water

MDPI

Review

Solutions Based on Nature to Face Water Stress: Lessons from the Past and Present

Daniel O. Suman [1,*], Manuela Morais [2] and Carlos Hiroo Saito [3]

[1] Department of Environmental Science and Policy, Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA
[2] Laboratory of Water, School of Sciences and Technologies, University of Évora, Parque Industrial e Tecnológico, R. da Barba Rala No. 1, 7005-345 Évora, Portugal; mmorais@uevora.pt
[3] Center for Sustainable Development, Department of Ecology, Institute of Biological Sciences, University of Brasilia, Campus Universitário Asa Norte, Brasilia 70910-900, DF, Brazil; carlos.h.saito@hotmail.com
* Correspondence: dsuman@earth.miami.edu; Tel.: +1-305-742-8762

Abstract: Nature-based solutions (NbS) to water scarcity, environmental degradation, climate change, and biodiversity losses are enjoying increasing implementation throughout the world. This manuscript reviews three case studies from Brazil, Panama, and Portugal that illustrate NbS and searches for commonalities that may assist their usefulness in new sites. The Tijuca Forest in Rio de Janeiro is a remarkable story of centuries of forest management and restoration that initially aimed at providing water security for the capital of the country during the XIX Century while it was still a monarchy. Today, it is recognized as a UNESCO World Heritage Site. The Panama Canal Watershed produces water for canal operations, electricity generation, and drinking water for half the country's population. Traditional water mills and weirs near streams in the Alentejo Region, Portugal, have largely been abandoned due to the damming of the Guadiana River. Yet today, weirs are increasingly recognized for their important contribution to water provisioning in this dry region. All have a primary goal related to water provisioning, yet their ecosystem benefits are multiple. The cases offer important lessons for adaptation to climate change, cultural benefits from traditional human activities, and concerns about social equity.

Keywords: ecosystem restoration; watershed management; nature-based solutions; reforestation; weirs; governance; Tijuca Forest; Rio de Janeiro; Panama Canal; Alentejo Region; Portugal

Citation: Suman, D.O.; Morais, M.; Saito, C.H. Solutions Based on Nature to Face Water Stress: Lessons from the Past and Present. *Water* **2024**, *16*, 2301. https://doi.org/10.3390/w16162301

Academic Editors: Barry T. Hart and Avi Ostfeld

Received: 1 July 2024
Revised: 8 August 2024
Accepted: 12 August 2024
Published: 15 August 2024

1. Introduction

In recent decades freshwater scarcity has been increasingly recognized as a global systemic risk and elevated to the center of global concern [1]. The fact that the theme of World Water Day 2007 was "Coping with Water Scarcity" illustrates this [2].

Although water scarcity often has its roots in water shortage, there are several ways of defining water scarcity, so it can be considered a relative concept. Scarcity can occur at any level of supply or demand because of the lack of correspondence between availability and demand, or it can be related to access or the expected water quality related to the increasing degradation of groundwater and surface water [3]. Temporal or geographical imbalances between availability and demand are largely responsible for water scarcity [4,5] because these can generate conflicts between water users. The imbalance between the forcing drivers relative to demand (high population growth and economic development) on the one hand and the forcing drivers relative to availability (droughts and wide climate variability) on the other, can make this water scarcity dramatically real and acute. Thus, spatial and temporal considerations are important determinants of water scarcity, and therefore, to water security [6]. A feature of any "desirable" water-secure future must be the existence of healthy ecosystems, which require water to maintain the life of these ecosystems [7].

Usually, coupled water scarcity and water availability are analyzed by considering surface water because surface fresh water is the most readily available resource to meet water demands and, thus, is considered the first indicative of blue-water availability [8]. Nevertheless, considering a systemic view of water (its whole cycle and flows), it is necessary to consider the interdependence between blue and green water and how the entire landscape can help to produce and maintain water [9]. Water is essential for maintaining the ecological integrity of aquatic and terrestrial ecosystems, as well as for providing the quality that allows for the subsistence and well-being of the human beings who depend on these ecosystems [10]. However, the use of water resources has already exceeded the alarm level in many regions of the world [11], resulting in the decline of the water table [12,13], degradation of aquatic ecosystems [14], and losses of wetlands [15–17]. Furthermore, the impacts of climate change, which result in changes in abiotic factors, such as precipitation and temperature levels, affect species and biological populations and how they interact with other organisms and their habitats, which alters the structure and function of ecosystems and the goods and services that natural systems provide to society [18]. In addition to insufficient water quantity, water pollution also aggravates local water-scarcity risks. These phenomena can be exacerbated when they occur in regions with few water resources or where water resources are poorly managed, resulting in imbalances between the demand for water and the supply capacity of the natural system [19].

The ecological concepts of sources, sinks, and recycling can help to provide a useful understanding of water basins, water cycles, and flows [20]. When considering the systemic view, applied not only for the elements in a structural perspective of landscapes [21] but for the entire process and feedback controls, we can see not only that healthy ecosystems need water but also that healthy ecosystems can produce water [22]. In other words, water should absolutely be considered connected to the landscape where it runs. The way to recover water should rely on nature-based solutions [23–25].

This paper reflects on the role of ecosystems in water production and conservation and how this systemic approach to water conservation can be improved by analyzing past experiences as supportive lessons, similar to the way ancient urban facilities could inspire us to harvest water in cities in water-scarce regions [26]. Examples from different areas of the world illustrate the long existence of what are presently named "nature-based solutions" (NbS).

2. The Nature-Based Solutions and Water Security

Nature-based solutions (NbS) are defined as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [27]. The NbS concept aims at highlighting positive outcomes for society (so-called 'solution') as a gift offered or promoted by nature if we consider and respect its flows and chains. It may present some overlap with other concepts used to propose ecosystem management for societal benefits, such as ecological engineering, green/blue infrastructure, ecosystem approach, ecosystem-based adaptation/mitigation, ecosystem services approach, or natural capital [28]. NbS can be an important strategy to increase water security supported by a systemic approach that considers water security as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, ensuring protection against waterborne pollution and water-related disasters, and preserving ecosystems in a climate of peace and political stability" [29]. Scott et al. [30] (p. 281) present a different definition that is more ecosystem-based and adds a perspective of resilience: "Water security constitutes the sustainable availability of adequate quantities and qualities of water for resilient societies and ecosystems in the face of uncertain global change". Stable and resilient ecosystems can reduce uncertainty, enhance overall water security by improving both water availability and quality, prevent water-related disasters, and achieve increased water-body resilience to climate change [31]. Ecosystem restoration in Iceland presented positive results on runoff dynamics and flood prevention, addressing a decrease in high discharge peaks and a reduction of erosion rates in the rivers due to the lower soil erodibility [23]. In China, a mangrove landscape restoration and protection project in the Fengxinglong Ecological Park at the junction of the Sanya and Linchun Rivers provided a reduction of shoreline erosion while water was being purified [32]. The contributions of mangrove forests and salt marshes to a reduction of flooding in deltas throughout the world are well documented [33]. Additionally, ecosystem restoration of mangroves provides greater carbon sequestration benefits than afforestation for mitigating global climate change [34].

Vegetation–water interdependencies should be considered because vegetation influences water recycling from local to continental scales. Within this coupled system, tropical trees extract deep soil water and pump it into the atmosphere, circulating water through evapotranspiration to precipitation processes [35]. Vegetation should be regarded as a water 'recycler' [31], illustrating the interdependence between green and blue water [9].

NbS can offer the main or only viable solution in each particular context, facing challenges that gray infrastructure cannot address (due to aging or inadequacies with respect to climate change). For example, the third Rhone River Correction Project in the canton of Valais, Switzerland, aims to return space to the floodplain that had been eliminated. After recognizing that the past interventions in that river were incapable of flood and disaster prevention, authorities decided to widen the river corridor, creating additional space for the river to improve the landscape and biological diversity and restore the ecological functions of the river and the natural dynamics of the ecosystem as much as possible [36]. By embedding an ecosystem services approach, NbS can represent innovative solutions within the principles and practice of integrated water resources management (IWRM), leading to water resilience and improving people's livelihoods.

The following sections describe three cases of NbS implementation from Brazil, Panama, and Portugal. Subsequently, we comment on what these experiences can teach us today, as we aim for a sustainable future where ecosystem services can be fully provided under an ecocentric framework.

3. Some Nature-Based Solution Case Studies

The three case studies whose sites are shown in Figure 1 represent different continents (Europe, North America, and South America), latitudes, and climatic regimes. Together, they illustrate that NbSs have applicability in diverse ecosystems and climatic regions and suggest lessons that can be appropriate to other interventions throughout the world.

Figure 1. Map of the three case studies discussed in this manuscript.

3.1. The Forest Landscape Restoration in Tijuca Tropical Rain Forest, Brazil

"Rio de Janeiro's Carioca Landscapes between the Mountain and the Sea (Brazil)" was inscribed on UNESCO's World Heritage List in 2012 (Figure 2). According to UNESCO's Decision 36 COM 8B.42, an outstanding contributing factor was that "*the mountains and open green areas of the Tijuca National Park, together with Corcovado and the hills around the Guanabara Bay still retain a similar combination of forest and open observation points as at the time of colonization and allow access to vistas of the city from many high vantage points that demonstrate very clearly the extraordinary fusion between culture and nature in the way the city has developed*". The Tijuca Forest, the core landscape of this set that impressed UNESCO, remains less than twenty kilometers from the city center, occupying a large area of land on the southern slopes of the Tijuca and Papagaio peaks, encompassing the Alto da Boa Vista and the Pedra do Conde [37].

Figure 2. Rio de Janeiro's Carioca Landscapes between the mountain and the sea (Photo, Keyko Carolina Saito).

