UNIVERZA V LJUBLJANI
BIOTEHNIŠKA FAKULTETA

Simon POLJANŠEK

DENDROKRONOLOGIJA ČRNEGA BORA (*Pinus nigra* Arnold) NA OBMOČJU ZAHODNEGA DELA BALKANSKEGA POLOTOKA

DOKTORSKA DISERTACIJA

Ljubljana, 2013

UNIVERZA V LJUBLJANI
BIOTEHNIŠKA FAKULTETA

Simon POLJANŠEK

DENDROKRONOLOGIJA ČRNEGA BORA (*Pinus nigra* Arnold) NA OBMOČJU ZAHODNEGA DELA BALKANSKEGA POLOTOKA

DOKTORSKA DISERTACIJA

DENDROCHRONOLOGY OF BLACK PINE (*Pinus nigra* Arnold) IN THE WESTERN PART OF THE BALKAN PENINSULA

DOCTORAL DISSERTATION

Ljubljana, 2013

Doktorska disertacija je zaključek podiplomskega študija Bioznanosti s področja Upravljanja gozdnih ekosistemov na Biotehniški fakulteti Univerze v Ljubljani. Nastala je na Gozdarskem inštitutu Slovenije, na Oddelku za prirastoslovje in gojenje gozdov.

Na podlagi statuta Univerze v Ljubljani ter po sklepu senata Biotehniške fakultete in sklepa komisije za doktorski študij Univerze v Ljubljani z dne 22. 4. 2013 je bilo potrjeno, da kandidat izpolnjuje pogoje za opravljanje doktorata znanosti na interdisciplinarnem doktorskem študijskem programu Bioznanosti, znanstveno področje upravljanje gozdnih ekosistemov. Za mentorja je bil imenovan doc. dr. Tomislav Levanič.

Komisija za oceno in zagovor:

Predsednik: doc. dr. Aleš KADUNC
Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za gozdarstvo in obnovljive gozdne vire

Član: doc. dr. Tomislav LEVANIČ
Gozdarski inštitut Slovenije

Članica: doc. dr. Jožica GRIČAR
Gozdarski inštitut Slovenije

Datum zagovora: 6. 5. 2013

Delo je rezultat lastnega raziskovalnega dela. Podpisani se strinjam z objavo svojega dela na spletni strani Digitalne knjižnice Biotehniške fakultete. Izjavljam, da je delo, ki sem ga oddal v elektronski obliki, identično tiskani verziji.

Simon Poljanšek

Ključna dokumentacijska informacija (KDI)

ŠD Dd
DK GDK 561.24:174.4Pinus nigra Arnold (292.464)(043.3)=163.6=111
KG *črni bor/dendroklimatologija/rekonstrukcija/Balkanski polotok/densitometrija/širine branik/suša/vulkani/temperatura/padavine*
KK
AV POLJANŠEK, Simon, univ. dipl. inž. gozdarstva
SA LEVANIČ, Tomislav (mentor)
KZ SI-1000 Ljubljana, Jamnikarjeva 101
ZA Univerza v Ljubljani, Biotehniška fakulteta, Interdisciplinarni doktorski študij Bioznanosti
LI 2013
IN DENDROKRONOLOGIJA ČRNEGA BORA (*Pinus nigra* ARNOLD) NA OBMOČJU ZAHODNEGA DELA BALKANSKEGA POLOTOKA
TD doktorska disertacija
OP XI, 101 str., 4 sl., 6 pril., 110 vir.
IJ sl
JI sl/en
AI Za območje osrednjega dela areala črnega bora (*Pinus nigra* Arnold) na zahodnem delu Balkanskega polotoka je bila iz sedmih medsebojno ujemajočih se lokalnih kronologij širin branik izračunana prva regionalna kronologija. Dodatno so bili letni debelinski prirastki vzorčeni na severovzhodnem ter severozahodnem robu razširjenosti bora na Balkanskem polotoku. Slednja lokacija se nahaja v submediteranskem delu Slovenije, tu sta bili izmerjeni tudi gostoti ranega in kasnega lesa. Izdelana regionalna kronologija širin branik črnega bora se ujema s predhodno objavljenimi regionalnimi kronologijami sosednjih območij. Na širino branik dreves z območja submediteranskega dela Slovenije negativno vplivajo nadpovprečne poletne temperature, na gostoto ranega lesa pa imajo pozitiven vpliv zgodnje poletne padavine. V Bosni in Hercegovini (BiH), kjer je trajanje sončnega obsevanja predstavljeno kot posredni kazalnik vlažnostnega stresa, je bil odkrit na širino branik značilni negativni vpliv trajanja sončnega obsevanja obdobja junij-julij. Medtem je bila na severovzhodni meji balkanskega dela areala, v jugozahodni Romuniji, izračunana značilna korelacija med širino branik in standardiziranim padavinskim indeksom obdobja junij-avgust. Vpliv klime na širino branik črnega bora z območja BiH je stabilen do sredine druge polovice 20. stoletja, potem je klimatski signal oslabljen. Najverjetnejši vzrok za šibkejši klimatski signal so značilne spremembe v ciklonih nad Balkanskim polotokom in s tem manjši sušni stres za drevesa. Trajanje sončnega obsevanja je rekonstruirano do leta 1660, padavinski indeks pa do leta 1688. Značilna leta, prepoznana s preseganjem izbranih mejnih vrednosti rekonstrukcije, so bila pojasnjena z drugimi objavljenimi in neobičajnimi dogodki, ki vplivajo na rast: sušami, poletnimi deževji, hladnimi poletji in vulkanskimi izbruhi.

Key words documentation (KWD)

DN Dd
DC FDC 561.24:174.4Pinus nigra Arnold (292.464)(043.3)=163.6=111
CX *Black pine/dendroclimatology/reconstruction/Balkan Peninsula/densitometry/tree-ring width/drought/volcanoes/temperature/precipitation*
CC
AU POLJANŠEK, Simon
AA LEVANIČ, Tomislav (supervisor)
PP SI-1000 Ljubljana, Jamnikarjeva 101
PB University of Ljubljana, Biotechnical Faculty, Interdisciplinary Doctoral Programme in Biosciences
PY 2013
TI DENDROCHRONOLOGY OF BLACK PINE (*Pinus nigra* ARNOLD) IN THE WESTERN PART OF THE BALKAN PENINSULA
DT doctoral dissertation
NO XI, 101 p., 4 fig., 6 ann., 110 ref.
LA sl
AL sl/en
AB For the central part of the black pine (*Pinus nigra* Arnold) distribution area on the Balkan Peninsula, seven site chronologies were developed, which match each other and form the first regional tree-ring width chronology. Regional chronology matches the published regional chronologies from the neighbouring regions. Additionally, one site each in north-eastern and north-western margin of the black pine distribution on the Balkan Peninsula was sampled. The north-western site is located in sub-Mediterranean Slovenia where, additionally, the density of early- and latewood was measured. Here has mean summer temperature negative influence on the tree-ring widths, while early summer precipitation positively affects the earlywood density. In Bosnia and Herzegovina (BiH), moisture stress was associated with sunshine hours, and statistically significant influence of June-July sunshine hours on the tree-ring widths was discovered. In the north-eastern margin of the black pine distribution from the Balkan Peninsula, in the south-western part of Romania, statistically significant correlation between tree-ring widths and standardized precipitation index from the June-August period was calculated. Climate signal in tree-ring widths from BiH area is stable till the second half of the 20th century, while later on the signal weakens. The most plausible reason is the difference in cyclones over the Balkan Peninsula and reduced drought stress for trees. Sunshine hours were reconstructed back to the year 1660, and precipitation index back to 1688. The extreme years, identified with thresholds and reconstructions, were recognized with the aid of previously published and archived unusual events: droughts, floods, cool summers and volcanic eruptions.

Kazalo vsebine

Kazalo slik

Kazalo prilog

1 PREDSTAVITEV PROBLEMATIKE IN HIPOTEZE

1.1 OPREDELITEV RAZISKOVALNEGA PROBLEMA

1.1.1 Dendrokronologija

V najširšem pomenu besede je dendrokronologija znanost datiranja branik, ki vključuje preučevanje informacijskih vsebin v strukturi datiranih branik in uporabo teh informacij v okoljskih ter zgodovinskih vprašanjih (Kaennel in Schweingruber, 1995). Poleg starosti drevesa, klime, motenj širše okolice in lokalnih rastnih razmer ter naključnih oz. nepojasnjenih dejavnikov (Cook, 1985) vplivajo na delovanje kambija tudi rastne razmere tekočega in predhodnega rastnega leta, v katerem je drevo kopičilo hranilne snovi (Fritts, 1976). Debelinska rast dreves se tako odziva na variabilnost za rast ugodnih in neugodnih dejavnikov, kar se kaže v variabilnem debelinskem prirastku. Leto, v katerem najmanj 80 % analiziranih dreves odreagira z manjšim ali večjim prirastkom glede na prejšnjo rastno sezono, imenujemo značilno leto (Schweingruber, 1983; Schweingruber in sod., 1990). V primeru, ko imamo kronologijo z neznanim letom nastanka branik, lahko na podlagi značilnih let in variabilnosti zaporedja širin branik v postopku datacije in sinhronizacije določimo leto nastanka vsake izmed branik (Fritts, 1976). Informacije o lastnostih branik in letu njihovega nastanka uporabimo za študije odzivnosti dreves na klimatske spremembe in za rekonstrukcijo pretekle klime (npr. Sarris in sod., 2007; McCarroll in sod., 2012), ali pa na primer za preučevanje vpliva defoliacije, gnojenja in gojitvenih del ter soljenja cest (npr. Büntgen in sod., 2009; Jyske, 2008; Levanič in Oven, 2002).

Vpliv okoljskih dejavnikov na rast dreves se ne kaže samo v širini branik, marveč tudi v širini ranega in kasnega lesa (npr. Lebourgeois, 2000), anatomskih značilnosti lesnih vlaken (npr. Wimmer, 2002), znotraj letni dinamiki kambijeve cone (npr. Gričar in Čufar, 2008; Mäkinen in sod., 2008), izotopski sestavi branik (npr. Hafner in Levanič, 2009; McCarroll in Loader, 2005), zadrževanju setov iglic (Jalkanen in sod., 2000; Poljanšek in sod., 2011, priloga F) in gostotnih profilih branik (npr. Cown in Parker, 1978). Gostoto branik merimo z uporabo rentgenskih žarkov (Schweingruber in sod., 1978), nadomestne podatke pravih vrednosti gostote pa lahko izmerimo po metodi odboja modrega spektra (Campbell in sod., 2007; McCarroll in sod., 2002).

Za pridobitev vzorcev debelinske rasti se v primeru poseka dreves odvzamejo odrezki dreves oziroma koluti. Lahko pa se uporabi prirastni sveder (Grissino-Mayer, 2003), s katerim se iz stoječega drevesa na nedestruktiven način odvzame izvrtek. Ta v primeru, da smo z usmeritvijo svedra zadeli sredino debla, obsega debelinske prirastke od zadnje branike do stržena. Pri odvzemu vzorcev se izogibamo kompresijskemu lesu, zato moramo upoštevati ekscentričnost debla. Sveder je zato vedno vzporeden z izohipso. Za hitrejšo in lažjo uporabo prirastnega svedra je v uporabi pripomoček, ki je vezni člen med prirastnim svedrom in baterijskim vrtalnikom (Poljanšek in Levanič, 2012b, priloga D). Pridobljene izvrtke posušimo in pravilno orientirane pritrdimo na lesene nosilce. Izvrtke vzdolžno zbrusimo tako, da so pod povečavo celice lesa jasno vidne v vseh branikah. Površino vzorca poslikamo vzdolž njegove celotne dolžine s sistemom ATRICS (Levanič, 2007). Sliko vzorca uvozimo v program WinDendro™ (Regent, 2013), v katerem določimo in izmerimo širine branik. Rezultate meritev, na primer zaporedja širin branik, izvozimo v program PAST-4 (Sciem, 2013), v katerem preverimo skladnost zaporedij širin branik med vzorcema, vzetima z nasprotnih strani drevesa, ter med drevesnimi, lokalnimi in regionalnimi kronologijami. Skladnost preverimo na dva načina. Pri vizualni oceni ujemanja dveh kronologij na intervalu prekrivanja gre za (do neke mere) subjektivno oceno. Ob tej oceni smo najbolj pozorni na ujemanje vrednosti letnih parametrov branik v značilnih letih in na morebitne izpadle, manjkajoče branike (glej poglavje 1.1.2). Drugi način preverbe je uporaba dveh statističnih kazalnikov, ki skladnost tudi numerično ovrednotita. To sta t_{BP} (Baille in Pilcher, 1973) ter koeficient časovne skladnosti GLK% (Eckstein in Bauch, 1969). Vrednost t_{BP} je koeficient korelacije med primerjanima kronologijama, medtem ko GLK% izračuna delež skladnega gibanja obeh kronologij; npr., ali se prirastek v posameznem letu v obeh kronologijah hkrati poveča ali zmanjša, ne glede na velikost. Končni rezultat preverbe skladnosti dveh zaporedij širin branik znotraj istega drevesa ponazarja kronologijo drevesa. Medsebojno ujemajoče drevesne kronologije z iste lokacije združimo v rastiščne oziroma lokalne kronologije, regionalna kronologija izbrane drevesne vrste pa se izračuna na podlagi dendrokronološke mreže lokalnih kronologij širšega območja. Primere takih mrež že poznamo npr. iz območja Alp, Apeninskega polotoka ter Aljaske (Büntgen in sod., 2009; Di Filippo in sod., 2007; Schweingruber in sod., 1993).

Na delovanje kambija in s tem na nastanek branike vpliva več dejavnikov (Cook, 1985), zato vsaka branika vsebujejo širok spekter okoljskih informacij. Stalni dejavniki so starost drevesa, klima ter motnje ožje in širše okolice. Vpliv neklimatskih dejavnikov bližnje in daljne okolice zmanjšamo z ustreznim izborom rastišč, drevesne vrste ter vzorčenih dreves, starost drevesa oziroma starostni trend pa izničimo s procesom standardizacije.

Standardizacija pomeni iskanje primerne regresijske krivulje in računanje razlik med prilagojenimi in dejanskimi vrednostmi (Levanič, 1996). Pri tem sta v uporabi programa dplR (Bunn, 2010) in ARSTAN 4.1d (Krusic in Cook, 2007). Razlike med izračuni omenjenih programov niso značilne, zato je izbira delovnega okolja prepuščena uporabniku (Poljanšek in sod., 2010, priloga E). S standardizacijo se izračunata standardizirani (ang: *standardized*) kronologiji; standardna kronologija (ang: *standard chronology*) in kronologija ostankov (ang: *residual*). Standardna kronologija ima več nizkofrekvenčne variabilnosti (se pravi, da vsebuje cikle z nizko frekvenco, to so dolgoročne spremembe) kot kronologija ostankov, zato je v rekonstrukcijah klime, kjer se pričakuje več variabilnosti klimatskega dejavnika in spreminjanje le-tega na daljši časovni skali, bolj uporabna (npr. Briffa in sod., 2001; Esper in sod., 2002). V primeru, ko linearna povezava med standardno kronologijo in klimatskim dejavnikom ni visoko statistično značilna, lahko to povezavo matematično izboljšamo z uporabo standardiziranih z-vrednosti (npr. Ljungqvist, 2010) oziroma s tehtanim izračunom regionalne kronologije iz več lokalnih, pri čemer je utež za lokalno kronologijo s preučevanim klimatskim signalom pojasnjena varianca (McCarroll in sod., 2003). Pri tem označuje klimatski signal statistično značilno korelacijo med preučevanim parametrom branike in klimatskim dejavnikom.

Za preučevanje klimatskega signala oziroma vpliva klime na rast dreves potrebujemo večletne kvalitetne in preverjene klimatske podatke. Najboljše je, če lahko pridobimo podatke vremenskih postaj, ki stojijo na približno enaki nadmorski višini in v neposredni bližini oziroma čim bliže lokaciji vzorčenja dreves. V primeru, da v bližini ni vremenskih postaj, imajo manjkajoče podatke, so nezanesljive ali pa so časovni nizi prekratki, potem uporabimo meteorološke podatkovne baze, kot je na primer Histalp (Auer in sod., 2007). Histalp vsebuje podatke o temperaturi, padavinah, trajanju sončnega obsevanja ter zračnem pritisku za izbrana mesta alpskega in širšega območja, vse do Bosne in Hercegovine (BiH).

Medtem ko baza Histalp daje izmerjene podatke posameznih vremenskih postaj, omogoča internetna aplikacija KNMI Explorer (van Oldenborgh, 1999) na podlagi CRU sistema (Jones in Harris, 2008) uporabo homogeniziranih izmerjenih vremenskih podatkov, iz katerih lahko izračunamo vrednosti izbranega klimatskega dejavnika za poljubno izbrano točko ali območje v naravi.

1.1.2 Odzivnost rasti dreves na klimo

Različne drevesne vrste se različno odzivajo na različne klimatske dejavnike (García-Suárez in sod., 2009), zato je za izbiro drevesne vrste pomembna odločitev, kateri klimatski signal želimo preučiti. Ključna je tudi izbira rastišča. Na ekstremnih rastiščih sta starost dreves in klima ključna dejavnika, ki vplivata na letni debelinski prirastek (Fritts, 1976). Za ekstremno štejemo tisto rastišče, na katerem so, za izbrano drevesno vrsto, rastne razmere slabe. To je lahko v osrednjem delu ali pa na robu areala razširjenosti izbrane vrste. Zato se značilni klimatski signal v širinah branik pričakuje takrat, ko je na ekstremnem rastišču opravljen ustrezen izbor drevesne vrste, katere debelinsko priraščanje, zaradi večkratnega ali daljšega neugodnega stanja klimatskih dejavnikov v času rastne sezone, poteka v stresu. V praksi klimatski signal pomeni, da se parameter branike dobro odziva na variiranje klime. Pri preučevanju rasti dreves z ekstremnih rastišč nas lahko ovirajo morebitne izpadle ali/in zelo ozke branike (Wilmking in sod., 2012). Do izpada oziroma izklinjenja branik pride, ko zaradi hudega stresa kambijeva cona ne proizvede letne prirastne plasti po celotni višini debla, od krošnje navzdol oziroma po celotnem obodu debla. Izpadle branike so pogoste pri drevesih, ki rastejo na robu areala razširjenosti (Wilmking in sod., 2012), zato so tovrstna območja najprimernejša za preučevanje vpliva klime na rast dreves. Medtem ko so tovrstne raziskave pogoste v borealnih gozdovih (npr. Briffa in sod., 1992; Schweingruber in sod., 1993; Lindholm in sod., 2009), zmernem pasu Evrope (npr. Mäkinen in sod., 2003), območju Alp (npr. Rolland, 1993; Levanič, 2005; Büntgen in sod., 2006) ter pretežnem delu mediteranskega bazena (npr. Touchan in sod., 2005), pa je vpliv klime na rast dreves slabo raziskan na območju zahodnega dela Balkanskega polotoka. Drevesna vrsta, ki je primerna za raziskave o vplivu klime na rast dreves in katere osrednji del areala leži na neraziskanem območju, je črni bor (*Pinus nigra* Arnold).

1.1.3 Črni bor (*Pinus nigra* Arnold)

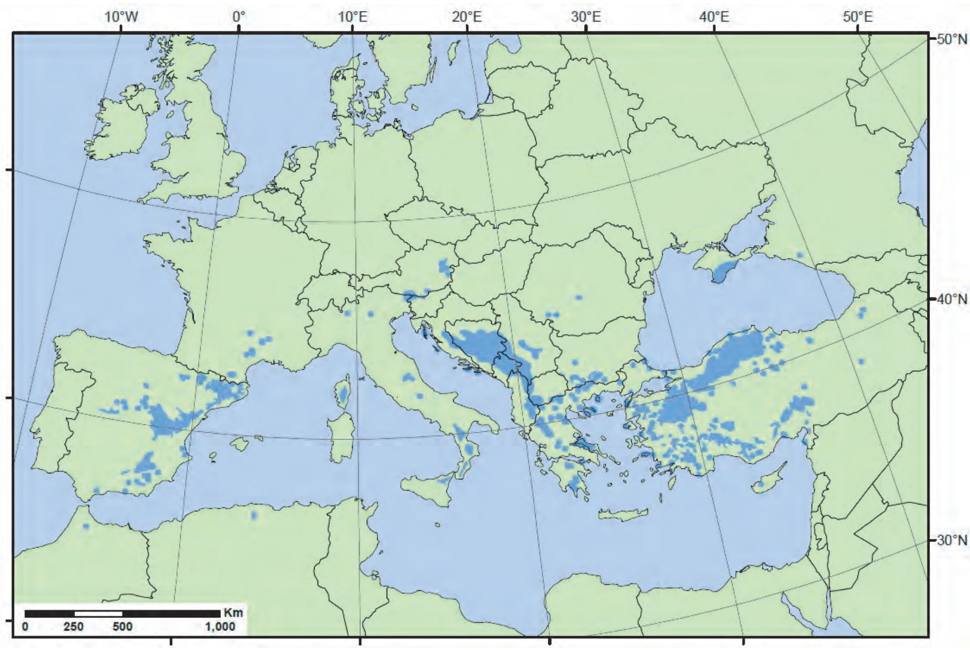
Črni bor spada med dvoigličaste bore, je enodebelno drevo in dosega višine od 30 pa do 40 m (Brus, 2004). Raste tudi na najbolj ekstremnih rastiščih z bazično podlago (slika 1). Na nekaterih rastiščih dosega starosti do 800 let (Wimmer in Grabner, 1998). Mlajša drevesa imajo stožčasto krošnjo, medtem ko je pri starejših izrazito dežnikasta (Vidaković, 1991). Pri vizualni oceni starosti dreves prek podobe krošnje je potrebna previdnost, kajti dežnikasta krošnja lahko obstaja tudi pri relativno mladih drevesih, rastočih na slabo rodovitnih, oziroma ekstremnih rastiščih (Fritts, 1976). Naravni areal črnega bora je izrazito nesklenjen in se razteza po zahodnem delu Sredozemlja, južni Evropi, Mali Aziji in nekaterih predelih severozahodne Afrike (slika 2). Zaradi velike morfološke in genetske variabilnosti ga stroka deli v več podvrst (Vidaković, 1991); na pretežnem delu zahodnega dela Balkanskega polotoka raste podvrsta *P. nigra bosniaca*, medtem ko se na območju Dunaja pojavlja *P. nigra austriaca*, v Romuniji pa *P. nigra banatica*. Branika ima lepo vidno mejo med ranim in kasnim lesom ter veliko odzivnost na klimo (Wimmer in sod., 2000), zato je to primerna vrsta za preučevanje vpliva klime na debelinski prirastek dreves (Strumia in sod., 1997; Martin-Benito in sod., 2011).

