Water Balance of Mediterranean *Quercus ilex* L. and *Pinus halepensis* Mill. Forests in Semiarid Climates: A Review in A Climate Change Context

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Abstract: Forests provide many environmental services, especially those related to the water cycle. In semiarid areas where water is a limiting factor for ecosystem functioning, forested areas can have a strong impact on ground water recharge. In these areas, proper knowledge of forests' water balance is necessary to promote management practices that may ensure ecosystem properties and environmental services like water or carbon fixation. In this article, we review several ecohydrology topics within the framework of Mediterranean water-limited environments in two representative ecosystems: Kermes oak (*Quercus ilex* L.) and Aleppo pine (*Pinus halepensis* Mill.) forests. Both are the commonest species in countries that surround the Western Mediterranean Basin. We analysed the Blue and Green water components, i.e., green water is the water demand of forests, represented by evapotranspiration and interception; while blue water is the part of the balance involving runoff and deep percolation, which can be regarded as water directly usable by society. In general, different studies conducted in Mediterranean areas have pointed out that the water balances of *Q. ilex* and *P. halepensis* forests have low values for the Blue to Green water (B/G) ratios. Adaptive forest management like forest thinning can compensate for these ratios. Thinning has demonstrated to reduce losses by interception, but at same time, it can also increase individual tree transpiration and evaporation rates. However, these practices lead to higher B/G ratios when considering the whole stand. In future global change scenarios, in which drought conditions are expected to intensify, management practices can improve the water balance in these ecosystems by minimizing the risk of plant mortality and species replacement due to intense competence by water resources.

Keywords: drought; blue water; green water; groundwater recharge; silviculture; global change projections

1. Introduction

Forests provide many environmental services, especially water-cycle related ones. Forested areas are capable of reducing the flood risk and protecting soil from erosion, mainly due to higher interception, infiltration, and evapotranspiration rates than in non-forested areas [1–3]. They are also capable of producing other resources, like wood, fruits, and seeds, or even acting CO_2 sinks [4].

However, in semiarid environments, where water is a limiting factor for ecosystem functioning, it is generally considered that forested areas have a negative impact on water availability given the reduction in streamflow and ground water recharge (blue water) [5,6], and therefore, in the water used directly by society. However, they are still able to enhance biodiversity and provide important aesthetic values [7]. Notwithstanding, a new paradigm maintains that, even for arid zones, there is an optimum tree cover that improves water availability [8]. Therefore, in these areas, proper knowledge about forests' water balance is necessary to promote management practices that may ensure both ecosystem stability and environmental services.

According to climate change projections, a general increase in temperature is expected [9], which may have important impacts on forests. In fact, a rising temperature and changes in precipitation regimes have already been related to dieback and forest decay processes worldwide [10,11]. In semiarid zones, like the Mediterranean Basin, this increment in temperature is expected to happen along with reduced rainfall, and would lead to more frequent extreme droughts [12].

Mediterranean species have several mechanisms and ontogenetic adaptations to drought because lack of water in the Mediterranean has been an evolutionary driver [13]. However, especially intense or lasting episodes of drought can trigger events of decay or mortality that could lead to species shifting processes and forest cover alterations which would, in turn, promote those functional strategies to be more tolerant to drought conditions vs. those that are not [14,15]. These alterations may have an impact on all the above-mentioned forests' environmental services, particularly water cycle-related ones. For this reason, studying forests' water balance in semiarid zones and a better understanding of its drivers are especially relevant for developing sustainable water management policies.

The aim of this paper is to review the ecohydrological components of forested areas located in dry and semiarid areas, such as those in southeast Spain, formed by *Quercus ilex* L. and *Pinus halepensis* Mill. forests. These two evergreen trees commonly co-occur in Mediterranean forests [16,17], but usually they form monospecific forests of *P. halepensis*, a pioneer coniferous species with a high germination rate after disturbances like wildfires, and the *Q. ilex* tree, which is a late successional evergreen hardwood tree.

In this article, we have reviewed the main topics related to the forest ecohydrology of water limited ecosystems, from the functional characteristics of each species that faces water scarcity and the water balance's main characteristics for forests stands in arid and semiarid environments, to the role of hydrology-oriented silviculture practices to promote a better management of water yield, including the potential effects of the estimated climate scenarios on these water balances.

2. Plant Functional Characteristics and Strategy to Cope with Drought

Plant traits determine the functional characteristics of plants and how they respond to the environment [18–20]. Functional traits, such as life form (tree, shrubs, herbaceous), life habits (evergreen, semi-deciduous, and deciduous), branching architecture, leaf area, specific leaf area, or hydraulic conductivity, establish differences in the structure of a forest and, consequently, in the soil water balance in several vegetation types [21]. Forest canopy characteristics also determine the volume of water flows across a vegetation canopy, such as interception, stemflow, and throughfall [22]. Soil characteristics, such as soil bulk density, soil particle size, porosity, field capacity content, or wilting point moisture content, will also determine water availability for plants and, therefore, the water flows from the surface to the water table [23]. In addition to above ground traits, plant belowground traits, like root system morphology or rooting depths, are key factors that determine water uptake patterns and transport to aerial plant parts [24].