Presently, the Tijuca Forest belongs to a protected area, the Tijuca National Park (22°55′–23°00′ S, 43°11′–43°19′ W), with a total of 39.51 km^2 of Atlantic Forest biome containing rich biodiversity, including several endangered fauna species, among others, the margay (*Leopardus wiedii*), the brown howler monkey (*Alouatta guariba*), and the endemic frog *Thoropa lutzi* [38–40]. Additionally, this protected area has a total of 254 taxa recorded among ferns and lycophytes, with seven species identified as endangered, including *Anemia blechnoides*, *Lytoneuron tijucanum*, *Pteris congesta*, *Anemia gardneri*, *Asplenium cariocanum*, *Doryopteris rediviva*, and *Lytoneuron quinquelobatum* [41]. The mountainous and rugged terrain includes Pico da Tijuca, Corcovado, and Pedra da Gávea, the last, considered to be the largest seaside monolith in the world. The Park presents a unique natural beauty, contrasting the green of the forest with the ancient rocky surfaces and the sea. The rocks that form the mountains of Tijuca National Park are aged around 1.7 billion years. The park's climate, due to the geographic orientation of the Tijuca Massif, presents abundant rainfall, with no dry period in winter. The annual precipitation typically varies from 2000 to 2500 mm, although 3300 mm can be reached in exceptionally rainy years [38].

Sites located up to 500 m high have a humid tropical climate (Aw type in the Köppen classification, with mean monthly temperatures varying from 25 °C in February to 19 °C in June, and an annual mean temperature of about 22 °C [38]. Meanwhile, above this altitude, temperate conditions occur. The hydrography of Tijuca National Park is quite extensive, with several small streams (Maracanã, Carioca, Cachoeira, and das Almas, among others, with very modest water flow [42]). It is estimated that 20% of the total average annual rainfall is absorbed by the preserved tropical rainforest, with the help of the leaf litter and its associated biogenic activity on the top of the soil, which provides high infiltration rates and storage of rainwater in the soil (Figure 3). Due to these roles of the forest cover, only 30% of the precipitation converges into the river channels during the rainy periods, resulting in modest flow, but with a perennial supply of basic river discharges [43]. Several waterfalls are also present, the most famous being the Cascatinha Taunay.

Figure 3. Atlantic Forest biome, Brazil, with its structure of intercepting and infiltrating rainfall (Photo, Carlos Hiroo Saito).

Today's impressive landscape resulted from an enormous effort to restore the tropical rainforest. In fact, the Tijuca Forest is a replanted tropical forest, resulting from pioneering reforestation experiences with native species and forest and watershed management started in the 19th century. Initially, it aimed to provide water security for Rio de Janeiro, the capital of colonial Brazil, which continued as the capital of the Brazilian Empire after the independence proclamation in 1822 and as the capital of the Republic of Brazil from 1989 to the mid-20th century.

The forest remained intact throughout almost the entire 18th century, as land squatters that supplied the city with food were restricted to the edge of the urban area on land where the new city would later emerge. The location preferences of peasants probably were guided by the abundance of water for food production.

In the second half of the 18th century, coffee plantations emerged in Rio de Janeiro and quickly spread around the hills surrounding the city, due to favorable local climate conditions and soil. However, by the beginning of the 19th century, the abandoned coffee farms and eroded slopes resulted in severe environmental degradation. From 1817 to 1818, Dom João VI, King of the United Kingdom of Portugal, Brazil, and the Algarves, and still living in Brazil, issued orders to (1) stop the forest devastation in the springs near the city; (2) plant trees next to the springs of some rivers; and (3) carry out assessments allowing the government to expropriate areas with springs and place them under protection. These measures were not effective and had only a modest implementation.

It is important to note the main source of freshwater in the region was the small rivers and streams that flowed from the hills surrounding Guanabara Bay because there were no large rivers nearby. Additionally, the wells in the lower regions around the bay were almost always subject to the intrusion of brackish water. The degraded hills, due to coffee plantations, put the provision of drinking water in Rio de Janeiro at risk, aggravated by the severe droughts in the empire's capital (now an independent country from Portugal) during the second quarter of the 19th century (particularly 1824, 1829, 1833, and 1844). The Brazilian Emperor at that time (Dom Pedro II), was cognizant of the relationship between land use and water availability, as well as the importance of vegetation to produce a continuous supply of water [44].

It took more than ten years for the government to implement appropriate land purchases, and several more to initiate forest management practices. From 1862 to 1874, Major Manuel Gomes Archer, the designated forest manager, implemented an extensive reforestation process, working personally with a few slaves and following the following criteria of prioritizing some slopes more threatened by erosion and areas for restoring the water flow of rivers and streams; employing seedlings, in opposition to seeds or already grown young trees; and using apparently random combinations of species, based on personal knowledge of the distribution and incidence of the species in the region's original forests [41]. During this 13-year period, over 60,000 trees were planted, with a survival rate of around 80 percent [37]. In his last report, written in 1874, Major Archer concluded that all stream sources with restored vegetation had released more water or remained at a stable level compared to the same period before 1862 [42]. After Major Archer, Baron d'Escragnolle continued reforestation and, additionally, began landscaping work for beautification purposes, aimed at public use and contemplation. Under the coordination of the renowned French landscaper Auguste Glaziou, the forest received corners, leisure areas, fountains, and lakes.

In the 19th century, capturing water from the Tijuca National Park became a strategic activity that was essential for supplying the city's water supply. At the end of that century, a complete network of small dams was established, capturing water from several rivers in the park. After many years of relative abandonment, the 1940s saw a revitalization of the Tijuca Forest, under the leadership of Raymundo Ottoni de Castro Maya, with the opening of restaurants and the consolidation of internal roads and landscape projects by Roberto Burle Marx.

Finally, in 1961, the area of the Tijuca Massif gained the status of a protected area under the name of the Rio de Janeiro National Park, with 33 km^2, changing its name to the present one (Tijuca National Park) on 8 February 1967. On 4 July 2004, a Federal Decree expanded the Park's limits to the present extension of 39.51 km^2, incorporating locations such as Parque Lage, Serra dos Pretos Forros, and Morro da Covanca. Today Tijuca National Park is considered the largest urban park in the world and leads park visits in Brazil (more than 4 million visitors in 2023).

The success of reforestation activities in the past led to the present UNESCO's recognition of landscape value. In addition to the original central target ecosystem service of water security, the entire ecosystem has benefited, supporting today's high biodiversity and offering social opportunities for leisure and climate regulation for residents. This example shows how an NbS can jointly deliver a group of ecosystem services, even when it initially targeted only one.

3.2. Panama Canal Watershed

The 82 km long Panama Canal is one of the world's major shipping routes. Approximately 4% of global maritime trade (about 14,000 transits annually) passes through the canal, with primary routes to and from East Asia and the east coast of the USA, as well as Europe to East Asia and the west coast of the Americas. The canal also contributes about USD 2.5 billion annually to the Panamanian treasury or about 3% of the nation's GDP. The direct contributions of the Panama Canal Authority to the National Treasury were USD 2.08 billion in 2021 or about 3.1% of the country's GDP in that year [45,46]. The Panama Canal Authority (ACP) (referred to today simply as "Canal de Panamá") operates the canal, governed by its organic law that guarantees a significant degree of autonomy by the National Constitution and requires that the ACP lead the coordination with other institutions with sectoral authority in the canal area. The canal operates with a series of locks that raise and lower vessels from the ocean to the freshwater Lake Gatun, which was created by damming the Chagres River over a century ago. Ocean-going vessels travel 33 km through Lake Gatun before being lowered to the other ocean through another series of locks. In 1935 an additional dam was constructed upstream on the Chagres River to provide additional water security for canal operations—resulting in the formation of Lake Alajuela (Figure 4).

Figure 4. Map of the Panama Canal Watershed showing the canal and Gatun and Alajuela Lakes and protected areas (in color). (Source: https://pancanal.com/; https://es.m.wikipedia.org/wiki/Archivo:Areas_protegidas_de_la_cuenca_hidrografica_de_panama.jpg#globalusage accessed on 13 August 2024).

After more than a century of operations with the original locks, in 2016, the ACP completed a major project that constructed wider locks handling larger Neopanamax vessels. Unlike the original locks that release some 200 million liters of water to the ocean during each transit, the new locks have the capability of incorporating water reuse chambers resulting in less water per transit. The ACP claims that this water recycling saves the equivalent water used in six daily transits [47]. Nevertheless, since 2019, the recycling chambers have not been used consistently, and as a result, water use for canal operations is higher than ever [48]. Water recycling has important potential because climate-change predictions for Panama suggest that precipitation may decrease by about 10% over current values in the coming decades [49,50]. The canal watershed has experienced significant droughts in recent years (partially explained by strong El Niño events predicted to be more extreme with climate change) that have led the ACP to reduce transits by one-third in 2023–2024 [51]. The 2023 season was the third driest in the history of the canal watershed, with 30% less precipitation than expected, and as a result, the canal's reservoirs only could store about half of the normal water volume [52]. Normally, some 36–39 vessels transit the canal daily. However, in 2023, the ACP was forced to reduce daily transits to 22 [53]. Low water flows during the 5-month dry season (January to May) compounded with strong El Niño events in 1982–1983 and 1997–1998 also resulted in major decreases in canal transits.

Additionally, Lake Gatun and Lake Alajuela are also the source of drinking water for about 2 million residents of Panama City and Colon (about half of the country's population). The lower water levels in the canal reservoirs resulted in decreased supplies of potable water to metropolitan areas in 2023–2024 [54]. Added to the decrease in precipitation in the canal watershed from climate change, the increasing water demands from growing urban populations (the population of metropolitan Panama City increased from 1,216,000 to 2,016,000 persons between 2000 and 2024 [55].), and the land-use changes resulting from the deforestation of the canal's watershed have increased the vulnerability of future operations of the canal.

