World Federation of Scientists

Slovenian Science Foundation

Slovenian Forestry Institute

INTERACTION BETWEEN FOREST AND WATER

Final report on activities of **Simon Poljanšek**,
a **World Federation of Scientists** and
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INTERACTION BETWEEN FOREST AND WATER

A case study for the Rižana watershed

ABSTRACT

Rižana river flow, presenting a main water source for Slovenian coastal area, is already in falling trend. Some due to the reduced precipitation in the area, some due to increased forest cover. How much of the precipitation will be used by forest, is dependable upon many factors. Species selection is one of them, as tree species differ in their water use. This research is focused on *Pinus nigra* with isohydric and *Quercus petraea* anisohydric behaviour. Species of anisohydric behaviour use more water than trees with isohydric behaviour. From water management point of view, selection of *P. nigra* forest would be better, but is this species also suitable for this area in the light of climate change? Based on long-term forecast and how species response to climate, we can draw some conclusion on species suitability. Climatic factors, used in this research, were precipitation, air temperature and available water, calculated out of precipitation and river flow data. Dendroclimatological analysis of two species from six sites showed, that site *P. nigra* chronologies better matched each other than *Q. petraea* site chronologies did. Second, measure of common variability is better in *P. nigra* chronologies. And third, response to climate is to some extent site specific, however, conclusion can be drawn, that *P. nigra* trees had stronger response to calculated available water, while *Q. petraea* to precipitation. Strong climatic influence is also observed in inter-annual density fluctuations in tree-rings of *P. nigra*. Based on our results and reports in literature on the isohydric and anisohydric behaviour of *P. nigra* and *Q. petraea*, we can conclude, that future growth of both species will be in summer time more limited due to climate change and lack of water. We can, furthermore, expect future decrease in Rižana flow, due to replacing of *P. nigra* with *Q. petraea* trees, as expected in succession. For deeper understanding of water-forest interaction and for improved modelling of evapotranspiration in Rižana watershed, we suggest direct sapflow measurements and use of forest stand density and forest cover data, as a part of future work.

INTRODUCTION

Forests have numerous positive influences on water sources. By slowing down the speed of wind and water run-off, they improve soil fertility and reduce soil erosion. Preventing of erosion keeps water, originating from forested areas at higher quality levels, compared to, for example, sloping agricultural fields- a main source of river sediment (Keesstra et al., 2009). But forest protection takes its toll, as trees also use water (Chaturvedi et al., 1988). However, role of forests in water cycle is not black-and-white. Some researchers claim that the impact of reforestation or afforestation on water yield is negative, while others argue the opposite. It seems that the impact of forest on water yield is dependable upon catchment scale; trees reduce runoff at the small catchment scale, while at larger scales, trees are more clearly linked to increased precipitation and water availability (Ellison et al., 2012). Without argument, trees come in first contact with precipitation in the form of interception. This is a process by which precipitation is caught and held by vegetation, then either distributed as runoff to the ground, or lost by evaporation without reaching the ground (Figure 1). Evaporation rate increases with rainfall intensity, as splash, when a raindrop hits the canopy, creates small droplets, which evaporate even into saturated atmosphere (Grip and Hällgren, 2005). Leaf area influences both, interception and evaporation and differentiates within the season and between conifers and deciduous trees (Swank and Miner, 1968). In timing of fully developed crown, for example, birch intercepts double amount of water, compared to defoliated winter crown, while black pine (*Pinus nigra* Arnold) intercepts a third more (Zabret et al., 2016). Furthermore, some measurements show, that *P. nigra* could intercept as much as 51% of annual rainfall (Zabret and Šraj, 2015). Removal of forest cover would undoubtedly decrease interception and increase river flow (Hibbert and Forest, 1979), but on the long term irreversibly endanger soil protection, especially on complex and sensitive karst surface (Dai et al., 2017).

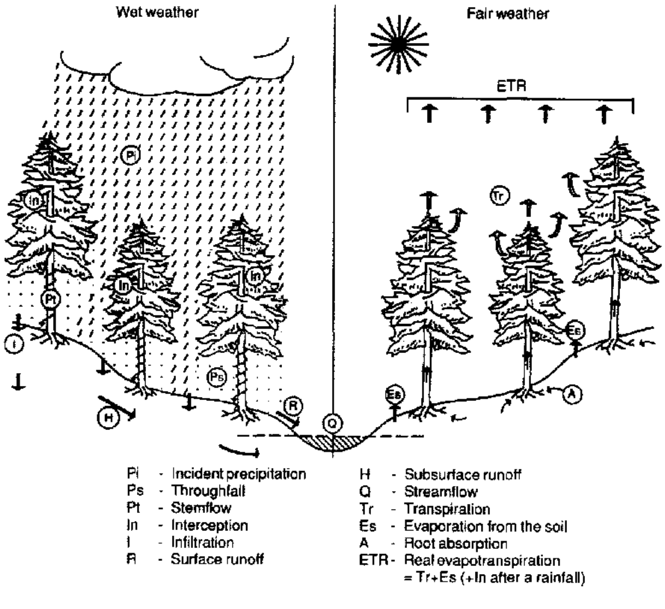


Figure 1: The water cycle in a forest (Humbert and Najjar, 1992).

Influence of (altered) vegetation on river flow

Solution for forested areas with water quantity issues and danger of erosion, could be selection of most appropriate tree species and definition of species and forest density (Bréda et al., 1995). Manipulated forests would still provide water function, but with reduced water consumption/demand. How changing vegetation cover influences river flow has already been observed, using paired watersheds that have undergone forest harvest, species conversion, or long-term observations (Brown et al., 2005; Joffre and Rambal, 1993). Researchers discovered, that interactive effects of climate change, represented by changes in observed precipitation trends, and forest management regime, significantly alter expected streamflow most often during extreme events, ranging from a decrease of 59% to an increase of 40% in streamflow, depending upon management (Kelly et al., 2016). Idea, that vegetation might be managed to compensate for hydrologic responses due to climate change to help mitigate effects of extreme changes in precipitation, is elsewhere confirmed (Alden, 1983; Hibbert and Forest, 1979). Comparing deciduous trees to conifers, increases water yield from small catchments more when conifers are removed, compared to the removal of deciduous hardwoods or shrubs (Bosch and Hewlett, 1982). It is also important to note, that as forest cover negatively impacts annual and “non-vegetation” period water supply but positively when studying low discharge flows (Brogna et al., 2017). This suggests presence of the thin line between forest as a water retention in events of extreme precipitation and forest as a water user.

However, determination of most suitable tree species for selected area, is a difficult task. Most appropriate method to achieve this goal would be direct measures of the water, used by individual tree species (Dawson, 1996; Lundblad et al., 2001; Vertessy et al., 1997; Wullschleger et al., 1998). As such measurements are performed on individual trees, would be next, but also a critical step in linking plant physiology and hydrology, an extrapolation of water use measurements to a stand level (Hatton and Wu, 1995). To be able to do so, similar response of trees in a stand must be confirmed. In dendroclimatology, common response of individual trees to environmental factors is evaluated using expressed population signal; EPS (Cook and Kairiukstis, 1990). EPS presents a measure of the common variability in a time series of annual radial tree growth, that is dependable upon number of trees sampled. Using EPS, we can quantify, how much did the trees act as individuals and how much of their response was common to other trees in a stand. Common signal in trees sampled is then used in climate-tree growth studies, in which influence of individual climate factor on tree growth is tested; e.g. (Poljanšek et al., 2013). This way, suitability of selected tree species is argued in the light of climate change. Selected species needs to be adapted, or to have potential to overcome already present climate change. As response to climate change and air temperature rise, trees will extend growing season (Chmielewski and Rötzer, 2001), but may also become increasingly vulnerable in response to future warming and drought, even in environments that are not normally considered water-limited (Allen et al., 2010; Sarris et al., 2007).