Both *Q. ilex* and *P. halepensis* are typical Mediterranean species with an evergreen life form. However, some morphological differences will establish different plant hydrological responses. *P. halepensis* is a conifer with two needles per brachyblast, while *Q. ilex* has a flat sclerophyllous leaf blade (Table 1). These leaf characteristics (i.e., flat and larger leaf size and needle for Q. ilex and *P. halepnesis*, respectively), with differences in the degree of sclerophylly, produce a leafy canopy type which, along with differences in the conducting system and branching architecture, would cause some differences in the water flow through the canopy between both species [25]. As regards the belowground structure, *P. halepensis* presents a moderate to shallow root system that determines the capacity to acquire water from soil (Table 1). In contrast, *Q. ilex* has a deep root system [26] that it uses to explore and draw water from deep soil layers [24]. In spite of the morphological differences between these species, forest characteristics (tree density, basal area, vegetation cover, species composition and structure, etc.) are also variables that determine the water flow through a canopy and the soil water balance results [23,27]. In this context, differences in the depth and volume of the explored soil layers, and finally, in the soil water balance between Mediterranean pine forests and *Q. ilex* forests, should be expected.

Table 1. Morpho-functional traits and strategies of resistance to water deficit between *Pinus halepensis* and *Quercus ilex*.

		P. halepensis	*Q. ilex*
Plant functional traits			
Life form		Tree	Tree
Leaf habits		Evergreen	Evergreen
Life histories		Seeder	Resprouter
Plant height		15–20 m	8–25 m
Functional strategy to cope drought		Isohydric species	Anisohydric species
		Drought avoidance	Drought-tolerant
Cel-water relationships			
Ψ_{tlp}	−MPa	2.2	3.9
Π_o	−MPa	1.7	2.8
E_{max}	−MPa	13	13
WSD_{tlp}	%	17	30
Gs_{max}	mmol m^{-2} s^{-1}	270	250
Stomata closure at midday		Strong	Moderate
Photochemical efficiency PSII		Low photoinhibition	High photoinhibition
SLW	mg cm^{-2}	18.5	21.0
Lethal leaf temperature	°C	50	45
Xylem conducting system			
D_{max}	μm	13.6	16.7
PLC_{50}		−4.7	−5.5
LSC	m^2 MPa^{-1} s^{-1} 10^{-8}	9.54	5.96
Ks	m^2 MPa^{-1} s^{-1} 10^{-4}	1.52	1.04
Root system			
Rooting depth		Medium/Deep	Deep
R/S		Low	High
kh_{root}	kg s^{-1} m^2 MPa^{-1} 10^{-4}	0.42	2.49

Adapted from Vilagrosa et al. [28], with modifications. Legend: Ψ_{tlp}, water potential at the turgor loss point; Π_o, osmotic potential at full turgor; E_{max}, cell wall elasticity modulus; WSDtlp, water saturation deficit upon turgor loss; Gs_{max}, maximum stomatal conductance values at full hydration; SLW, specific leaf weight; PLC_{50}, water potential at 50% loss of hydraulic conductance; D_{max}, vessel or tracheid average diameter; LSC, leaf specific conductivity; Ks, shoot-specific conductivity; R/S, root to shoot ratio; Kh_{root}, whole root system hydraulic conductivity. See the reference list in the Supplementary file.

Under dehydration conditions, the drought resistance strategy is the ability to maintain plant functionality and, ultimately, plant survival [29]. Indeed, it has been pointed out that plants can adopt two main functional strategies to face drought: isohydric and anisohydric plant responses [30–32]. Isohydric plants keep the water potential relatively stable, independently of environmental conditions and soil water fluctuations. In contrast, anisohydric species track environmental fluctuations in water availability with a variable water potential according to water availability [33,34]. Iso- and anisohydric

strategies have been linked to water use and drought resistance strategies, such as drought avoidance and drought tolerance [20,29]. In this context, species such as *Q. ilex*, which allow their tissues to dehydrate as water availability declines, present drought tolerance or dehydration tolerance [29]. These species have specific functional characteristics and mechanisms related to an anisohydric response, and are able to tolerate more intense stressful conditions as cell-water relationships focus on delayed stomatal closure (Table 1). They also present moderate stomatal control at midday and allow photoinhibition processes. Another relevant issue to this strategy is resistance to xylem cavitation. In general, these species display high xylem cavitation resistance with a moderate water flow through stems (i.e., low-moderate leaf specific conductivity, LSC), which determines moderate gas exchange rates [20,35].

