12	12	12	16	16	16	20	20	20	**16**	**16**	**16**

Figure 11 - Sampling site RS_5 in Sp19 and Au19, with the presence of subsistence agriculture, high artificialization of margins and pollution.

The assessment of the fluvial ecosystem did not change between sampling periods, with an improvement potential of 52.4% being calculated, the highest values recorded of all sites (Table 16). The main reason for this assessment is the high artificialization of the margins, which consequently leads to low quality of the riparian corridor. Then the riverbed in this location had a low heterogeneous substrate and a lot of debris. The water, beyond the brownish-yellow hue, showed a lot of turbidity, which reduces the effectiveness of its regulation and maintenance services

At this site, it is suggested to raise people's awareness of the practice of more sustainable agriculture, limiting and controlling the use of fertilizers. There must also be an inspection of any effluent discharge points taking into account the proximity of urbanized areas. The improvement of margins with shrub species may be a measure to guarantee the filtration of runoff from the surrounding agricultural land.

Table 16 - Assessment of the river ecosystem at site RS_5.

River Ecosystem		Riverbanks Left	Riverbanks Right	Riverbed	Water	Total
Season	Maximum evaluation	30	30	20	25	105
Spring 2019	Evaluation performed	11	12	11	16	50
	Improvement potential (%)	63.3	60	45	36	**52.4**
Autumn 2019	Evaluation performed	11	12	11	16	50
	Improvement potential (%)	63.3	60	45	36	**52.4**
Spring 2020	Evaluation performed	11	12	11	16	50
	Improvement potential (%)	63.3	60	45	36	**52.4**

Ribeira de Silveirinhos presents a low diversity of land use types with only four types of soil present throughout the watercourse (forests, surface water bodies, bushes, and agriculture). Eucalyptus monoculture and the presence of invasive species are the main cause of the lack of good regulation and maintenance services in the studied sites. This monoculture causes the decrease and quality of habitats and there is a reduction in the rate of decomposition of its leaves, which are poorer in nutrients (nitrogen and phosphorus), which limits the performance of decomposers (Feio & Ferreira, 2019). Several studies already demonstrate the feasibility of establishing a mixture with eucalyptus and native tree species, representing advantages in forest and landscape restoration as well as in the ecosystem services provided (e.g. Amazonas et al., 2018). Also, the railway runoff along the stream, despite being a local characteristic, negatively influences the conditions evaluated and consequently the water quality. The result of these factors is degraded habitats with low diversity. Koch (2018), in a study to evaluate the landscape basins of the PSeP rivers, already demonstrated the great improvement potential of the ecosystem, with the need for intervention in the entire watercourse. The cultural services evaluated in this area did not show relevant improvement potentials. However, it is proposed to introduce native species throughout the study area, and it was interesting to accompany it with ecological information on the pedestrian paths for the public.

Intermittence of water flow, in addition to having effects on biodiversity, affects ecological functions in ecosystems. Datry et al. (2018) developed a conceptual model on ecosystem services provided during the different hydrological phases in most intermittent rivers (flow, pools, and drought). Also adopting CICES' logistics, they determined that in the flow phase the services provided are similar to those of a perennial river. However, when pools are recorded, the provisioning and, regulation and maintenance services are completely changed and lost when it dries. Services involving biota, such as bioremediation, are specially altered by the effects of intermittency, resulting in water quality problems (Datry et al., 2018). However, it is not possible to compare these results with those obtained in this work because there was no evaluation of the surface water bodies when it was in a drying period, due to difficulties in the correct assessment. Moreover, it is important to note that the desiccation of the river also affects the provision of services for the surrounding land occupations and that this has been taken into account, as detrimental to the provision of services, especially those of regulation and maintenance.

In summary, Figure 12 shows the improvement potentials for the ecosystem services (A) and river ecosystems (B) in the sampling sites along the sampling periods. It should be noted that in the Au19 samples at sites RS_1, RS_2, and RS_3 there is an overvaluation due to the assessment of only one landscape element. However, the improvement potential for the ecosystem services remains stable along the route and the improvement potential for river ecosystems is increasing in the downstream direction. This increase is due to the proximity of areas with high anthropic intervention, which ecologically affects the area, especially concerning the status of the riverbanks.