Rižana watershed, pines and oaks

Combination of expanding forest areas, denser forest with older, bigger trees on one side and with climate change, manifested in reduced precipitation and increased air temperatures on the other side, results in inadequate water source in Rižana watershed. In the summer, region faces water demand that is higher than amount of available water and for this reason is water pumped from other systems, which increases water price. Rižana river flow, presenting a main water source for Slovenian coastal area, is similar to other Slovenian rivers already in falling trend (Jurko, 2009). Combination of decreased precipitation and increased air temperature, increased demand of households, industry and agriculture, results in summer water shortage events (Claessens et al., 2006). In future such events will be more frequent, greater and longer lasting (IPCC, 2013). Lack of water for public use is already occurring in several countries throughout the world, which makes analysis on forest water cycle and impact of forest on water management highly important (Grip and Hällgren, 2005).

In Rižana watershed area are present two common forest species but with different strategy when it comes to drought; sessile oak (*Quercus petraea* (Matt.) Liebl.) and *P. nigra*. In presented work, we tested if there is a difference between named two species in their response to precipitation, air temperature and amount of available water. The mechanism underlying the stomatal responses to drought differs between with the two contrasting plant water strategies; isohydric and anisohydric (Barns, 1996; Picon et al., 1996b). For example, species of anisohydric behaviour, like *Quercus calliprinos* trees, can use 30% more water than *P. halepensis* with isohydric behaviour (Klein et al., 2013).

- **Isohydric** trees are known for their **drought avoidance**, which is generally found in species with high stomatal sensitivity to drought. Stomatal regulation can occur before any alteration in leaf water status, as for example in *Pinus pinaster*. Results on growth and sap flow responses for a 3-year period, including stressful drought, are suggesting that *P. nigra* is in this group (Forner et al., 2014; Tardieu and Simonneau, 1998).
- Other group of trees are **anisohydric**, have **drought tolerance**. Such species have lower stomatal sensitivity but displaying structural and functional adaptive traits such as osmoregulation, allowing the plant improved tolerance of reduced water status. Decreasing leaf conductance has been associated with decreasing leaf water potential. *Quercus petraea*, is a deciduous drought-tolerant species with a deep rooting pattern, allowing efficient soil water extraction, occurring in low elevation and non-hydromorphic sites (Picon et al., 1996a). However, the large vessels of *Quercus* are very sensitive to cavitation and lose functionality later in the season, when moisture decreases and narrower conduits are formed to take their place in the sap flow (Klein, 2014).

Goal of the study

For reasons given, it is therefore important to individually investigate interaction between forest and water in watershed, with emphasis on the question: can tree species selection influence water availability? Based on literature overview on isohydric behaviour of pines and anisohydric of oaks and climate forecast for water-limited areas, we set our objectives to:

- Develop dendrochronological network of two most common tree species in a selected watershed.
- Investigate response of *Q. petraea* and *P. nigra* to climatic factors.
- Identify most influential climatic factor on tree growth of individual species.
- Analyse how stabile in time is response of species to selected climatic factor.
- Suggest future forest structure, based on species suitability in the light of climate change and with goal to increase summer water flow.

MATERIAL AND METHODS

Area selection

Rižana river watershed, situated in south-western part of Slovenia (Figure 2), is with 220 km^2 relatively small (Janža, 2010). This area is represented as karstic, with limestone or flysch bedrock and little or no run-off. Area of once deciduous forests was in the past times heavily cleared for cattle and timber industry (Kranjc, 2009). With no forest to protect forest soil, strong winds and water eroded forest soil, until more or less only bedrock remained (Kaligarič and Ivajnšič, 2014). To prevent complete devastation of the forest soil, black pine was planted alongside with some other broadleaves, but only black pine succeeded in harsh environment (Zorn et al., 2015). Nowadays, have black pine plantations lost their vitality, therefore they will have to be substituted with younger pines or with more appropriate deciduous trees in order to preserve the forests (Sanković, 2015). It is important to stress out, that young black pine trees do not regenerate in a formed stand (Arnšek, 2009; BRUS et al., 2016). Tree species, found here are black and red (*P. sylvestris*) pine, oak sp. (petraea, *cerris* and *pubescens*) and other broadleaves such as *Tilia*, *Acer*, *Ostrya, Fraxinus* etc.

In Sub-Mediterranean Slovenia, *P. nigra* and *Quercus sp*. had already been investigated for climate signal and influence of precipitation recognized (Ogrin, 1992), however, study was not focused on explicit watershed but in general area (Ogrin, 2005). From investigated site, one *P. nigra* chronology is available, on which climate signal was already investigated (Poljanšek and Levanič, 2012a). In order to investigate the response of tree species to amount of water from particular watershed using broader network of sites, additional sampling was required. Sites (Figure 2) were carefully selected to form a network of sampled sites inside the Rižana watershed area (Janža and Prestor, 2002). In the process forestry plans were used in cooperation with the Slovenian Forestry Service.

Objectives for site selection were:

- equally distributed sites across the Rižana watershed,
- presence of both species on each site/stand or close to each other,
- presence of as old trees as possible and
- not damaged trees (intact stem and crown).

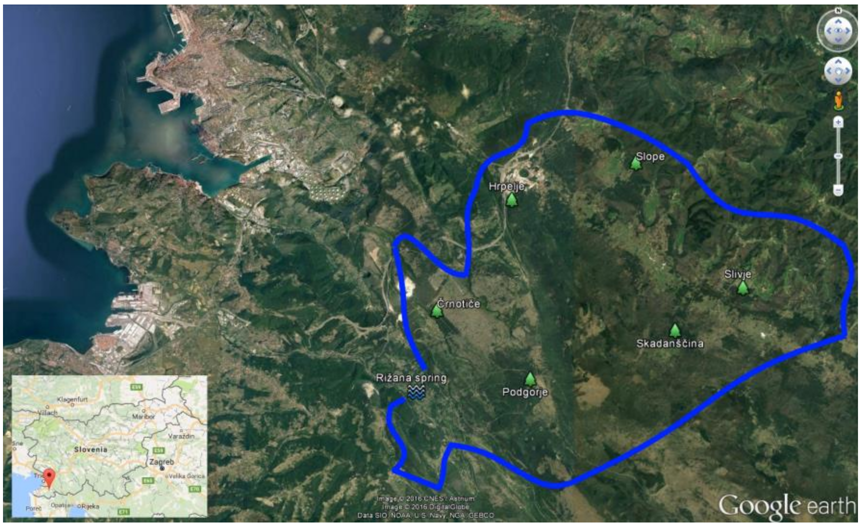


Figure 2: Sampling sites (green tree icons) with river Rižana spring (blue-ish wave icon) and approximate presentation of the watershed area edge (blue line).