At the opposite end of this spectrum, we find plant species that strictly regulate water losses to avoid dehydration (drought avoidance or dehydration avoidance strategy; [29]). This strategy is used by isohydric plants (Table 1). *P. halepensis* has been assessed as adopting an isohydric strategy that maintains efficient stomatal regulation by avoiding water deficit according to a water saver mechanism and moderate photoinhibition [28,36–39]. *P. halepensis* also shows low resistance with a high water deficit, as evidenced by lower to moderate xylem cavitation resistance compared to *Q. ilex* [19]. *P. halepensis* needles lose turgidity at relatively high leaf water potentials (−2.2 MPa, corresponding to a cellular water content that comes close to 83%), while *Q. ilex* displays stomatal closure at −3.9 MPa (Table 1). In contrast, *Q. ilex* has been assessed as a drought-tolerant anisohydric species [20,36] with delayed stomatal closure to allow gas exchange rates under more intense drought conditions. This species presents a lower water supply capacity to leaves (low leaf-specific conductivity, LSC), but excellent resistance to xylem cavitation, which are considered tolerance mechanisms [19,20]. In addition, *Q. ilex* mainly presents dehydration tolerance mechanisms, but also has avoidance mechanisms, such as deep rooting, to allow water absorption in dry summer months. These different functional strategies and functional mechanisms reflect the wide array of variety in functional traits that distinct species can develop to adapt to the environment and to produce differences in the soil water balance depending on which species dominates in ecosystems.

3. Water Balance in *Quercus ilex* Forests

The climate range of *Q. ilex* goes from semi-arid to humid environments, where the former are considered marginal forests. Most *Q. ilex* forests are restricted to upper catchment environments, where local hydrological characteristics may be very important for downstream water availability. In humid environments, their influence reaches 30%–60% of downstream freshwater, while this role in semiarid to arid environments rises to 70%–95% [40]

Despite the fact that the water contribution of these forests to lower catchment areas is significant, their water consumption is also relevant, which usually leads to a blue-green water ratio (B/G) below the unit. This range widely varies with climate range, and lowers when moving from humid to semi-arid environments. Limousin et al. [41] studied a humid *Q. ilex* forest and obtained a B/G ratio of 0.55, which lowered to 0.29 when 33% of the throughfall was excluded, although both values could be overestimated as soil evaporation was not considered. Following the climate range, Joffre et al. [42] reported lower B/G values in three sub-humid catchments, with B/G ratios going from 0.32 to 0.44. Similarly, Bellot et al. [27] studied a sub-humid catchment and obtained a B/G ratio of 0.23 when studying a catchment with *Q. ilex* as the main forest species.

Thus, when continuing with the climate gradient of the *Q. ilex* B/G ratio, very little information can be found about the B/G ratio of semi-arid *Q. ilex* forests, and most of it only refers to dehesas systems, i.e., typical Mediterranean pasture in some places of southwest Spain mixed with big *Q. ilex* trees. Ceballos and Schnabel [43] calculated the water balance of a semi-arid catchment in a dehesa land use and obtained a low B/G ratio that ranged from 0.01 to 0.2, which could have been underestimated as no deep percolation was considered. Likewise, Campos et al. [44] used satellite information to calculate the water balance of a semi-arid dehesa and reported an average B/G balance of 0.2 over five years. On the contrary, only one study has reported a water balance of a semi-arid natural *Q. ilex*

forest [45]. Its results are summarized in Table 2, with B/G ratios below the unit for both years, where evapotranspiration (ET) appears to consume most water, and the blue water contribution is basically produced by deep drainage, with almost negligible runoff and streamflow [45]. The results from both the dehesas system and the natural *Q. ilex* forest, are consistent with the typical response of semi-arid ecosystems. In this systems, ET usually dominates the global stand water balance, followed by canopy interception, and blue water contribution occurs mainly after strong precipitation events [45,46]. Both formations show high seasonality in the B/G ratio, where the maximum water contribution takes place in fall and winter (Figure 1). Despite this, there is one period when B/G exceeds the unity in both environments, where the low values indicate the scarce water contribution of semi-arid *Q. ilex* forests and the high water requirements to maintain them. This scarce water contribution and high water demand highlight the marginality of some coppice forests, and, therefore, their difficulty when facing the warmer and drier climates conditions expected to occur in the future in the Mediterranean Basin [12].
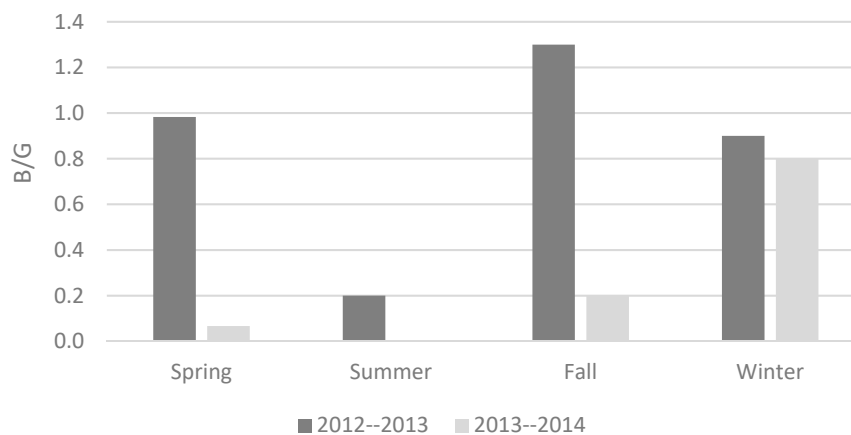
Figure 1. The blue to green water (B/G) ratio for a *Q. ilex* coppice forest in 2012–2013 and 2013–2014. Precipitation values were 534 mm and 271 mm for 2012–2013 and 2013–2014, respectively.