The Panamanian Government's policy until the 1980s promoted the "conquest of the jungle" and encouraged small farmers to colonize forested lands and convert them to pasture for cattle ranching and the cultivation of crops [56]. Wadsworth [57] compared maps from 1952 and 1978 and concluded that, during this period, about 30% of the watershed had been deforested. Other studies note that, between 1974 and 1991, the canal watershed lost about 43% of its forests to urbanization, cattle ranching, and crop cultivation [58,59]. Constructed and administered by the United States, the Panama Canal and the colonial Canal Zone began a period of gradual transition to Panamanian control with the signing of the Panama Canal Treaties in 1976, resulting in complete Panamanian administration at the close of the century. During this transition period, the binational canal administration increasingly recognized the importance of protecting the watershed of the Chagres River to guarantee the water supply for canal operations. A new environmental ethic based on the importance of canal operations developed during the administrative transition of the canal. Perspectives of scientists, canal administrators, environmentalists, and politicians coalesced around recognition of the importance of the canal's watershed and the green forest infrastructure that provided water for the canal's operations [56]. Additional concerns focused on the increased sedimentation in the two lakes caused by the erosion of deforested lands in the watershed. To this end, Panama created Chagres National Park in 1984 to protect the upper watershed of the Chagres River, and the efforts of today's ACP and the Ministry of the Environment have significantly reduced deforestation within the park boundaries. At the same time, the creation of the national park created adverse impacts on the thousands of small farmers who live inside the boundaries of the protected area and are limited in the land that they can farm using shifting agricultural techniques.

The passage of Law 19 in 1997, which created the Panama Canal Authority, increased efforts to protect the watershed. The ACP adopted its regulation (Agreement 116) formalizing its environmental and watershed management responsibilities [60]. The formal canal watershed, as defined by the ACP, consists of 343,521 ha covering seven political districts, or about 4.5% of the national territory. The average annual precipitation in the canal watershed ranges from 2500 to 4000 mm, with higher values in the primary tropical forest of Chagres National Park [61]. Some 127,326 ha lie on the western side of the canal (37.08% of the watershed). Much of the land on the canal's western flank has been deforested and today is grassland for cattle ranching. Three national parks (Chagres, Soberanía, and Camino de Cruces) account for much of the land on the 216,195 ha on the eastern side of the canal, and indeed, some two-thirds of the forested lands in the watershed [62]. Although urbanization and agricultural expansion have accounted for land conversion on the eastern side of the canal, the land degradation is more extreme on the western portion of the canal's watershed.

Recognizing the importance of wise land use on the watershed, the ACP has embarked on significant efforts during the past 20 years, particularly in the lands on the western bank of the canal which have seen 75% of ACP's investment in reforestation and sustainable agricultural activities (Martinez, R., personal communication, 10 June 2024). One of the initial incentives to promote both environmental and social sustainability was a cooperative program of the ACP and ANATI (National Land Titling Authority) to survey land holdings and grant land titles to small farmers. Formal titles created legal security for small farmers and set the foundation for further support from the ACP. By 2023, more than 10,000 land titles had been registered, largely in the Capira District in the western portion of the canal's watershed [51]. The ACP has created six watershed committees and 26 local committees of locally elected members to facilitate ACP watershed management efforts and convey community needs and concerns to the ACP [51].

ACP's efforts have been channeled through its Program of Environmental Economic Incentives (PIEA), which began in 2010 with the aim of fostering sustainable land uses and forest protection, thus providing water resources for canal operations and drinking water for half of Panama's population. Interventions in rural areas, described below, improve environmental conditions and the livelihoods of rural residents, income for families, and employment. PIEA activities have been concentrated in the watersheds of the Cirí–Trinidad Rivers in the extreme western area of the canal watershed.

Reforestation for conservation and commercial purposes is one major PIEA project. Establishing vegetative protective cover helps increase dry-season water flows into Lake Gatun and avoids sedimentation of the lake reservoirs and associated dredging costs [63,64]. By the end of 2021, over 3000 ha had been reforested, with the planting of 790,000 trees. Over 1200 small- and medium-sized agricultural producers have benefited in Capira, Colón, and La Chorrera Districts. These benefits include shade for crops, wind breaks, soil improvement, water conservation (quantity and quality), increased water infiltration and reduction of erosion and sedimentation, carbon fixation, and support for biodiversity. The ACP also utilizes payments for environmental services (PES) as incentives to maintain the existing forested lands in the canal watershed. The ACP approved regulations formalizing PES application in 2018 [65]. By 2023, over 400 private owners of some 5150 ha of existing forested lands have received financial benefits (about USD 100/ha/yr) under this program [51,66].

PIEA has generated significant support for agroforestry projects—including planting coffee, cacao, and fruit trees. The ACP supported the creation in 2012 of the Asociación de Productores de Café de la Subcuenca de Ríos Cirí Grande y Trinidad (ACACPA) to support sustainable and environmentally friendly production and commercialization of coffee [67]. Shade-grown coffee farms have replaced the deforested lands used for cattle ranching (Figures 5 and 6). ACP incentives include support for plantation establishment and payment for farmers' work for the initial year; provision of materials, tools, and fertilizer; and technical support for an additional two years as the coffee farms become sustainable. ACACPA's 90 members successfully planted some 4000 ha of shade-grown, organic robusta coffee by the end of 2021. Panama's Ministry of Commerce and Industry recognized the trademark of "Cuencafé" in 2018, and today, it is sold as a whole bean or ground.

Figure 5. Shade-grown coffee berries in the Panama Canal Watershed (Photo, Jorge Muñoz).

Additional PIEA efforts focus on improved agricultural practices to reduce soil erosion (and sedimentation of the canal's reservoirs), increase yields, and improve farmers' livelihoods. Interventions include the promotion of improved grasses for pasture, planting of riparian buffers, living fences, planting of trees in pastures, cattle crossings of streams to avoid erosion, crop rotation, and organic fertilizers.

Figure 6. Shade-grown coffee bushes in the Panama Canal Watershed (Photo, Jorge Muñoz).

The ACP recognizes the close relationship between wise land use in the canal's watershed to guarantee sustainable flows of water for canal operations and provision of potable water for half of Panama's population while simultaneously supporting the livelihoods of thousands of small farmers who reside in the canal watershed. Will the ACP's impressive efforts be sufficient to guarantee sufficient water for these multiple needs in the future? Additional areas of action must include water-conservation measures by all users, a revision of water pricing, repair and update of potable water infrastructure to minimize water losses, continual use of the water-recirculating chambers in the Neopanamax locks, and increased reforestation of the canal watershed. The current discussion surrounds the possible extension of the canal's legal watershed to the west with the diversion of water from the Río Indio or to the east with a transfer of water from the reservoir of the Bayano River [68,69]. Water for the canal is clearly a primary national objective for Panama. The future portends growing conflicts among watershed stakeholders over the use of increasingly scarce water [19]. We believe that reforestation efforts in the existing canal watershed should be prioritized and enhanced before diverting water from adjacent watersheds, which would lead to significant adverse social and environmental impacts.

3.3. The Ancient Weirs in Riverbeds—Alentejo Region, Southern Portugal

The Alentejo is Portugal's largest region (Figure 7). However, despite occupying around one-third of the national territory (31,551 km^2), it is characterized by an aging and poorly qualified population, with a low capacity to attract young people. Its gross domestic product (GDP) per capita is below the national average. This region has the highest rate of desertification and the lowest population density in Portugal (5% of the national population) [70].

Historically, the main sector of economic activity in Alentejo has been extensive agriculture and livestock farming—well adapted to climatic and environmental conditions [70,71]. The rural population is traditionally linked to the valorization of the natural heritage in a territory with high biodiversity and many endemic species of conservation interest. However, today, the structure of this territory is potentially threatened by increasing changes in land use, with the progressive replacement of traditional extensive agriculture by intensive irrigated agriculture [72,73]. This production model emerged on a large scale after the 2002 construction of the Alqueva Dam, mainly due to a long-standing public investment in the Alqueva irrigation system [48]. The project, with a long history (the first Alentejo Irrigation Plan dates from 1957), was designed to supply water to Portugal's driest region, which is most prone to water scarcity and physical and human desertification processes [74,75].

Figure 7. Location in red of the Alentejo Region in Portugal (38°34′0.12″ N; 7°54′0″ W) (https://en.wikipedia.org/wiki/Alentejo_Region accessed on 13 August 2024).

The Alentejo's typical Mediterranean climate is characterized by warm and dry summers and cool and wet winters. The mean annual air temperature is around 18 °C, and the mean annual precipitation is around 900 mm with a strong north–south gradient, reaching values below 500 mm in the southeastern part of the region [76]. Thus, the river flow regime is intermittent, with torrential flows in autumn/winter (November, December, and January) and interruptions in summer (June, July, August, September, and October), with long dry reaches, even on the main international Guadiana River (regulated since 2002 due to the construction of the Alqueva Dam system) [77].

In the past, the rural population, uneducated and impoverished, adapted the agricultural production model to the cycles of nature, taking advantage of natural resources and finding natural solutions [72]. An example of these practices are the water mills located on the banks of the Guadiana River and its tributaries, used to produce flour from different cereals (Figure 8). The existence of water mills dates to at least the 13th century [78]. However, in the 19th century, the number of mills reached its peak, due to the increasing population, and continued into the 20th century as a natural mode of production for large plantations [79,80].