Odziv črnega bora na klimo je že preučen z robnih območij njegovega centralnega dela areala na Balkanskem polotoku. Klimatski signal je že bil preučen v Albaniji (Levanič in Toromani, 2010), submediteranskem delu Slovenije (Ogrin, 1989) in Avstriji (Leal in sod., 2008). Raziskav o vplivu klime na letni debelinski prirastek črnega bora iz zahodnega dela Balkanskega polotoka pa še ni. Raziskava iz Albanije, z jugozahodnega dela razširjenosti črnega bora na Balkanskem polotoku (Levanič in Toromani, 2010), je pokazala, da širina branik črnega bora negativno korelira z nadpovprečnimi junijskimi temperaturami tekočega leta ter z nadpovprečnimi avgustovskimi in septembrskimi temperaturami predhodnega leta, na debelinski prirastek pa ima pozitiven vpliv nadpovprečna količina padavin preteklega avgusta in septembra.

Iz tega sledi, da je klimatski signal v širinah branik črnega bora z jugozahodnega dela Balkanskega polotoka bolj kompleksen, kot je klimatski signal drugih drevesnih vrst z večjih geografskih širin (npr. Briffa in sod., 1988; Lindholm in sod., 2009) ali z območja Alp (npr. Trachsel in sod., 2012), kjer je rast dreves odvisna predvsem od temperatur, oziroma z manjših geografskih širin, kot na primer iz območja Sredozemlja, kjer je rast dreves odvisna predvsem od padavin (npr. Touchan in sod., 2005; Touchan in sod., 2010). V zmernih geografskih širinah, kjer je tudi Balkanski polotok, variabilnost samo temperatur ali padavin ne pojasni v zadostni meri variabilnosti rasti dreves (Fritts, 1976), lahko pa variabilnost temperatur in padavin pojasnimo z variabilnostjo sončnega obsevanja (Stahle in sod., 1991). Parameter število ur sončnega obsevanja (oziroma oblačnost) se zaradi neposrednega vpliva na fotosintezo in s tem na izotope ogljika uporablja tudi v rekonstrukcijah klime za območja z manjšim vlažnostnim stresom, kjer je bolj kot temperatura za fotosintezo pomembna stopnja sončnega obsevanja (Young in sod., 2010).

Slika 1: Črni bor (*P. nigra banatica*) na ekstremnem rastišču na njegovem severovzhodnem robu areala na Balkanskem polotoku v jugozahodnem delu Romunije (foto: Simon Poljanšek)

Figure 1: Black pine (P. nigra banatica) on extreme site in his north-eastern margin of distribution on the Balkan Peninsula in the south-western part of Romania (photo: Simon Poljanšek)



Slika 2: Karta naravne razširjenosti črnega bora (*P. nigra*), povzeto po: EUFORGEN (2013)

Figure 2: Map of natural distribution of black pine (P. nigra), after: EUFORGEN (2013)

1.1.4 Stabilnost klimatskega signala v času

Prvo izmed načel dendrokronologije je, da so fiziološki in biološki procesi, ki vplivajo na debelinsko rast dreves v sedanjosti, imeli enak vpliv tudi v preteklosti; »sedanjost je ključ do preteklosti« (Fritts, 1976). Načelo o stabilnosti klimatskega signala v času moramo preveriti, preden pristopimo k rekonstrukciji klimatskega dejavnika. Če je prišlo v dobi merjenih klimatskih podatkov do sprememb v stabilnosti klimatskega signala, rekonstrukcija ni več zanesljiva, saj je zelo težko zagotoviti, da se obdobja slabše odzivnosti v preteklosti niso dogajala. Ali je klimatski signal značilen skozi celotno obdobje merjenih klimatskih podatkov, se lahko preveri z metodo drseče korelacije (npr. Dean in Anderson, 1974). Ta izračunava korelacijski koeficient v časovnem oknu, ki se pomika za eno časovno enoto po celotni dolžini razpoložljivih podatkov. V literaturi se pojavljajo različne dolžine oken; v raziskavi na severovzhodnem robu areala črnega bora na Balkanskem polotoku (Levanič in sod., 2012) je bilo, podobno kot v nekaterih predhodnih raziskavah (npr. Luterbacher in sod., 1999; Pauling in sod., 2006), uporabljeno 30-letno okno, medtem ko smo v osrednjem delu tega areala temperaturni in padavinski signal preverili z 31-letnim oknom (Poljanšek in sod., 2012b).

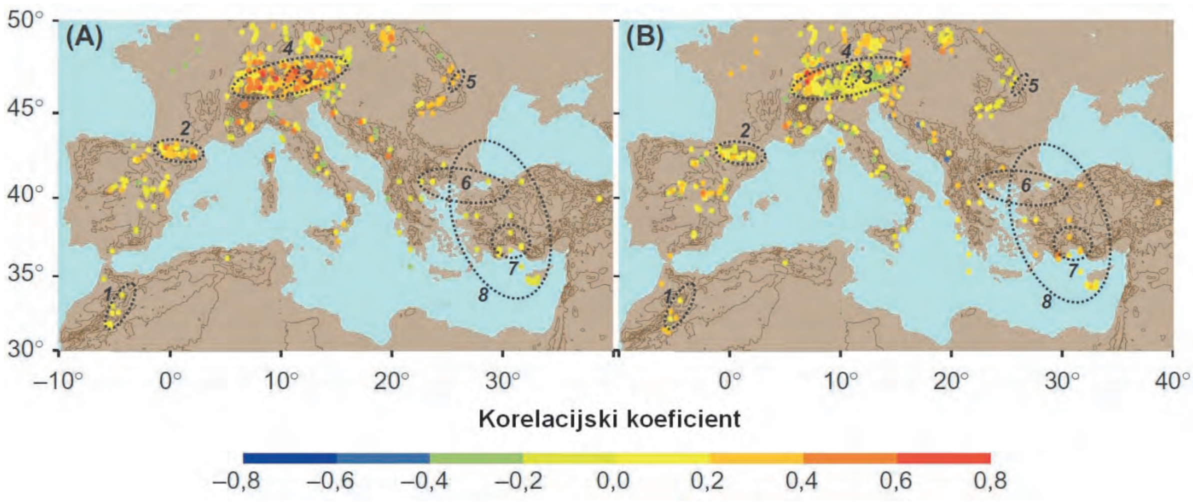
Klimatski signal v času je lahko stabilen ali pa spremenjen zaradi klimatskega ali antropogenega vpliva. Strumia in sodelavci (1997) so opazili spremenjen odziv rasti črnega bora na količino padavin v okolici Dunaja; medtem ko se je v zadnjih 150 letih odziv na majske padavine zmanjšal, se je na julijske značilno povečal. Sprememba naj bi bila posledica povišane koncentracije ogljikovega dioksida in nitratov v ozračju (Leal in sod., 2008). O močnejšem odzivu dreves na padavine v sredini 20. stoletja poročajo tudi iz območja Pirenejev (Andreu in sod., 2007), medtem ko iz Grčije (Sarris in sod., 2007) in območja italijanskih Alp (Coppola in sod., 2012) poročajo o zmanjšanem odzivu oziroma celo o spremembi vpliva nadpovprečnih temperatur iz negativnega v pozitiven (Amodei in sod., 2012). Medtem ko za šibkejši signal v širinah branik munike (*Pinus heldreichii* Christ.) v Albaniji domnevajo, da je posledica slabših klimatskih podatkov oziroma ne-ekstremnosti rastišča in zato slabega odziva dreves (Seim in sod., 2012), so v Romuniji spremenjeni odziv rasti dreves na klimo pripisali rudniškim aktivnostim (Kern in sod., 2009), v južni Nemčiji pa emisijam SO_2 (Wilson in Elling, 2004). Na drugačen odziv debelinske rasti na klimatske dejavnike bi lahko vplivala tudi sprememba v klimi Sredozemlja iz obdobja od 1960 do začetka 1990. To obdobje je opisano kot desetletje z izjemno spremenljivim sončnim obsevanjem (Mariotti in Dell'Aquila, 2012) oziroma s povečanim padavinskim trendom v 60-ih letih 20. stoletja (Xoplaki in sod., 2003), pa tudi kot obdobje zmanjšane sončne aktivnosti, katere vpliv so odkrili npr. v spremembah v rasti sibirskega brina (*Juniperus Siberica* Burgsd) (Shumilov in sod., 2007).

1.1.5 Rekonstrukcija klime

Pretekle vrednosti okoljskih dejavnikov izračunamo tako, da parametre linearnega regresijskega modela med merjenimi vrednostmi klimatskega dejavnika in opazovanega parametra branike uporabimo v linearni enačbi, kjer vrednost klimatskega dejavnika ponazarja odvisno spremenljivko, vrednost parametra branik pa neodvisno spremenljivko. Linearni model, razvit za obdobje, ko imamo na voljo kvalitetne klimatske podatke, se tako uporabi za rekonstrukcijo izbranih klimatskih podatkov v obdobje pred instrumentalnim zbiranjem podatkov, ko so parametri branik na voljo, podatki o klimi pa ne (Fritts in sod., 1971). Pred izračunom rekonstrukcije se kakovost modela preveri s količnikoma RE (Fritts, 1976) in CE (Cook in sod., 1999).

Statistični test RE (ang: »*reduction of error*«) oceni, koliko boljša od povprečne vrednosti klimatskega dejavnika iz obdobja kalibracije je naša izračunana rekonstrukcija. CE (ang: *coefficient of efficiency*) je podoben kazalnik, le da namesto uporabe povrečne vrednosti klimatskega dejavnika iz obdobja kalibracije uporabimo obdobje verifikacije. Obdobji kalibracije in verifikacije dobimo, ko celotno obdobje merjenih klimatskih dejavnikov delimo na dve, navadno enako dolgi obdobji. Pri rekonstrukciji je pomemben tudi parameter EPS (ang: *expressed population signal*), ki zaradi odvisnosti od števila vzorčenih enot in povprečne korelacije med njimi pove, ali majhen vzorec vsebuje signal velike populacije. Za rekonstrukcijo lahko uporabimo tisti del kronologije, kjer je parameter EPS višji kot 0,85 (Briffa in Jones, 1990; Wigley in sod., 1984), ali vsaj 0,80.

Z rekonstrukcijami lahko preučujemo variabilnost klimatskega dejavnika v preteklosti ter odgovorimo na vprašanje, ali so se klimatske spremembe, podobne sedanjim, v preteklosti že dogajale in kako so se nanje drevesa odzivala. Poleg tega nam rekonstrukcije pomagajo pri omejevanju variabilnosti projekcij klimatskih sprememb v prihodnosti oziroma pri izboljšanju postavljenih modelov. Za območja Francije, Italije ter Iberskega polotoka so iz obdobja od 15. do 19. stoletja na voljo prve instrumentalne meritve klimatskih podatkov (Camuffo in sod., 2010). V območjih, kjer dolgoletnih klimatskih podatkov ni, so rekonstrukcije zato zelo pomembne (Luterbacher in sod., 2012). Z območja Mediteranskega bazena so že predstavljene daljše rekonstrukcije temperatur oziroma padavin Atlasa v Afriki, Pirenejev, Alp, Karpatov ter območja Egejskega morja, medtem ko za območje Dinaridov še ni razvita niti dendrokronološka mreža niti še ni izračunana rekonstrukcija (slika 3).



Slika 3: Lokacije in s korelacijskim koeficientom predstavljen klimatski signal 847 kronologij širin branik širšega območja Mediteranskega bazena. Pearsonovi koeficienti korelacije so izračunani glede na mrežo temperaturnih (A) in padavinskih (B) koeficientov obdobja junij-avgust. Krogi in številke označujejo območja in rekonstruirani klimatski dejavnik dolžine > 600 let; 1. Atlas, rekonstrukcija suše; 2. Pireneji, temperatura; 3. avstrijski del Alp, temperatura; 4. Alpe, temperatura; 5. Karpati, temperatura; 6. Egejsko morje, padavine; 7. jugozahod Turčije, padavine; 8. vzhodni Mediteran, padavine (povzeto po: Luterbacher in sod., 2012).

Figure 3: Location and correlation coefficient of climate sensitivity of 847 TRW chronologies within the Greater Mediterranean Region. Pearson's correlation coefficients are computed against gridded June-August: (A) temperature and (B) precipitation indices. Black circles and numbers refer to climate reconstructions > 600 years; 1. Atlas, reconstruction of drought; 2. Pyrenees, temperature; 3. Austrian Alps, temperature; 4. Alps, temperature; 5. Carpathians, temperature; 6. Aegean Region, precipitation; 7. Southwest Turkey, precipitation; 8. Eastern Mediterranean, precipitation (after: Luterbacher et al., 2012).

Na sliki 3 je razvidno, da za območje med Egejskim morjem in avstrijskim delom Alp že obstajajo objavljene kronologije. V mednarodni podatkovni zbirki dendrokronoloških podatkov (ITRDB), prosto dostopni na internetu, so na voljo kronologije, organizirane po avtorjih, regijah, drevesnih vrstah ter merjenih parametrih branik (NOAA, 2012). V zbirki so za območje zahodnega dela Balkanskega polotoka kronologije širin branik smreke (*Picea abies* L.) iz Senja na Hrvaškem ter Vlasiča in Jahorine v BiH, vsa vzorčenja je opravil Schweingruber. V Črni gori je Schweingruber na prelazu Čakor vzorčil tudi omoriko (*Picea omorika*) (NOAA, 2012). Prav tako je bilo v BiH, v krajih Ravno borje (Kuniholm, 1981) in Duboka (Kuniholm in Striker 1983), opravljeno vzorčenje črnega bora, katerih maloštevilni vzorci so bili uporabljeni v dendrokronološki raziskavi širšega območja Egejskega morja (Hughes in sod., 2001). Dendrokronološko raziskavo je v BiH opravil tudi Accetto (1979), ko je preučil pomlajevanje črnega bora v okolici kraja Bugojno ter munike na planoti Prenj (Accetto, 1980).

Rezultati meritev debelinske rasti, ki jih je objavil Accetto (1979, 1980), so podane le kot grafična slika (same meritve niso na voljo), medtem ko so druge meritve z zahodnega dela Balkanskega polotoka objavljene v digitalni obliki (NOAA, 2012). Objavljene kronologije so zaradi tega na voljo za široko uporabo, a ker obsegajo le meritve največ petih dreves na eno lokacijo, so statistično premajhen vzorec za razvoj dendrokronološke mreže in reprezentativno predstavitev celotnega območja oziroma za uporabo teh kronologij v dendroklimatološki analizi vpliva klimatskih dejavnikov. Za zanesljivo izdelano dendrokronološko mrežo debelinskih prirastkov potrebujemo sistematičen pristop k vzorčenju na klimatske dejavnike odzivne drevesne vrste. Organiziran pristop izdelave kronologije izbrane drevesne vrste in rekonstrukcijo klimatskega dejavnika lahko že zasledimo na nekaterih sosednjih območjih zahodnega dela Balkanskega polotoka. V Romuniji, na vzhodnem delu Balkanskega polotoka, so rekonstruirali 1000-letno poletno temperaturo, temelječo na kronologiji širin branik cemprina (*Pinus cembra*) (Popa in Kern, 2009), ter dodatno preučili še vpliv klime na prirastke treh drugih drevesnih vrst (*Picea abies* L. Karst., *Abies alba* Mill. in *Fagus sylvatica* L.) (Kern in Popa, 2007). V Bolgariji, jugovzhodnem delu Balkanskega polotoka, so izdelali 655- in 305-letno kronologijo munike in molike (*Pinus peuce* Gris.) (Panayotov in sod., 2009) ter rekonstruirali poletno temperaturo (Trouet in sod., 2012). V Albaniji so v tisočletni kronologiji munike preučili klimatski signal, niso pa še predstavili nobene rekonstrukcije (Seim in sod., 2012).

Z vzorčenjem prirastkov na več lokacijah in izdelavo skupne regionalne iz več lokalnih kronologij pričakujemo, da bomo zajeli klimatski signal, ki ne bo samo lokalen, temveč bo ponazarjal odziv dreves na klimo širšega območja. Prostorsko jakost klimatskega signala ter kako veliko območje izdelana kronologija pokriva, preverimo prek spletnega programa KNMI Explorer (van Oldenborgh, 1999). Ta omogoča primerjavo naše izbrane kronologije z raznovrstnim naborom klimatskih parametrov izbranega območja iz CRU-sistema (Jones in Harris, 2008) ter slikovni prikaz izračuna korelacijskih vrednosti. Poznavanje velikosti vplivnega območja klimatskega dejavnika na izbrano kronologijo pomaga pri razumevanju in razlagi v rekonstrukciji identificiranih značilnih oziroma ekstremnih let. V našem primeru so značilna leta definirana kot leta, v katerih so rekonstruirane vrednosti presegle mejno vrednost, postavljeno na dveh standardnih odklonih od povprečne vrednosti (Touchan in sod., 2005) oziroma na izbranem centilu (Touchan in sod., 2008).

1.2 RAZISKOVALNE HIPOTEZE

Naš cilj je bil izdelati dendrokronološko mrežo črnega bora za območje zahodnega dela Balkanskega polotoka, preučiti vpliv na rast najbolj vplivnega klimatskega dejavnika ter rekonstruirati izbrani dejavnik v obdobje pred zbiranjem merjenih klimatskih podatkov. Z ozirom na naše cilje smo postavili naslednje hipoteze:

1. Lokalne kronologije črnega bora z različnih rastišč, nadmorskih višin in matičnih podlag se med seboj ujemajo, kar dokazuje skupen klimatski signal, ki nam omogoča sestavo regionalne kronologije črnega bora za BiH.
2. Regionalna kronologija črnega bora zahodnega dela Balkanskega polotoka se ujema z regionalnimi kronologijami sosednjih območij.
3. Klimatski signal v maksimalni gostoti kasnega lesa je bolj izrazit kot v širini branik.
4. Na širino branik črnega bora z ekstremnih rastišč vplivajo zgodnje poletne temperature in padavine, medtem ko na maksimalno gostoto kasnega lesa v braniki vplivajo pozno poletne temperature in padavine.
5. Regionalna kronologija črnega bora omogoča rekonstrukcijo najbolj vplivnega vremenskega dejavnika v obdobje pred instrumentalnimi meritvami.
6. Odziv črnega bora na klimo se skozi čas ne spreminja.

2 ZNANSTVENA DELA

2.1 435 LET DOLGA KRONOLOGIJA ČRNEGA BORA (*Pinus nigra*) ZA CENTRALNO-ZAHODNI DEL BALKANSKEGA POLOTOKA.

Poljanšek S., Ballian D., Nagel T. A., Levanič T. 2012. A 435-Year-Long European Black Pine (*Pinus nigra*) Chronology for the Central-Western Balkan Region. Tree-Ring Research, 68, 1: 31-44.

Opisujemo razvoj prve regionalne kronologije črnega bora (*Pinus nigra* Arnold) za območje centralno-zahodnega dela Balkanskega polotoka; Bosne in Hercegovine (BiH), temelječo na sedmih lokalnih kronologijah iz različnih krajev preučevanega območja. Analiza značilnih let v lokalnih kronologijah je pokazala skupen signal (verjetno klimatski) - najmanj pet pozitivnih (1876, 1930, 1941, 1969) in devet negativnih značilnih let (1874, 1880, 1891, 1931, 1943, 1963, 1971, 1987, 2000) je bilo skupnih za vseh sedem preučevanih rastišč. Lokalne kronologije so bile medsebojno primerjane s statističnimi parametri in vizualnim ujemanjem. Iz lokalnih kronologij smo za območje BiH razvili 435 let dolgo kronologijo širin branik črnega bora in jo primerjali z že obstoječimi kronologijami iz Črne gore, Grčije, Albanije, Avstrije (območje Dunaja) in Francije (Korzika). Statistične in vizualne podobnosti med regionalnimi kronologijami potrjujejo močan regionalni signal kronologije BiH, zato lahko novo razvito kronologijo z zahodnega dela Balkanskega polotoka vključimo v dendrokronološko mrežo za črni bor.

TREE-RING RESEARCH, *Vol. 68(1), 2012, pp. 31–44*

A 435-YEAR-LONG EUROPEAN BLACK PINE (*PINUS NIGRA*) CHRONOLOGY FOR THE CENTRAL-WESTERN BALKAN REGION

S. POLJANŠEK[1], D. BALLIAN[2], T. A. NAGEL[3], and **T. LEVANIČ[1]***

[1]Slovenian Forestry Institute, Večna pot 2, SI-1000 Ljubljana, Slovenia

[2]University of Sarajevo, Faculty of Forestry, Zagrebačka 20, 71000 Sarajevo, Bosnia and Herzegovina

[3]Biotechnical faculty, Department of Forestry, Večna pot 83, SI-1000 Ljubljana, Slovenia

ABSTRACT

We describe the development of the first black pine (*Pinus nigra* Arnold) regional chronology for the central-western Balkan area, Bosnia and Herzegovina (BiH), based on seven site chronologies from different parts of the country. Pointer-year analysis identified a common signal (possibly climate) in the site chronologies—at least five positive (1876, 1930, 1941, 1969) and nine negative pointer years (1874, 1880, 1891, 1931, 1943, 1963, 1971, 1987, 2000) are common to all seven study sites. Site chronologies were compared using statistical parameters and visual crossdating, from which we constructed a 435-year-long tree-ring width chronology for *P. nigra* for BiH and compared it with existing *P. nigra* chronologies from Montenegro, Greece, Albania, Austria (Vienna region), and France (Corsica). The resulting statistical and visual similarity indicated that the chronology has a strong regional signal and therefore can be included in the dendrochronological network for *P. nigra* for the Western Balkans.