When expressing ET as a % of gross precipitation, the values in both ecosystems are similar to those obtained in more humid *Q. ilex* forests [41,47]. On the contrary, when absolute ET values are considered (depth, mm), the ET of the semiarid forests does not even reach the transpiration rate of the humid *Q. ilex* forests [41,47]. Nevertheless, the values are similar to that of a low-density woodland during a drought period (191 $\pm$ 20 mm) reported by Infante et al. [48]. The fact that the transpiration of a sub-humid low density forest under drought conditions is comparable to that of a semiarid one, indicates the adverse conditions that these forest have to face, which are even harder for natural *Q. ilex* forests as tree competence is stronger.

Table 2. Water balance of *Pinus halepensis* and *Quercus ilex* forests in two water years, 2012–2013 and 2013–2014, which are respectively wet and dry. P is gross precipitation, ET + Int is evapotranspiration and interception, R_{off} is runoff, and R is potential deep drainage. B/G represents the blue to green water ratio. Adapted from Ruiz-Yanetti [49] and del Campo et al. [43]. Site names: Mela (MEL), Cabeço d'or (CAB), Ventós (VEN), Sierra de Águilas (SAG).

Years	Species	Site Name	P (mm)	ET + Int (%)	Roff (%)	R (%)	B/G
2012–2013	*P. halepensis*	MEL	911	72	0.5	27.6	0.39
		CAB	417	82.1	0.4	17.6	0.22
		VEN	425	79.9	0.3	19.8	0.25
		SAG	420	79.4	0.3	20.3	0.26
	Q. ilex		534	51	0	49	0.9
2013–2014	*P. halepensis*	MEL	318	91.1	0.4	8.5	0.1
		CAB	146	95.1	0.4	4.6	0.05
		VEN	114	97.8	0.2	2	0.02
		SAG	142	91.4	0.3	8.3	0.09
	Q. ilex		271	81	0	19	0.2

The B/G ratios show high seasonality when compared over a one-year period, where the maximum water contribution takes place in spring and fall. Despite there being one period when B/G exceeds the unity (Figure 1), the low values indicate the scarce water contribution of marginal *Q. ilex* forests and high water requirements to maintain them. This scarce water contribution and high water demand highlight the marginality of some coppice forests and, therefore, their difficulty when facing the warmer drier climate conditions expected to occur in the future in the Mediterranean Basin [12].

4. Water Balance in *Pinus halepensis* Forests

P. halepensis forests also show a highly variable B/G rate that ranges from 0.8 to 0.06, according to a rainfall gradient that increases with precipitation [21,46,49]. The *P. halepensis* stands under these climatic conditions usually show a high percentage (referring to annual rainfall) of green water, above 90% [49], which can rise to 100% during especially dry years when annual precipitation drops to 260 mm [50]. In these cases, it can be even higher than 100% due to the use of water stored in deeper soil layers [51,52].

As formerly addressed, this species has been widely used for afforestation purposes, even in quite arid areas where annual rainfall barely exceeds 300 mm [53]. This has posed questions about the sustainability of these forests under such dry conditions, which have led to current water balance studies to analyze their sustainability. In fact, it has been regarded that afforestation significantly impacts local water balances, by presenting higher evapotraspiration values than the non afforested areas adjacent to them. In line with this, Rohatyn et al. [2] studied the effects of *P. halepensis* afforestation on the water yield along a semiarid climatic gradient. These studies point out that when this afforestation is located in more humid environments, it displays marked decreases in water yields, nearly 30% of precipitation, which means 200 mm/year in absolute terms. However, in dry-land afforestation, this reduction in water yield lowers by about a 20% and involves 50 mm/year, which indicates that the effect of *P. halepensis* afforestation on the water balance varies with climate. There are more studies that have addressed this response of afforestation to climate variability. Helman et al. [3] have found that higher values of water use efficiency are reached in dry land afforestation of *P. halepensis.* The same has been observed for other *Pinus* species present in semiarid environments, like *P. brutia* and *P. pinea.* In addition, it is noteworthy that stands located in these climates show ecohydrologycal and ecophysiological adjustment to drought, which leads to stronger resilience to these conditions in comparison to other stands located in more humid places [54–56].

In order to continue with this climate response, Ruiz-Yanetti [57] calculated the water balance of four *P. halepensis* stands with the HYDROBAL® model [58–60] for a three-year study period. These stands had tree densities that ranged from 489 to 968 trees ha^{-1}, and were located along a rainfall

gradient (from 300 mm to 610 mm) in the province of Alicante (southeast Spain). Their results indicated high variability between two selected wet and dry years (Table 2); and low values of B/G ratios and the green water fluxes reached percentages above 90% total rainfall under water scarcity conditions.