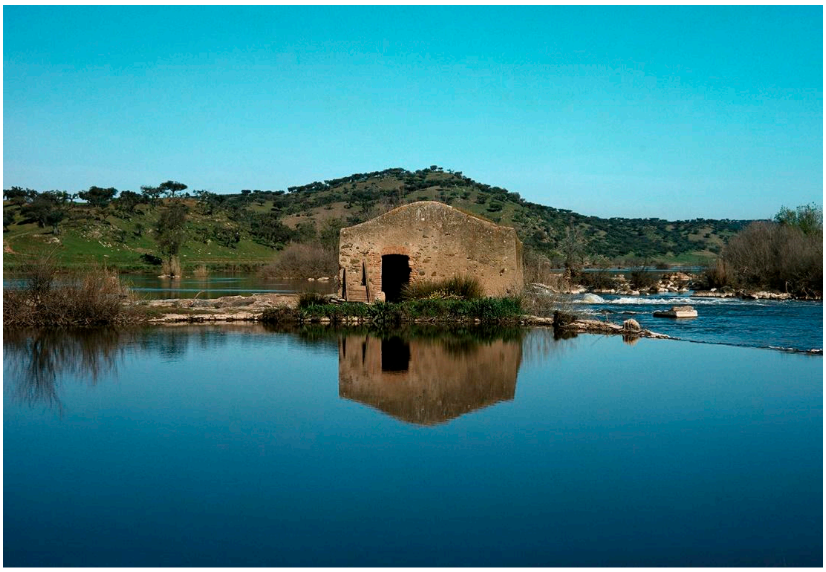

Figure 8. Water mills located on the banks of the Guadiana River, Southern Portugal (Municipality of Mérola). The weir is located in front of the mill. (Photo, Luís Pavão).

In 2002, during the construction of the Alqueva Dam, around a hundred mills of different shapes and sizes were identified, built in such a way that their architectural structure was not damaged when the flow rose (i.e., during winter after flood events) and submerged the structure for periods of up to four months [80]. In very rainy years, when the water level remained very high, preventing the mill from operating on the main river (i.e., the Guadiana River), millers would search for similar structures on adjacent tributaries with less water flow, where they would remain until the water level dropped in the Guadiana.

Guita [80] identified 80 mills in an area of 1279 km^2 on the Guadiana and its tributaries, the smallest with drainage basins of 15 to 20 km^2. In the municipality of Mértola, he noted that one mill existed for every 16 km^2 of surface area. Mill activity remained active until the 1960s when more than 30 mills were in operation. The five remaining mills operating in the 1980s closed before 1990.

These structures were kept in operation by weirs built in the riverbed with diversions that channeled water where it was needed to grind grains. On the Guadiana River and its tributaries, the dams were made of stones, fitted perpendicularly to the flow of water, with the thickest section facing the outside of the construction, forming an arch closed at the top by slabs [80] (Figure 9). These technologically simple but very resistant structures, designed by master craftsmen, demonstrate knowledge of hydraulic engineering that is remarkable for its simplicity, having withstood the passage of centuries. Today, after more than 100 years in some cases, the weirs are completely integrated into the landscape and form part of the cultural heritage. From an ecological perspective, they constitute important water-retention zones, creating lentic habitats that are maintained all year round, even during dry summer periods. Consequently, they are important refuge areas for aquatic and terrestrial species, promoting biodiversity, ecological integrity, and the conservation of ecosystems. On the other hand, these weirs, due to their heritage value, and also because they retain water in natural pools, are important recreational areas for local populations and are visited and preserved by local people.

Figure 9. General view of a water mill and weir on a temporary stream (Guadiana River basin, Portugal) (Photo, Manuela Morais).

The mills, often built at pristine river sites, had the disadvantage of being relatively isolated and distant from the population centers. Also, for this reason (i.e., the distance to the supply centers), great care was taken to maintain the weirs that supplied the water retained in the natural pools and additionally provided easily accessible food (fish caught in natural pools).

Abandonment of the mills and weirs was due to several factors, including the substantial reduction of bread baked in farmhouses, because of the mechanization of agriculture [79]. Also decisive in this process were the migratory flows of the rural population towards the industrialized centers of Portugal and Europe in the 1960s. Additional factors were (1) the transformation of people's eating habits, in which bread lost its value; (2) the lack of able men to work as millers; (3) the colonial war between Portugal and its African countries in the 1960s, which lasted until April 1974, with young people being recruited all over the country; and (4) the competition from milling factories and the increased production and widespread consumption of industrialized bread [71,79]. Generally, it was precisely these reasons that led to the deactivation of traditional milling systems in Portugal and other European countries.

The abandonment of mills, particularly the lack of maintenance of many weirs, led to the desiccation of the natural pools and, consequently, the loss of biodiversity and ecosystem degradation, increasingly being aggravated by the extreme drought phenomena and the extension of the dry summer period resulting from climate change in the region.

4. Discussion

The three case studies briefly described above illustrate how ecosystem balance is delicate and how human interventions in supporting natural processes can effectively enhance ecosystem services. Although the cases vary in time, space, and scale, we can distill several important lessons from their experiences, which can offer useful information in other restoration scenarios.

The cases are illustrative of compliance with global agreements and policy goals. All are fully aligned with the 2030 Agenda for Sustainable Development (AfSD), with its Sustainable Development Goals (SDGs) and its Target 6.6 ("*By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*") to support the achievement of the goal to ensure availability of water for all (SDG 6). Additionally, they exemplify the recent United Nations General Assembly recognition of the importance of the ecosystem approach for the integrated management of land, water, and living resources to face water scarcity when it approved the United Nations Decade on Ecosystem Restoration (2021–2030). The UNGA's A/RES/73/284 Resolution asserts that member states should "foster political will, the mobilization of resources, capacity-building, scientific research and cooperation and momentum for ecosystem restoration at the global, regional, national and local levels, as appropriate" and "to mainstream ecosystem restoration into policies and plans to address current national development priorities and challenges due to the degradation of marine and terrestrial ecosystems, biodiversity loss and climate change vulnerability, thereby creating opportunities for ecosystems to increase their adaptive capacity and opportunities to maintain and improve livelihoods for all".

The Brazil and Panama cases highlight the important benefits, particularly of water provisioning, resulting from the restoration and protection of tropical rainforests. Deforestation of the Tijuca Rainforest adjacent to Rio de Janeiro about two centuries ago caused severe soil erosion and diminished the water supply for this important city in the Portuguese colony. The Brazilian Emperor (Dom Pedro II) understood the relationship between a sustainable water supply and wise forest management, protection of vegetation near springs, and reforestation. As a result of these farsighted decisions, the Tijuca Rainforest (now a remnant of the endangered Mata Atlântica) has gained national protection as Tijuca National Park and international recognition as a UNESCO World Heritage Site of cultural importance. Several centuries later, in Panama in the 1970s, administrators of the Panama Canal became aware that the increasing deforestation in the canal watershed threatened the operations of the canal, particularly during the 5-month dry season. To protect the forest and its contribution to freshwater, the country designated several national parks on the eastern bank of the canal that strictly limited further forest clearing. During the past decade, canal authorities have dedicated significant efforts to support forest protection on the western side of the canal in areas with many small farms. These efforts include reforestation projects, payments to farmers to protect existing forests, and support for the cultivation of shade-grown coffee on lands that were previously pasture. The Panama experience is recent compared to the Brazilian case, yet the results to date are positive.

The interdependence between ecosystem restoration and water, particularly in tropical forest ecosystems, is clear. Forested headwater regions and also their protected springs are considered critical in sustaining water provision because they control flows within a catchment basin/watershed [81,82]. The role of forests in water provision and regulation was recognized and attributed to several categories of ecosystem services, including provisioning services (freshwater provision) and regulating services (flood regulation and water purification, among others) [83], as can be seen in Figure 10. These functions are a consequence of interactions between ecological processes and ecosystem structures [84]. According to Bonell [85], forest soils have many macropores associated with the high density of roots and soil fauna activity that facilitate infiltration and the vertical bypassing of the unsaturated matrix to reach the saturated zone more quickly. These characteristics help forests both to regulate and provide water for the catchment basin.

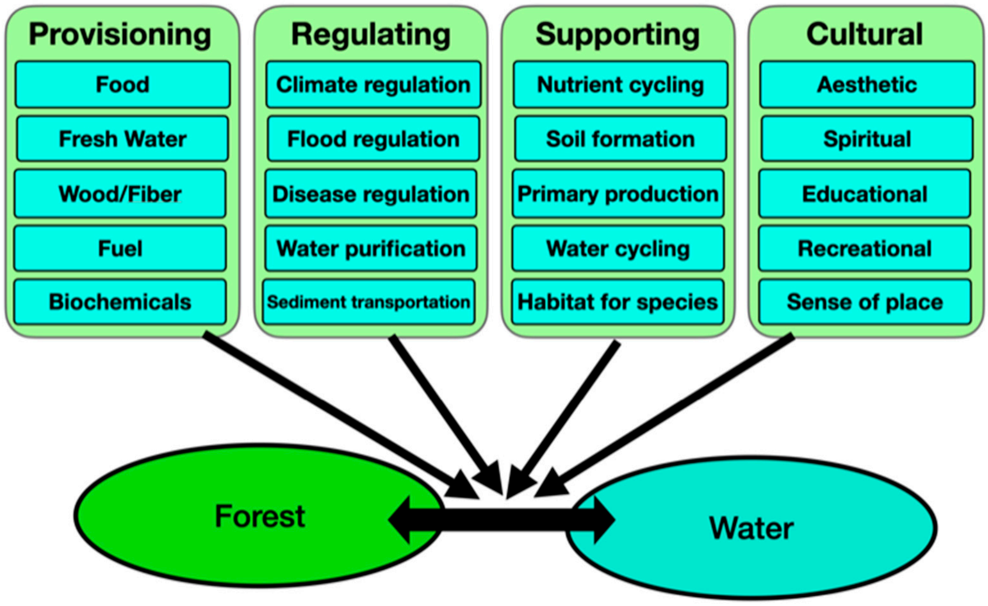

Figure 10. Ecosystem services and benefits that forests provide. Figure based on [83].