Keywords: Pinus nigra, climate change, Bosnia and Herzegovina, dendroclimatology, dendrochronology.

INTRODUCTION

Dendrochronological research has a long tradition in the western and central part of the Mediterranean, such as Spain, France, Italy, Morocco, Tunisia, and Algeria (Martinelli 2004). However, the eastern part of the Mediterranean region had been largely overlooked until 1999 (Touchan and Hughes 1999), after which this situation improved as dendrochronological studies started to emerge in Jordan, Syria, Cyprus, Lebanon, and Turkey (Touchan *et al.* 2005b; Sevgi and Akkemik 2007; Touchan *et al.* 2007; Touchan *et al.* 2008). Currently, long chronologies for different tree species are available, as well as long-term reconstructions of different climatic parameters (see Touchan *et al.* 2007). Other studies have also realized the importance of the lack of data in the eastern region of the Mediterranean. Allen *et al.* (2010) clearly identify that data are needed on tree growth, climate-growth, as well as climate-mortality relationships.

In Bulgaria and Romania dendrochronological research is progressing. Panayotov *et al.* (2010) compiled a 758-year-long chronology for *Pinus heldreichii* Christ. and a 340-year-long chronology for *Pinus peuce* Gris., while Popa and Kern (2009) developed a 1,000-year-long chronology of *Pinus cembra* L. for Romania and reconstructed summer mean temperature anomalies for the period AD 1163–2005. In Austria, Strumia *et al.* (1997) studied the response of black pine (*Pinus nigra* Arn.) to precipitation and reported a high sensitivity to summer rainfall, whereas Leal *et al.* (2008) observed a decreasing sensitivity of the response to spring-summer precipitation towards the end of the 20th Century.

Dendrochronological work in Greece, Cyprus and in countries of the Near East (Turkey, Syria, Lebanon) is also well developed (Kuniholm and Striker 1983; Touchan *et al.* 2005a). At this stage, new chronologies have been constructed

*Corresponding author: tom.levanic@gozdis.si

and the first regional reconstructions of climate parameters have been published, including a long regional oak tree-ring width chronology (Kuniholm and Striker (1983) as well as the reconstruction of spring-summer precipitation for the Eastern Mediterranean (Touchan *et al.* 2005b) and a study of the association between signature years and the seasonal patterns of atmospheric circulation (Hughes *et al.* 2001).

Dendrochronological work in Albania, unlike that in Greece and the Near East, is being slowly developed by research teams from various countries. The first chronology of *P. nigra* from Albania and its response to climate was published by Levanič and Toromani (2010), while Seim *et al.* (2010) constructed a 1,000-year-long tree-ring width and tree-ring density chronology for *P. heldreichiii* in Albania.

In contrast to the rapid and systematic development of dendrochronological networks all around the Mediterranean basin, the Western Balkan region, which includes Montenegro, Bosnia and Herzegovina (BiH) and Croatia, has been less intensively investigated by dendrochronologists, and systematic dendrochronological work focusing on chronology development and climate-tree growth relationships, or addressing different dendroecological questions, has been largely absent. We are aware of two dendroecological studies by Accetto (1979) on the growth dynamics and natural regeneration of *P. nigra* and *P. heldreichii* in Central BiH. That study was limited to a relatively small area and focused more on stand dynamics than on the development of long chronologies. There are only a few chronologies from this region in the International Tree-ring Data Bank — *P. nigra* chronologies from Ravno Borje (Kuniholm 1981) and *Picea abies* chronologies from Jahorina, Čakor and Vlasić (Schweingruber 1996a). Although Kuniholm and Striker (1983) built a network of more than 50 Greek and Turkish sites, only one chronology from Duboka, Serbia, originates from the region we studied.

The Balkan Peninsula in Southeastern Europe is *ca.* 550,000 km^2 in size. It has a strong north-south temperature gradient, which can be viewed as a climatic transition from the strong Mediterranean conditions in Greece to temperate conditions toward the Alps, as well as a strong east-west precipitation gradient, resulting in a diverse climate throughout the region. Forests in this region are diverse, and forest communities on southern slopes, shallow soils and limestone bedrock in the Mediterranean climate zone of the western part of the Peninsula are especially susceptible to the predicted increase in temperature and decrease of precipitation (Pachauri and Reisinger 2007). For these reasons, the Balkan Peninsula is an important region for dendrochronological and dendroclimatological work, which has been exploited in its eastern, but not in its western part. We therefore decided to initiate systematic dendrochronological work on *P. nigra* in the western part of the Balkan Peninsula. *P. nigra* grows on extreme sites, has a wide ecological amplitude and distribution range, and responds well to environmental changes (see Fritts 1976). Its natural range of distribution extends from the vicinity of Vienna, Austria, in the north to Greece in the south, and covers all western Balkan countries. *P. nigra* can grow on different substrates and bedrock, such as limestone, dolomite, and serpentine-peridotite (Vidaković 1991; Isajev *et al.* 2004). Our study had the following goals:

- construction of tree-ring width chronologies for *P. nigra* on many natural sites in Bosnia and Herzegovina,
- development of a regional *P. nigra* chronology for Bosnia and Herzegovina,
- comparison of pointer years between sites and between neighboring countries,
- connection of the newly developed *P. nigra* chronology with other *P. nigra* chronologies from the Balkan Peninsula and neighboring countries.

MATERIALS AND METHODS

Sampling Locations

Seven *P. nigra* sites were sampled in BiH. They ranged in elevation from 500 m to 1,500 m a.s.l., with a southern aspect at higher elevations and a northern aspect at lower elevations (Table 1, Figure 1). Apart from the other six sites, trees at Šipovo (SIP) were sampled on the northern and

Table 1. Basic characteristics of the *P. nigra* sampling locations in Bosnia and Herzegovina.

Site	Code	Latitude N	Longitude E	Elevation [m]	Slope [°]	Aspect	Bedrock
Blace	BLA	43°31′	18°07′	950	50	SE	Dolomite
Konjuh	KON	44°17′	18°32′	1,100	45	S	Serpentine
Krivaja	KRI	44°13′	18°29′	500	60	NE	Serpentine
Perućica	PER	43°19′	18°42′	1,450	55	S	Limestone
Prusačka rijeka	PRU	44°04′	17°21′	1,100	65	S	Limestone
Šator	SAT	44°11′	16°36′	1,300	55	S	Dolomite
Šipovo	SIP	44°17′	17°12′	1,100	60	S & N	Limestone

southern side of the slopes above the gorge. All study sites had a low stand density, so the sampled trees had plenty of growing space and no between-tree competition. Many sampled trees were growing on a ridge (see Figure 2). All study sites were more or less pure *P. nigra* stands with only a minor occurrence of other tree species (*e.g.* *Fraxinus ornus* L., *Pinus sylvestris* L., *Quercus petraea* Liebl., and *Quercus pubescens* Wild.). According to local foresters, some locations have had frequent forest fires (also visible as fire scars on the stem) caused by lightning, and some sites have been heavily affected by intensive resin collection (such trees were not sampled). The

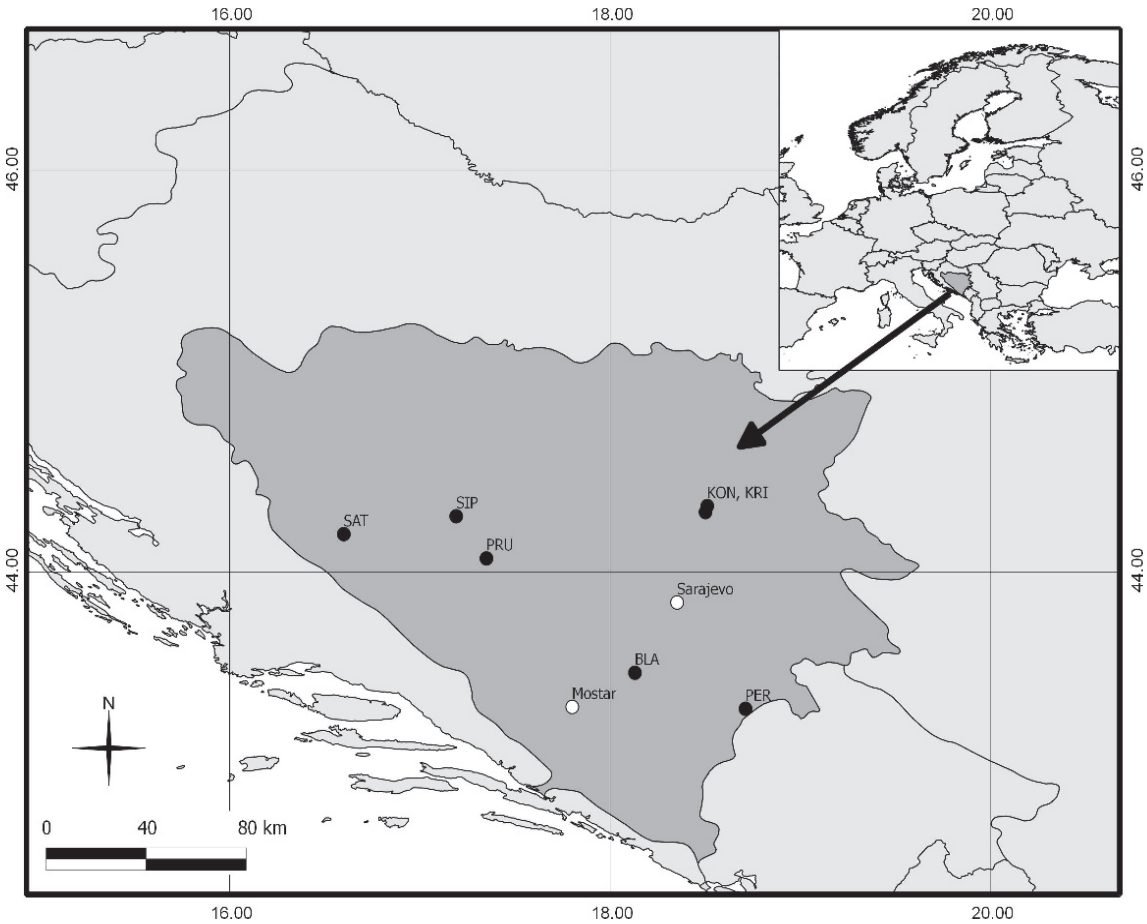


Figure 1. Sampling sites (●) of *P. nigra* in Bosnia and Herzegovina (dark gray area); Blace (BLA), Konjuh (KON), Krivaja (KRI), Perućica (PER), Prusačka rijeka (PRU), Šator (SAT) and Šipovo (SIP); meteorological stations (○) Mostar and Sarajevo.

Figure 2. Typical site with *P. nigra* growing on a steep limestone slope of the Prusac gorge, Bosnia and Herzegovina (photo: Simon Poljanšek).

sampling locations were evenly distributed across BiH and covered the majority of the sites where *P. nigra* is found in natural stands (Figure 1).

Main Characteristics of Black Pine (*Pinus nigra* Arn.)

P. nigra is a widespread species on the Balkan Peninsula. It can be found in a wide altitudinal range, from 500 to 2,000 m a.s.l. and can measure as much as 50 m in height and over 1 m in diameter. On some extreme sites it can reach over 500 years of age (Brus 2004). It has distinct annual rings with clearly visible earlywood and latewood. Resin ducts are abundant and mainly in the latewood, and missing or false rings can occur, especially on extreme sites. *P. nigra* is not shade-tolerant, but can resist low winter and high summer temperatures. Its thick bark makes it more fire resistant than other tree species in the area. All *P. nigra* subspecies are mountain species that occupy intermediate plains and more or less steep slopes of the wider Mediterranean region. In low elevations of the Mediterranean part of its distribution, natural *P. nigra* stands are found on north-facing slopes, whereas in alpine and continental areas, they are located on south-facing slopes (Bussotti 2002). *P. nigra* is well adapted to extreme sites with summer heat and a lack of precipitation. It can grow on steep, rocky slopes where soils are highly erodible and on dolomite, limestone, or serpentine-peridotite bedrock where growth conditions for other tree species are too extreme. Sites on serpentine-peridotite are particularly interesting as this bedrock type is characterized by low fertility, low soil moisture, calcium deficiency, high concentrations of heavy metals, and low plant nutrients. Serpentine-peridotite substrate varies from pH 5.5–8 (Proctor and Woodell 1975; Stevanović *et al.* 2003). Because trees on these sites grow slowly, we can expect to find very old individuals. Such trees are highly suitable for the development of long chronologies or investigation of climatological and ecological questions related to tree growth (Leal *et al.* 2008; Linares and Tíscar 2010).

Sampled Trees

Old, dominant or co-dominant trees with a healthy trunk and no signs of resin exploitation were selected for sampling. From each tree, two cores from opposite sides were taken at breast height (1.3 m) and perpendicular to the slope to avoid compression wood. On extreme terrain, we took only one core per tree, or the core was taken at a greater height than normal (*i.e.* 1.5–2 m). Cores were air-dried and glued on wooden holders, and sanded with progressively finer sandpaper until a high-polish surface was achieved (Stokes and Smiley 1996). Samples were scanned using the ATRICS system (Levanič 2007) and measured using WinDENDRO software (www.regentinstruments.com). The width of each annual ring was measured to the nearest 0.01 mm.

Climate

Geographically, the Balkan Peninsula represents an important north-south transect and a

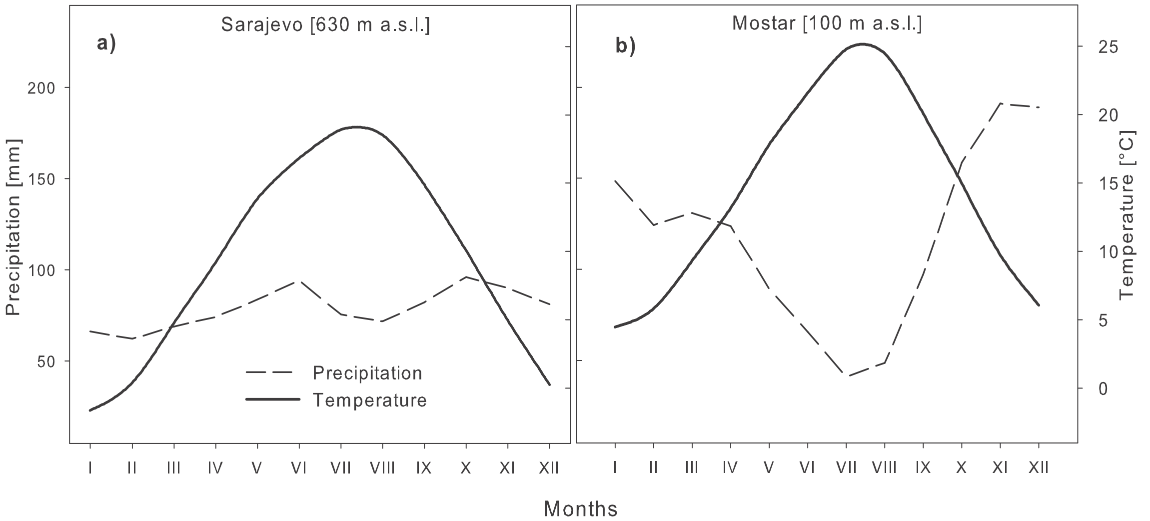


Figure 3. Climate diagram based on the HISTALP dataset (Auer *et al.* 2007) for the period 1881–2006 for (a) Sarajevo and (b) Mostar.

climatic transition zone between the Mediterranean and Central European synoptic - temperate zone (Eastwood 2004). Although the vegetation in BiH belongs to the Mediterranean vegetation community (Eastwood 2004), it is enriched by diverse geographical features. This leads to high species diversity and makes BiH one of Europe's biodiversity hotspots (Gibson *et al.* 2003).

BiH is located in the northwestern part of the Balkan Peninsula, between 42°26′ to 45°15′N and 15°44′ to 19°41′E. It is bordered by Croatia to the north, west, and south, by Serbia to the east, and by Montenegro to the southeast. Because of its geographical position, proximity to the Adriatic Sea, and distinct topography, the northern part of the country has a moderate continental climate with July temperature around 20°C and 700–800 mm of annual precipitation (Pintarić 1999). In the central mountainous area severe winters with abundant snowfall prevail. Warm humid air from the Adriatic Sea often collides with cooler air above the Dinaric Alps, and as a consequence, the Čvrsnica (2,000 m a.s.l.), Prenj (1,900 m a.s.l.) and Džamija (1,800 m a.s.l.) mountain peaks receive abundant precipitation — annual precipitation on these peaks averages from 3,000–5,000 mm, among the highest recorded in Europe. Bjelašnica (2,000 m a.s.l.), located behind the first range, still receives more than 1,800 mm of yearly precipitation, although there can be large differences between years, with a maximum of 3,157 mm in 1900 and a minimum of 627 mm in 1954 (Federal Hydrometeorological Institute of Bosnia and Herzegovina).

Mountain ranges in BiH have an important impact on climate. They reduce the influence of the Mediterranean and enhance the influence of the continental climate over a very short distance. Western BiH has a typical sub-Mediterranean climate pattern with warm and wet late autumn and winter months (6.5°C average winter temperature and 650 mm precipitation) and hot and dry summers (22°C and 250 mm precipitation). As there are three types of climate that influence the BiH area, a mixed climatic influence is observed in weather station data that are provided by the HISTALP climate database project (Auer *et al.* 2007). The variability of climate in BiH is well-represented by two meteorological stations—Mostar and Sarajevo. The Mostar meteorological station (Figure 3b) represents a typical sub-Mediterranean climate—the temperature is high in July-August (25°C average monthly temperature) and precipitation is most abundant from October to January (700 mm). Winter is not particularly cold (6°C) and summer is very dry (245 mm from May-August). The climate of the inner part of BiH is well-represented by the meteorological station in Sarajevo (Figure 3a); it is a moderate continental climate—mountain ridges oriented north-south prevent the Mediterranean climate from reaching deep into the country, which results in cool summers (17°C average monthly temperature) and equally distributed precipitation over the year (1,000 mm of annual precipitation).

Statistical Methods

Crossdating of chronologies was done with PAST-4^{TM} 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). False and missing rings were counted across all tree-ring series per site and summed. Additionally, quality control using program COFECHA was applied to check for measurement errors (Holmes 1983). If necessary, measurements were repeated, rechecked, or removed from further processing if recognized as unusable. Reasons why certain trees were removed from the sample pool were growth anomalies connected with historical resin collection, overgrown wounds, or occurrence of compression wood deep inside the trunk. In three cases we were not able to measure tree-ring widths on the entire core, just on their older sections. This caused a small decrease in sample depth after 1900. Because the sample depth in the last 100 years is more than adequate, we are confident that this did not influence the overall results.

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 widths was fit with a cubic smoothing spline with a 50% frequency response at 67% of the series length to remove non-climatic trends related 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. Two chronologies were produced this way—a standard chronology and a residual chronology containing only high-frequency variations with statistically removed autocorrelation (Cook 1985; Cook *et al.* 1990).

The regional chronology was calculated in ARSTAN using the same parameters as for the site chronologies. The main difference between the site chronologies and the regional chronology is that we first composed a file containing all individual raw TRW series and then ran ARSTAN to produce a standard and residual regional chronology.

Signal strength in site chronologies was tested using Expressed Population Signal - EPS (Wigley *et al.* 1984; Briffa and Jones 1990). Calculation of EPS is based on a 50-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 future climate reconstructions that may be carried out with 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).

Pointer years (PYs) were calculated for each site and compared between sites to search for a common forcing in the tree-ring widths. According to Schweingruber *et al.* (1990), PYs are defined as years when at least 80% of 13 trees respond with an increase or decrease in tree-ring width. An exception was made for sites KRI and PRU where, because of the small number of accepted samples, conditions for PYs were set at 90% of 10 trees for KRI and 83% of 12 trees for BLA. PYs were calculated with non-standardized tree-ring series. We also identified "Regional" PYs , defined as pointer years that were common on at least four out of seven site chronologies. Finally, the results of the PY analysis were compared with PYs calculated from various tree species in BiH, Greece, Italy, Turkey, and Serbia in a study by Hughes *et al.* (2001).

RESULTS

Construction of Site Chronologies

Seven *P. nigra* site chronologies of different length between 198 and 430 years were built for

Table 2. Basic data of the site chronologies.

Site	Time Span	Length	Trees	Cores	Trees Excluded	False Rings	Missing Rings	Average t_{BP}	Min-Max t_{BP}	Average GLK%
BLA	1625–2010	386	21	41	9	0	2	13.5	10.5–16.9	73.1
KON	1626–2010	385	24	45	6	0	31	17.8	13.5–23.9	74.8
KRI	1667–2010	344	18	29	8	7	7	14.6	10.8–17.1	73.1
PER	1603–2010	408	33	50	9	3	7	13.9	8.93–20.1	71.3
PRU	1694–2010	317	15	22	5	0	15	12.1	8.63–13.8	63.3
SAT	1813–2010	198	20	40	4	3	16	13.0	10.4–17.2	73.3
SIP	1576–2005	430	35	58	12	4	19	11.4	8.47–15.8	68.1

Bosnia and Herzegovina (Table 2). On each site we found trees that could not be crossdated with others; such trees were removed from the data pool. The highest number of excluded trees was at SIP (12 out of 35; 34%); however, the highest proportion of trees excluded was at KRI (8 out of 18; 44%). Because trees at KRI were used for the industrial exploitation of resin, only 18 trees were found without visible damage to the trunk, and only 10 could be crossdated. A similar problem occurred at PRU, where, because of the extremely steep slope, only 15 trees could be sampled and just 10 of them crossdated (Table 2).