Considering the whole study period, they found significant differences in the mean values of Interception (Int) and net precipitation (Pnt) between the sites with different vegetation covers (Figure 2). These results suggest their strong influence on water balance and agree with the idea that in afforested areas with a high tree density, interception reaches high values that can emphasise drought stress under water limitation conditions [61]. They also found that actual evapotranspiration (Eta) was significantly higher, more than 54% of total precipitation, in those places where tree density was lower. This effect was also observed by several authors [28,39,62] who indicated that the amount of water transpired for one tree was prone to be higher than that transpired by a stand because an individual tree frequently has more biomass for its maintenance and could be affected by high potential evapotranspiration.
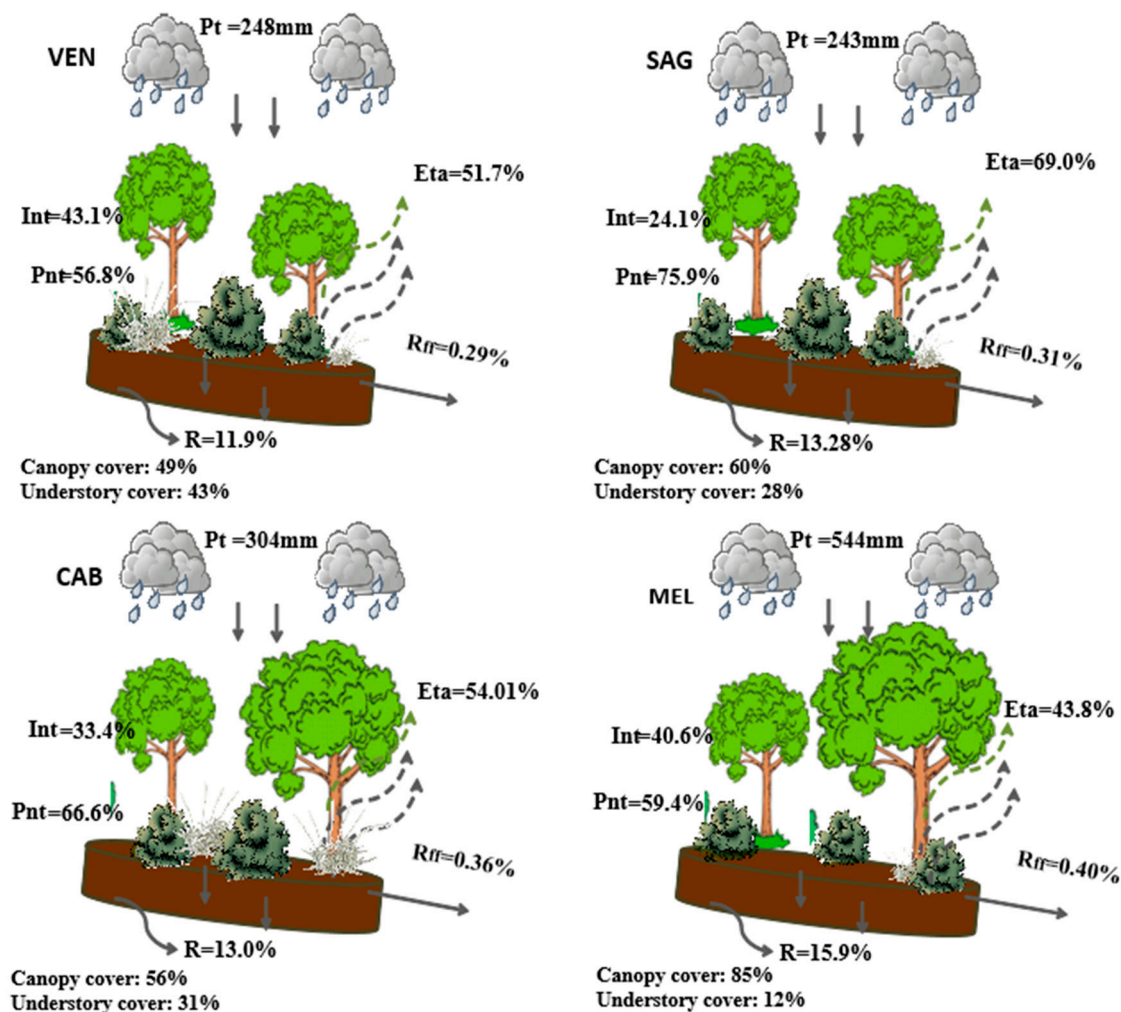
Figure 2. Water balance diagrams in the different forests along a gradient of precipitation. The water flow values estimated by the HYDROBAL® model according to the pine afforestation obtained at each site. Values are a percentage (%) in relation to total precipitation. Abbreviations: Net precipitation (Pnt); Interception (Int); Runoff (Rff); actual evapotranspiration (Eta); potential recharge (R). Site names: Ventós (VEN); Sierra de Águilas (SAG), Cabeço d'or (CAB); Mela (MEL).

5. The Role of Mediterranean Forests in Aquifer Recharge for Semiarid Areas

In most semiarid areas, droughts and scarce rainfall often turn groundwater into the main source of freshwater. In southeast Spain, approximately 80% of the water demand for society is supplied

from aquifers. In recent decades, the pressure placed on this resource has grown due to the increasing population in these areas and to lack of precipitation associated with drought intensity, which is even expected to grow with climate change [63]. Therefore, hydrological management is an important tool to protect water resources in these areas and also to gain a better understanding of aquifer recharge.