Field work

Altogether, six sites were selected (Table 1). For each site, a micro location was selected to optimize climatic signal, embedded in radial growth of sampled trees. On each site, both species and up to 16 trees were sampled, except on limestone site Slivje and Slope, no oak trees were found. For this reason, and to still ensure equally distributed sites across river watershed, closest oak stands were chosen, although on flysch bedrock (Table 1). Using increment borer and EU patented tool (Poljanšek and Levanič, 2012b), were from each tree, two cores from opposite sides taken at breast height (1.3 m) and perpendicular to the slope to avoid compression wood (Figure 3).

Figure 3: Sampling tree growth using increment borers on oak (left) and pine (right).

Samples of radial increments from bark to pith (centre of the stem) were extracted from the stem, carefully placed into plastic straws and *in situ* marked with identity number. At this point it is worth mentioning, that *Q. petraea* can genetically mix with *Q. pubescens*. Precautions, like bud inspections were taken, however, some hybrids could be mistaken for *Q. petraea* and sampled.

Table 1: Sampling sites

Site	n. of pines	n. of oaks	bedrock	altitude (m a.s.l.)
Slivje (Loče)	15	16	limestone (flysch)	580 (550)
Slope (Artiže)	17	16	limestone (flysch)	630 (690)
Skadanščina	16	6	limestone	530
Hrpelje	16	11	limestone	500
Podgorje	15	5	limestone	480
Črnotiče	15	12	limestone	410

Laboratory

Sample preparation, measuring of the tree-ring widths

In the laboratory, samples were taken from the straws and placed on a cardboard, dried and glued on wooden holders. Surface of the samples is then grinded to ensure clearly visible tree-rings. Samples were then scanned using ATRICS system, developed in this laboratory by my menthor; Tom Levanič (Levanic, 2007). In this process, samples were captured image by image. Finally, the image of complete sample is stitched together into one "panoramic photo". Image is then imported into dendrochronological program; WinDendro^{TM} or CDendro (http://www.cybis.se/forfun/dendro/index.htm), where tree-ring widths are measured to the nearest 0.01 mm. After tree-rings of all samples were measured, cross dating of chronologies was done by PAST-4TM software (www.sciem.com) using both visual on-screen comparisons and statistical parameters, such as the t-value after Baillie and Pilcher (t_{BP}) (1973) and Gleichläufigkeits coefficient (GLK%) (Eckstein and Bauch, 1969). Individual tree-ring width (TRW) series were standardized to remove long-term trends (Cook, 1985), and all basic statistical parameters of TRW were calculated using ARSTAN for Windows (Cook and Holmes, 1999). Each series of tree-ring width was fit with a cubic smoothing spline with a 50% frequency response at 67% of the series length to remove non-climatic trends due to age, size, and the effects of stand dynamics (Cook and Briffa, 1990). Each year's ring width was divided by the year's value of the fitted curve to give a dimensionless index with a mean of one. Index values were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike criterion and combined across all series using biweight robust estimation of the mean to exclude the influence of outliers. Standard chronology was produced this way (Cook, 1985) and used in analysis.

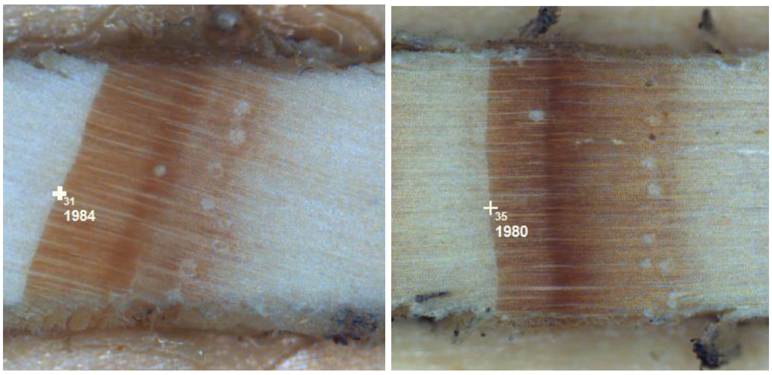
Signal strength in site chronologies was tested using Expressed Population Signal - EPS (Briffa and Jones, 1990; Wigley et al., 1984). Calculation of EPS is based on a 30-year moving window with a 25-year overlap. For each window, ARSTAN calculates the average between-tree correlation, number of trees included, and EPS. We also calculated the usable portions of the chronologies to ensure the reliability of any climate signal calculation that may be carried out with using this dataset. The usable portion of a chronology was defined as the part where a minimum number of trees maintains an EPS value above 0.85 (Briffa and Jones, 1990).

Inter-annual density fluctuations observations

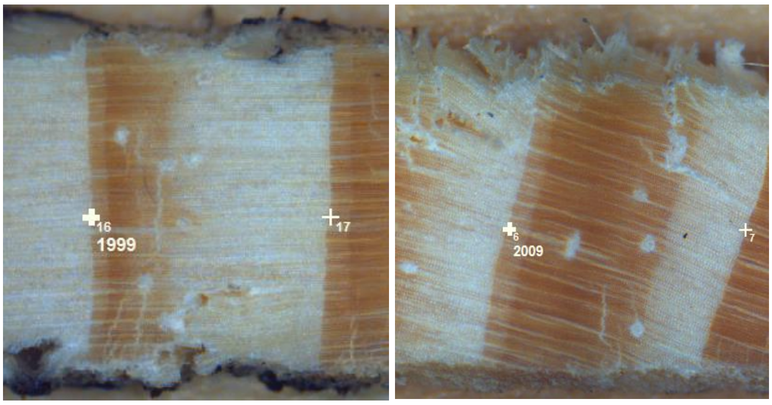
Inter-annual density fluctuations observations (IADFs) in tree rings are generally considered as structural anomalies caused by deviations from the "normal course" of xylogenesis during growth season. In Mediterranean, tropical, semi-arid and arid regions, where trees suffer »double stress«, even a double ring is caused by the interruption of the normal course of growth during a season; one of the zones of growth of such a ring; IADF, is also known as a false ring (Cherubini et al., 2003). Generally, can be formation of IADFs triggered directly by environmental changes, especially in precipitation and temperature, that affect cambial activity and cell differentiation. It can also be the result of limited photosynthesis, due to defoliation induced by biotic or abiotic constraints (De Micco et al., 2016). For this reason, offer IADF analysis additional information on status of biotic factors in the timing of wood formation and allow us depended understanding of environment. In previous investigations, false rings in *P. nigra* were used to reconstruct early growing season precipitation (Wimmer et al., 2000). IADFs were investigated only on *P. nigra* samples. During tree-ring measurements, observation of IADFs was noted and depending on their position in the tree-ring, divided into four categories (Figure 4). IADFs were searched for in each of the sample after cross validation of the developed chronologies. This way were IADFs given a correct year. IADFs were counted on all cores, number of IADFs in individual category in given year was used in Pearson correlation calculation.