In some trees, false rings and missing rings were detected. Missing rings were identified in cases where one core had a ring in a certain year and the core from the opposite side did not. For example, at BLA we collected 41 cores and found just two missing rings (Table 2). Seven missing and false rings were identified at KRI. The largest number of missing rings was found at KON (31 altogether). Trees within sites crossdated very well, as values of coefficients t_{BP} and GLK% were high at all locations (Table 2). The highest maximum (23.9) and average values (17.8) of t_{BP} were found at KON, and the lowest values were found at SIP (15.8 and 11.4, respectively).

In general, all tree rings were narrow (mean value below 1 mm). The widest TRW was found at PRU (4.29 mm) and the narrowest at KRI (0.11 mm) (Table 3). The lowest standard deviation was found at SIP (0.25) and the highest at SAT (0.66). The highest values of mean sensitivity were at BLA, KRI, PER, and SAT, while KON, PRU, and SIP had values below 0.20. Values of the first-order autocorrelation in the raw chronologies were high, meaning that growth conditions in the previous year influence tree-ring width in the current year. Autocorrelation in the standardized chronologies were slightly lower than in the raw chronologies and completely negligible in the residual chronologies.

Table 3. Tree-ring width (TRW) statistics for raw chronologies, including mean, standard deviation (st. dev.), minimum and maximum tree-ring width, mean segment length, expressed population signal (EPS), mean sensitivity (MS), as well as first-order autocorrelation ac(1) for the raw, standard, and residual chronologies.

	Raw Chronology							ac(1)		
Site	Mean	St. dev.	Min-Max	mssl*	EPS > 0.85	MS	r_{BT}**	RAW	STD	RES
BLA	0.77	0.29	0.16–2.30	263	1830	0.22	0.39	0.73	0.68	0.00
KON	0.74	0.43	0.21–3.52	330	1705	0.19	0.48	0.87	0.74	0.00
KRI	0.70	0.47	0.11–3.33	280	1745	0.24	0.46	0.84	0.49	0.03
PER	0.98	0.42	0.25–2.30	291	1660	0.23	0.39	0.84	0.65	0.00
PRU	0.99	0.49	0.29–4.29	277	1825	0.17	0.37	0.85	0.57	−0.01
SAT	1.44	0.66	0.23–3.33	165	1870	0.23	0.43	0.88	0.57	−0.00
SIP	0.75	0.25	0.20–0.87	292	1730	0.15	0.29	0.81	0.67	0.01

*Mean sample segment length.
**Correlation among trees (r_{BT}) calculated with residual tree-ring series.

Table 4. Comparison of t_{BP} (upper triangular of matrix) and GLK% (lower triangular of matrix) coefficients between site chronologies.

Site	BLA	KON	KRI	PER	PRU	SAT	SIP
BLA	*	10.4	9.6	9.0	11.7	5.2	7.8
KON	66.9	*	12.7	10.6	13.4	6.4	12.1
KRI	66.9	68.0	*	4.6	6.7	1.9	7.0
PER	65.7	67.4	57.3	*	9.9	7.5	10.2
PRU	70.8	69.9	63.4	67.4	*	5.6	11.2
SAT	64.9	61.4	51.5	66.4	65.4	*	5.0
SIP	63.6	74.1	68.1	69.9	70.7	67.6	*

Similarities between site chronologies were high. All site chronologies crossdated well, except between SAT and KRI and PER and KRI (Table 4). Average values of t_{BP} and GLK% coefficients for combinations of site pairs were 8.5 and 66.1, respectively. The highest value was found between PRU and KON (13.4) and the lowest between KRI and SAT (1.9). All GLK% coefficients were high, with the exception of the above-mentioned combinations with a low t_{BP} value. The KRI site did not crossdate well with PER and SAT, but did match well with BLA (9.6) and KON (12.7). Residual site chronologies are presented in Figure 4.

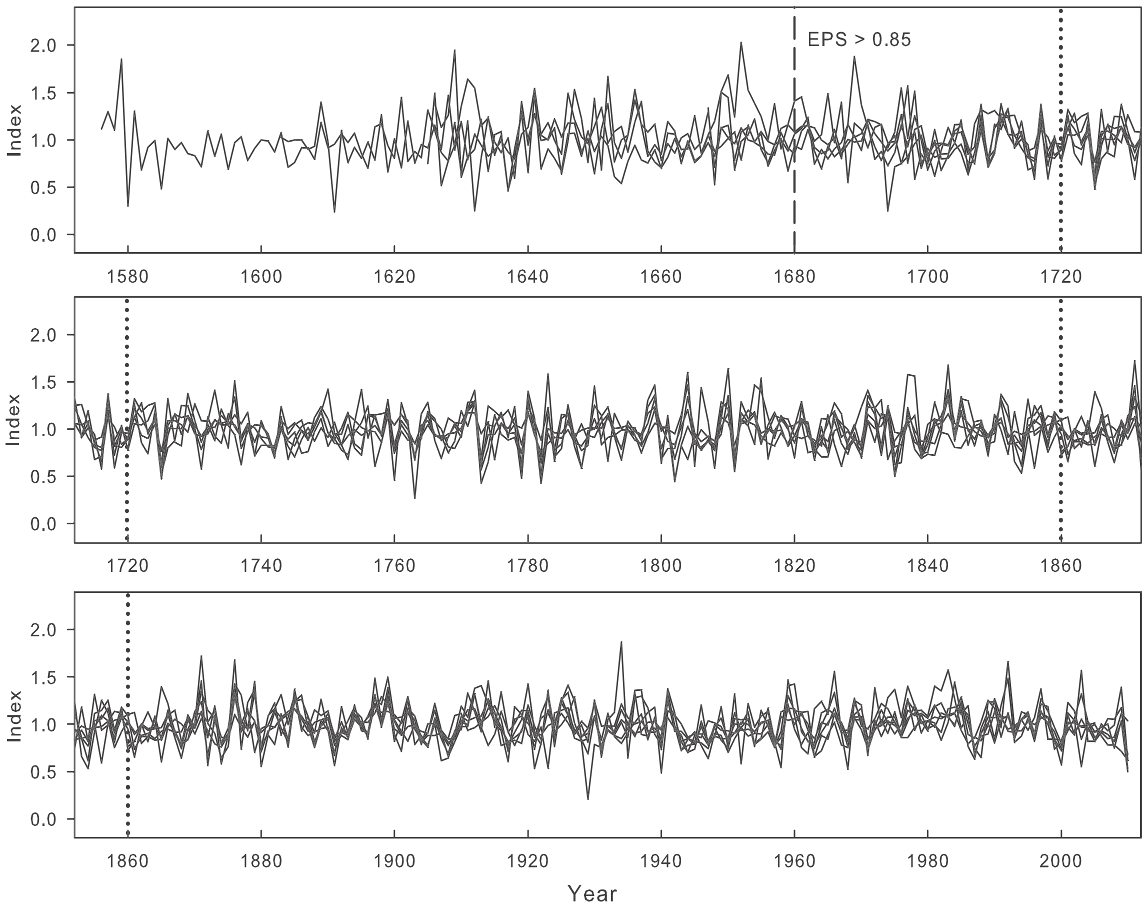


Figure 4. Residual chronologies for *P. nigra* from seven locations in BiH. The dashed line represents the point on the chronology where the EPS value exceeds 0.85, vertical dotted lines show connections between parts of the figure.

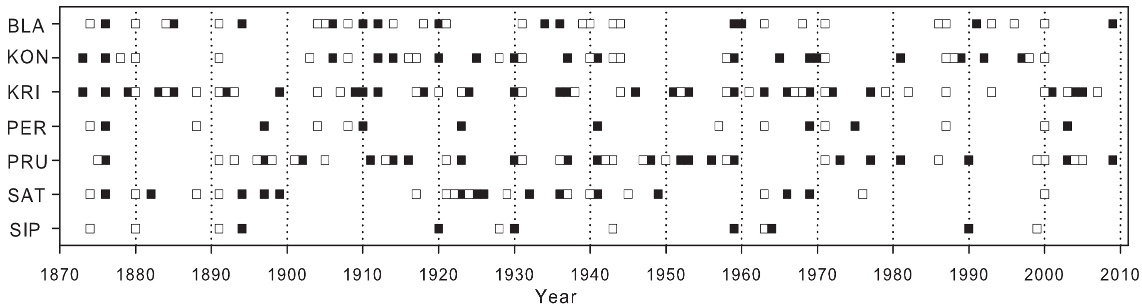


Figure 5. Pointer years at all 7 locations (■ represents a positive pointer year and □ a negative). Scale of the x-axis is set to the common period 1873–2009 with sufficient sample depth on all seven sites.

Pointer Years

Pointer years (PYs) were studied at all seven locations. Altogether we found 287 positive and 308 negative PYs (Figure 5). We identified five positive (1876, 1930, 1941, 1959, 1969) and nine negative (1874, 1880, 1891, 1931, 1943, 1963, 1971, 1987, 2000) PYs common to at least four out of seven sites.

Out of 14 positive PYs published in Hughes *et al.* (2001), two were present in at least four of our sites (1930, 1959), while three positive PYs (1897, 1910, 1936) were found at three of our sites. Negative PYs seemed to be more local and had less similarity with those published, because only one year (1928) in Hughes *et al.* (2001) was found to be common to two of our sites.

Regional Chronology for *P. nigra* in Bosnia and Herzegovina

A regional chronology for *P. nigra* was compiled from all seven site chronologies. All site chronologies crossdated well with the regional chronology, with t_{BP} values being equal or greater than 7.8 and GLK% values being equal or greater than 65.7 (Table 5). The highest t_{BP} value was found between the regional chronology and the site chronology KON (17.7), and the highest GLK% coefficient was found between the regional chronology and the site chronology PRU (74.0).

Analyses of raw chronologies, included in the calculation of the regional chronology, confirmed the extreme growth conditions at all seven sites. The average tree-ring width was 0.87 mm, but more than half of all tree rings were narrower than 0.77 mm. Seventy-five percent of all tree rings were less than 1.04 mm wide. The narrowest ring was 0.11 mm and the widest 4.29 mm. The widest TRW were found in juvenile period of the trees (above 1 mm), but with increasing age the average TRW fell under 0.80 mm; the raw chronology is presented in Figure 6a and the residual chronology in Figure 6b, while sample depth is presented in Figure 6c. After AD 1666, the sample depth exceeded 20 trees. Fifty trees included in the chronology were present after 1706, and after 1833, 100 trees were included. The highest number of trees covers the period from 1875 until the present, with more than 110 trees.

Table 5. Comparison of BiH regional *P. nigra* chronology with site chronologies (the respective chronology was temporarily removed from the regional chronology prior to comparison).

Site Chronologies	Start Year	End Year	Overlap	t_{BP}	GLK%
BLA	1624	2010	386	13.0	68.8
KON	1625	2010	385	17.7	73.6
KRI	1666	2010	344	9.4	65.7
PER	1602	2010	408	13.3	71.4
PRU	1693	2010	317	16.4	74.0
SAT	1812	2010	198	7.8	68.9
SIP	1575	2005	430	13.3	73.8

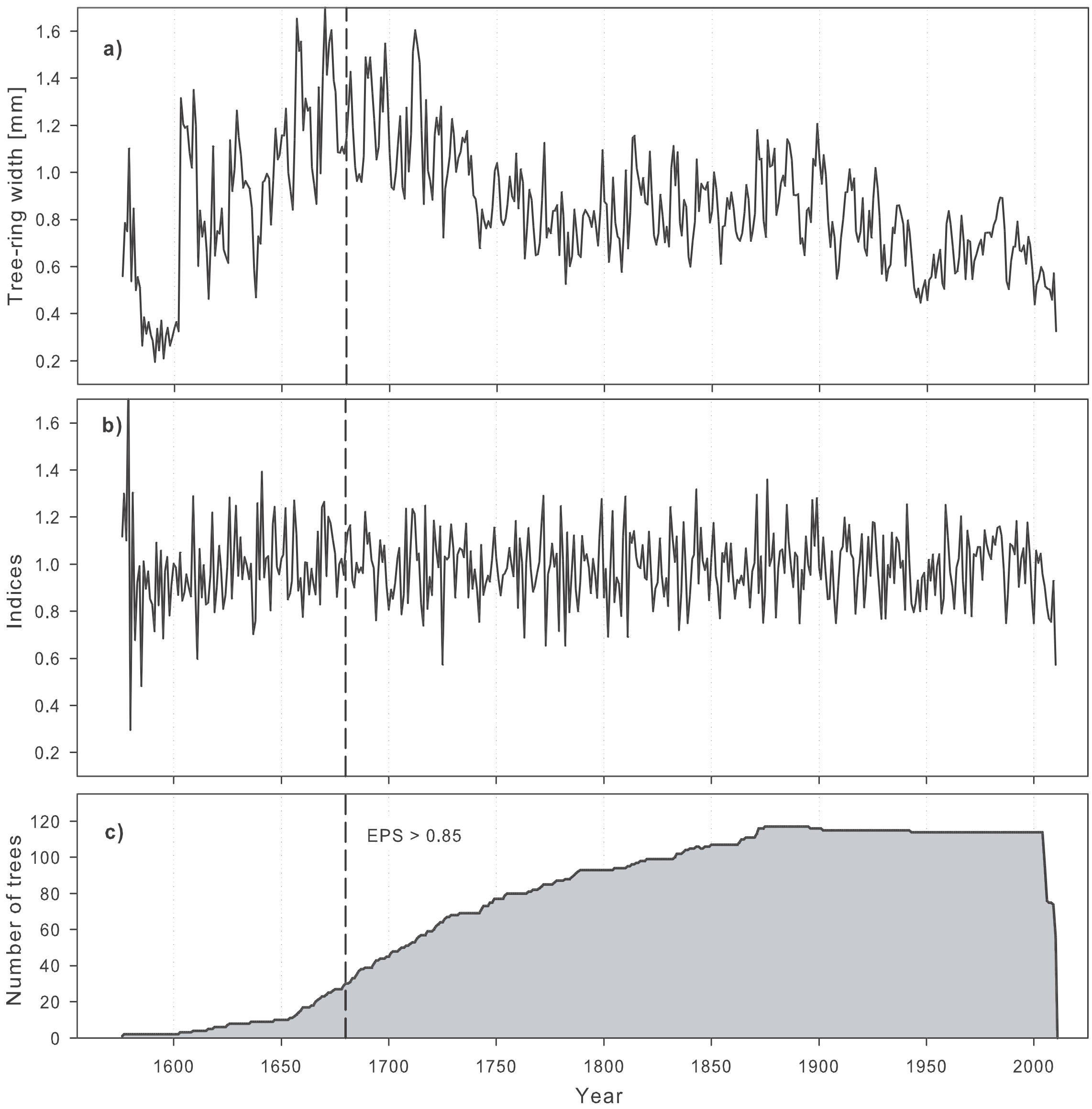


Figure 6. *P. nigra* regional raw (a) and residual chronology (b) with sample depth (c) for Bosnia and Herzegovina. The dashed line represents the point on the chronology where the EPS value exceeds 0.85.

Comparisons with Other *P. nigra* Chronologies from the Broader Region

The BiH regional *P. nigra* chronology was compared with other regional *P. nigra* chronologies for Southern Europe (Mediterranean area), Austria, and Switzerland, available in the Tree-Ring Data Bank or acquired through exchange with other laboratories. The highest t_{BP} and GLK% coefficients were found between the BiH and Montenegro chronologies (13.5 and 71.1, respectively) – Table 6. Both parameters were also high when comparing the BiH chronology with chronologies from Albania, Austria, France, and Greece, ranging between 6.0 and 7.8 for t_{BP} and 52.0 and 69.1 for GLK%. We found a minor connection or no connection at all between the BiH chronology and chronologies from Slovenia, Switzerland, Turkey, Cyprus, and Spain.

Table 6. Comparison of BiH regional *P. nigra* chronology to other regional chronologies.

Chronologies	Start Year	End Year	Overlap with BiH Chronology	t_{BP}	GLK%
Albania (Levanič and Toromani 2010)	1769	2007	238	7.8	69.1
Austria, regional chronology (Grabner, personal communication)	1318	1996	430	7.5	64.4
Cyprus (Touchan and Hughes 2007)	1553	2002	427	1.4	52.0
France, Corsica (Schweingruber 1996b)	1517	1980	405	6.0	58.8
Greece, Langada (Schweingruber 1996c)	1825	1981	156	2.4	60.8
Greece, Zagradeniye (Huges *et al.* 2001)	1706	1979	274	7.2	63.7
Greece, Scotida (Kuniholm and Riches 2004)	1751	2003	253	6.8	65.0
Greece, Taygetos (Kuniholm and Groneman 2005)	1657	1999	343	4.9	57.1
Italy, Sicily (Schweingruber 1996d)	1772	1980	208	4.2	57.2
Montenegro (Levanič, preliminary results)	1593	2006	414	13.5	71.1
Slovenia (Levanič, preliminary results)	1798	2008	210	4.1	62.1
Spain (Fuster 1996)	1686	1989	303	0.0	51.0
Switzerland (Hobi 2008)	1892	2007	115	2.3	59.6
Turkey (Touchan *et al.* 2005)	1770	2002	232	2.3	55.8

DISCUSSION

We present the first 435-year-long regional chronology for *P. nigra* for Bosnia and Herzegovina. It was compiled from seven site chronologies originating from different substrates, elevations, and slopes, evenly dispersed across the country. The regional chronology has a sufficient sample depth and an EPS > 0.85 from AD 1675 until the present. It is as long as *P. nigra* chronologies from nearby regions such as Cyprus, Corsica, and Montenegro (Schweingruber 1996b; Touchan and Hughes 2007; Levanič unpublished) and in some cases even longer than chronologies for Slovenia (unpublished data), Switzerland, Greece, and Albania (Schweingruber 1996c; Hobi 2008; Levanič and Toromani 2010). The length of the BiH regional chronology is close to the maximum age of *P. nigra* of *ca.* 500 years (Brus 2004). With the additional coring of dead wood or the collection of wood samples from old houses, it might be possible to construct an even longer *P. nigra* chronology, as was the case with the *P. cembra* chronology by Popa and Kern (2009) or with the oak and pine chronologies by Kuniholm and Striker (1983). In the latter case, the length of living tree chronologies was extended with oak and pine samples from churches, mosques, and houses, but the length of the *P. nigra* chronology from Duboka (Serbia) is only 342 years long and has not yet been extended (Kuniholm and Striker 1983).

The BiH regional *P. nigra* chronology correlates well with other *P. nigra* regional chronologies from the Balkan Peninsula or surrounding regions. The highest value of t_{BP}, 13.5, found between BiH and Montenegro is not surprising because the chronologies from Montenegro are located *ca.* 50 km ESE from the PER in BiH. High values were also observed with the Albanian (7.8) and Austrian (7.5) *P. nigra* chronologies. These results indicate the existence of a north-south transect and will be used to develop a *P. nigra* dendrochronological network for the Balkan Peninsula.

Comparing the BiH regional *P. nigra* chronology with those from Cyprus, Spain, Italy, and Slovenia shows very few similarities. Although this was expected for the chronologies from Cyprus, Spain, and Italy because of the longer distances to these sites and different environmental conditions, it was surprising for the chronology from Slovenia particularly, because sites used to build the Slovenian *P. nigra* chronology are located between sites in BiH and Austria. This calls for further sampling on extreme sites in Slovenia, Croatia and northern BiH to connect the BiH regional chronology with that from Slovenia.

The small number of common PYs between our study and the study by Hughes *et al.* (2001) is not unexpected as the distance between the majority of sites is large. Moreover, there are a variety of other environmental factors (*e.g.* elevation, topographic features, edaphic conditions) that may account for differences among these sites.

The potential of the BiH *P. nigra* chronology for dendroclimatological studies has not yet been tested. However, sufficient sample depth, high t_{BP} values between site chronologies, a large number of common pointer years, and high EPS values suggest that there must be a common signal in the tree rings. Similar research in Albania on the climate sensitivity of *P. heldreichii* (Seim *et al.* 2010) and *P. nigra* (Levanič and Toromani 2010) confirms that *Pinus* has a high potential for dendroclimatology in the region. Additionally, the newly constructed chronology for BiH could be used to date wooden artifacts, such as houses and religious objects or icons, from different parts of the country.

ACKNOWLEDGMENTS

We express our thanks to the forestry personnel from the Bosansko Grahovo, Konjuh, Konjic, Prusačka Rijeka, Šipovo, and Konjic forestry districts and to the rangers from Perućica National Park. This work was supported by the Slovenian Research Agency through the program and research group ''Forest, biology, ecology and technology'' P4-0107 and a doctoral study grant from Simon Poljanšek. We are also thankful to the Federal Hydrometeorological Institute of Bosnia and Herzegovina for supplying us with the meteorological data used in this study. We are grateful to Dr. Michael Grabner, BOKU Vienna, Austria for providing us Austrian regional *P.nigra* chronology.

REFERENCES

Accetto, M., 1979. Regeneration, growth and development of natural stands of Austrian Pine (*Pinus nigra* Arnold) on dolomite – limestone sites of Western Bosnia. *Research Reports Forestry and Wood Technology*. no. 17.

Allen, C. D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, E. H. Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J.-H. Lim, G. Allard, S. W. Running, A. Semerci, and N. Cobb, 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management* 259(4):660–684.