Aquifer recharge depends on several factors, such as geology, climate conditions, and the type of land cover in each catchment [58,64]. Several studies have demonstrated that the main driver with a direct impact on aquifer recharge is rainfall [19,58,63,64]. Indeed, strong linear relationships between rainfall and aquifer recharge have been found for semiarid areas, with correlation coefficients up to 0.9 [65]. It is important to mention that for semiarid zones, most rainfall events present quite a low intensity and a short duration, and very few are able to have any real influence on aquifer recharge. In fact, Andreu et al. [66] found that only those events with over 15 mm were able to produce an effective recharge, which represents only 9%–17% of the total amount of precipitation recorded during their study period. This also implies a high seasonality for recharge events as many rainfall episodes occur in spring and autumn.

It is also noteworthy that the existing soil water content before a rainfall event has a relevant influence on deep drainage. In fact, the higher it is in previous soil moisture, the higher recharge events are [19,64]. Vegetation, therefore, also plays an important role in recharge. Most forested areas have a negative impact on blue water fluxes, but are capable of reducing the risk of erosion and floods. Bellot et al. [59] found that forested areas reduced recharge fluxes by 36.9% in semiarid areas due to a higher evaporative demand, with shrub stands being the most favourable for aquifer recharge. Likewise, Ruiz-Yanetti [57] studied the role of the most representative vegetation covers and plant vertical structure located in aquifer recharge areas in southeast Spain. These authors found that forested stands with more stratification and structure complexity reduced both soil water content and recharge due to increased interception and evapotranspiration. They concluded that the more favourable landscape structure to promote aquifer recharge in these areas would be 16% of the surface covered with shrubs and *P. halepensis* with low levels of stratification, while the rest of the surface would be covered with plenty of tussocks like *Stipa tennacisima*.

6. Forest Management Effects on the Transpiration of Mixed Forests

Hydrology-related silviculture has been proposed to adapt forests to climate changes [67]. In Mediterranean forests, it could be a useful tool to both ensure ecosystem resilience and blue water incomes under more water scarce conditions. In *P. halepensis* stands, it has been observed that thinning practices can reduce water losses by interception. These practices also increment the use of water by the remaining trees, but transpiration at the stand level is lower than in non-thinned stands [46,68,69].

When considering mixed *Q. ilex* and *P. halepensis* forests, the different strategies in seasonal transpiration patterns and the ability to acquire water at different soil depths or soil water contents may condition the species' co-existence [70,71]. Del Castillo et al. [72] observed that both species used the same amount of water during the wet season, which also occurs in the growing season, but shifted to distinct water sources during the summer drought period. David et al. [73] reported that the deep root system of *Q. ilex* (up to 13 m) allows this species to access groundwater and to, therefore, remain physiologically active during summer drought periods. Meanwhile, pine species tend to rely more on shallow soil moisture during summer drought periods by following a drought avoidance strategy and by limiting water flows to the atmosphere [74]. Furthermore, this difference in the water uptake depth appears to be stimulated in mixed forests because *Q. ilex* surrounded by *P. halepensis* explores deeper water sources than in monospecific formations [72].

Experimental results that support the differentiated water uptake strategies in *Q. ilex* and *P. halepensis* in a mixed forest are also presented in this review (Figure 3). Tree transpiration was measured in both species co-occurring in a semiarid mixed forest two years after a thinning silvicultural treatment (see [45] for experiment details). The comparison showed significantly higher tree transpiration values in *Q. ilex* than in *P. halepensis*, where the biggest differences were from early summer to late autumn

periods (Figure 3). Likewise, a negative linear relationship ($R^2 = 0.71$) was found between the oak and pine transpiration ratio ($\ln T_{oak}/T_{pine}$) and the soil water content during the growing season, which indicates that *Q. ilex* obtained a higher transpiration rate with a lower soil water content. Conversely, this relationship became non-significant after the growing season.
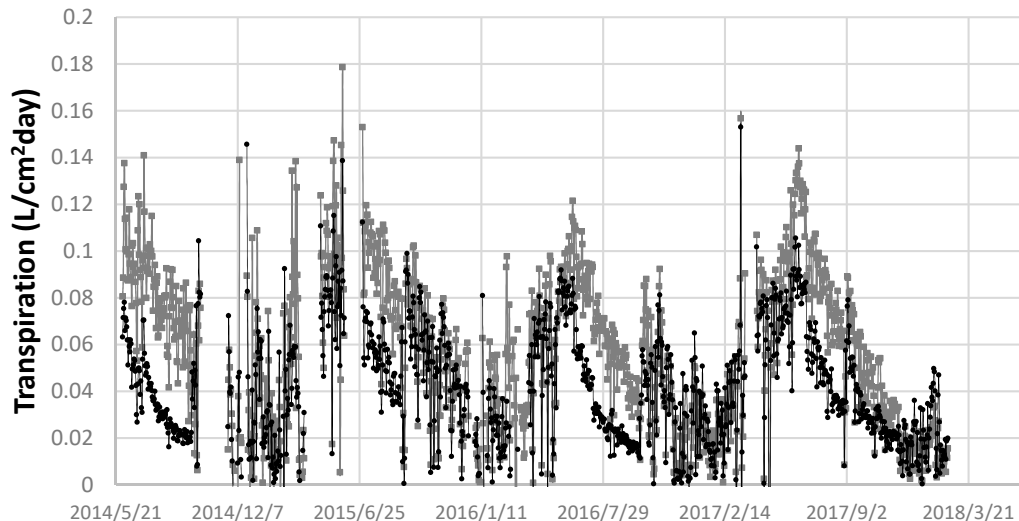
Figure 3. Transpiration (litres per cm^2 of sapwood area per day) of *Q. ilex* (grey) and *P. halepensis* (black) during the study period.