The role of forests in water provision and regulation can be seen in a systemic view by its action on the hydrological cycle. It can pump water into the atmosphere by evapotranspiration [35] or promote infiltration, storing water during the wet season and then slowly releasing it during the dry season. In this way, the Tijuca Forest in Brazil keeps rivers and streams with a modest but everlasting flow, and in Panama, forests also provide water for economic purposes, particularly during the dry season. Similarly, the ancient weirs in the riverbeds of Portugal's Alentejo Region address water scarcity through water storage. NbSs recognize interconnections between surface and groundwater and between green and blue water in a systemic way. Restored forests can retain more water, and this change in the hydrological distribution increases the availability of water for more plant growth. Meanwhile, more water will infiltrate and, therefore, will be available to return to surface water by groundwater surface discharge at springs. Ecological restoration per NbSs slows down water cycling; decreases erosion and flooding; reduces water flushed away; and improves the timing of water provisioning, keeping water in the local system. It is the opposite of the intensification of the water cycle [86].

All three cases illustrate that, while there may have been a sole principal objective of NbS activity, multiple benefits commonly result. The pioneering restoration experiences with native species in the Tijuca Forest aimed to solve the problem of the water supply to Rio de Janeiro. However, in the 20th century, restaurants opened, and landscaping projects were implemented in the protected forest. Today Tijuca National Park is an important site for tourism and public recreation. As a UNESCO World Heritage Site and Biosphere Reserve, the site is recognized for its spectacular cultural landscape and high biodiversity in the endangered Atlantic Forest. As an urban forest, Tijuca also serves as an important climate regulator and helps reduce air pollution. Likewise, in recent times, the protection of the forests surrounding the Panama Canal had the primary purpose of providing a sustainable water supply for canal operations. Nevertheless, today, the forests are also important for providing potable water for half of Panama's population and also generating electricity. The national parks in the watershed are also biodiversity hotspots, important links in the Mesoamerican Biological Corridor, and sites for ecotourism. Other efforts in the watershed assist small farmers to adopt sustainable agricultural techniques and improve their livelihoods. Thus, the ecosystem and social benefits of forest protection are multiple. Similarly, in Portugal's Alentejo Region, weirs on streams that served as hydraulic structures to support water mills that ground cereal grains in the past today help to moderate stream flow and retain water, particularly during dry seasons; attract wildlife; and are sites where people can recreate. All these examples illustrate that, while NbSs may initially focus on one ecosystem service, it can benefit a broad array of ecosystem services that also benefit local communities. A key feature of NbS is the capability to deliver groups of ecosystem services together—even if only one was originally targeted by the intervention [21]. Moreover, ecosystem services (as a concept per se detached and distinguished from economic fields such as valuation or privatization) link societal and environmental systems [87].

NbS are well-suited to address different variables of climate change (increased temperatures, changes in annual precipitation, extended dry days, and heavier rainfall). Climate scenarios for the Panama Canal Watershed and the Alentejo Region in Portugal suggest futures of diminished annual rainfall, and all three sites are projected to experience extended periods of consecutive dry days [88,89]. Dereczynski et al. [89] predict longer dry seasons, shorter wet seasons, and increased rainfall during heavy rain events in the Tijuca Forest. Similar scenarios are predicted for Panama and Central America [90]. Forest protection in the Tijuca Forest and Panama helps to maintain water flows in streams during dry periods and mitigate rapid runoff carrying high sediment loads during heavy rain events. Additionally, reforestation and the protection of existing forests serve as carbon sinks and help mitigate climate change.

The IPCC estimates [88] that a decrease in water availability is expected in the Alentejo Region in Portugal, with huge implications for the hydrological regime of intermittent rivers. An extension of the dry season is expected, which will cause fragmentation of aquatic habitats and loss of biodiversity. Consequently, these pressures threaten the sustainability of ecosystems, the provisioning of ecosystem services, and ultimately, human well-being. More broadly for the Mediterranean region, historical records show that the frequency and intensity of droughts have increased since 1950 and that the length of the dry period without flow is extending over time [91]. Temporary rivers with intermittent hydrological characteristics are, therefore, expected to cover more than 50 percent of the global hydrographic network [77,92]. Currently, it will be difficult to restore the ancient mills to produce cereal flour as was conducted in the past. However, the weirs and their supporting hydraulic structures that retain water are gaining increased importance by promoting water retention during the dry season. During the summer, these weirs, perfectly integrated into the riverbeds, are sites where aquatic and terrestrial species converge (Figure 11). Aquatic species recolonize the system from these sites after the flow restarts with the first autumn rains. Terrestrial species seek refuge in these cooler places that provide water and food. On the other hand, these hydraulic structures, many of them integrated into the Guadiana Valley National Park (https://natural.pt/protected-areas/parque-natural-vale-guadiana?locale=en accessed on 13 August 2024), are protected as places of leisure for local populations. These restoration actions with natural materials (stones and sand), which rescue ancestral knowledge rooted in regional culture, contribute to compliance with environmental policies, and, above all, constitute local NbSs that promote biodiversity and natural heritage by increasing (i) the water-retention capacity; (ii) the availability of habitats for aquatic and terrestrial species; (iii) the water quality and ecosystem integrity; (iv) the groundwater recharge; and (iv) ecosystem services also related to the promotion of the values of built heritage. In Southern Portugal, within the scope of different national and European policies, of which the Water Framework Directive stands out requiring the achievement of Good Status for all water bodies (Directive 2000/60/CE), actions that include the rehabilitation/reinforcement of ancient infrastructures (mills and dams) are a priority [93].

(**a**)

(**b**)

Figure 11. A family of wild boars (**a**) and a fox (**b**) drinking water in a weir photographed with a night camera (Guadiana River watershed, Southern Portugal). (Photo, André Oliveira).

NbSs often tend to emphasize ecosystem benefits above benefits to communities. Both are integral components of the coupled human–natural system. The UN Resolution on the United Nations Decade on Ecosystem Restoration (2021–2030) warns that ecosystem restoration "needs to be carried out in ways that balance social, economic and environmental objectives and with the engagement of relevant stakeholders, including indigenous peoples and local communities". While the Tijuca Forest provides a sustainable water supply for nearby urban residents and areas for recreation and cultural appreciation, the case suggests that social impacts may not always have been so positive. Due to its historical context as a Portuguese colony, and prior to the abolition of slavery, the Emperor determined priorities, targeting the well-being of the Empire's capital (Rio de Janeiro), and using slaves for reforestation. Were communities displaced by restoration efforts? In Panama, the designation of Chagres National Park in 1984 strictly limited the ability of small farmers residing within the park's boundaries to clear additional land for agricultural purposes. While authorities have offered opportunities for additional livelihood activities, questions remain regarding social equity. On the other hand, canal authorities are actively engaged in promoting sustainable agricultural techniques that reduce sedimentation and rapid runoff from streams in the watershed.

Finally, an important factor in the successful implementation of NbSs is good governance, institutional coordination, meaningful public involvement, and strong political will.

In Panama, the ACP possesses clear competence to coordinate interventions of other state agencies and non-governmental organizations in the canal's watershed through clear statutory and constitutional mandates. The ACP encourages citizen involvement through watershed management councils that bring community concerns to the ACP and also permit authorities to explain their concerns and interventions. This is an example of nested governance [94].

The Tijuca Forest case in Brazil offers a different historical context. Abandoned coffee cultivation and the risk of strong water scarcity due to droughts led to degraded slopes in the capital of the Brazilian Empire. As restoration was a direct order of the Emperor and numerous slaves were used as workforce, the case is not completely compatible with today's realities. Nevertheless, the Tijuca Forest highlights some lessons about governance.

This large ecological restoration effort required 13 years and, considering the present labor laws, today could take much longer to meet the goal. On the other hand, modern machines and reforestation tools could hasten positive outcomes. Both a strong commitment from the government and compliance with restoration requirements are essential. Moreover, considering the long timeframe required to obtain results and climate-change scenarios, restoration efforts demand strong political will that persists despite short-term political changes.

Finally, after successful ecological restoration, the result must be protected. The creation of a protected area (Tijuca National Park plus recognition of World Heritage status by UNESCO) combines environmental protection with recreational uses. Similarly, a large portion of the Panama Canal Watershed enjoys national park designation. Protected status accompanied by an environmental education program with historical and cultural components could help people, politicians, and decision makers appreciate the restored landscapes.

Restoration efforts in Brazil and Panama offer clear and strong economic and social benefits. The benefits of ecosystem restoration in Alentejo are not so immediate, however. Most of the Portuguese water mills and their weirs have been abandoned, even though they constitute an important cultural heritage and are integrated into the rivers' ecological functioning. In a few rare cases, parish councils consider them to be recreational areas for local people and have undertaken restoration efforts. New incentives for restoration may provide opportunities for Alentejo. The European Union's new economic growth strategy has placed climate change at the center of political decisions through the launch of the European Green Deal (EGD) [95]. In line with this strategy, the EU launched the Water4All partnership in the Horizon Europe program as an integrated approach to water security in Europe because 'water is central to all components of the EGD'. The Water4All partnership was created to combat issues of fragmentation in research and innovation on water-related topics and to facilitate change in water security and management in Europe (in the sense of the more holistic approach referred to by Scott et al. [96]. In this context, initiatives and calls for projects have been promoted to implement more sustainable solutions together with stakeholders. The European Union aims to encourage cooperation and provide technical assistance, particularly to European Neighborhood Policy South countries, to develop effective green growth and climate-governance mechanisms, especially given the region's particular vulnerability to climate change [97]. In this context, NbSs gain increasing relevance as actions that address societal challenges through protection, sustainable management, and ecosystem restoration, benefiting both biodiversity and human well-being. The restoration of weirs, which are an integral part of the functioning of rivers and landscapes in Southern Portugal, could be framed within this more holistic approach. They can function as living examples of NbSs rescued from the past, which, if well managed, would contribute to water retention, the promotion of biodiversity, and the fight against climate change in a region where water will be a scarce resource.