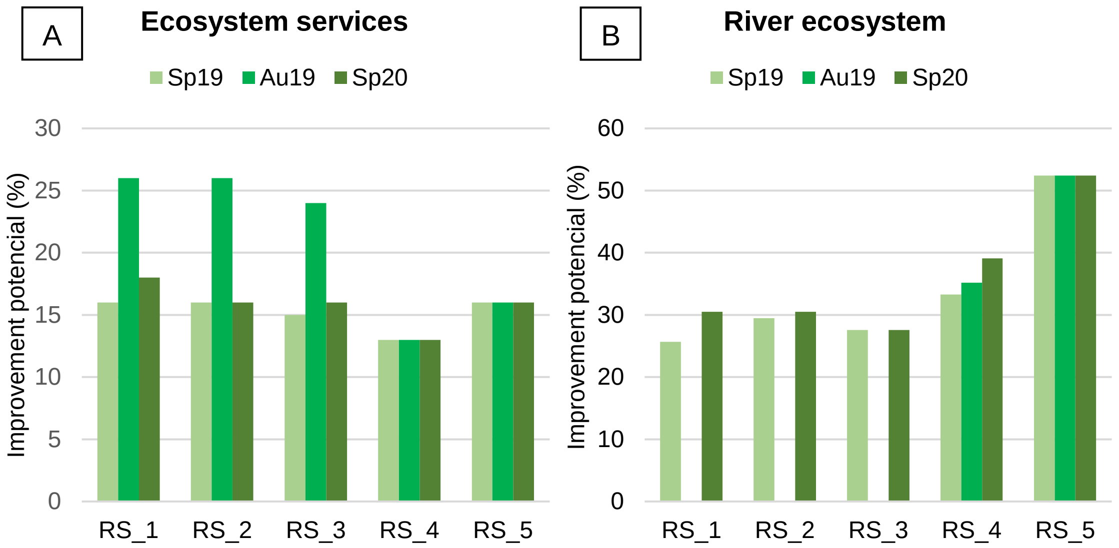

Figure 12 - Results of the improvement potentials (%), for Sp19, Au19 and Sp20 at each sampling site. The graph on the left (A) shows the assessment of the services provided by the landscape elements signalled at the locations. The graph on the right (B) shows the assessment of the river ecosystem.

4. Conclusions

The results of this work allowed us to draw some conclusions about the ecological quality of Ribeira de Silveirinhos. According to the WFD methodology, for lotic systems, and the assessment of the physical and chemical parameters as well as the benthic macroinvertebrate communities, the conclusion is that the entire stream needs interventions to improve its ecological status and thus achieve at least the classification of "good". However, it was found that the community of macroinvertebrates in intermittent rivers has high structural variability. Mechanisms of resistance and resilience allow species and communities to persist in intermittent rivers during the dry phases and recolonize quickly once the flow returns. As for the techniques for characterizing and assessing ecosystem services and the river ecosystem of Ribeira de Silveirinhos, despite being subjective (high dependence of the observer), they provide important information based on *in situ* analysis, with more detailed and real information. What is verified is a lack of diversity in the PSeP area, which diminishes the quality of the ecosystem services and does not allow it to reach the real potential of the area.

The different tools used in this study, although they have proven to be effective in assessing water systems, were not created to assess intermittent rivers. Indeed, evaluation models targeted to assess intermittent rivers are scarce, namely taking into account their temporal variability and peculiar ecology. Nowadays, where we face the challenge of climate change with the greatest occurrence of extreme events, and rivers as fragile ecosystems are susceptible to several threats. According to this, as it is expected that the number of intermittent rivers will increase worldwide, especially in regions where severe climatic droughts occur. In order to achieve a better recovery of these ecosystems, it is suggested to reduce the area occupied by forest of invasive species and eucalyptus, using for example the removal of the outer bark. This technique will make it impossible for the water to flow in the stem, maintaining good soil fixation, acting as a precautionary agent in high rainfall events. Restoration of riverside vegetation is essential, as its loss has effects on the structures of aquatic food webs, reducing specific diversity.

Future works to continue the scientific researches on these types of ecosystems, to better understand their ecological standards and their functioning are necessary. In order to find an adequate assessment for the ecological classification of intermittent rivers and, consequently, their conservation and better management.

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