Missing rings

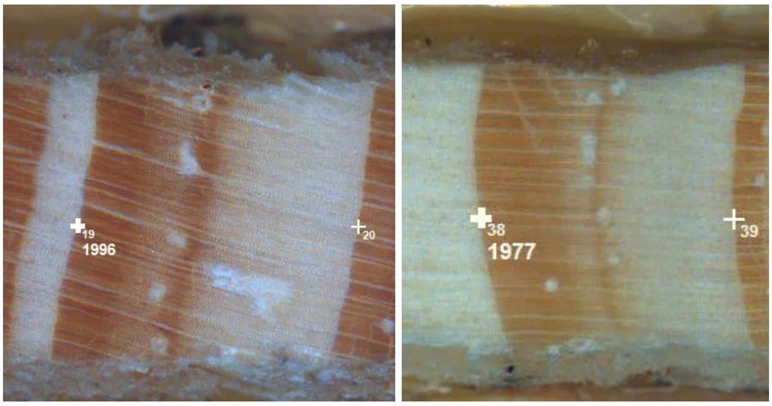
In cases, when trees experience severe stress, absence of wood formation can occur on the part of circumference, or along the tree stem. This way, by using the term "missing" or "partially missing" ring, we label annual increment, not fully grown on the whole circumference or tree height. In year of stress, trees will not be able to obtain energy to cover expenses of wood formation on entire height or circumference (Wilmking et al., 2012). For example, when trees are defoliated in the middle of growth season, lack of energy results in caseation of the tree-ring formation and only on part of the stem, where cambium was active before stressful event, can tree-ring of current year be noticed (Poljanšek et al., 2014). Missing rings can be detected in comparison of two or more individual tree chronologies among themselves, as well as among other tree chronologies. In our case, only *P. nigra* was examined for missing rings, as in oaks, at least earlywood is formed in each year, as essential part for water transport from roots to crown.



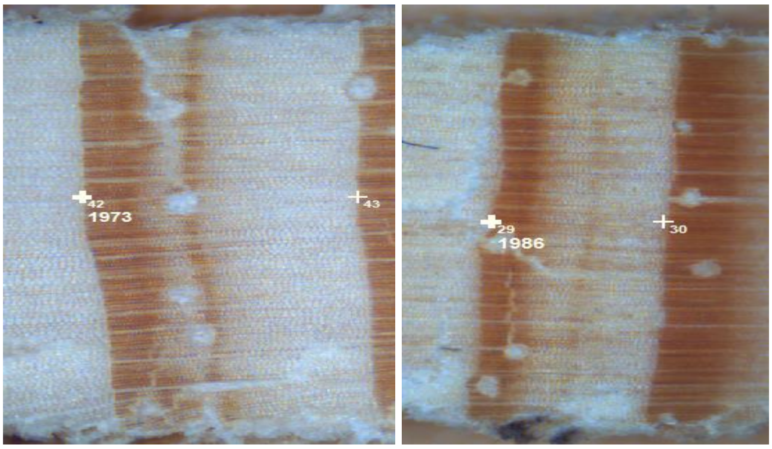
cat. 1; Latewood middle: Lm



a) cat. 2; Latewood end: Le



b) cat. 3; Latewood start: Ls



c) cat. 4; Earlywod: E

Figure 4: Inter-annual density fluctuations, divided into four categories, as follows: a) denser cells in the middle of the latewood, less dense cells at the end of latewood, c) less dense cells after the beginning of latewood and d) latewood like cells in the earlywood.

Effect of climate on tree growth

To connect variability in tree-ring widths to climate, we accessed precipitation and air temperature data from two meteorological stations; Kubed (Figure 5) and Kozina (both in the centre of investigated area). Temperature and precipitation data from Kubed covers the 1950-1990 period and precipitation from Kozina 1966-2011. Additional data from broader region were also available in online datasets such as CRU (http://www.cru.uea.ac.uk/) and Histalp (http://www.zamg.ac.at/histalp/). This enables us to compare and to double check climate data of extreme events and their spatial affect. River flow data for the time period 1966-2011 is available from Kubed station, located after the Rižana spring.

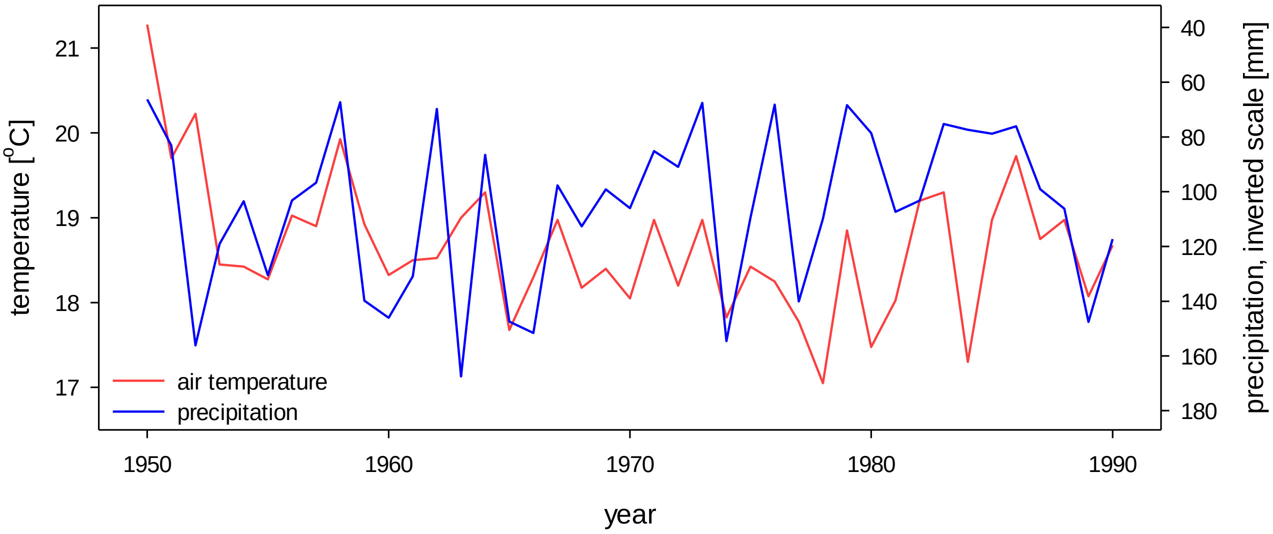


Figure 5: Climate data on periodic May-August air temperature and precipitation, as measured at local station Kubed.

Based on the *catchment water balance* method, was the potential amount of available water calculated as the difference between precipitation and Rižana river flow. The calculation was based on a simplified understanding of the water cycle. After every precipitation event, part of the water is stored in the system as soil moisture, while the remaining part of the precipitation runs off or percolates into the underground karst waters and from there to the Rižana spring. The calculated amount of available water is therefore presented as the water either stored within the basin inside vegetation, or already used for photosynthesis and growth. Higher available water amounts are the result of a higher amount of precipitation, enabling greater tree growth; less available water represent a lack of water, soil moisture stress and tree growth restrictions. Using monthly precipitation data, along with surface and streamflow from this catchment area, available water was calculated as follows: first, the original, measured monthly precipitation data in mm or ml per m^2, were converted to m^3 per m^2 using data on the catchment area surface. Next, the precipitation rate was multiplied by the surface area of the catchment, giving the total monthly amount of precipitation in m^3. This monthly amount of precipitation from the catchment was then divided by the number of seconds in an average month.

This way the maximum possible discharge in m^3 per s was calculated, as if there was no water use in the area, the same as for the measured river discharge. Out of many available river flow data, the mean monthly values of river flow turned out to be the most appropriate for our study. Finally, the difference between the maximum possible discharge and the mean values of river flow was calculated (Figure 2). The catchment water balance method defines available water as the amount of water retained in the ecosystem, which is calculated as the measured discharge subtracted from the maximum possible river flow. Influence of climate factors; temperature, precipitation and available water on radial growth of black pine and sessile oak, was investigated using Pearson correlation coefficient. Time series of climate factor were compared to individual site TRW chronologies of both species. Correlation coefficients were calculated on monthly basis, to define start, peak and end of the season. Finally, stability of the climate signal was tested using running correlation between TRW and climatic factor, as a measure of how influence of climate changes through time. Period from the last formed ring and backward in time, till EPS still exceeds 0.85, is used.