Auer, I., R. Böhm, A. Jurkovic, W. Lipa, A. Orlik, R. Potzmann, W. Schöner, M. Ungersböck, C. Matulla, K. Briffa, P. Jones, D. Efthymiadis, M. Brunetti, T. Nanni, M. Maugeri, L. Mercalli, O. Mestre, J.-M. Moisselin, M. Begert, G. Müller-Westermeier, V. Kveton, O. Bochnicek, P. Stastny, M. Lapin, S. Szalai, T. Szentimrey, T. Cegnar, M. Dolinar, M. Gajic-Capka, K. Zaninovic, Z. Majstorovic, and E. Nieplova, 2007. HISTALP—historical instrumental climatological surface time series of the Greater Alpine Region. *International Journal of Climatology* 27(1):17–46.

Baillie, M. G. L., and J. R. Pilcher, 1973. A simple cross-dating program for tree-ring research. *Tree-Ring Bulletin* 33:7–14.

Briffa, K. R., and P. D. Jones, 1990. Basic chronology statistics and assessment. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, edited by E. R. Cook, and L. A. Kairiukstis, pp. 137–152. Kluwer academic publishers, Dordrecht, Boston, London.

Brus, R., 2004. *Drevesne Vrste na Slovenskem* (Tree species on Slovenian area; in Slovenian). Mladinska založba, Ljubljana.

Bussotti, F., 2002. Seed dispersal in pines. In *Ecology and biogegraphy of Pinus*, edited by D. M. Richardson, pp. 281–293. C.A.B. International, CABI Publishing, Cambridge.

Cook, E. R., 1985. *Time Series Analysis Approach to Tree Ring Standardization*. Ph.D. dissertation, University of Arizona, Laboratory of Tree-Ring Research, Tucson.

Cook, E. R., and K. R. Briffa, 1990. A comparison of some tree-ring standardization methods. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, edited by E. R. Cook, and L. A. Kairiukstis, pp. 153–162. Kluwer Academic Publishers, Dordrecht, Boston, London.

Cook, E. R., and R. L. Holmes, 1999. Program ARSTAN – chronology development with statistical analysis (users manual for program ARSTAN). *Laboratory of Tree-Ring Research, University of Arizona*, 18.

Cook, E. R., K. Briffa, S. Shiyatov, and V. Mazepa, 1990. Tree-ring standardization and growth trend estimation. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, edited by E. R. Cook, and L. A. Kairiukstis, pp. 104–162. Kluwer Academic Publishers, Dordrecht, Boston, London.

Eastwood, W. J., 2004. East Mediterranean vegetation and climate change. In *Balkan Biodiversity: Pattern and process in the European hotspot*, edited by H. I. Griffiths, B. Krystufek, and J. M. Reed, pp. 25–48. Kluwer, Dordrecht.

Eckstein, D., and J. Bauch, 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt* 88(4):230–250.

Fritts, H. C., 1976. *Tree Rings and Climate*. Academic Press, London, New York, San Francisco.

Fuster, M. G., 1996. *Pinus nigra* – Andrinal, Spain (noaa-tree-3283), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Gibson, D. C., R. Sisse, and S. Dug, 2003. Bosnia and Herzegovina – biodivesity assessment. *USAID/Bosnia and Herzegovina*, 74.

Hobi, M. L., 2008. *Wachstumsreaktionen von Buche, Waldföhre und Schwarzföhre auf einen Waldbrand*. Master thesis, ETH Zurich, Departement für Umweltwissenschaften UWIS.

Holmes, R. L., 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69–78.

Hughes, M. K., P. I. Kuniholm, J. K. Eischeid, G. Garfin, C. B. Griggs, and C. Latini, 2001. Aegean tree-ring signature years explained. *Tree-Ring Research* 57(1):67–73.

Isajev, V., B. Fady, H. Semerci, and V. Andonovski, 2004. EUFORGEN Technical Guidelines for genetic conservation and use for European black pine (*Pinus nigra*). *International Plant Genetic Resource Institute*, 6.

Kuniholm, P. I., 1981. *Pinus nigra* – Ravno Borje, Bosnia and Hercegovina (noaa-tree-3810), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Kuniholm, P. I., and C. L. Striker, 1983. Dendrochronological Investigations in the Aegean and Neighboring Regions, 1977–1982. *Journal of Field Archaeology* 10(4):411–420.

Kuniholm, P. I., and N. Riches, 2004. *Pinus nigra* - Scotida forest Kastoria, Greece (noaa-tree-3813), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Kuniholm, P. I., and C. Groneman, 2005. *Pinus nigra* - Taygetos forest, Greece (noaa-tree-3814), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Leal, S., D. Eamus, M. Grabner, R. Wimmer, and P. Cherubini, 2008. Tree rings of *Pinus nigra* from the Vienna basin region (Austria) show evidence of change in climatic sensitivity in the late 20th century. *Canadian Journal of Forest Research* 38(4):744–759.

Levanič, T., 2007. ATRICS – A new system for image acquisition in dendrochronology. *Tree-Ring Research* 63(2): 117–122.

Levanič, T., and E. Toromani, 2010. Austrian pine (*Pinus nigra* Arnold.) tree-ring width chronology from northeast Albania-preliminary results. In *TRACE – Tree rings in Archaeology, Climatology and Ecology*, pp. 104–109. Otočec, Slovenija, Helmholtz -Zentrum Potsdam, Deutsches Geoforschungszentrum.

Linares, J. C., and P. A. Tíscar, 2010. Climate change impacts and vulnerability of the southern populations of *Pinus nigra* subsp. salzmannii. *Tree Physiology* 30(7):795–806.

Martinelli, N., 2004. Climate from dendrochronology: Latest developments and results. *Global and Planetary Change* 40: 129–139.

Pachauri, R. K., and A. Reisinger, Editors. *IPCC, 2007: Climate Change 2007: Synthesis Report*, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2007; 104 pp.

Panayotov, M., P. Bebi, V. Trouet, and S. Yurukov, 2010. Climate signal in tree-ring chronologies of *Pinus peuce* and *Pinus heldreichii*; from the Pirin Mountains in Bulgaria. *Trees – Structure and Function* 24(3):479–490.

Pintarić, K., 1999. Forestry and Forest Reserves in Bosnia and Herzegovina. In *Virgin Forests and Forest Reserves in Central and East European Countries: History, Present Status and Future Development*, edited by J. Diaci, pp. 1–15. Department of Forestry and Renewable Forest Resources, Biotechnical faculty, University of Ljubljana, Ljubljana.

Popa, I., and Z. Kern, 2009. Long-term summer temperature reconstruction inferred from tree-ring records from the Eastern Carpathians. *Climate Dynamics* 32(7):1107–1117.

Proctor, J., and S. R. J. Woodell, 1975. The ecology of serpentine soils. *Advances in Ecological Research* 9:255–365.

Schweingruber, F. H., 1996a. *Picea abies* - Jahorina and Vlašič, Bosnia and Hercegovina (noaa-tree-4724), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Schweingruber, F. H., 1996b. *Pinus nigra* - Col de Sorba, Mount Renoso, France (noaa-tree-4389), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Schweingruber, F. H., 1996c. *Pinus nigra* - Langada (Sparta), Greece (noaa-tree-4500), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Schweingruber, F. H., 1996d. *Pinus nigra* - Aetna Linguaglossa, Italia (noaa-tree-4304), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Schweingruber, F. H., D. Eckstein, F. Serre-Bachet, and O. U. Bräker, 1990. Identification, presentation and interpretation of event years and pointer years in dendrochronology. *Dendrochronologia* 8:9–38.

Seim, A., K. Treydte, U. Büntgen, J. Esper, P. Fonti, H. Haska, F. Herzig, W. Tegel, and D. Faust, 2010. Exploring the potential of *Pinus heldreichii* Christ. for long-term climate reconstruction in Albania. In *TRACE – Tree rings in Archaeology, Climatology and Ecology*, Otočec, pp. 75–82. Slovenija, Helmholtz-Zentrum Potsdam, Deutsches Geoforschungszentrum.

Sevgi, O., and U. Akkemik, 2007. A dendroecological study on *Pinus nigra* Arn. at different altitudes of northern slopes of Kazdaglari, Turkey. *Journal Of Environmental Biology/ Academy Of Environmental Biology, India* 28(1):73–75.

Stevanović, V., K. Tan, and G. Iatrou, 2003. Distribution of the endemic Balkan flora on serpentine I. — obligate serpentine endemics. *Plant Systematics and Evolution* 242(1):149–170.

Stokes, M. A., and T. L. Smiley, 1996. *An Introduction to Tree-Ring Dating*. The University of Arizona Press, Tucson.

Strumia, G., R. Wimmer, and M. Grabner, 1997. Dendroclimatic sensitivity of *Pinus nigra* Arnold in Austria. *Dendrochronologia* 15:129–137.

Touchan, R., and M. K. Hughes, 1999. Dendrochronology in Jordan. *Journal of Arid Environments* 42(4):291–303.

Touchan, R., and M. K. Hughes, 2007. *Pinus nigra* – Armiantos, Cyprus (noaa-tree-5546), National Climatic Data Center, NESDIS, NOAA, US Department of Commerce.

Touchan, R., D. M. Meko, and A. Aloui, 2008. Precipitation reconstruction for northwestern Tunisia from tree rings. *Journal of Arid Environments* 72(10):1887–1896.

Touchan, R., G. Funkhouser, M. Hughes, and N. Erkan, 2005a. Standardized Precipitation Index reconstructed from Turkish tree-ring widths. *Climatic Change* 72(3):339–353.

Touchan, R., Ü. Akkemik, M. K. Hughes, and N. Erkan, 2007. May-June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings. *Quaternary Research* 68(2):196–202.

Touchan, R., E. Xoplaki, G. Funkhouser, J. Luterbacher, M. K. Hughes, N. Erkan, Ü. Akkemik, and J. Stephan, 2005b. Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. *Climate Dynamics* 25(1):75–98.

Vidaković, M., 1991. *Conifers: Morphology and Variation*. Grafički zavod Hrvatske, Zagreb.

Wigley, T. M. L., K. R. Briffa, and P. D. Jones, 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology* 23:201–213.

Received 10 May 2011; accepted 15 October 2011.

2.2 323 LET DOLGA REKONSTRUKCIJA SUŠE ZA JZ OBMOČJE ROMUNIJE, OSNOVANA NA ŠIRINI BRANIK ČRNEGA BORA (*PINUS NIGRA* ARNOLD).

Levanič T., Popa I., Poljanšek S., Nechita C. 2012. A 323–year long reconstruction of drought for SW Romania based on black pine (*Pinus nigra* Arnold) tree-ring width. International Journal of Biometeorology : (v tisku).

Povišanje temperature in nižanje količine padavin sta največji prihodnji grožnji stabilnemu gospodarjenju z ekosistemu v Romuniji. Za potrebe razumevanja odziva ekosistema in širših socialnih posledic okoljskih sprememb smo izdelali 396 let (1615-2010) dolgo kronologijo širin branik (TRW) vrste *Pinus nigra* var. *banatica* (Georg. et Ion.) s klimatskih signalom suše. Izračunali smo statistično povezavo med širinami branik in dvema vremenskima parametroma; mesečno količino padavin (PP) in standardiziran padavinski indeks (SPI). PP in SPI korelirata statistično značilno s TRW (r = 0,54 in 0,58) in sta stabilna v času. Statistični testi, ki merijo natančnost in sposobnost napovedovanja modela, so vsi značilni. SPI je bil rekonstruiran nazaj do leta 1688, z identificiranimi značilno suhimi in mokrimi leti po metodi centilov. Z rekonstrukcijo smo odkrili dve do sedaj nepoznani značilno sušni leti v Romuniji- 1725 in 1782. Ti dve leti sta bili skoraj tako sušni kot leto 1946, znano kot leto »velike lakote«. Ker za omenjeni leti ni na voljo nobenih lokalnih zgodovinskih zapisov, smo rezultate primerjali s sosednjimi deželami in odkrili, da sta bili obe leti značilno sušni v širši regiji (Slovaška, Madžarska, Anatolija, Sirija in Turčija). Medtem je bilo obdobje 1800-1900 relativno zmerno, s samo dvema zmerno značilnima letoma, kar se tiče vremena. Obdobje 1900-2009 pa je bilo opazno zaradi visokega števila mokrih in sušnih ekstremov- identificirali smo pet mokrih in tri značilno suhe dogodke (eden izmed njih je bil v letu 1946).

Int J Biometeorol
DOI 10.1007/s00484-012-0596-9

ORIGINAL PAPER

A 323-year long reconstruction of drought for SW Romania based on black pine (*Pinus Nigra*) tree-ring widths

Tom Levanič · Ionel Popa · Simon Poljanšek · Constantin Nechita

Received: 15 May 2012 / Revised: 16 September 2012 / Accepted: 17 September 2012

Abstract Increase in temperature and decrease in precipitation pose a major future challenge for sustainable ecosystem management in Romania. To understand ecosystem response and the wider social consequences of environmental change, we constructed a 396-year long (1615–2010) drought sensitive tree-ring width chronology (TRW) of *Pinus nigra* var. *banatica* (Georg. et Ion.) growing on steep slopes and shallow organic soil. We established a statistical relationship between TRW and two meteorological parameters—monthly sum of precipitation (PP) and standardised precipitation index (SPI). PP and SPI correlate significantly with TRW (r=0.54 and 0.58) and are stable in time. Rigorous statistical tests, which measure the accuracy and prediction ability of the model, were all significant. SPI was eventually reconstructed back to 1688, with extreme dry and wet years identified using the percentile method. By means of reconstruction, we identified two so far unknown extremely dry years in Romania—1725 and 1782. Those 2 years are almost as dry as 1946, which was known as the "year of great famine." Since no historical documents for these 2 years were available in local archives, we compared the results with those from neighbouring countries and discovered that both years were extremely dry in the wider region (Slovakia, Hungary, Anatolia, Syria, and Turkey). While the 1800–1900 period was relatively mild, with only two moderately extreme years as far as weather is concerned, the 1900–2009 period was highly salient owing to the very high number of wet and dry extremes—five extremely wet and three extremely dry events (one of them in 1946) were identified.

Keywords Dendroclimatology · Standardised precipitation index · Summer drought reconstruction · Domogled National Park · Climate change

T. Levanič (✉) · S. Poljanšek
Slovenian Forestry Institute,
Večna pot 2,
1000 Ljubljana, Slovenia
e-mail: tom.levanic@gozdis.si

I. Popa · C. Nechita
Forest Research and Management Institute,
Calea Bucovinei 73bis,
Campulung Moldovenesc 725100, Romania

C. Nechita
Faculty of Forestry, "Ştefan cel Mare" University of Suceava,
Suceava 72000, Romania

Introduction

An increase in temperature and decrease in precipitation, forecast by various climate change scenarios for the southern part of Romania, constitute one of the main challenges for sustainable forest ecosystem management in Romania (IPCC 2007). Knowledge of past precipitation dynamics and, more specifically, of past frequencies and intensity of drought in southern Romania has yielded new information on the history of the paleoclimate in the Balkans and, in particular, of what we can expect in the future (Busuioc et al. 2007; Manea et al. 2005).

In contrast to Western and Northern Europe, where paleoclimatic investigations provide a good and reliable picture of temperature and precipitation dynamics in the last two millennia (Pauling et al. 2006; Büntgen et al. 2011), only limited research has been carried out in relation to Eastern Europe and the Balkan regions. Most studies have focused on temperature reconstructions (Popa and Kern 2009; Büntgen et al. 2007) and few on precipitation (Kern et al. 2009; Büntgen et al. 2011; Büntgen et al. 2010). Some climate-growth studies in this region have focused on a more complex response of trees to temperature and precipitation

Published online: 08 October 2012

(Panayotov et al. 2010; Panayotov and Yurukov 2007) or have explored the potential of trees to identify extreme climate conditions (Panayotov et al. 2011). Reconstruction of drought indices (such as the standardised precipitation index [SPI] or Palmer drought severity index [PDSI]) is even rarer (Esper et al. 2007; Nicault et al. 2008; Touchan et al. 2005a) than temperature or precipitation reconstruction, although drought indices can give a better insight into a tree's response than temperature or precipitation data alone. In contrast to PDSI (Palmer 1965), which takes into account a complex pool of different meteorological variables, such as monthly precipitation, potential evapotranspiration and various soil parameters, data which are sometimes non-existent in certain parts of the world (at least on an extended time scale), SPI is based on monthly precipitation data only (McKee et al. 1993). This makes calculations easier and it can also be applied in parts of the world with limited access to, or non-existent, meteorological data necessary to calculate more complex drought indices.

The natural distribution area of black pine (*Pinus nigra*) is SE Spain, Italy, France, Corsica, the Balkan Peninsula and Turkey (Isajev et al. 2004). Black pine is a light demanding species, growing on exposed locations dispersed within the distribution area, rarely forming bigger enclosed populations. This results in huge genetic diversity and the formation of different subspecies and varieties (Isajev et al. 2004). In Romania, the natural distribution area is in the southwestern part, in the Banat region, where *Pinus nigra* var. *banatica* (Georg. et Ion.) grows on extreme sites. The Banat region also delineates the north-eastern boundary of natural distribution of *P. nigra* and is the only region of Romania in which *Pinus nigra* grows naturally. Sites on which the studied species is at the margin of its natural distribution are particularly important in providing information on the plasticity of the species, which is crucial for understanding the survival strategies of forests and forest trees with respect to different changing environmental factors (drought, steep slopes and shallow soils).

Black pine has been the focus of many studies dealing with growth dynamics in relation to climate in the western and central part of the distribution area (Strumia et al. 1997; Leal et al. 2008; Martín-Benito et al. 2010; Linares and Tíscar 2010; Martín-Benito et al. 2008; Lebourgeois et al. 2011), with much less attention given to the eastern distribution boundary of this species.

This study is the first tree-ring based precipitation and SPI reconstruction, which also identifies dry and wet periods for southern Romania over the past three centuries. In order to achieve these two major goals, it was necessary to construct a drought sensitive tree-ring width chronology, to identify the main driving growth factors of *Pinus nigra* var. *banatica* (Georg. et Ion.) from the Banat area and to identify the impact of extreme drought on tree growth. This study is additionally important because it was carried out on the only natural *Pinus nigra* var. *banatica* (Georg. et Ion.) site in Romania, which is also the eastern boundary of this species' natural distribution. The knowledge gained will also be important for the sustainable evolution of fragile black pine ecosystems in Romania.

Materials and methods

Site description

The study area is located within the Banat region in southwest Romania, specifically in Domogled National Park (N44°52′, E 22°24′) (Fig. 1). The studied *P. nigra* site is the only natural forest population of black pine in Romania, situated on the southern slope of the Cerna Valley near Mt. Domogled. The altitude of the sampling site varies between 800 and 1,100 ma.s.l., on a steep slope (over 30 °C). The slope is characterized by significant vertical fragmentation, with many limestone cliffs (Patroescu et al. 2008). The base vegetation on the site is black pine (*Pinus nigra* var. *banatica* [Georg. et Ion.]), *Carpinus orientalis*, *Corylus colurna*, various shrubs (such as *Sorbus borbasi*) and grasses. The soil at the study location is shallow, organic, on limestone and dolomite bedrock. The site is affected by frequent fires, but the thick bark of *P. nigra* prevents major injury or death being inflicted on these trees. Only if the fire is severe do the older trees die (as was the case in 2000, when a large fire destroyed more than 90 ha of the park).

The climate of the studied region (Fig. 2) is continental with a sub-Mediterranean influence. In general, the winters are cold (down to −30 °C, average −4.8 °C in January), while summers are hot, the hottest month being July, with 26.5 °C average. The amount of precipitation is the highest in May and June (altogether 168.6 mm), the driest months are July, August and September, with just 162.8 mm in this particular period. The total annual amount of precipitation is not very high—only 629.6 mm on average.

Tree-ring chronology development

Old, dominant or co-dominant trees with healthy trunks and no signs of resin collection were selected for sampling. Two cores from opposite sides were taken from each tree at breast height (1.3 m) and perpendicular to the slope to avoid compression wood. On extreme terrain, we took only one core per tree, or the core was taken at a greater height than normal (i.e., 1.5–2 m). Altogether, 45 trees were sampled and 83 cores collected. Cores were air-dried and glued onto wooden holders, and sanded with progressively finer sandpaper until a highly polished surface was achieved (Stokes and Smiley 1996). The collected samples were processed in two laboratories in Romania and Slovenia. Samples were

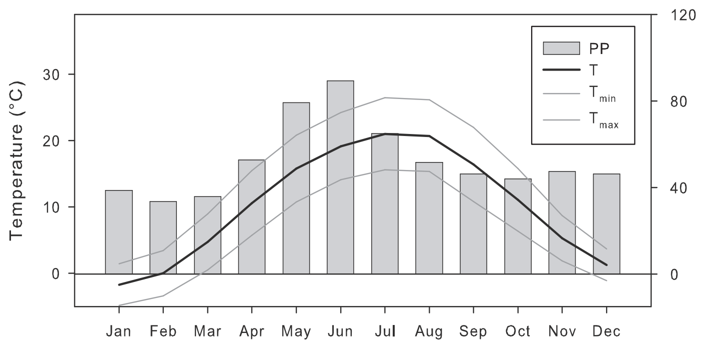
Fig. 1 Location of the research plot in Romania (*white dot*); *black star* indicates Romania's capital Bucharest

measured using LINTAB with the TsapWin system (Romania) and scanned using the ATRICS system (Levanič 2007), as well as measured using WinDENDRO software (Slovenia). In both cases, the width of each annual ring was measured to the nearest 0.01 mm.

Chronologies were cross dated with PAST-4™ software (www.sciem.com) using both visual on-screen comparisons and statistical parameters, such as the t-value after Baillie and Pilcher (t_{BP}) (Baillie and Pilcher 1973) and Gleichläufigkeit coefficient (GLK%) (Eckstein and Bauch 1969). False and missing rings were counted across all tree-ring series per site and summed. Quality control was additionally applied using the COFECHA program to check for measurement errors (Holmes 1983). If necessary, measurements were repeated, re-checked, or removed from further processing if recognized as unusable. Certain trees were removed from the sample pool because of growth anomalies connected with resin collection in the past, a decayed inner part of the trunk, overgrown wounds or the occurrence of compression wood deep inside the trunk. Additionally, some trees were excluded owing to their very slow growth (impossible to measure tree-ring widths), or because we were unable to cross date them. After the exclusion of such trees, 37 or 82 % of all sampled trees were retained for analysis.