5. Conclusions

Growing worldwide recognition of the importance of water and concern about its limited availability to meet human and ecological needs considering global climate change are leading to new strategies and solutions, including NbSs. Guidance for the transition to a socio-environmental approach to ecosystem management exists at the global level through the 17 UN Sustainable Development Goals [98], at the European level through the European Green Deal [95], and through policies and programs in many nations. We must invest in a new productive rationality based on the limits of the laws of nature, ecological potential, social justice, the production of social meanings, and human creativity that integrates "knowledge" without exclusion.

Nature-based solutions present a credible means to address key societal issues, such as climate change, biodiversity loss, and environmental justice. Policy dialogues and global awareness-raising initiatives need to be actively and consistently implemented to promote participation, develop a broad knowledge base, and support the adoption of nature-based solutions on a large scale. For example, the promotion of interdisciplinary or even transdisciplinary research into approaches to water scarcity, as well as the integration of stakeholders, offers the possibility of creating clear frameworks and understanding ecosystem functions and the coupled human–natural system. In fact, the factors affecting the demand for water, such as changes in land use, perceptions of water scarcity, and attitudes towards water use, are framed in social science understandings of how these factors can be influenced by government policies and social norms [99]. Furthermore, a new opportunity is emerging to make the social sciences more effective in improving water management and understanding the drivers of water scarcity [100,101]. This approach promotes public and private investment in nature-based solutions and is an essential component of the transformational change needed to make our societies and economies more sustainable and just.

Author Contributions: Conceptualization, D.O.S., M.M. and C.H.S.; investigation, D.O.S., M.M. and C.H.S.; writing—original draft preparation, D.O.S., M.M. and C.H.S.; writing—review and editing, D.O.S., M.M. and C.H.S.; funding acquisition, D.O.S., M.M. and C.H.S. All authors have read and agreed to the published version of the manuscript.

Funding: The European Union's ERASMUS AMIGO 2019-1-KA107-060632 funded the authors' travel between Portugal (University of Évora), Brazil (University of Brasilia), and the USA (University of Miami).

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. UN-Water. *Coping with Water Scarcity: A Strategic Issue and Priority for System-Wide Action*; UN-Water: Geneva, Switzerland, 2006.
2. UN-Water. *Coping with Water Scarcity: Challenge of the Twenty-First Century*; UN-Water: Geneva, Switzerland, 2007.
3. Steduto, P.; Faurès, J.-M.; Hoogeveen, J.; Winpenny, J.; Burke, J. *Coping with Water Scarcity—An Action Framework for Agriculture and Food Security*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2012.
4. Mekonnen, M.M.; Hoekstra, A.Y. Four billion people facing severe water scarcity. *Sci. Adv.* **2016**, *2*, e1500323. [CrossRef]
5. van Beek, L.P.H.; Wada, Y.; Bierkens, M.F.P. Global monthly water stress: 1. Water balance and water availability. *Water Resour. Res.* **2011**, *47*, W07517. [CrossRef]
6. Mishra, B.K.; Kumar, P.; Saraswat, C.; Chakraborty, S.; Gautam, A. Water security in a changing environment: Concept, challenges and solutions. *Water* **2021**, *13*, 490. [CrossRef]
7. Cosgrove, W.J.; Loucks, D.P. Water management: Current and future challenges and research directions. *Water Resour. Res.* **2015**, *51*, 4823–4839. [CrossRef]
8. Falkenmark, M. Meeting water requirements of an expanding world population. *Philos. Trans. B R. Soc.* **1997**, *352*, 929–936. [CrossRef]
9. Falkenmark, M. Society's interaction with the water cycle: A conceptual framework for a more holistic approach. *Hydrol. Sci. J.* **1997**, *42*, 451–466. [CrossRef]
10. Vanham, D.; Alfieri, L.; Flörke, M.; Grimaldi, S.; Lorini, V.; de Roo, A.; Feyen, L. The number of people exposed to water stress in relation to how much water is reserved for the environment: A global modelling study. *Lancet Planet. Health* **2021**, *5*, e766–e774. [CrossRef] [PubMed]
11. Yang, D.; Yang, Y.; Xia, J. Hydrological cycle and water resources in a changing world: A review. *Geogr. Sustain.* **2021**, *2*, 115–122. [CrossRef]
12. Bierkens, M.F.; Wada, Y. Non-renewable groundwater use and groundwater depletion: A review. *Environ. Res. Lett.* **2019**, *14*, 063002. [CrossRef]
13. Camacho, C.; Negro, J.; Elmberg, J.; Fox, A.D.; Nagy, S.; Pain, D.J.; Green, A.J. Groundwater extraction poses extreme threat to Doñana World Heritage Site. *Nat. Ecol. Evol.* **2022**, *6*, 654–655. [CrossRef]
14. Palmer, M.; Ruhi, A. Linkages between flow regime, biota, and ecosystem processes: Implications for river restoration. *Science* **2019**, *365*, eaaw2087. [CrossRef] [PubMed]
15. Davidson, C.N. How Much Wetland Has the World Lost? Long Term and Recent Trends in Global Wetland Area. *Mar. Freshw. Res.* **2014**, *65*, 934–941. [CrossRef]

16. Verhoeven, J.T.A. Wetlands in Europe: Perspectives for restoration of a lost paradise. *Ecol. Eng.* **2014**, *66*, 6–9. [CrossRef]
17. Spencer, T.; Schuerch, M.; Nicholls, R.J.; Hinkel, J.; Lincke, D.; Vafeidis, A.T.; Reef, R.; McFadden, L.; Brown, S. Global coastal wetland change under sea-level rise and related stresses: The DIVA Wetland Change Model. *Glob. Planet. Chang.* **2016**, *136*, 15–30. [CrossRef]
18. Weiskopf, S.R.; Rubenstein, M.A.; Crozier, L.G.; Gaichas, S.; Griffis, R.; Halofsky, J.E.; Hyde, K.J.W.; Morelli, T.L.; Morisette, J.T.; Muñoz, R.C.; et al. Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Sci. Total Environ.* **2020**, *733*, 137782. [CrossRef] [PubMed]
19. Wheeler, K.G.; Hussein, H. Water research and nationalism in the post-truth era. *Water Int.* **2021**, *46*, 1216–1223. [CrossRef]
20. Seckler, D. *The New Era of Water Resources Management: From "Dry" to "Wet" Water Savings*; International Irrigation Management Institute (IIMI): Colombo, Sri Lanka, 1996. Available online: https://www.iwmi.cgiar.org/publications/iwmi-research-reports/iwmi-research-report-1/ (accessed on 13 August 2024).
21. Saito, C.H. O estruturalismo na ecologia da paisagem. *Braz. J. Ecol.* **1998**, *2*, 47–56.
22. Beschta, R.L.; Ripple, W.J. The role of large predators in maintaining riparian plant communities and river morphology. *Geomorphology* **2012**, *157–158*, 88–98. [CrossRef]
23. Keesstra, S.; Nunes, J.; Novara, A.; Finger, D.; Avelar, D.; Kalantari, Z.; Cerdà, A. The superior effect of nature based solutions in land management for enhancing ecosystem services. *Sci. Total Environ.* **2018**, *610–611*, 997–1009. [CrossRef]
24. WWAP (United Nations World Water Assessment Programme)/UN-Water. *The United Nations World Water Development Report 2018: Nature-Based Solutions for Water*; UNESCO: Paris, France, 2018; ISBN 978-92-3-100264-9.
25. Michels-Brito, A.; Ferreira, J.C.R.; Saito, C.H. The source-to-sea landscape: A hybrid integrative territory management approach. *Sci. Total Environ.* **2024**, *931*, 172961. [CrossRef]
26. Saito, C.H.; Morais, M.M. Learning from the past: What cultural heritage can teach us about water storage and management. In *The Palgrave Handbook of Global Sustainability*; Brinkmann, R., Ed.; Palgrave Macmillan: Cham, Switzerland, 2022; pp. 437–457. [CrossRef]
27. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. *Nature-Based Solutions to Address Global Societal Challenges*; IUCN: Gland, Switzerland, 2016; ISBN 978-2-8317-1812-5. [CrossRef]
28. Nesshöver, C.; Assmuth, T.; Irvine, K.N.; Rusch, G.M.; Waylen, K.A.; Delbaere, B.; Haase, D.; Jones-Walters, L.; Keune, H.; Kovacs, E.; et al. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Sci. Total Environ.* **2017**, *579*, 1215–1227. [CrossRef]
29. UN-Water. *Water Security and the Global Water Agenda: A UN-Water Analytical Brief*; UN University: Hamilton, ON, Canada, 2013; ISBN 978-92-808-6038-2.
30. Scott, C.A.; Meza, F.J.; Varady, R.G.; Tiessen, H.; McEvoy, J.; Garfin, G.M.; Wilder, M.; Farfán, L.M.; Pablos, N.P.; Montaña, E. Water security and adaptive management in the arid Americas. *Ann. Assoc. Am. Geogr.* **2013**, *103*, 280–289. [CrossRef]
31. WWAP (United Nations World Water Assessment Programme)/UN-Water. *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*; UNESCO: Paris, France, 2012; ISBN 978-92-3-104235-5/978-92-3-001045-4.
32. Zheng, N.; Ma, H.; Peng, C.; Liu, Y.; Grotewal, R.; Klaus, U. Resilient ecology and landscape systems of the Fengxinglong Ecological Park, Sanya. *Landsc. Archit. Front.* **2018**, *6*, 32–41. [CrossRef]
33. Van Coppenolle, R.; Schwarz, C.; Temmerman, S. Contribution of mangroves and salt marshes to nature-based mitigation of coastal flood risks in major deltas of the world. *Estuaries Coasts* **2018**, *41*, 1699–1711. [CrossRef]
34. Song, S.; Ding, Y.; Li, W.; Meng, Y.; Zhou, J.; Gou, R.; Zhang, C.; Ye, S.; Saintilan, N.; Krauss, K.W.; et al. Mangrove reforestation provides greater blue carbon benefit than afforestation for mitigating global climate change. *Nat. Commun.* **2023**, *14*, 756. [CrossRef] [PubMed]
35. Aragão, L.E.O.C. The rainforest's water pump. *Nature* **2012**, *489*, 217–218. [CrossRef] [PubMed]
36. Bender, G. Correcting the Rhone and the Valaisans: Three centuries of works and debate. *Rev. Géographie Alp.* **2004**, *92*, 62–72. [CrossRef]
37. Maya, R.O.C. *A Floresta da Tijuca*; Bloch Edições: Rio de Janeiro, Brazil, 1967. Available online: http://objdigital.bn.br/objdigital2/acervo_digital/div_obrasgerais/drg605826/drg605826.pdf (accessed on 27 June 2024).
38. Dorigo, T.A.; Siqueira, C.C.; Oliveira, J.C.F.; Fusinatto, L.A.; Santos-Pereira, M.; Almeida-Santos, M.; Maia-Carneiro, T.; Reis, C.N.C.; Rocha, C.F.D. Amphibians and reptiles from the Parque Nacional da Tijuca, Brazil, one of the world's largest urban forests. *Biota Neotrop.* **2021**, *21*, e20200978. [CrossRef]
39. Freitas, S.R.; Neves, C.L.; Chernicharo, P. Tijuca National Park: Two pioneering restorationist initiatives in Atlantic forest in southeastern Brazil. *Braz. J. Biol.* **2006**, *66*, 975–982. [CrossRef]
40. Oklander, L.I.; Rheingantz, M.; Rossato, R.S.; Peker, S.; Hirano, Z.M.B.; Monticelli, C.; Dada, A.N.; Di Nucci, D.L.; Oliveira, D.; de Melo, F.R.; et al. Restoration of Alouatta guariba populations: Building a binational management strategy for the conservation of the endangered brown howler monkey of the Atlantic Forest. *Front. Conserv. Sci.* **2024**, *5*, 1401749. [CrossRef]
41. Mynssen, C.M.; Bicalho, M.B.; Sylvestre, L.S.; Rocha, T.; Siqueira, M.F. Ferns and Lycophytes as new challenges: Richness of ferns and lycophytes from Tijuca National Park, an urban forest. *Rodriguésia* **2023**, *74*, e00782023. [CrossRef]
42. Drummond, J. The garden in the machine: An environmental history of the Tijuca Forest (Rio de Janeiro, Brazil), 1862–1889. *J. Environ. Hist.* **1996**, *1*, 83–104. [CrossRef]