RESULTS

Tree-ring widths

Individual tree TRW chronologies from each site were successfully cross dated and site chronologies for both species developed. Some missing rings were found in the process of tree-ring measurements, but majority were detected in the process of the site chronology development. some missing rings were detected in *P. nigra* (Table 2 and 4). In cases, when partially missing ring is observed (Figure 6), it's existence is noted and where possible, width measured. From all sites, Črnotiče had the highest number of missing rings; five altogether, followed by site Hrpelje with one. At Črnotiče site had *P. nigra* tree n. 08 missing rings in 1978 and 1973, n. 12 in 1948 and n. 14 in 1947 and 1951. At Hrpelje site, had *P. nigra* n. 12 missing ring in 1927.

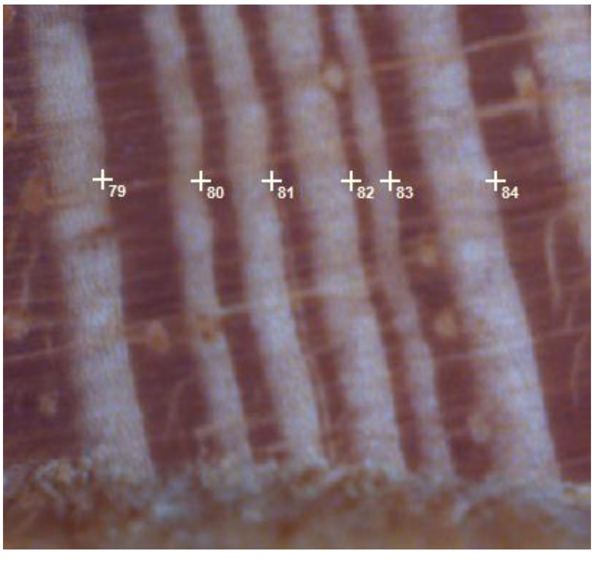


Figure 6: Numbered tree-rings with partially missing tree-ring, formed after the 81th ring.

All developed pine and oak site chronologies have adequate number of years, or length, to perform climate-tree growth analysis, but the EPS values are not sufficiently high for all oak site chronologies (Table 2 and 3). Higher EPS values in pine chronologies, compared to results on oak chronologies, generally coincide with better match of individual chronologies to master chronology (Table 2, and 3; for the time of comparison, was compared site chronology removed from the master chronology). Not significant EPS values were found on sites with the youngest oaks sampled; on Podgorje and Loče (Table 3), therefore for this site, analysis of the influence of climatic factors on radial growth is not recommended. On average, was match between site chronologies better in pines (bottom-left half of the Table 4), compared to oak chronologies (upper-right half of the Table 4).

Table 2: Results on age of sampled P. nigra trees.

Site	Time Span	Length	Trees	EPS > 0.85	[t_{BP}/GLK%]	Missing rings
Črnotiče	1901-2015	115	15	1913	12.7/82.2	5
Hrpelje	1899-2015	117	18	1922	13.1/82.9	1
Podgorje	1939-2015	77	15	1957	19.3/86.4	0
Skandanščina	1932-2015	84	16	1957	17.1/82.7	0
Slivje (Loče)	1933-2015	83	16	1957	11.0/82.5	0
Slope (Artiže)	1908-2015	108	18	1927	23.7/81.0	0

Table 3: Results on age of sampled Q. petraea trees

Site	Time Span	Length	Trees	EPS > 0.85	[t_{BP}/GLK%]
Črnotiče	1906-2015	110	12	1970	13.4/74.5
Hrpelje	1937-2015	79	10	1970	8.1/77.8
Podgorje	1948-2015	68	5	/	1.7/56.6
Skandanščina	1945-2015	71	6	1970	3.2/79.6
Slivje (Loče)	1943-2015	73	15	/	9.4/69.9
Slope (Artiže)	1844-2015	172	16	1970	14.7/79.1

Table 4: Correlation values between P. nigra (bottom-left halve of table) and Q. petraea (upper-right halve of the tables) site standardized chronologies and correlation values between the two species. Period of correlation calculation is 1949-2015.

	Slope (Artiže)	Črnotiče	Hrpelje	Podgorje	Skadanščina	Slivje (Loče)
Slope (Artiže)		0.14	0.37	0.12	0.33	0.22
Črnotiče	0.66		0.63	0.50	0.51	0.23
Hrpelje	0.78	0.76		0.55	0.70	0.42
Podgorje	0.62	0.82	0.71		0.45	0.16
Skadanščina	0.71	0.64	0.68	0.68		0.35
Slivje (Loče)	0.61	0.57	0.56	0.51	0.60	

Effect of climate on tree growth

Correlation coefficients between TRW and climatic factors showed some common response of both species to climate. Radial growth of both investigated species was positively influenced by late winter-early spring air temperature and negatively by summer air temperature. In summer, a positive influence of precipitation on growth of both species was noted and connected to positive influence of available soil water and reduced drought stress because of precipitation itself. In pine TRW site chronologies, was signal of periodic May-August available water, stronger than that of measured precipitation, except for Slivje site (Figure 7).

Quite opposite was found in oaks, where stronger signal of precipitation than available water was discovered in majority of the sites (Figure 8, Table 7). Exception was Artiže flysh site, with stronger signal in available water. Overall, was the highest correlation between pine TRW and any tested climatic factor found at Skandanščina site with available water from the period May-August; r=0.69 (n=45). Close second, with same climatic factor, was climatic signal from Hrpelje pine TRW; r=0.67 and Podgorje; r=0.62 (n=45 in both calculations). In oaks, was the highest correlation also calculated for Skandanščina site, but between TRW and periodic May-August precipitation: r=0.70 (n=20), while available water from this site had correlation of 0.48 (n=45).


Slope *P. nigra*
Slivje *P. nigra*
Skandanščina *P. nigra*
Podgorje *P. nigra*
Hrpelje *P. nigra*
Črnotiče *P. nigra*
Kojnik *P. nigra*

Figure 7: Correlation coefficients between tree-ring widhts of P. nigra from individual sites (with added Kojnik site from previous research) and climate data; T- air temperature, P- precipitation and GW-ground or available water.

Figure 8: Correlation coefficients between tree-ring widths of Quercus sp. and climate data; T- air temperature, P- precipitation and GW- ground or available water.

Regarding influence of climatic factors on radial growth in the period of 46 years, had radial growth of pine trees more stable response to available water than oaks (Figure 9), furthermore, had all pine site chronologies significant correlation values for the period of available climate data. In oaks, only sites Skandanščina, Hrpelje and Črnotiče had significant values, while Podgorje and flysch sites Artiže and Loče, were marked as unreliable in climate signal analysis.