Individual tree-ring width (TRW) series were standardized to remove long-term trends (Cook 1985) and all basic

Fig. 2 Climate of the studied region. *Bars* delineate precipitation; the *thick black line* is average monthly temperature, while *thin grey lines* show minimum and maximum average monthly temperatures



statistical parameters of TRW were calculated using ARSTAN for Windows (version ARS41d_xp) (Cook and Holmes 1999). Each tree-ring width series was first power transformed to stabilize variance and then fitted with a cubic smoothing spline with a 50 % frequency response at 200 years 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 subtracted from the year's value of the fitted curve to obtain variance-stabilized residuals (Cook and Peters 1997). Index values were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike criterion and combined across all series using a biweight robust estimation of the mean to exclude the influence of outliers.

Three chronologies were produced in this way including a standard chronology, i.e., a biweight robust mean of all series included, a residual chronology containing a very strong common signal and statistically removed autocorrelation, and an ARS chronology with a pooled autoregression model (persistence) reincorporated into the residual chronology (Cook 1985; Cook et al. 1990). All three chronologies were tested against the climate data and that with the highest correlation was selected for the reconstruction.

Chronology confidence for climate reconstruction was assessed using two criteria—expressed population signal (EPS) and subsample signal strength (SSS) (Wigley et al. 1984). EPS is an absolute measure of chronology error that determines how well a chronology based on a limited number of trees represents the theoretical population chronology (Cook and Kairiukstis 1990). It is calculated from the between-tree correlation and the number of trees included in the calculation. EPS can have a value between 0 and 1 and values greater or equal to 0.85 are considered to be adequate to ensure that a chronology is suitable for climate reconstruction, although chronologies (or sections of them) with EPS just below the threshold can still be highly correlated with climate parameters and can be used in climate reconstruction, providing they are of good statistical quality (Cook and Kairiukstis 1990). As a second criterion, we used SSS to calculate the usable portion of the chronology for climate reconstruction and to define the maximum length of the potential climate reconstruction (Wigley et al. 1984; Briffa and Jones 1990). SSS is calculated from data on sample depth and the between-tree correlation. The same threshold as for EPS also applies for SSS (Briffa and Jones 1990).

Climate data

We used two sources of climate data—a local source from Baile Herculane meteorological station and a gridded CRU TS 3.1 temperature and precipitation dataset (Mitchell and Jones 2005). When comparing these two datasets, it was found that the local climate dataset, which contains only precipitation data, is short (from 1976 till 2008) and incomplete, with a lot of missing data. This makes the local dataset useless for climate reconstruction and, in particular, for calibration and verification of the model. Gridded data, on the other hand, are cross-checked, better documented and homogenised. We therefore opted for the CRU TS 3.1 dataset (acquired via http://climexp.knmi.nl/), which spans the 1901–2009 period and has a grid resolution of 0.5°× 0.5° (Mitchell and Jones 2005). In using gridded data, we were aware that gridded datasets are not as precise in some regions as in others, owing either to a relatively small number of meteorological stations included in the calculation of the gridded data or to the relatively short period of collecting meteorological data (New et al. 2002). The Balkan Peninsula is one such region, with a relatively low density of high quality meteorological data or the lengths of the available datasets are limited to the post World War II period. In the present case, the studied site is surrounded by four meteorological stations (Belgrade [SRB], Cluj [RO], Sibiu [RO] and Timisoara [RO]) with high quality, homogenised, long datasets (at least from 1888 to the present) that are included in the CRU TS 3.1 database, and with several meteorological stations with datasets from 1951 to the present that are also included in the CRU TS 3.1 database (van Oldenborgh 1999). In order to ensure that the CRU dataset does indeed depict the distribution and amount of precipitation of the studied region, we compared it to a short local precipitation dataset—the correlation was 0.71, high enough to confirm the similarity of the two datasets.

The standardized precipitation index (SPI) (McKee et al. 1993), calculated on the basis of the CRU climate dataset, was used to detect drought periods. SPI is a drought index that takes into account only precipitation and is less complex to calculate than the other widely used drought index, the Palmer drought severity index or PDSI (Palmer 1965). The main difference between the two indices is that SPI better describes drought events and shows more variability on a shorter time scale (less than 9 months) than PDSI. This makes SPI better for detecting short-term droughts than PDSI (Ceglar and Kajfež-Bogataj 2008). SPI was calculated for the 1902–2009 period; the year shorter time period compared to the full length of the meteorological data is because the calculation of SPI also takes into account monthly precipitation of the previous year. SPI is a measure of drought based on the probability of precipitation for a given time period. Its key feature is the flexibility to measure drought on different time scales, in our case we used 1, 3, 6, 12 and 24 months. From the physiological point of view, prolonged drought periods (months to years) can have a major impact on tree growth, and can even cause some tree species to die-off (for more information on tree response to drought see McDowell et al. 2008). SPI values are derived by comparing the total cumulative precipitation over a specific time interval with months having the average cumulative precipitation for that same time interval over the entire length of the record. For example, 3 months SPI for August takes into account cumulative precipitation for the last 3 months, including the analysed month—June, July and August—and, similarly, 6 months SPI for August takes into consideration the months from March to August. SPI values range from 2.00 and above (extremely wet) to −2.00 and less (extremely dry), with near normal conditions ranging from 0.99 to −0.99.

Climate reconstruction

We applied a bootstrapped Pearson's correlation coefficient to identify the dependency between the residual chronology and the monthly sum of precipitation for the 1901–2009 period; different combinations of seasonalized climate variables for precipitation were also correlated with the residual chronology. Additionally, the residual chronology was correlated with the SPI for 1, 3, 6, 12 and 24 months for the 1902–2009 period in order to test the influence of a prolonged lack of precipitation on tree-ring formation. The spatial strength and outreach of the correlation between residual tree-ring width chronology and monthly sum of precipitation was tested using Climate Explorer from KNMI (van Oldenborgh 1999).

To assess the accuracy of the model used for climate reconstruction, the measured data were split into two equally long datasets: calibration and verification periods (Fritts 1976). The procedure was then repeated with reversed periods. The reliability and prediction capacity of the linear model was tested using Pearson's correlation coefficient (r), mean squared error (MSE), reduction of error (RE) (Fritts 1976) and coefficient of efficiency statistics (CE) (Cook et al. 1994). All parameters were computed for both calibration and verification periods (National Research Council 2006). If RE and CE coefficients are above zero, then the relationship has a predictive value and the transfer function can be calculated and applied on the regional chronology until the year in which the EPS value decreases to below 0.85 (or for as many years as the degree of replication of the chronology allows).

Reconstruction of the climate was based on calibration and verification of the tree-ring width indices against known climate parameters, in our case precipitation and SPI, the latter introduced by McKee et al. (1993). A linear model was used to compute the relationship between residual chronology and climate data.

R statistical package (R Development Core Team 2009) was used for all statistics in the paper, except standardisation, for which ARSTAN was used. For specific climate-related calculations, R library *BootRes* (Zang 2009) was used.

Results

Chronology

We developed a 396-year long tree-ring width chronology for the only *P. nigra* natural stand in Romania (Fig. 3). The chronology is based on 37 trees; the time period covered by the individual tree-ring sequences is between 1615 and 2010. The average age of the analysed trees is 225 years, with a minimum of 148 and a maximum of 396 years. The mean tree-ring width in the raw chronology was 0.92±0.52 mm. The raw chronology has a high first order auto-correlation in the raw series (0.77±0.07), indicating that nutrient storage in the previous year has an important influence on the following year's growth. The mean sensitivity, a measure of the tree's response to annual changes in the environmental conditions, was 0.30 (0.24 and 0.39) for the raw chronology.

Between-tree correlation is an important measure in chronology construction. In our case, the average between-tree correlation was 0.45±0.20. The average correlation between individual chronologies and the site chronology was 0.63. The variance explained by the first principal component is 44.96 %, showing that a major part of the variability can be ascribed to one single factor (presumably climate). This was also confirmed by a high signal to noise ratio (SNR) of 23.03. Subsample signal strength (SSS), the value that defines the maximum length of potential reconstruction by calculating the year in which the EPS value exceeds a certain threshold, whereby 0.85 is widely accepted (Wigley et al. 1984), exceeded the threshold value of 0.85 in the year 1758 and 0.80 in the year 1688. This indicates that the portion of the chronology prior to 1688 needs to be upgraded with more cores from very old trees (or buildings).

Comparison of our chronology with other *P. nigra* chronologies from neighbouring regions showed that it compares particularly well with *P. nigra* chronologies from Bosnia and Herzegovina and Montenegro (t_{BP}> 8.0), moderately well with chronologies from Bulgaria, Albania, N. Greece and Austria (t_{BP}>5.0), and non-significantly with chronologies from S. Greece, S. Turkey and Italy (t_{BP}<4.0). Although we only sampled on one site, we achieve a good regional signal and good regional agreement with *P. nigra* chronologies from the wider region, in particular from the western part of the Balkan Peninsula.

The quality and spatial strength of the climate signal of the chronology, tested using spatial correlation in KNMI Climate Explorer (van Oldenborgh 1999), showed that the residual chronology correlates best with July precipitation ($0.5>r>0.6$, $p<0.05$) in the region covering the south-western part of Romania, north-western part of Bulgaria

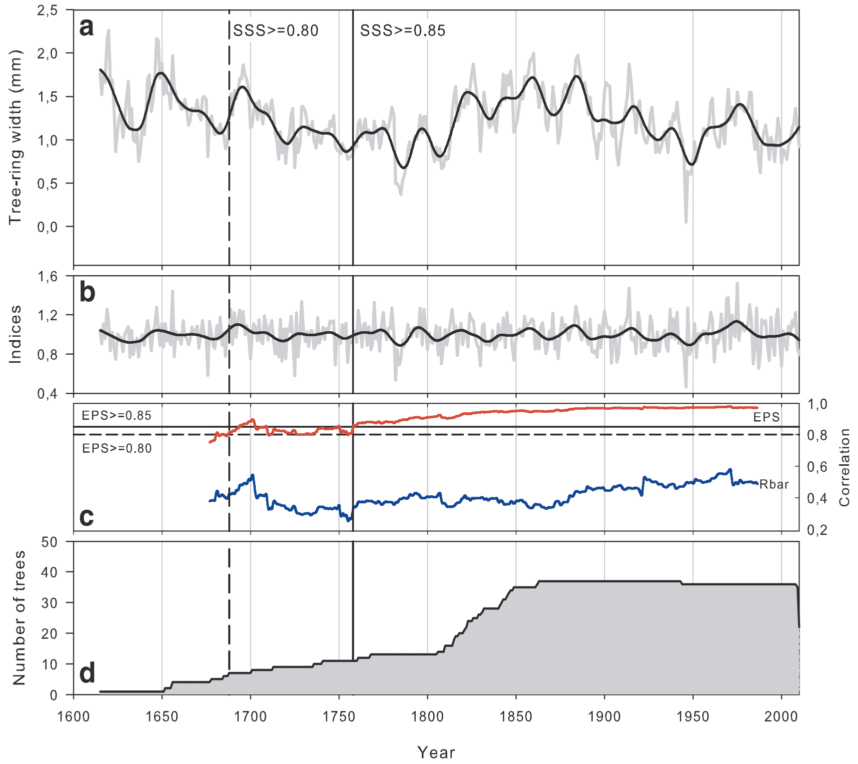


Fig. 3 Raw (**a**) and residual (**b**) chronology for *P. nigra* from Baile Herculane with expressed population signal (EPS) and Rbar (**c**) and sample depth (**d**). The *solid vertical black line* indicates part of the chronology where subsample signal strength (SSS)>0.85, while dashed black vertical line depicts part of the chronology where SSS>0.80. Low frequency variability of the raw and residual chronology is marked with the spline (*thick black line*)

and eastern part of Serbia, which corresponds to the vicinity of the sampling location (Fig. 4). A slightly lower spatial correlation (0.4>r>0.5, p<0.05) can be observed in a significant part of the Balkan Peninsula. This makes our chronology a good proxy for large-scale climate reconstruction, especially in combination with newly developed *P. nigra* chronologies from the Balkan Peninsula (Poljanšek et al. 2012).

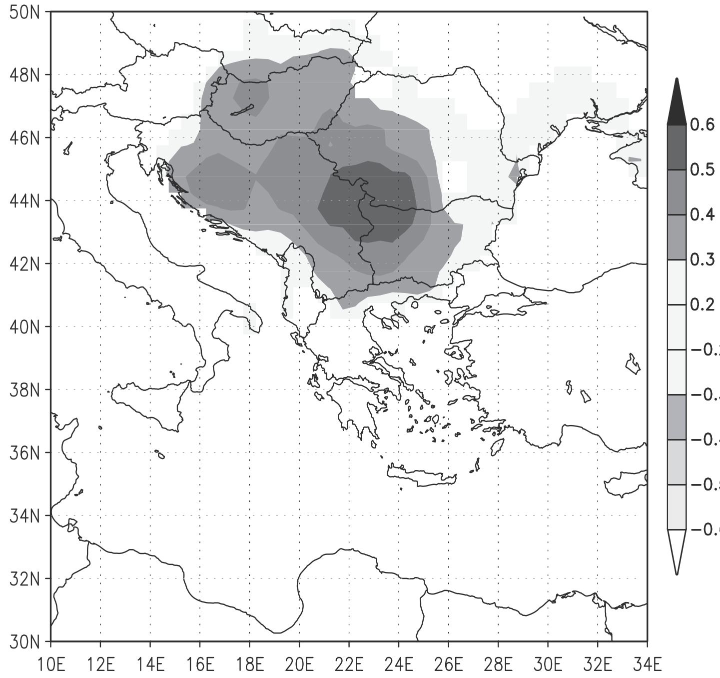


Fig. 4 Spatial correlation between tree-ring indices (residual chronology) and gridded CRU TS 3.1 July precipitation (significance level is 95 %) for the 1901–2009 period

Response function development and temporal stability of the signal

Initial exploratory data analysis of the CRU TS 3.1 dataset confirmed that there was no significant temporal autocorrelation in any of the precipitation variables. Using bootstrapped correlation analysis, we identified July precipitation as the most important factor influencing *P. nigra* growth at the studied site (r=0.54, p< 0.01). Correlation analysis for the period spanning from the previous September to the current September showed that July is almost twice as important for tree-ring formation as the next most significant month, June. Since the site is very extreme in respect to the lack of precipitation, it plays an important role in tree growth, so above average precipitation in July promotes tree growth and significantly affects tree-ring width (Fig. 5).

Additionally, we calculated the SPI, a measure of the influence of drought on tree growth, and correlated it with tree-ring indices (Fig. 5). SPI takes into account lack of precipitation in the user-defined period; in our case, we used a 3-month SPI, which takes into account precipitation in the previous two and the current months. The relationship between residual chronology and 3-month August SPI gave a high correlation value —r=0.58 (p<0.01), which is even higher than in the case of precipitation. It is worth mentioning that SPI takes into account a longer time period than the sum of monthly precipitation (3 vs. 1 month) and as such it better reflects the influence of the lack of summer precipitation on tree growth, so it better depicts the most sensitive period for the formation of tree rings.

The temporal stability of the correlation between tree-ring indices, July precipitation and 3-month August SPI was tested using a 30-year running correlation for the 1902–2009 period (Fig. 6). The running correlation varies between 0.4 and 0.7 and never falls below the significance level for the 30-year running correlation (r≥0.349, p<0.05). Between 1903 and 1950, there is a slight decrease in the relationship, from 0.6 down to 0.4, and an increase after 1965 until 2009. Since these oscillations are not particularly large, it can be concluded that the relationship between residual chronology and precipitation is stable in time and that it reflects a stable relationship among July precipitation, 3-month August SPI and tree growth.

Reconstruction of 3-month August SPI, and identification of extremely dry and wet years

Response function analysis identified July precipitation and 3-month August SPI as the most important factors for climate prediction and climate reconstruction. July precipitation explains 29 %, and 3-month August SPI 34 % of the total variance. The quality of both models was tested using a split-sample calibration and verification procedure. The 1902–2009 period was split into two equally long periods for calibration and verification—1902–1955 and 1956–2009. RE, CE and MSE parameters were calculated to validate the predictive power of the model (Table 1). All parameters were also calculated with calibration and verification periods reversed.

Cross-validation indicated that both models performed well in the estimated July precipitation and 3-month August SPI. Both models also indicated a stable relationship over the calibration and verification period of the available measured data. Based on this, we used the entire calibration period (1902 to 2009) to develop a linear model for the reconstruction. However, since both models take into account precipitation and the 3-month August SPI model performs better with respect to higher explained variability of the model and combined effect over 3 months (June-August), we decided to do the final reconstruction only for

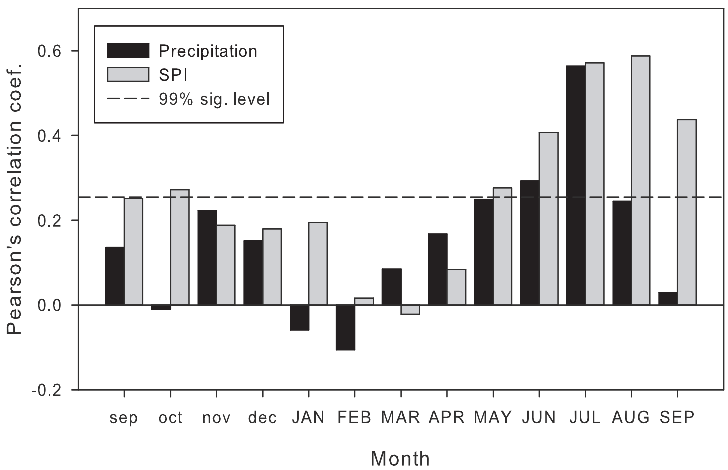


Fig. 5 Correlation between tree-ring indices and precipitation (*black bars*) and 3-month standardised precipitation index (SPI) (*grey bars*) from previous to current September. *Dashed line* indicates 99 % significance level

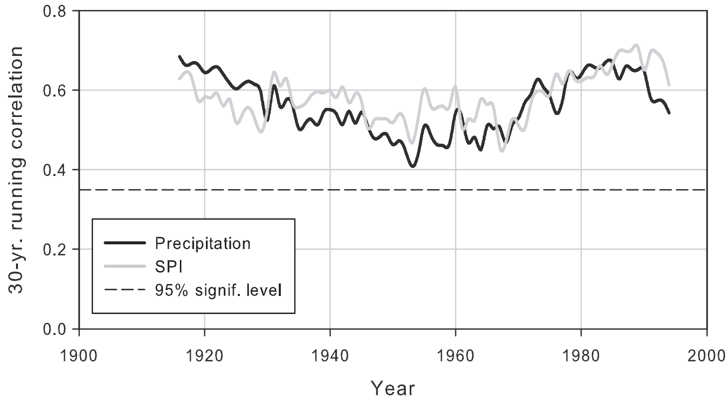


Fig. 6 Temporal stability of the correlation between July precipitation, 3-month August standardised precipitation index (SPI) signal and residual chronology. 30-year running mean was used for the analysis; *dashed line* depicts 95 % significance threshold of the correlation coefficient

the 3-month August SPI. The linear model used for the reconstruction of 3-month August SPI is shown in Eq. 1.

$$Aug.SPI = -3.1637 + 3.1598 * RES \quad (1)$$

$$\left(r^2{}_{adj} = 0.34; p < 0.000\right)$$

Reconstructed values coincide well with the calculated values (Fig. 7). Minimum and maximum of the reconstructed 3-month August SPI are between −1.70 and 1.63, with the average being the same as for measured data, and standard deviation being smaller than for measured data (±0.58). In addition to good performance of the model in average years, the reconstructed 3-month August SPI also performs well in extremely dry and wet years. As an example, 1946 was extremely dry, with a lengthy drought. Trees responded with very narrow or even missing rings, and the model correctly predicted very dry conditions in the June–August period. In extremely wet years (such as 1969), trees did not respond so intensively to the above average amounts of precipitation in the June–August period. It seems that they reach their response limit to precipitation sooner and cannot take full advantage of the above average amount of precipitation, or there was some other environmental factor that limited their growth.

The model fits well in extremely dry (such as 1946 and 2000) and wet years (such as 1970 and 1975). Since the calculation of SPI takes into account a longer period, in our case 3 months, this model also better reflects climatic conditions in the growing season than the model for July precipitation.

Based on the good agreement between calculated 3-month SPI for August and tree-ring indices, the reconstruction can be expanded into the past (Fig. 8). Since the length of the chronology with SSS>0.85 is 253 years, the 3-month August SPI index can be reconstructed for the 1758–2010 period. If the SSS threshold is lowered to 0.80, the part of the chronology suitable for climate reconstruction can additionally be extended to 323 years (1688–2010 period).