43. Coelho Netto, A.L. A interface florestal-urbana e os desastres naturais relacionados à água no maciço da tijuca: Desafios ao planejamento urbano numa perspectiva sócio-ambiental. *Rev. Do Dep. De Geogr.* **2005**, *16*, 46–60. [CrossRef]
44. Martins, M.F.V. A floresta e as águas do Rio: A Inspeção Geral de Obras Públicas e as intervenções urbanas para abastecimento e reflorestamento na primeira metade do século XIX. *Intellèctus* **2015**, *14*, 21–47. [CrossRef]
45. Panama Canal Authority's Direct Contributions to the National Treasury from FY 2016 to FY 2021, by Type. Available online: https://www.statista.com/statistics/1011908/panama-canal-authority-contributions-national-treasury-type/ (accessed on 27 July 2024).
46. Panama: Gross Domestic Product (GDP in Current Prices from 1989 to 2029). Available online: https://www.statista.com/statistics/454680/gross-domestic-product-gdp-in-panama/ (accessed on 27 July 2024).
47. From Cross-Fillings to Long-Term Solutions: How the Panama Canal Is Addressing the Issue of Water Head On. Available online: https://pancanal.com/en/how-the-panama-canal-is-addressing-the-issue-of-water-head-on/ (accessed on 30 July 2024).
48. Calvo Gobbetti, L.; Ríos Córdoba, K. Impacto de la ampliación del Canal de Panamá en las confiabilidades hidrica y de calado. *Rev. I+D Tecnológico* **2024**, *20*, 49–60. [CrossRef]
49. CEPAL (Comisión Económica para America Latina y el Caribe); Fondo Nórdico de Desarrollo (FND); Banco Interamericano de Desarrollo (BID); Secretaria Nacional de Energia de Panamá; y Ministerio de Energia y Minas de la Republica Dominicana. Impactos Potenciales del Cambio Climático en el Ámbito Hidroelectrico en Panamá y la Republica Dominicana. LC/MEX/TS.1217/28. Ciudad de Mexico, Mexico, 2017. Available online: https://repositorio.cepal.org/server/api/core/bitstreams/afca41c0-8cdf-47ab-af33-855265f2d0cd/content (accessed on 13 August 2024).
50. Hidalgo, H.G.; Amador, J.A.; Alfaro, E.J.; Quesada, B. Hydrological climate change projections for Central America. *J. Hydrol.* **2013**, *495*, 4–112. [CrossRef]
51. Canal de Panamá. Informe 2023. Available online: https://pancanal.com/wp-content/uploads/2021/09/Informe-2023EspFINAL.pdf (accessed on 26 June 2024).
52. Canal de Panamá. Agua y el canal. Available online: https://pancanal.com/agua/ (accessed on 26 June 2024).
53. Maritime Executive. Panama Canal to Add Back Daily Transits as Rainy Season Approaches (16 April 2024). Available online: https://maritime-executive.com/article/panama-canal-to-add-back-daily-transits-as-rainy-season-approaches (accessed on 26 June 2024).
54. Sandoval, Y.; Mojica, Y. Las Bombas del Idaan No Funcionan al 100% Cuando Baja el Nivel del Lago Alajuela; Acuden a Carros Cisterna. La Prensa (Panama). 18 May 2024. Available online: https://www.prensa.com/economia/las-bombas-del-idaan-no-funcionan-al-100-cuando-baja-el-nivel-del-lago-alajuela-acuden-a-carros-cisternas/ (accessed on 26 June 2024).
55. Panama City, Panama Metro Area Population 1950–2024. Available online: https://www.macrotrends.net/global-metrics/cities/22063/panama-city/population#google_vignette (accessed on 30 July 2024).
56. Carse, A. *Beyond the Big Ditch: Politics, Ecology, and Infrastructure at the Panama Canal*; MIT Press: Cambridge, MA, USA, 2014.
57. Wadsworth, F. Deforestation: Death to the Panama Canal. In *US Strategy Conference on Tropical Deforestation*; USAID: Washington, DC, USA, 1978; pp. 22–24.
58. Buckingham, K.; Hanson, C. *The Restoration Diagnostic—Case Example: Panama Canal Watershed*; World Resources Institute: Washington, DC, USA, 2015.
59. Dale, V.H.; Brown, S.; Calderón, M.O.; Montoya, A.S.; Martinez, R.E. Projected land-use change for the Eastern Panama Canal Watershed and its potential impact. In *The Rio Chagres, Panama: A Multidisciplinary Profile of a Tropical Eatershed*; Harmon, R.S., Ed.; Springer: Dordrecht, The Netherlands; Berlin/Heidelberg, Germany, 2010; pp. 337–345.
60. Canal de Panamá. Acuerdo No. 116—Por el cual se aprueba el Reglamento sobre Ambiente, Cuenca Hidrográfica y Comisión Interinstitucional de la Cuenca Hidrográfica del Canal de Panamá (27 July 2006). Available online: https://pancanal.com/wp-content/uploads/2021/09/acuerdo116-1.pdf (accessed on 26 June 2024).
61. Instituto Geográfico Nacional "Tommy Guardia". *Atlas Nacional de Panamá*; Instituto Geográfico Nacional "Tommy Guardia": Panama, Panama, 1988.
62. Simonit, S.; Perrings, C. Bundling ecosystem services in the Panama Canal watershed. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 9326–9331. [CrossRef] [PubMed]
63. Ogden, F.L.; Crouch, T.D.; Stallard, R.F.; Hall, J.S. Effect of land cover and use on dry season river runoff, runoff efficiency, and peak storm runoff in the seasonal tropics of Central Panama. *Water Resour. Res.* **2013**, *49*, 8443–8462. [CrossRef]
64. Zafirah, N.; Nurin, N.A.; Samsurijan, M.S.; Zuknik, M.H.; Rafatullah, M.; Syaki, M.I. Sustainable ecosystem services framework for tropical catchment management: A review. *Sustainability* **2017**, *9*, 546. [CrossRef]
65. Canal de Panamá. 2610- EAC- 115 Norma Ambiental para Pagos por Servicios Ambientales (PSA) en la Cuenca Hidrográfica del Canal de Panamá (1 March 2018). Available online: https://pancanal.com/wp-content/uploads/2022/03/EAC-115-pagos-por-servicios-ambientales.pdf (accessed on 26 June 2024).
66. Martínez, R. Programa de Incentivos Económicos Ambientales (PIEA). Presentation to University of Miami Students, Watershed Management Section, Canal de Panamá, Corozal, Panama. 11 March 2024.
67. Moreno, O.; Aguilar, J. Towards a knowledge management system for the strengthening of coffee production: A case study in the Panama Canal Basin, Panamá Oeste province. *Green Technol. Sustain.* **2024**, *2*, 100056. [CrossRef]
68. Eco TV (Panama). Bayano es 3 veces más caro que un Embalse en Río Indio, Explicó Canal de Panamá (18 January 2024). Available online: https://www.youtube.com/watch?v=0ArOyH9DIXc (accessed on 24 June 2024).