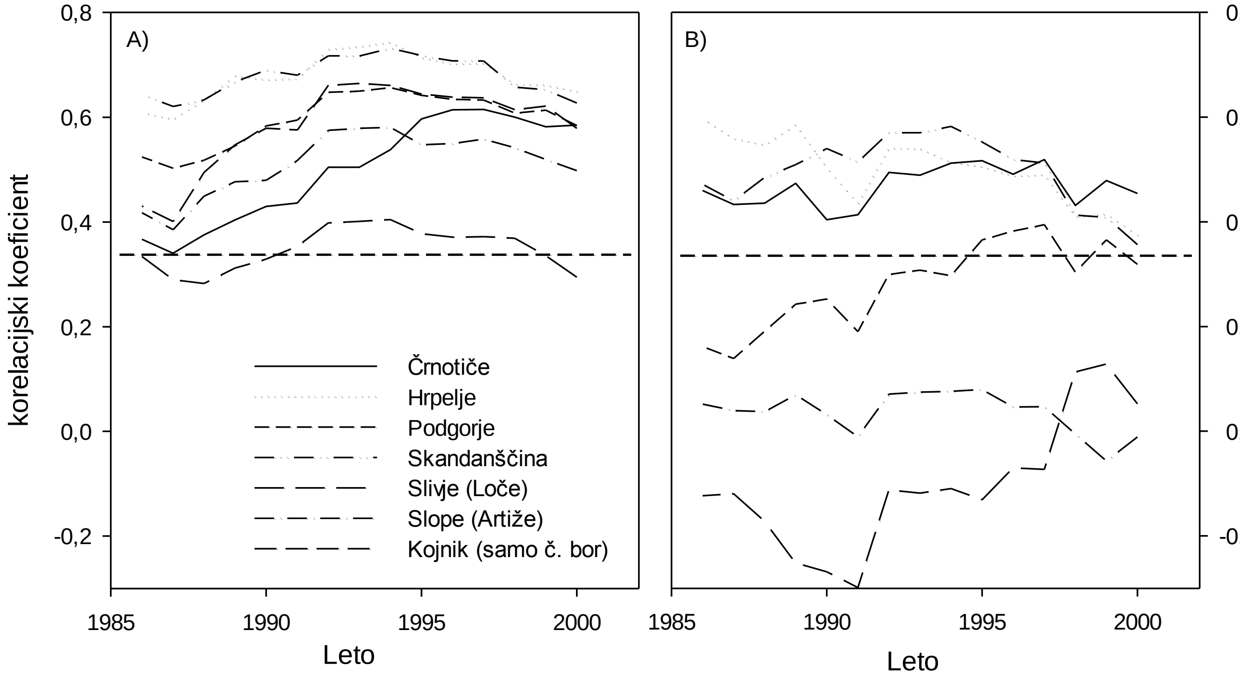


Figure 9: Time stability of the response of trees to climate. A in pines, B in oaks.

Inter-annual density fluctuations

In common period between TRW and climate data measured at the Kozina station, number of TRW sample depth did not change. This way, no pondering was needed in statistical analysis of IADFs, as number of samples did not change. Simple Pearson correlation with sample size of 56 years showed, that IADFs, positioned in the middle of latewood (Lm; cat.1) and latewood end (Le; cat.2) were significantly influenced by July available water, with r=-0.35 (p=0.017) and r=-0.38 (p=0.010), respectively (Table 5). IADFs, observed at the latewood start (Ls; cat.3) was influenced by available water in May; r=-0.45 (p=0.002). No significant connection to available water was observed in IADFs from earlywood (E; cat.4), however, there was significant influence of May air temperature and precipitation (both n=56); r=0.33 (p=0.036) and r=-0.35 (p=0.003), respectively (Table 5).

Table 5: Pearsons' correlation coefficients between number of IADF and climate coefficient with sample size. Only significant values are shown. IADF as follows: Latewood middle: Lm; Latewood end: Le; Latewood start: Ls; Earlywod: E.

Category	Air temperature (n=56)	Precipitation (n=56)	Available Water (n=46)
1; Lm	June; r=0.33, p=0.012	July; r=-0.30, p=0.017	July; r=-0.35, p=0.017
2; Le		July; r=-0.34, p=0.006	July; r=-0.38, p=0.010
3; Ls	June; r=0.23, p=0.090	February; r=0.22, p=0.075 May; r=-0.42, p=0.000	May; r=-0.45, p=0.002
4; E	May; r=0.33, p=0.036	May; r=-0.35, p=0.003	

Two categories of IADF were also found in same tree-ring (Figure 10), but due to rare occasion, connection to climate of both IADFs was not investigated into details. IADFs from such cases were appointed to the most common category of IADF, observed in other samples in the same year. Aside to IADFs, were in some cases present abnormal wooden cells, reminding on callus cells (Figure 11).

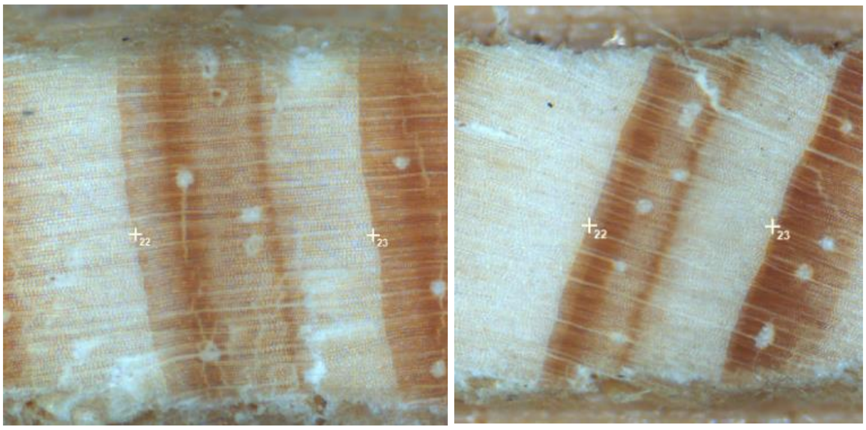


Figure 10: Example, when two categories of IADFs were found in the same ring.

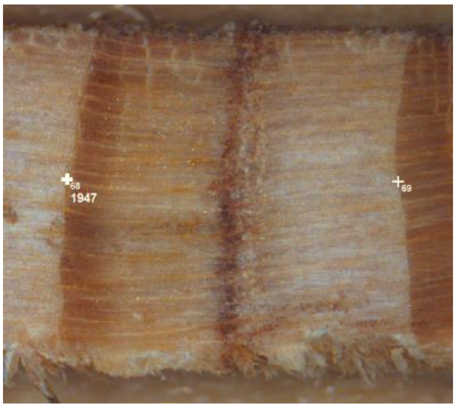


Figure 11: Result of unknown disturbance in the earlywood.

Table 6: Number of observed IADFs per category for particular year, based on all P. nigra sites. Latewood middle: Lm; Latewood end: Le; Latewood start: Ls; Earlywood: E.