An important question in climate reconstruction is how well extreme events can be reconstructed. We used a similar approach to that of Touchan et al. (2008), in which extreme events were identified with percentiles. We set the threshold values lower than Touchan because climate in the studied region was less extreme than in Tunisia, such that, extremely wet events were defined as those with values above (or equal to) the 83rd percentile, while values below (or equal to) the 17th percentile were identified as extremely dry events. For the 3-month August SPI reconstruction, the 83rd percentile corresponds to 0.86, while the 17th percentile corresponds to

Table 1 Calibration and verification of the linear model for the reconstruction of July precipitation and 3-month August standardised precipitation index (SPI)

Variable	July precipitation		3-months August SPI	
	cal. 1956–2009 ver. 1902-1955	cal. 1902–1955 ver. 1956-2009	cal. 1956–2009 ver. 1902-1955	cal. 1902–1955 ver. 1956-2009
RE	0.29	0.27	0.28	0.36
CE	0.29	0.27	0.28	0.36
MSE	690.98	646.72	0.68	0.66
r_{cal}^2	0.27	0.31	0.36	0.30
r_{ver}^2	0.31	0.27	0.30	0.36
r_{whole}	0.53		0.58	

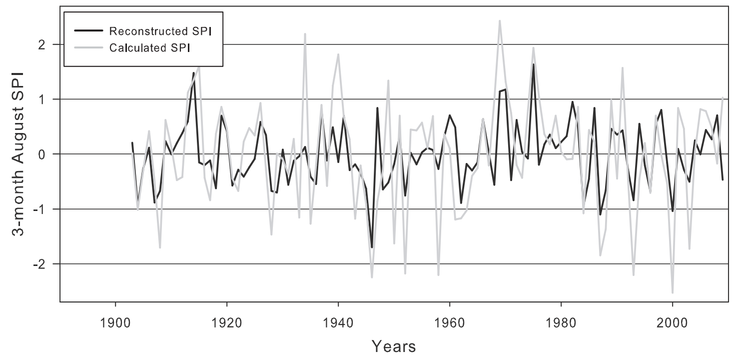


Fig. 7 Comparison of measured (*grey*) and reconstructed (*black*) 3-month August standardised precipitation index (SPI) in the period of available precipitation data for the calculation of 3-month SPI (1901–2009)

−0.98. With the 3-month August SPI model, we reconstructed eight out of 19 extreme summer events in the period of the existing meteorological data (1901–2009); three out of eight were extremely dry and five out eight extremely wet summer periods.

The strength of SPI is that it takes into account a longer period for calculation of the lack of precipitation, and thus provides a more reliable picture of water availability in the growing period. With the 3-month August SPI model, we reconstructed 16 extreme events in the period 1688–2010—eight wet and eight dry. The 1900–2009 period is characterized by the highest number of extreme events; five wet (1914, 1969, 1970, 1975 and 1982) and three dry (1946, 1987 and 2000) events were reconstructed. The year 1946 was the driest year in our 323-year long reconstruction; while another 2 years were less dry but still very dry. There were five wet periods in the 1900–2009 period, two of them (1914 and 1975) were extremely wet and the remaining three very wet.

The 1800–1900 period was almost without extreme years, since we reconstructed only two of them, one wet (1884) and one dry (1830), but even these two extreme years were only at the limit of acceptance for being extreme. The 1700–1800 period was comparable to 1900–2009, with six extreme years, two wet (1729 and 1770) and four dry years (1725, 1748, 1782 and 1784). Identified wet years

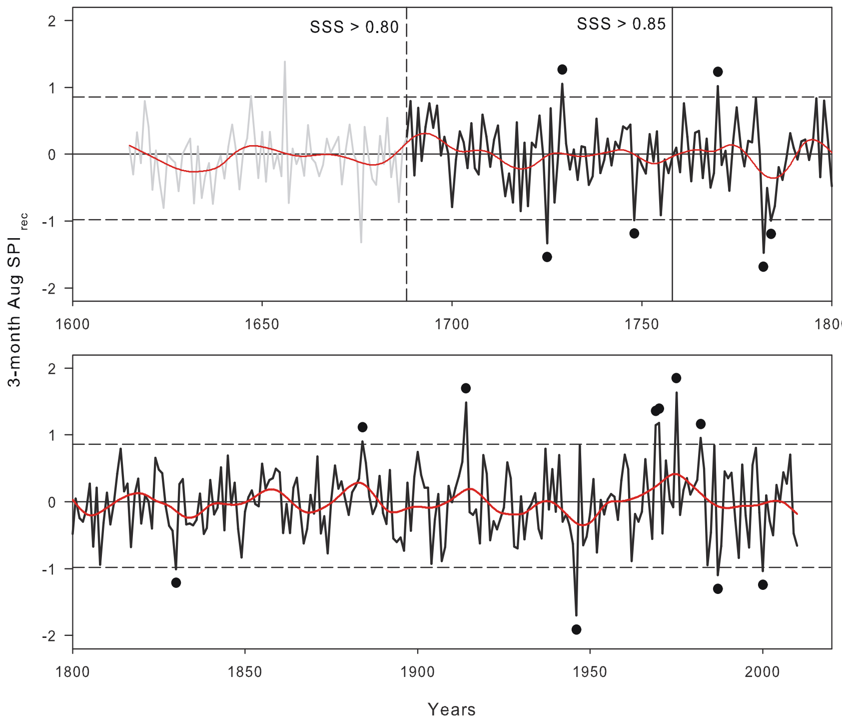


Fig. 8 Reconstructed 3-month August standardised precipitation index (SPI) for the 1688–2010 period. The period before 1688 (*grey line*) is not reliable due to too small subsample signal strength (SSS); the period between 1688 and 1757 has SSS>0.80, its start is marked with a *vertical dashed line*. This period can be potentially used for reconstruction; the period after 1757, the start of which is marked with a *vertical solid line*, has SSS>0.85, and reconstruction is therefore meaningful. The *horizontal dashed line* depicts the 15th and 85th percentiles, while values above/below the *dashed line* correspond to extremely wet/dry years (also marked with *black circles*)

were not particularly extreme; they were merely above the threshold value. Both two reconstructed dry years—1725 and 1782—were extremely dry, 1782 being the second and 1725 the third driest year in our reconstruction.

Discussion

The *P. nigra* trees used in this study were growing on an extreme site, where drought and water availability are the main limiting factors for their growth. This ecological limitation of growth is expressed by the high positive correlation of the index chronology with precipitation from the growth period May to July. A similar pattern is shown by the SPI index for the summer period. A similar response to the late spring–summer precipitation deficit was observed in the Mediterranean basin for *P. nigra* (Martín-Benito et al. 2010; Lebourgeois et al. 2011; Touchan et al. 2010), Central Europe (Leal et al. 2008) and the western Balkans (Panayotov et al. 2010; Panayotov et al. 2011; Kern and Popa 2007; Popa and Kern 2009). The water stress is accentuated by the shallow soil, with low water capacity, specific to the sampling site and natural vegetation conditions of black pine in Romania.

Reconstruction of the 3-month August SPI three centuries back in time gives an opportunity to identify potentially dry and wet summers and compare their extremeness with known extreme years in the meteorological dataset, as well as with the results of other reconstructions in the wider area. Our reconstruction of the 3-month August SPI identified 16 years with values above or below the threshold (Fig. 8); eight of them were identified as wet and eight as dry years. Of those 16 extreme years, two were identified as extremely wet (1914 and 1975) and three as extremely dry (1725, 1782 and 1946). While the extremely dry 1946 is widely known in Romanian history as a year of greatly reduced precipitation, as well as extreme poverty and hunger all over Romania (Busuioc et al. 2007), no documentary sources are available for the years 1725 and 1782, which were similarly extreme. Solely on the basis of the extremeness of the reconstructed values, it can be concluded that the years 1725 and 1782 were extremely dry and that poverty and famine probably raged in the country at that time, too. Although Romanian sources do not provide any evidence as far as these two extreme years are concerned, we found reports describing 1725 as "the year with major drought in Anatolia and Syria" (Touchan et al. 2007) and 1782 as "the year with drought in the Western Black Sea region of Turkey" (Akkemik et al. 2005), as well as "the year with extremely low water in the Danube river due to lengthy drought" (Büntgen et al. 2010).

The last three centuries have been fairly varied in terms of the frequency of dry and wet extreme years. The highest concentration of wet and dry years took place between 1900 and 2000—in this period, we identified five wet and three dry summer periods (Fig. 8). In contrast, the period between 1800 and 1900 had almost no extreme summers, since only one wet and one dry year was reconstructed. The 1700–1800 period was more extreme than 1800–1900 but less than 1900–2000. For the 1700–1800 period, we identified two wet and four dry events, with two of them belonging to the group of most extreme dry years (1725 and 1782). They were as dry as the extreme year of 1946.

Comparison of medium frequency variation in our reconstruction with temperature, precipitation or drought reconstructions from neighbouring regions shows similarities in the parts in which dry (or wet) events seem to have affected the wider region and to have lasted longer than a single year. Such exceptional periods, with extended lack of precipitation, were 1781–1784 reported by Büntgen et al. (2010) for Slovakia and 1946–1949 reported for Slovakia (Büntgen et al. 2010), Bulgaria (Panayotov et al. 2010), Hungary (Kiss 2009) and Bosnia and Herzegovina (Poljanšek, submitted). We also identified periods comparable with other reconstructions in terms of above average amounts of precipitation—1881–1885 (Akkemik et al. 2005), 1912–1914 (Büntgen et al. 2010) and 1969–1975 (Popa and Kern 2009; Panayotov et al. 2010; Touchan et al. 2005b).

In view of the prediction of a severe decrease in precipitation in southern and western Romania according to present climate change scenarios (Manea et al. 2005), knowledge of the occurrence of past droughts (intensity and frequency) is undoubtedly greatly needed. A long-term, precipitation sensitive chronology is one of the most precise and reliable sources of information in a region with relatively short instrumental climate data. The *P. nigra* tree-ring index chronology from the Banat region proved to be a good and reliable proxy for precipitation in southwest Romania. This is also supported by the temporal stability of the correlation between precipitation and tree-ring width index. This precipitation reconstruction primarily shows one- to 2-year droughts and not prolonged periods of drought.

Our reconstruction shows that the number of extreme events fluctuates over time. The number of extreme events in the 18th century was similar to that in the 20th century. However, the number of extreme events in the 20th century has been increasing, with 1946 being the driest year in our reconstruction. According to climate prediction models, southern and eastern parts are the most vulnerable regions of Romania to drought (Barbu and Popa 2004). The years 2000 and 2003 were considered to be the driest years in the last 60 years in the southern part or Romania, with major implication for agriculture and water management (Croitoru et al. 2011). The year 2012 also seems to be a very dry year, based on the precipitation data until August 2012. The frequency of drought events has increased in recent decades from 33 % (1942–1953) to 80 % (1982–1990). The longest hydrological drought for southern Romania was recorded during 1980–1995 (Stefan et al. 2004). Two moderate–extreme drought periods were distinguished recently for the southwest region (near our study site), namely, 1992–1995 and 2000–2003 (Ghioca 2009). If the number of extreme drought events increases in the future, this will have a significant impact on forests, biodiversity and society in Romania. According to governmental documents, Romania is aware of the problems with water supply and measures are being taken to mitigate the consequences of the increasing number of drought events (Barbu 2005). However, if the extent and severity of drought increases in the future, this will inevitably lead to increased plant mortality and significant changes in ecosystems and Romanian society.

Acknowledgments This work was supported by the research project PN-II-RU-TE-2011-3-0040 in Romania, the program and research group "Forest Biology, Ecology and Technology" P4-0107 of the Slovenian Forestry Institute, a research grant by the Slovenian Research Agency (S. Poljanšek) and bilateral cooperation between Slovenia and Romania funded by the Slovenian Research Agency and National Authority for Scientific Research of Romania (ANCS). Fieldwork was carried out in Domogled-Valea Cernei National Park, and we are most grateful to its authorities for allowing us to implement tree sampling in it, as well as providing us with guides in the Park. We are grateful to Martin Cregeen for improving the English language.

References

Akkemik Ü, Dağdeviren N, Aras A (2005) A preliminary reconstruction (A.D. 1635–2000) of spring precipitation using oak tree rings in the western Black Sea region of Turkey. Int J Biometeorol 49 (5):297–302. doi:10.1007/s00484-004-0249-8

Baillie MGL, Pilcher JR (1973) A simple cross-dating programme for tree-ring research. Tree-Ring Bull 33:7–14

Barbu S (2005) National strategy on climate change of Romania 2005–2007. Romanian Ministry of Environment and Water Management, Bucharest

Barbu I, Popa I (2004) Monitoringul secetei în pădurile din România (Drought monitoring in the forests of Romania). Editura Tehnică Silvică, Campulung Moldovenesc

Briffa KR, Jones PD (1990) Basic chronology statistics and assessment. In: Cook ER, Kairiukstis LA (eds) Methods of dendrochronology: Applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, pp 137–152

Büntgen U, Frank DC, Kaczka RJ, Verstege A, Zwijacz-Kozica T, Esper J (2007) Growth responses to climate in a multi-species tree-ring network in the Western Carpathian Tatra Mountains, Poland and Slovakia. Tree Physiol 27(5):689–702. doi:10.1093/treephys/27.5.689

Büntgen U, Brázdil R, Frank D, Esper J (2010) Three centuries of Slovakian drought dynamics. Clim Dyn 35(2):315–329. doi:10.1007/s00382-009-0563-2

Büntgen U, Brázdil R, Dobrovolný P, Trnka M, Kyncl T (2011) Five centuries of Southern Moravian drought variations revealed from living and historic tree rings. Theor Appl Climatol 105(1):167–180. doi:10.1007/s00704-010-0381-9

Busuioc A, Dumitrescu A, Soare E, Orzan A (2007) Summer anomalies in 2007 in the context of extremely hot and dry summers in Romania. Rom J Meteorol 9(1–2):1–17

Ceglar A, Kajfež-Bogataj L (2008) Obravnava meteorološke suše z različnimi indikatorji (Analysis of meteorological drought with different indicators). Acta Agric Slov 91(2):407–425

Cook ER (1985) Time series analysis approach to tree ring standardization. Dissertation, University of Arizona, Tucson

Cook ER, Briffa KR (1990) A comparison of some tree-ring standardization methods. In: Cook ER, Kairiukstis LA (eds) Methods of dendrochronology: Applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, pp 153–162

Cook ER, Holmes RL (1999) Program ARSTAN—chronology development with statistical analysis (users manual for program ARSTAN). Report, Laboratory of Tree-Ring Research, University of Arizona, Tucson

Cook ER, Kairiukstis LA (eds) (1990) Methods of dendrochronology: Applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht

Cook ER, Peters K (1997) Calculating unbiased tree-ring indices for the study of climatic and environmental change. Holocene 7 (3):361–370

Cook ER, Briffa K, Shiyatov S, Mazepa V (1990) Tree-ring standardization and growth trend estimation. In: Cook ER, Kairiukstis LA (eds) Methods of dendrochronology: applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, pp 104–162

Cook ER, Briffa KR, Jones PD (1994) Spatial regression methods in dendroclimatology: a review and comparison of two techniques. Int J Climatol 14:379–402

Croitoru A, Toma F, Dragota C (2011) Meteorological drought in central Romanian plain (between Olt and Arges rivers). Case study: year 2000. Riscuri Si Catastrofe 9:113–120

Eckstein D, Bauch J (1969) Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. Forstwissenschaftliches Centralblatt 88(4):230–250

Esper J, Frank D, Büntgen U, Verstege A, Luterbacher J, Xoplaki E (2007) Long-term drought severity variations in Morocco. Geophys Res Lett 34(17):L17702. doi:10.1029/2007gl030844

Fritts HC (1976) Tree rings and climate. Academic Press, London

Ghioca M (2009) Drought monitoring using self-calibrating Palmer's indices in the southwest of Romania. Rom Rep Phys 61:151–164

Holmes RL (1983) Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull 43:69–78

IPCC (2007) In: Solomon S, Qin D, Manning M et al (eds) Climate Change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, p 996

Isajev V, Fady B, Semerci H, Andonovski V (2004) EUFORGEN technical guidelines for genetic conservation and use for European black pine (*Pinus nigra*). Report, international plant genetic resource institute. IPGRI Esco, Rome

Kern Z, Popa I (2007) Climate–growth relationship of tree species from a mixed stand of Apuseni Mts., Romania. Dendrochronologia 24(2–3):109–115. doi:10.1016/j.dendro.2006.10.006

Kern Z, Popa I, Varga Z, Széles É (2009) Degraded temperature sensitivity of a stone pine chronology explained by dendrochemical evidences. Dendrochronologia 27(2):121–128. doi:10.1016/j.dendro.2009.06.005

Kiss A (2009) Historical climatology in Hungary: role of documentary evidence in the study of past climates and hydrometeorological extremes. Időjárás 113(4):315–339

Leal S, Eamus D, Grabner M, Wimmer R, Cherubini P (2008) Tree rings of Pinus nigra from the Vienna basin region (Austria) show evidence of change in climatic sensitivity in the late 20th century. Can J For Res 38(4):744–759. doi:10.1139/x07-189

Lebourgeois F, Mérian P, Courdier F, Ladier J, Dreyfus P (2012) Instability of climate signal in tree-ring width in Mediterranean mountains: a multi-species analysis. Trees 26(3):715. doi:10.1007/s00468-011-0638-7

Levanič T (2007) ATRICS - A new system for image acquisition in dendrochronology. Tree-Ring Research 63 (2):117–122

Linares JC, Tíscar PA (2010) Climate change impacts and vulnerability of the southern populations of Pinus nigra subsp. salzmannii. Tree Physiol 30(7):795–806. doi:10.1093/treephys/tpq052

Manea F, Trusca V, Alecu M, Draghici I, Popescu A, Vasile C, Busuioc A, Andrei L (2005) Romania's third national communication on climate change under the United Nations framework convention on climate change. Ministry of Environment and Water Management, Bucharest

Martín-Benito D, Cherubini P, del Río M, Cañellas I (2008) Growth response to climate and drought in *Pinus nigra* Arn. trees of different crown classes. Trees 22(3):363–373. doi:10.1007/s00468-007-0191-6

Martín-Benito D, del Río M, Cañellas I (2010) Black pine (*Pinus nigra* Arn.) growth divergence along a latitudinal gradient in Western Mediterranean mountains. Ann For Sci 67(4):401

McDowell NG, Pockman WT, Craig A, Breshears DD, Cobb N, Kolb T, Plaut J, Sperry J, West A, Williams D, Yepez EA (2008) Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytol 178(4):719–739

McKee TB, Doesken NJ, Kliest J (1993) The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 17–22. American Meteorological Society, Boston, MA, USA, pp 179–184

Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Climatol 25(6):693–712. doi:10.1002/joc.1181

National Research Council (2006) Surface temperature reconstructions for the last 2,000 years. National Academies Press, Washington

New M, Lister D, Hulme M, Makin I (2002) A high-resolution data set of surface climate over the global land areas. Clim Res 21:1–25

Nicault A, Alleaume S, Brewer S, Carrer M, Nola P, Guiot J (2008) Mediterranean drought fluctuation during the last 500 years based on tree-ring data. Clim Dyn 31(2):227–245. doi:10.1007/s00382-007-0349-3

Palmer W (1965) Meteorological drought. Report no. 45, U.S. Weather Bureau. Washington D.C.

Panayotov M, Yurukov S (2007) Tree ring chronology of *Pinus peuce* from the Pirin Mts and possibilities to use it for climate analysis. Phytologia Balc 13(3):313–320

Panayotov M, Bebi P, Trouet V, Yurukov S (2010) Climate signal in tree-ring chronologies of *Pinus peuce* and *Pinus heldreichii*; from the Pirin Mountains in Bulgaria. Trees 24(3):479–490. doi:10.1007/s00468-010-0416-y

Panayotov M, Dimitrov D, Yurukov S (2011) Extreme climate conditions in Bulgaria—evidence from *Picea abies* tree-rings. Silva Balc 12(1):37–46

Patroescu M, Chincea I, Rozylowicz L, Sorescu C (eds) (2008) Padurile cu pin negru de Banat - Sit Natura 2000 (Banat black pine forests - Natura 2000 site). Editura Brumar, Timisoara

Pauling A, Luterbacher J, Casty C, Wanner H (2006) Five hundred years of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation. Clim Dyn 26 (4):387–405. doi:10.1007/s00382-005-0090-8

Poljanšek S, Ballian D, Nagel TA, Levanič T (2012) A 435-year-long European black pine (*Pinus nigra*) chronology for the central-western Balkan region. Tree-Ring Res 68(1):31–44

Popa I, Kern Z (2009) Long-term summer temperature reconstruction inferred from tree-ring records from the Eastern Carpathians. Clim Dyn 32(7):1107–1117. doi:10.1007/s00382-008-0439-x

R Development Core Team (2009) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria

Stefan S, Ghioca M, Rimbu N, Boroneant C (2004) Study of meteorological and hydrological drought in Southern Romania from observational data. Int J Climatol 24:871–881

Stokes MA, Smiley TL (1968) An introduction to tree-ring dating. 2nd edn. The University of Arizona Press, Tucson

Strumia G, Wimmer R, Grabner M (1997) Dendroclimatic sensitivity of *Pinus nigra* Arnold in Austria. Dendrochronologia 15:129–137

Touchan R, Funkhouser G, Hughes M, Erkan N (2005a) Standardized precipitation index reconstructed from Turkish tree-ring widths. Clim Chang 72(3):339–353. doi:10.1007/s10584-005-5358-9

Touchan R, Xoplaki E, Funkhouser G, Luterbacher J, Hughes M, Erkan N, Akkemik Ü, Stephan J (2005b) Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. Clim Dyn 25(1):75–98. doi:10.1007/s00382-005-0016-5

Touchan R, Akkemik Ü, Hughes MK, Erkan N (2007) May-June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings. Quat Res 68(2):196–202. doi:10.1016/j.yqres.2007.07.001

Touchan R, Meko DM, Aloui A (2008) Precipitation reconstruction for Northwestern Tunisia from tree rings. J Arid Environ 72 (10):1887–1896

Touchan R, Anchukaitis K, Meko D, Sabir M, Attalah S, Aloui A (2011) Spatiotemporal drought variability in northwestern Africa over the last nine centuries. Clim Dyn 37:237–252. doi:10.1007/s00382-010-0804-4

van Oldenborgh GJ (1999) KNMI climate explorer. Koninklijk Netherlands Meteorologisch Institut (KNMI), De Bilt, The Netherlands

Wigley TML, Briffa KR, Jones PD (1984) On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. J Clim Appl Meteorol 23:201–213

Zang C (2009) BootRes: The bootRes package for bootstrapped response and correlation functions. R package, 1st edn. www.R-project.org. Accessed 02 October 2012

2.3 DOLGOLETNA REKONSTRUKCIJA SONČNEGA OBSEVANJA/ VLAŽNOSTNEGA STRESA IZ ŠIRIN BRANIK ZA OBMOČJE BOSNE IN HERCEGOVINE

Poljanšek S., Ceglar A., Levanič T. 2013. Long-term summer sunshine/moisture stress reconstruction from tree-ring widths from Bosnia and Herzegovina. Climate of the Past, 9, 27-40.