In agreement with these results, several studies [74–77] have suggested that the ordinary soil depth at which most water is taken up in pines is 30–40 cm, while *Q. ilex* appears to reach deeper soil layers [72,73]. Indeed, the use of a deeper water source by *Q. ilex* would also explain it being able to maintain higher transpiration rates during drought periods. Likewise, according to these results, the early effects of forest management do not appear to alter the differentiated strategies of both species, but only to increase their water consumption [45].

7. Future Scenarios in a Global Change Context

Most climate models estimate an increase in temperature and a reduction in precipitation over the 21st century for the Mediterranean Region [9]. These changes have already been observed in recent decades for this region [9], particularly for the Iberian Peninsula [78,79]. On a local scale, specifically in the province of Alicante (southeast Spain), precipitations have shown a negative trend (-9.4 mm/decade) over the last six decades until 2012. The mean temperature significantly has shown a positive increment ($+0.18$ °C/decade, $p < 0.001$) during the same period [80]. In the future, and according to nine CMIP5 (Coupled Model Intercomparison Project Phase 5) climate models, reductions of 30% and 40% in mean precipitations are expected under climate scenarios RCP4.5 and RCP8.5 (Representative Concentration Pathways 4.5 and 8.5), respectively, for the 2040–2099 period with respect to the 1953–2012 period. Temperature is expected to rise at the same observed rate ($+0.2 \pm 0.07$ °C/decade) under the moderate climate scenario RCP4.5, and at a higher rate ($+0.73 \pm 0.18$ °C/decade) under the high scenario RCP8.5 during the 2040–2099 period [80].

The observed and expected changes in temperature and precipitation will have marked effects on ecosystems. According to Rivas-Martínez's [81] classification, using precipitation thresholds, bioclimatic belts will shift to the north, and the semiarid belt will cover a more extensive territory (Figure 4A) [80]. By the end of the 21st century, and with extreme climate scenarios, the subhumid belt is likely to disappear in the province of Alicante (Figure 4B), and the arid and semiarid belts are expected to cover more territory, both locally and globally (Figure 4A) [78,80,82]. These changes will have important effects on water balances. Moutahir [80] used the above-cited projected data and