Year	Lm	Le	Ls	E	Year	Lm	Le	Ls	E	Year	Lm	Le	Ls	E
2015	1			1	1975	3		3		1935				1
2014					1974		1	1	2	1934				1
2013	1	1			1973	5	6	23	5	1933		1		
2012	1	1			1972	2	8	13	3	1932		3	1	
2011	1	3			1971	9	24	3		1931				
2010					1970	3	1	2		1930	1			
2009		4	2		1969	17	7	2		1929	5		1	1
2008					1968	3		9	1	1928	3	3	6	
2007	3	2	3		1967	3	15	2		1927	2	1	1	1
2006					1966			2		1926				
2005	2	1	3		1965	2	6	7	3	1925			1	3
2004					1964	5	1	11	3	1924				3
2003		2	22		1963	5		11	4	1923	4		4	1
2002	4				1962	3	5	7		1922			16	6
2001		3			1961	1		7	4	1921			3	1
2000		3	3		1960			7	36	1920			1	6
1999		7	1		1959				1	1919	1			
1998	1	11			1958	1	1	27	31	1918			2	2
1997			4	1	1957			4	19	1917			5	9
1996		1	3		1956		2			1916			12	
1995	8	2			1955					1915			1	1
1994	16	18			1954	3	3	7	5	1914			1	1
1993	3	8	16	1	1953				2	1913				3
1992	4	16	5	1	1952	4	1	1	6	1912			1	2
1991		1	1		1951		2	1	1	1911			3	
1990	8	5	4		1950			4	6	1910				1
1989					1949	1				1909				1
1988	8	29			1948					1908				1
1987			1		1947		1	1	5	1907				
1986	8	15	12	9	1946	1	8		3	1906	1			1
1985	2		5	3	1945	1	1	8	8	1905			1	
1984	14	1	1	1	1944	2	5	3		1904				1
1983	2	4			1943	5	8	1	3	1903				1
1982	7	1	1		1942	4	6	1	6	1902				
1981	4			1	1941					1901				
1980	18	30			1940				2	1900				
1979	3	2	49	7	1939		5		1	1899				
1978					1938	2		1	2	1898				
1977	1		26	9	1937			5	1					
1976	3		5	1	1936				1					

Table 7: Years with the highest number of IADFs, organized by the IADF category; Latewood middle: Lm; Latewood end: Le; Latewood start: Ls; Earlywod: E. In the columns N, years with ten most extreme values of climatic factor are noted: numbers signify rank from 1 to 10, lowest periodic May-August available water are marked with W, highest temperature with T and lowest precipitation amount with P.

Lm	Year	N	Le	Year	N	Ls	Year	N	E	Year	N	Sum	Year	N
18	1980	4W	30	1980	4W	49	1979	3W, 7P	36	1960		61	1979	7P
17	1969		29	1988		27	1958	3T	31	1958	3T, 4P	60	1958	3T, 4P
16	1994		24	1971		26	1977		19	1957		48	1980	4W
14	1984		18	1994		23	1973	5P				44	1986	4T
10	1945	1P	16	1992		22	2003	1W				43	1960	
			15	1986	4T	16	1993	2W				39	1973	5P
			15	1967	7W	16	1922					37	1988	
			11	1998		13	1972					36	1977	
						12	1986	4T				36	1971	
						12	1916					34	1994	
						11	1964	7T						
						11	1963	10T						
						10	1952	2T						

DISCUSSION

Greater ages of pine trees than oaks (Table 2 and Table 3) can be explained by past land management. Through time, had native broadleaves, among them oak species, more or less successfully reappear under the shade of conifers, protected from strong winter winds and direct summer sunlight. This explains why black pine trees are older than oak species. Oak trees from investigated area, are in majority represented by sampled sessile oak Q. petraea, however some hybrids between Q. petraea and Q. robur can be found in investigated area. Aside to these two oak species, there are also Q. cerrius, and Q. pubescens. Differences in water usage between named oaks are said to be significant, however, research on species, included in our case, are scarce. In future research on water and forest interaction, oak species and other deciduous tree species should also be investigated. Part of future work could also be to measure separately latewood widths in oaks. Due to time constrain, only whole TRW was measured. Perhaps this step already would improve results on correlations between individual site oak chronologies. Low correlation values between individual site chronologies are not the only problem in oak chronologies. Sites Podgorje and Loče were disregarded as sites with common signal in oaks (Table 3). Results suggest, that the trees had too much of individual response to environmental factors for meaningful climate signal calculations. Better match among individual site chronologies as well as better common signal is found in pines (Table 2). The best match between individual site and master chronology was found for Slope chronology, and worst match with Slivje, a difference of 12.7 of t_{BP}.

Same difference was found in oak site chronologies, between the best Artiže and worst match Podgorje. For Podgorje, result is somehow expected, as only five and relatively young representative oak trees were found and sampled. However, the values of matching site to master chronology are lower in oak, compared to pine chronologies. Surprisingly, the best match of site to master chronology, was with Artiže. This means, that comparing radial growth of oaks, growing on flysch, showed common response to oaks, growing on limestone. According to EPS values, could Artiže site chronology be used for climate signal calculation, however signal stability was weak, no matter which climatic factor we used; temperature, precipitation or available water (Figure 9, only showing correlation with available water). Further investigations are needed to improve our understanding of climate-tree growth relationship of trees, growing on sites such as Artiže, Loče and Podgorje;

Effect of climate on tree growth

For all Pine sites, except for Slivje, a better correlation was found with available water for the period May-August, than with precipitation. In oak sites, this is valid only for Artiže flysch site, while on other oak sites, precipitation plays dominant role. Reason could be in bedrock type, as Artiže and Loče are on flysh, while all others are on limestone. Despite the fact, that only sites Skandanščina, Hrpelje and Črnotiče are reliable in oaks, as observed by their EPS (Table 3) and climate signal time stability (Figure 9), we can, based on results from three sites, point out the differences between two investigated species. Is the difference between stronger climatic signal of available water in pines, than compared to that in oaks, result of a different policy of water use, in isohydric and anisohydric behaviour? When in drought stress, *P. nigra* closes stomata and stops with photosynthesis sooner than *Q. petraea*, which continues pumping water and keeps stomata open, but risks cavitation. And from this response, originates the difference in climate signal of the investigated species. Similar was concluded by Forner (2014), that despite the fact that both investigated species (*Q. faginea* and *P. nigra*) were sensitive to water stress and decreased their water use during dry periods, stronger reductions in transpiration were found in *P. nigra*, an isohydric species that closed stomata during drought. By contrast, *Q. faginea*, a water spender in comparison with *P. nigra*, could sustain an active sap flow rate longer over the summer.

In general, investigated species, oak and pine, differ in crown (conifer, deciduous), which influences rainfall interception and albedo. Scots pine (*P. sylvestris*) has less albedo than, for example, *Q. robur* (Otto et al., 2014), so pines experience more heat than oaks due to sunlight. Is it possible, that pines could grow more with certain amounts of available water, but do not due to lower albedo and greater heat in crown, compared to oak? Greater influences of temperature on radial growth in pines than that in oaks is supported also by results on correlation between air temperature and TRW (Figure 7,Figure 8).

Some influence has undoubtedly also water storage capacity, defined as the amount of water, that can be lost without irreversible wilting. In conifers, the quantities of water stored in the stem, branches, and shoots seem to be considerable, sufficient to supply up to 200 hours of transpiration. For example, storage capacity in *P. sylvestris* is substantial and can supply up to 50% of the daily respired water during dry periods in the summer. As much as 1.5-1.7 mm per day can be withdrawn from storage within the tree (Waring and Franklin, 1979). How much of this water is used in particular drought stress, is difficult to address. Especially, as the water uptake in tree stem lags behind the transpiration by periods, ranging from minutes to several hours, and that the storage capacity is filled during the evening and the night, if ample water is available (Andersson, 2005). Estimates of water flow in whole trees expressed per unit leaf area or sapwood area, can be related to leaf water potential. The hydraulic design of trees influences water movement in trees, and spatial variation in hydraulic conductivity may have a large impact on leaf water potentials and thus on respiration (Tyree and Ewers, 1991). Connection to available water could perhaps be improved by detailed calculation of water amounts, including the amount of interception.