69. Voz de América. Proyecto en río Indio Buscaría Solucionar crisis del Canal de Panamá, pero se Necesitan Cambios en la Legislación. (8 Feburary 2024). Available online: https://www.vozdeamerica.com/a/rio-indio-solucion-crisis-hidrica-canal-panama/7477229.html (accessed on 24 June 2024).
70. CCDR, *Relatório Portugal 2020 na Região Alentejo 2017*. Orgão de Acompanhamento das Dinâmicas Regionais, Comissão de Coordenação e Desenvolvimento Regional do Alentejo. 2018. Available online: https://www.ccdr-a.gov.pt/wp-content/uploads/2018/07/Relatorio_Portugal2020_2017_F.pdf (accessed on 27 June 2024).
71. Cutileiro, J. *Ricos e Pobres no Alentejo. (Uma Sociedade Rural Portuguesa)*; Livros Horizonte: Lisboa, Portugal, 2004.
72. Pinto-Correia, T.; Godinho, S. Changing agriculture—Changing landscapes: What is going on in the high Valued montado. In *Agriculture in Mediterranean Europe: Between Old and New Paradigms (Research in Rural Sociology and Development*; Ortiz-Miranda, D., Moragues-Faus, A., Arnalte-Alegre, E., Eds.; Emerald Group Publishing Limited: Leeds, UK, 2013; Volume 19, pp. 75–90. [CrossRef]
73. Silveira, A.; Ferrão, J.; Muñoz-Rojas, J.; Pinto-Correia, T.; Guimarães, M.H.; Schmidt, L. The sustainability of agricultural intensification in the early 21st century: Insights from the olive oil production in Alentejo (Southern Portugal). In *Changing Societies: Legacies and Challenges. The Diverse Worlds of Sustainability*; Delicado, A., Domingos, N., de Sousa, L., Eds.; Imprensa de Ciências Sociais: Lisbon, Portugal, 2018; Volume 3, pp. 247–275. [CrossRef]
74. Veiga, B.; Duarte, L.; Vasconcelos, L. A Barragem do Alqueva para quem? Por uma contextualização pluridimensional do desenvolvimento no Alentejo—Portugal. In *IV Encontro Nacional da ANPPAS, Anais do IV Encontro Nacional da ANPPAS*; Associação Nacional de Pós-Graduação e Pesquisa em Ambiente e Sociedade: Brasilia, Brazil, 2008.
75. Sanches, R.; Pedro, J.O. *Empreendimento de Fins Múltiplos de Alqueva*; Empresa de Desenvolvimento de Infraestruturas do Alqueva (EDIA): Beja, Portugal, 2006.
76. Carvalho, A.; Schmidt, L.; Santos, F.D.; Delicado, A. Climate change research and policy in Portugal. *Rev. Clim. Chang.* **2014**, *5*, 199–217. [CrossRef]
77. Skoulikidis, N.T.; Sabater, S.; Datry, T.; Morais, M.M.; Buffagni, A.; Dörflinger, G.; Zogaris, S.; del Mar Sánchez-Montoya, M.; Bonada, N.; Kalogianni, E.; et al. Non-perennial Mediterranean rivers in Europe: Status, pressures, and challenges for research and management. *Sci. Total Environ.* **2017**, *577*, 1–18. [CrossRef] [PubMed]
78. Costa, M.R.; Costa, A.M.; Teixeira, E.R.; Ribeiro, F.V.; Santos, M.; Malobbia, S.; Matias, V. *Património Rural Construído do Baixo Guadiana*; Odiana: Algarve, Portugal, 2004; pp. 1–216. Available online: http://hdl.handle.net/10400.1/1823 (accessed on 13 August 2024).
79. Silva, R. Moinhos e moleiros no Alentejo oriental: Uma perspectiva etnográfica. *Etnográfica* **2004**, *8*, 221–242. [CrossRef]
80. Guita, R. Por baixo de cada moinho do Guadiana está um açude no Guadiana. In Proceedings of the Actes II Jornades de Molinologia = Actas II Jornadas de Molinología, Terrasa, Barcelona and Cérvoles, Lleida, Spain, 30 September–3 October 1998; pp. 351–363.
81. Baker, T.; Kiptala, J.; Olaka, L.; Oates, N.; Hussain, A.; McCartney, M. *Baseline Review and Ecosystem Services Assessment of the Tana River Basin, Kenya*; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2015; Volume 165.
82. Dib, V.; Brancalion, P.H.; Chan Chou, S.; Cooper, M.; Ellison, D.; Farjalla, V.F.; Filoso, S.; Meli, P.; Pires, A.P.; Rodriguez, D.A.; et al. Shedding light on the complex relationship between forest restoration and water services. *Restor. Ecol.* **2023**, *31*, e13890. [CrossRef]
83. Millennium Ecosystem Assessment. *Ecosystems and Human Well-being: Synthesis*; Island Press: Washington, DC, USA, 2005.
84. de Groot, R.S.; Wilson, M.; Boumans, R.M.J. A typology for the classification, description, and valuation of ecosystem functions, goods and services. *Ecol. Econ.* **2002**, *41*, 393–408. [CrossRef]
85. Bonell, M. Progress in the understanding of runoff generation dynamics in forests. *J. Hydrol.* **1993**, *150*, 217–275. [CrossRef]
86. Huntington, T.G. Evidence for intensification of the global water cycle: Review and synthesis. *J. Hydrol.* **2006**, *319*, 83–95. [CrossRef]
87. Engel, S.; Schaefer, M. Ecosystem services—A useful concept for addressing water challenges? *Curr. Opin. Environ. Sustain.* **2013**, *5*, 696–707. [CrossRef]
88. IPCC (Intergovernmental Panel on Climate Change). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2022. [CrossRef]
89. Dereczynski, C.; Silva, W.L.; Marengo, J. Detection and projections of climate change in Rio de Janeiro, Brazil. *Am. J. Clim. Chang.* **2013**, *2*, 25–33. [CrossRef]
90. Imbach, P.; Chou, S.C.; Lyra, A.; Rodrigues, D.; Rodriguez, D.; Latinovic, D.; Siqueira, G.; Silva, A.; Garofolo, L.; Georgiou, S. Future climate change scenarios in Central America at high spatial resolution. *PLoS ONE* **2013**, *13*, e0193570. [CrossRef]
91. Fader, M.; Giupponi, C.; Burak, S.; Dakhlaoui, H.; Koutroulis, A.; Lange, M.A.; Llasat, M.C.; Pulido-Velazquez, D.; Sanz-Cobeña, A. Water. In *Climate and Environmental Change in the Mediterranean Basin—Current Situation and Risks for the Future. First Mediterranean Assessment Report*; Union for the Mediterranean, Plan Bleu, UNEP/MAP: Marseille, France, 2020.
92. Rosado, J.; Morais, M.; Serafim, A.; Pedro, A.; Silva, H.; Potes, M.; Brito, D.; Salgado, R.; Neves, R.; Lillebø, A.; et al. Key factors in the Management and Conservation of temporary Mediterranean streams: A case study of the Pardiela river, southern Portugal (Guadiana catchment). In *River Conservation and Management*; Boon, P.J., Raven, P.J., Eds.; John Wiley & Sons, Ltd.: Chichester, UK, 2012; pp. 273–283.

93. Directive 2000/60/CE. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Available online: https://eur-lex.europa.eu/eli/dir/2000/60/oj (accessed on 13 August 2024).
94. Ostrom, E. Polycentric systems: Multilevel governance involving a diversity of organizations. In *Global Environmental Commons: Analytical and Political Challenges in Building Governance Mechanisms*; Brousseau, E., Dedeurwaerdere, T., Jouvet, P.A., Willinger, M., Eds.; Oxford University Press: Oxford, UK, 2012; pp. 105–125.
95. European Commission. The European Green Deal. European Commission: Brussels, Belgium. 11.12.2019 COM, 640 Final, 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN (accessed on 13 August 2024).
96. Scott, A.; Holtby, R.; East, H.; Lannin, A. Mainstreaming the environment: Exploring pathways and narratives to improve policy and decision-making. *People Nat.* **2022**, *4*, 201–217. [CrossRef]
97. Sandri, S.; Hussein, H.; Alshyab, N.; Sagatowski, J. The European Green Deal: Challenges and opportunities for the Southern Mediterranean. *Mediterr. Politics* **2023**, 1–12. [CrossRef]
98. UN General Assembly, Transforming Our world: The 2030 Agenda for Sustainable Development, A/RES/70/1, 21 October 2015. Available online: https://www.refworld.org/legal/resolution/unga/2015/en/111816 (accessed on 27 June 2024).
99. Wolters, E.A. Attitude–behavior consistency in household water consumption. *Soc. Sci. J.* **2014**, *51*, 455–463. [CrossRef]
100. Liu, J.; Yang, H.; Gosling, S.N.; Kummu, M.; Flörke, M.; Pfister, S.; Hanasaki, N.; Wada, Y.; Zhang, X.; Zheng, C.; et al. Water scarcity assessments in the past, present, and future. *Earth's Future* **2017**, *5*, 545–559. [CrossRef] [PubMed]
101. Lund, J.R. Integrating social and physical sciences in water management. *Water Resour. Res.* **2015**, *51*, 5905–5918. [CrossRef]