the eco-hydrological HYDROBAL® model to simulate the water balance in three pine forests that are representative of each bioclimatic belt in the province of Alicante (semi-arid, dry, subhumid). This author showed that negative trends are expected in the different water balance components, especially for the stands located on the subhumid belt, which is most likely to disappear in the future under the extreme climate scenarios (Figure 5).
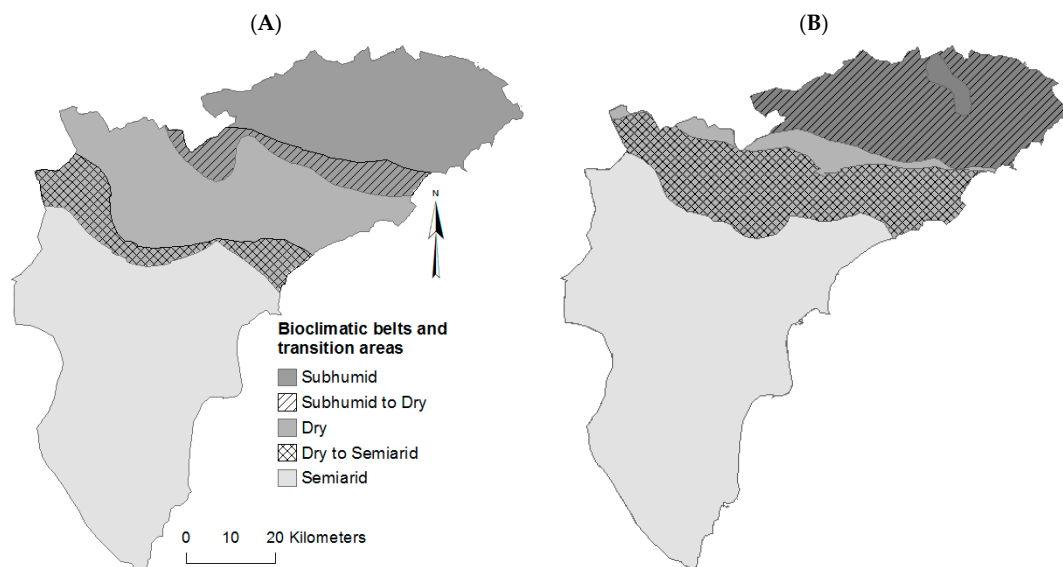
Figure 4. Shifts of the bioclimatic belts in the province of Alicante. (**A**) Changes observed between 1953–1982 and 1983–2012 (dashed areas show transition zones). (**B**) Changes estimated for 2070–2099 with respect to 1983–2012 period according to the high scenario RCP8.5 (Representative Concentration Pathways 8.5) (the average of nine CMIP5, Coupled Model Intercomparison Project Phase 5, climate models).
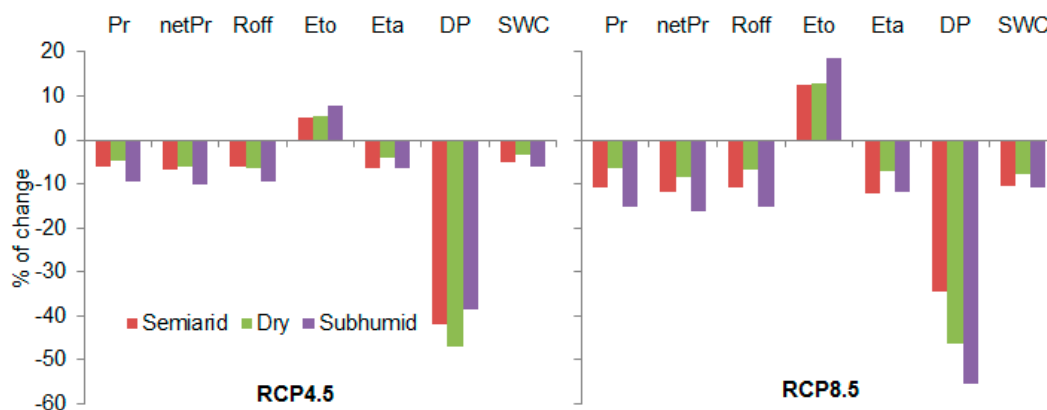
Figure 5. Percentage of change in the water balance components during the 30-year 2070–2099 period compared to 2010–2039 at the three pine sites along a climate gradient under the two RCP scenarios and in nine CMIP5 climate models. Pr: Precipitation, netPr: Net rainfall, Eto: reference evapotranspiration, Eta: actual evapotranspiration, DP: deep percolation, SWC: soil water content.

However, changes in the mean are not the only concern in the Mediterranean Region. Indeed, changes in the frequency, intensity, size, and temporal distribution of climate extremes are expected in this region [9], and will have different effects on water balance. Groundwater recharge in arid and semiarid environments is often restricted to heavy rainfall events [83]. However, the number of these rainfall events is likely to be lower in the future, which would reduce the chances for aquifer recharge despite their increasing size [63]. At the same time, the increasing size of these events will

reinforce the torrential characteristic of rainfall in this region, with most water input concentrating in just a few days. The precipitation concentration is also expected to increase the frequency and length of drought periods. In addition, the soil characteristics in these areas (i.e., deforested calcareous and marly soils and with a soil surface crust) will not favour water infiltration, but will reduce soil water content (SWC), which has been pointed out as the main hydrological variable to explain the observed variations in *P. halepensis* growth and phenology [84,85].

8. Conclusions

In general, the water balance of *Q. ilex* and *P. halepensis* forests shows low values for blue to green water ratios in Mediterranean ecosystems. For green water, evapotranspiration and interception are the main processes, which are strongly influenced by the complexity of vegetation composition and structure. On the other hand, groundwater recharge is the only relevant flux for the blue component of the balance. The bias towards green water grows during droughts, and these conditions have a negative impact on blue water because then there are fewer rainfall events capable of producing groundwater recharge.

Adaptive management practices can be followed to compensate for this unbalance and to promote blue water fluxes. Indeed, forest thinning practices can help to reduce losses by interception, but can also increase tree transpiration and soil evaporation rates. However, these practices lead to higher blue to green ratios when considering the whole stand. These silviculture practices have also been proposed to enhance the water yield of afforestation, especially in more humid places, while their effect has less potential in dryer ones, where it does not differ much from non afforested areas.

Climate change estimations predict that arid and semiarid conditions will extend, and the water balance simulations for these scenarios show negative trends for all water balance components. All the estimated scenarios predict a marked change in deep percolation and, therefore, in groundwater recharge. The cause of this is explained mainly by the fact that rainfall events will become less frequent and only a few will reach the precipitation threshold needed to produce them. Drought conditions are also expected to intensify, which could trigger plant mortality events and species replacement, as previously observed. This scenario could alter the composition and structure of communities, which would affect their water balances. Therefore, further research is needed to better understand how these drought-induced processes will affect the sustainability and water balances of Mediterranean forests.

Finally, given the forecasted higher frequency of droughts in semiarid forests, their water demand is expected to increase, while water will become scarcer. This would threaten their stability and resources. However, management practices could be key to compensating for this impact. Hence, more in-depth knowledge of the ecohydrology of these forests and their response to drought is needed to ensure the best application of these practices.

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