Inter-annual density fluctuations

Investigation on xylem formation on *P. nigra*, growing in Western part of Balkan Peninsula, showed, that earlywood to latewood transition happened in second quarter of May (Poljanšek et al., 2017, submitted). May temperatures and precipitation (for cat. 4; E) and available water (for cat. 3; Ls), is also been recognized as important trigger, based on the results from correlation calculation in this research. This is in accordance with results from Vienna basin (Austria), where false rings also related significantly to May precipitation (Wimmer et al., 2000). IADF is not strongly connected to amounts of available water, air temperature or precipitation, however, some highest presence can be appointed to extreme climate (Table 7). IADFs, positioned in the middle (Lm; cat.1) and end of latewood (Le; cat.2) were significantly influenced by July available water. Could influence of July available water, which in some years affected wood formation in the middle and in other times at the end of latewood formation, be connected to changes in timing of latewood formation? Research in Bosnia and Herzegovina showed, that timing of start, peak and end of wood formation, changes between seasons significantly (Poljanšek et al, submitted 2017).

Possible explanation for disturbances, observed in the earlywood (Figure 11), could be appointed to extreme heat or fire in close vicinity of sampled trees. Damaged cells have similar appearance as cells, damaged by the forest fire; personal observation, based on experience from other, fire damaged pines (Poljanšek et al., 2014). When cambium is in stress, caused by great heat or physical damage, cells produced differ from cells, formed in normal, non-stressed situation. Heat, caused for example by fire, damages cells and evokes creation of callus cells. This way, past fires were detected (Poljanšek et al., 2014), alongside with observed missing rings.

Could this be explanation for discovered missing rings; a connection to local forest fires, strong defoliation and similar causes? We could not connect presence of missing rings observed in pines with IADFs. Growth season of missing ring 1978 had no IADFs, also no in 1948. Year 1978 was a rather wet year, while for 1948 no climate data from investigated area exists. In other years of detected missing rings, only small number of IADFs were observed; 1927, 1947, 1951, 1981 and 1982. However, exception is year 1973 with 23 counted IADFs from the start of latewood, 5 in the middle and 6 at the end (Table 6). One would expect a closer connection between IADFs and missing rings, especially in dry years, but we discovered none. This fact calls for further investigations.

Future work

Skandanščina site is most promising for further investigation. This suggestion is based on results of correlation analysis between TRW and climatic factors (Figure 8), EPS values on chronologies (Table 3) and matching to other master and other pine chronologies (Table 4), as well as time stability of the signal (Figure 9). Continuation of this work would also represent analysis of percentage of forest and its structure in whole Rižana watershed area. Next, sapflow measurements (Smith and Allen, 1996) would not only confirm isohydric behaviour of pine and anisohydric of oak, but the transpiration of a trees from canopy could be measured and modelled (Granier and Loustau, 1994). Results would enable investigation of dependence of water use on stand structure (tree density, age of trees, etc.) and finally, estimation of how much water could be saved with proper species selection and adapted forest management.

When analysing stand structure in whole watershed, effect of forest fires could also be tested. Occasionally, ground and crown forest fires damage trees on larger areas (Jurc, 2001). Following wildfire, increased erosion rates and changes to runoff generation and pollutant sources may greatly increase fluxes of sediment, nutrients and other water quality constituents, potentially contaminating water supplies (Smith et al., 2011). But on the other side, a certain forest cover is removed, interception reduced and less water used. How this reflects on river flow has not been tested before. More importantly, structure of watershed area, in relation to forest-bush-meadow ratio should also be investigated and its dynamic through history. Not only, there is different water use, but also different albedo, which influences evaporation. It would be also interesting to address question on how crown status or time of the season influences evaporation; fully grown deciduous crown in summer has different evaporation and interception than crown in dormant winter time. In growing season, not only interception is greater, but trees have also active photosynthesis. Important question is also how will trees in the light of climate forecast react to increased CO_2, reduced precipitation and increased air temperatures? Aspects of numerous unknown “side” secondary effects such as nutrient limitations, root growth, abiotic factors, mycorrhiza should also not be overlooked (Ceulemans et al., 1999).

PUBLICATIONS

Based on previously sampled site and investigated influence of water on tree growth, and newly investigated sites of two species, three submissions can be pointed out:

1. Partial results of this study (based on one site-Kojnik) was **submitted** to the **Journal Environmental Earth Sciences**, with co-authors dr. Urša Vilhar and dr. Tom Levanič, also a supervisor during this funding. Manuscript was given number: ENGE-D-16-02673 and with the title "**GREEN WATER RECONSTRUCTED FOR RIŽANA WATERSHED, SW SLOVENIA**"

Abstract:

In this case study, set in southwest Slovenia, the feasibility of reconstructing green water (the combined amount of evaporated and transpired water in trees and available in the soil), was investigated. In a simplified scheme, the amounts of green water were calculated as the difference between precipitation and discharge of the Rižana river. Based on the methods of dendroclimatology, the climate signal was tested on black pine (*Pinus nigra* Arnold) trees growing in the southwestern part of the Rižana watershed near the Slovenian sea coast. Results showed that the measured tree-ring parameters of tree-ring width and density are strongly dependent on the amount of green water. The strongest correlation was between available green water in the period May-August and tree-ring width (r=0.61) and latewood width (r=0.64) (both n=46, p<0.001). The climate signal is significant and stable through time, which enabled the reconstruction of green water data into the period before instrumentally measured data. Green water data from the May-August period were extended from 1966 back to 1937 using tree-ring width, and back to 1940 using latewood width. With additional coring of older trees and the extension of existing chronologies, even longer reconstructions could be developed.

Environmental Earth Sciences

GREEN WATER RECONSTRUCTED FOR RIŽANA WATERSHED, SW SLOVENIA

--Manuscript Draft--

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Object of this study was (and will be) presented on two conferences in Slovenia:

2. Second Slovenian Congress on water;

   Podčetrtek, 19-20.4.2017

   http://www.kongresvode2017.si/

   Presenting results on **black pine** from site **Kojnik**, in central part of river watershed.

3. **River Basin Adaptation Conference;**

   Nova Gorica, 7-8.3.2017

   http://www.bewaterproject.eu/events/river-basin-adaptation-conference/abstract-submission/call-for-abstracts-form

   Abstract:

   Forests have numerous positive influences on water sources. By slowing down the speed of wind and water run-off, they reduce soil erosion which keeps water, originating from forested surface, at high quality levels. But protection takes its toll, as trees use water. This is problematic, especially in summer time, when demands on water for population, industry and agriculture, are the highest and precipitation insufficient. Solution could be a selection of tree species with general positive influence, but with reduced water demand. Rižana river is a water source for Slovenian coastal area. River flow is, like some other Slovenian rivers, already in falling trend. With forecast of decreasing precipitation and increasing air temperature, water shortages will be more frequent, greater and longer lasting. Also, demand of trees will increase leading to water stress and possible die back of most distressed trees, which would endanger soil protection. To investigate, if there is difference in response of trees to climate factors and moisture stress, most common trees species from this area were selected as a case study; oak species (namely *Quercus petraea*) and black pine (*Pinus nigra*). To quantify growth, trees were sampled using increment borer and tree-ring widths measured. In climate-tree ring analysis, correlation coefficient was calculated between climate monthly data (precipitation and air temperature) and tree-ring widths.

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