Predstavljamo prvo rekonstrukcijo sončnega obsevanja za območje severno-zahodnega dela Balkanskega polotoka. Sončno obsevanje je tesno povezano z vlažnostnim stresom v drevesih, ker sta vlažnostni stres in zato širina branik pod vplivom direktnega in posrednega vpliva trajanja sončnega obsevanja (temperatura, padavine, oblačnost in evapotranspiracija). Rekonstrukcija je osnovana na standardizirani z-vrednosti povprečne kronologije, izračunane iz meritev širin branik črnega bora, vzorčenih na sedmih lokacijah v Bosni in Hercegovini. Našli smo značilno, negativno korelacijo (r = -0,54, p <0.0001) s povprečnim številom ur trajanja sončnega obsevanja obdobja junij-julij z vremenske postaje Osijek (Hrvaška). Izračunani model je bil uporabljen za rekonstrukcijo trajanja sončnega obsevanja obdobja 1660-2010. Identificirali smo značilno sončna in oblačna poletja ter jih primerjali z dostopnimi zgodovinskimi viri suš, vulkanskih izbruhov in drugimi rekonstrukcijami iz širšega območja. Vsa značilna poletja z majhnim trajanjem sončnega obsevanja (1712, 1810, 1815, 1843, 1899 in 1966) smo povezali z vulkanskimi izbruhi.

Clim. Past, 9, 27–40, 2013
www.clim-past.net/9/27/2013/
doi:10.5194/cp-9-27-2013

Climate of the Past

Long-term summer sunshine/moisture stress reconstruction from tree-ring widths from Bosnia and Herzegovina

S. Poljanšek[1], **A. Ceglar**[2], **and T. Levanič**[1]

[1]Slovenian Forestry Institute, Večna pot 2, 1000 Ljubljana, Slovenia
[2]Biotechnical Faculty, Department of Agronomy, Chair of Agrometeorology, Jamnikarjeva 101, 1000 Ljubljana, Slovenia

Correspondence to: T. Levanič (tom.levanic@gozdis.si)

Received: 13 August 2012 – Published in Clim. Past Discuss.: 10 September 2012
Revised: 11 December 2012 – Accepted: 12 December 2012 – Published: 11 January 2013

Abstract. We present the first summer sunshine reconstruction from tree-ring data for the western part of the Balkan Peninsula. Summer sunshine is tightly connected with moisture stress in trees, because the moisture stress and therefore the width of annual tree-rings is under the influence of the direct and interactive effects of sunshine duration (temperature, precipitation, cloud cover and evapotranspiration). The reconstruction is based on a calibrated z-scored mean chronology, calculated from tree-ring width measurements from 7 representative black pine (*Pinus nigra* Arnold) sites in Bosnia and Herzegovina (BiH). A combined regression and scaling approach was used for the reconstruction of the summer sunshine. We found a significant negative correlation ($r = -0.54$, $p < 0.0001$) with mean June–July sunshine hours from Osijek meteorological station (Croatia). The developed model was used for reconstruction of summer sunshine for the time period 1660–2010. We identified extreme summer events and compared them to available documentary historical sources of drought, volcanic eruptions and other reconstructions from the broader region. All extreme summers with low sunshine hours (1712, 1810, 1815, 1843, 1899 and 1966) are connected with volcanic eruptions.

1 Introduction

Documentary proxies of climate data from the 15th to the 19th centuries are well distributed over the Mediterranean region and are particularly abundant in Italy, France and the Iberian Peninsula, while they are less frequently found for the Balkan Peninsula area, i.e., Greece, former Yugoslavian countries, Albania, Bulgaria and Romania (Camuffo et al., 2010). Dendrochronological studies of climate-tree growth relationships, such as the investigation of the southern part of Balkan Peninsula (Xoplaki et al., 2001), can help validate historical explanations of climate variability and its impact on human life. One of the first dendrochronological investigations on the Balkan Peninsula was a study covering the area of Greece, western Turkey, Cyprus and one location from Bosnia and Herzegovina (BiH), by which an Aegean master tree-ring chronology was constructed (Kuniholm and Striker, 1983). With additional sampling of old houses and mosques, the chronology was extended back to 7000 BC and one location each from Italy and BiH were added (Hughes et al., 2001). In the eastern part of the Balkan Peninsula, in south-western Bulgaria, 655-yr Bosnian pine (*Pinus heldreichii* Christ.) and 305-yr Macedonian pine (*Pinus peuce* Griseb.) chronologies were developed (Panayotov et al., 2010). Later, summer temperature was reconstructed (1768–2008), based on maximum latewood density measurements of *P. heldreichii* trees from a high-elevation stand in the Pirin Mountains in Bulgaria (Trouet et al., 2012). In Romania, the first 1000-yr Carpathian tree-ring width (TRW) stone pine (*Pinus cembra* L.) chronology has been established and summer mean temperatures reconstructed for the period 1163–2005 (Popa and Kern, 2009). In Albania, a 1391-yr TRW chronology (617–2008) was developed and maximum density measurements were acquired on living and dead *P. heldreichii* trees (Seim et al., 2010). A high positive correlation with summer, particularly August temperatures was found, but no significant correlation with precipitation. A similar study was performed on black pine (*Pinus nigra* Arnold) in Albania, whereby Levanič and Toromani (2010) developed a 238-yr TRW chronology. Tree-ring indices show

Published by Copernicus Publications on behalf of the European Geosciences Union.

a significantly negative response to summer temperatures and positive response to June precipitation. In sub-Mediterranean Slovenia, the formation of radial increments of *P. nigra* is stimulated by above-average winter and spring temperatures, while a negative impact of above-average temperatures in summer and during the entire vegetation period, from April through September, are clear (Ogrin, 2005). However, despite the numerous dendrochronological investigations across the Balkan Peninsula, climate reconstructions in the north-western part of Balkan Peninsula are still not available. Current dendrochronological investigations in developing TRW and maximum density chronologies from across the Balkan Peninsula – Slovenia (Hafner et al., 2011), Croatia, BiH (Poljanšek et al., 2012), and Montenegro (T. Levanič, personal communication, 2012), as well as Albania (Seim et al., 2012; Levanič and Toromani, 2010), Bulgaria (Trouet et al., 2012; Panayotov et al., 2010) and Romania (Levanič et al., 2012), should soon yield results that enhance our knowledge of past variation and contribute to dendroclimatological network of Balkan Peninsula (Luterbacher et al., 2012).

1.1 Climate of the studied area

Geographically, the Balkan Peninsula represents the border between Mediterranean and Central European climates. The combined impact determines the climate in the western part of the Balkan Peninsula as a mixture of continental climatic influence from the interior of the peninsula, mountain climatic influence from the Dinaric Alps and Mediterranean influence from the Adriatic Sea (Zupan Hajna, 2012). Annual precipitation and temperature regimes are characterised by seasonally diverse circulation patterns. In spring, an Atlantic High extending eastwards and over the Balkan Peninsula joins a low centre approaching from the southeast, causing a north–north-easterly flow over the eastern Mediterranean area. The extension of the summer Asian thermal low is evident throughout the eastern Mediterranean in all summer circulation patterns; however, it controls the weather in the region jointly with other principal pressure features (Kostopoulou and Jones, 2007). Multiproxy reconstructions of monthly and seasonal surface temperature fields for Europe back to 1500 show that the late 20th- and early 21st-century European climate is very likely warmer than that of any time during the past 500 yr (Luterbacher et al., 2004). In the light of projected climate change, heat waves in the Mediterranean region and on the Balkan Peninsula will intensify in the second half of the 21st century – they will be more frequent and will last longer (IPCC, 2007). According to predictions, the minimum daily temperature during the "worst heat" events is expected to rise by around 3 °C (Meehl and Tebaldi, 2004). In the eastern Mediterranean and the Middle East, there will be a gradual and relatively strong warming of about 3.5–7 °C between the 1961–1990 reference period and the period 2070–2099 (Lelieveld et al., 2012). The observed daytime maximum temperatures appear to be increasing most rapidly in the northern part of the region, i.e., the Balkan Peninsula and Turkey. Hot summer conditions that rarely occurred in the reference period may become the norm by the middle or end of the 21st century (Lelieveld et al., 2012). Moreover, a decrease in annual mean precipitation from 10 % to more than 20 % over some regions of the Mediterranean basin is expected by the end of the 21st century (IPCC, 2001). In the eastern part of the Mediterranean basin, the observed strong drought period of the end of the twentieth century seems to be the strongest of the last 500 yr (Nicault et al., 2008). It is therefore important to investigate whether extreme events have already occurred in BiH in the past and how trees responded to them. Results from our study can support study of climate, aridification processes (Kertész and Mika, 1999) and glaciation investigations (Hughes, 2010) from surrounding regions and BiH.

1.2 Species selection

Selecting tree species growing on sites with limited between-tree competition and climate as the prevailing growth-limiting factor maximises the climate signal in tree-rings (Fritts, 1976). *P. nigra* was chosen for this study, since it grows on extreme sites, has a good response to climate (Lebourgeois, 2000) and reaches ages up to 500 yr (Brus, 2004). The *P. nigra* area distribution covers the majority of the Mediterranean region (Vidaković, 1991), so the results of the climate-growth relationship from BiH can be compared to studies from other regions. Its growth response to climate has been studied in the western (Martín-Benito et al., 2010b, 2011) and eastern Mediterranean (Sevgi and Akkemik, 2007; Touchan et al., 2003), in the northern limit of its natural areal – in Austria (Leal et al., 2008) and south-eastern Romania (Levanič et al., 2012). Since the species is well-adapted to the Mediterranean and southern European climate, *P. nigra* tolerates summer droughts and high temperatures (Penuelas and Pilella, 2003), but poorly tolerates drought during early spring (Wimmer et al., 2000). Similar to trees in Spain (Martín-Benito et al., 2012) *P. nigra* growth on high elevated sites of Dinaric Mountains should be most strongly influenced by soil moisture. This environmental factor is in a tight connection with temperature, precipitation and cloud cover (Seneviratne et al., 2010). Variability in all these factors is explained with sunshine values, which also indirectly influences tree-growth (Fritts, 1976). Therefore, it should be possible to recover moisture stress-linked sunshine variance from tree-ring data (Stahle et al., 1991). As the different species respond to different climate parameters (García-Suárez et al., 2009), it is important to test the presence of sunshine/moisture stress in TRW of *P. nigra* in BiH.

In this paper we present results of climate/tree-growth analysis, based on a *P. nigra* TRW chronology from the north-western part of the Balkan Peninsula. The following aims were set:

- Identification of the climate signal in the tree-ring widths of *P. nigra* in BiH.
- Reconstruction of the most growth-limiting factor(s) for *P. nigra*.
- Identification of extreme climatic events in the past.
- Comparison of identified extreme events with published historical sources.

2 Materials and methods

2.1 Site description and tree-ring data

BiH is located between 42°26′–45°15′ north and 15°44′–19°41′ east, in the north-western part of Balkan Peninsula. Seven sites, dispersed along the main mountain chain in BiH, to cover the diverse climate of the studied region, were selected for this study (Fig. 1). The Krivaja and Konjuh sites are close to one another, but differ in altitude and aspect (Table 1). All sites are under the influence of a moist meridional maritime airflow from the Adriatic Sea, which often intrudes into the Balkan Peninsula where it collides with cooler air above the NW–SE oriented Dinaric mountain chain. This is the reason why there is a relatively high amount of precipitation over Dinaric mountains during growth season (Zupan Hajna, 2012). Average mean June–August temperature on high mountainous sites is 8.8 °C, while the amount of precipitation varies from 100 mm (Bjelašnica) to 280 mm (Čemerno station). Although there is more than 1000 mm (Bjelašnica) or 1600 mm (Čemerno) of annual of precipitation, the studied sites are in summer time generally dry because of mostly southern exposure, steep slopes and shallow soils.

Trees, used in this research, were sampled in the years 2005 and 2010. Individual TRW series were fitted with a cubic smoothing spline with a 50% frequency response at 67 % of the series length to remove non-climatic trends due to the tree's age, size, and the effects of stand dynamics (Cook and Briffa, 1990). Standardisation was done using ARSTAN for Windows, version 4.1d, the program provided by Cook and Krusic, Lamonth-Doherty Earth Observatory, Columbia University (http://www.ldeo.columbia.edu/trl). The signal strength in the standardised chronology was tested using the Expressed Population Signal – EPS (Wigley et al., 1984). The calculation of EPS was based on a 50-yr running window, with a 25-yr overlap. The usable portion of a chronology was defined as the part in which a minimum number of trees maintained an EPS value ≥ 0.85 (Briffa and Jones, 1990). The data are archived at the Slovenia Forestry Institute and the full details of the sites and sampling strategies are included in Poljanšek et al. (2012).

Fig. 1. Sampled sites, distributed along Dinaric mountains; Šator (SAT), Šipovo (SIP), Prusac (PRU), Blace (BLA), Peručica (PER), Konjuh (KON) and Krivaja (KRI), with meteorological station Osijek.

2.2 Climate data

Two different climate datasets, available for BiH, were used in this research. The Histalp dataset contains temperature and precipitation data from various locations in BiH, as well as sunshine data (1958–2007) for town Osijek in the continental part of Croatia (Auer et al., 2007). The second climate dataset consists of individual weather stations, provided by the Federal Hydrometeorological Institute of BiH. These stations are Bjelašnica (2000 m a.s.l.), Čemerno (1305 m a.s.l.), Sarajevo-Bjelave (630 m a.s.l.), Šipovo (460 m a.s.l.) and Tjentište (580 m a.s.l.). Some datasets have gaps in the annual base because climate data collection was disturbed twice due to a state of war. Bjelašnica mountainous weather station contains temperature data for time periods: 1895–1940, 1951–1992 and 2000-present, while precipitation data is available for time period 1952–2009. Sarajevo-Bjelave has a complete dataset from 1888 until the present. Other weather stations stopped collecting data due to disruption in 1992; Šipovo (1965–1992), Tjentište (1964–1992) and Čemerno (1958–1992).

2.3 Statistical analysis

Pearson's correlation coefficient (r) was used to evaluate the relationship between annual radial growth of *P. nigra* and climate factors: precipitation, temperatures and sunshine. Simple mean of all standardised site chronologies was compared to monthly mean temperatures, monthly sum of precipitation and sunshine hours, to identify the most strongly correlated growth factor. In addition to simple monthly climate values, a number of seasonal climate data variables were generated and correlated with the tree-ring indices as well. After identification of the sunshine seasonal variable, we normalised the individual site chronologies using z-score values (Ljungqvist, 2010) and calculated their

Table 1. General characteristics of sampled sites and number of trees sampled (*n*) in Bosnia and Herzegovina.

Site	Latitude/Longitude	Elevation	Slope	exposure	Bedrock	*n*	Time span	EPS ≥ 0.85
Blace	43°31′ N/18°07′ E	950 m	50°	SE	dolomite	21	1625–2010	1830
Konjuh	44°17′ N/18°32′ E	1100 m	45°	S	serpentine	24	1626–2010	1705
Krivaja	44°13′ N/18°29′ E	500 m	60°	NE	serpentine	18	1667–2010	1745
Peručica	43°19′ N/18°42′ E	1450 m	55°	S	limestone	33	1603–2010	1660
Prusac	44°04′ N/17°21′ E	1100 m	65°	S	limestone	15	1694–2010	1825
Šator	44°11′ N/16°36′ E	1300 m	55°	S	dolomite	20	1813–2010	1870
Šipovo	44°17′ N/17°12′ E	1100 m	60°	S & N	limestone	35	1576–2005	1730

correlation coefficient with the most influential sunshine variable. Squared correlation coefficient (r^2) shows the proportion of explained variance in each chronology and this value was used for the weighted mean regional chronology calculation (McCarroll et al., 2003). The significance of the summer sunshine signal strength between site chronologies in the two different time periods; the period of sunshine data (1958–2007) and the period pre-sunshine data (1813–1957) were tested using a z-test for the two correlation coefficients (Kanji, 1993). Linear model between regional chronology and sunshine season variable was calculated using linear regression. To assess the quality of the linear model for sunshine reconstruction, the period of the measured sunshine hours (1958–2007) was split into two equally long periods for calibration (1983–2007) and verification (1958–1982). The procedure was then repeated with the periods reversed. The reliability and prediction skill of the model was tested using reduction of error (RE) (Fritts, 1976), coefficient of efficiency (CE) (Cook et al., 1999) and the proportion of explained variability (r^2). If RE and CE coefficients are higher than zero, the relationship has a predictive value, then a transfer function can be calculated and applied on the regional chronology. Applications of the transfer function on the chronology over a period of time for which there is no climate data results in reconstruction of the climate. We used this approach on the chronologies from 2010 to the year of 1660, when value of EPS drops below 0.85 threshold (Table 1). Finally, years of extreme summer sunshine values were defined as years with summer sunshine values of above or below a specified threshold. Positive and negative thresholds were calculated as one and two standard deviations (SD) from the mean value. The mean value of sunshine hours was calculated over the entire period of reconstruction (1660–2010). Positive values denote sunny summers, while negative values denote less-sunny summers. We used the term "less-sunny" to denote years with an unusually (below 1 or 2 SD) low number of mean June–July sunshine hours. Because the solar radiation can be reduced not only by the cloud cover (Suehrcke, 2000; Arking et al., 1996), but also by other factors, such as volcano eruptions (Handler, 1989), forest fires (Chubarova et al., 2008) and other aerosols (Satheesh and Krishna Moorthy, 2005; Moosmüller et al., 2009), we decided that the term less-sunny is the most appropriate.

3 Results

3.1 Climate signal analysis

Climate signal in the TRW of *P. nigra* was analysed using Pearson's correlation coefficient between climate data and mean standardised chronology; an average of seven site chronologies. The highest correlation coefficients for temperature and precipitation data were found using Bjelašnica weather station. There are positive correlations between spring temperature and summer precipitation and negative with summer temperature and tree growth. Above average number of sunshine hours in June and July has a significant negative effect on tree growth. Additionally, the correlation improves if months are combined into spring and summer periods (Fig. 2). According to the results of the correlation analysis, the strongest correlation among sunshine values was found with mean June–July sunshine hours ($r = -0.44$, $n = 50$, $p < 0.01$). This climate proxy was tested for the long-term reconstruction. Between TRW and temperature, the strongest correlation was calculated with mean June–August temperature ($r = -0.45$, $n = 87$, $p < 0.001$), but this negative influence is more likely indirect, rather than direct, because temperature on mountainous sites cannot negatively influence tree-growth. The mean summer temperature at the Bjelašnica weather station site of 10 °C does not exceed the optimal temperature for tree growth, set at 20 °C for the moderate climate zone (Fritts, 1976). Negative influence of above average temperature on *P. nigra* growth is reasonable in area where summer temperature exceeds 20 °C, e.g. in Mediterranean area (Ogrin, 2005) but not at high elevations, where the majority of our sites are located. Precipitation signal is also significant ($r = 0.34$, $n = 59$, $p < 0.01$), but lower than temperature signal. Sunshine is not the growth limiting factor on this site, but its values are closely connected to moisture stress, which most logically drives the tree-growth (Alavi, 2002).

3.2 Transfer function development

We used z-test to test the differences in inter-correlations of seven site chronologies between the periods with and without sunshine data (1813–1957 and 1958–2007) – Table 2. The period of pre-sunshine data is omitted with the

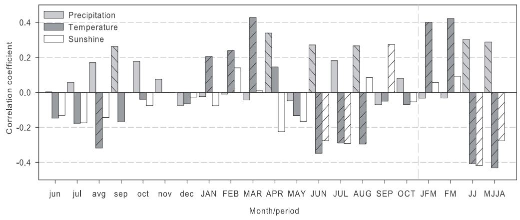


Fig. 2. Correlation coefficients (columns) between standardised chronology (average of seven site chronologies) and climate data from Bjelašnica weather station; precipitation with light grey, temperature with dark grey and sunshine hours with white columns (Osijek weather station). Columns with pattern represent significant value (95 %).

Table 2. Correlation values (Pearson's r) between the TRW series (individual site chronology and average, calculated as simple mean of all sites) over the calibration (upper triangle-period of measured sunshine data) and in the remainder of the common period (lower triangle-period before the measured sunshine data). No statistically significant differences were discovered between any of the pairs of correlation coefficients (z-test for two correlation coefficients).

	Calibration period of measured sunshine data 1958–2007							
Site	Blace	Konjuh	Krivaja	Peručica	Prusac	Šator	Šipovo	average
Blace		0.33	0.30	0.42	0.39	0.06	0.36	0.61
Konjuh	0.45		0.39	0.62	0.51	0.34	0.55	0.78
Krivaja	0.32	0.42		0,36	0.39	0.33	0.44	0.66
Peručica	0.52	0.59	0.40		0.65	0.37	0.62	0.78
Prusac	0.40	0.61	0.38	0.57		0.42	0.70	0.79
Šator	0.08	0.30	0.22	0.25	0.33		0.43	0.55
Šipovo	0.30	0.52	0.47	0.62	0.58	0.25		0.79
average	0.66	0.80	0.66	0.79	0.78	0.48	0.74	

Period before measured sunshine data 1813–1957.

length of the shortest site chronology from Šator (1813–2010). The z-test confirmed that the results of correlation values among individual site chronologies in the period of sunshine data (1958–2007) and in the period of pre-sunshine data (1813–1957) do not differ. This confirms that the relative strength of the climate signal in the seven proxies remains constant through time. There are several ways in which the seven site chronologies can be combined to reconstruct the climate of the past (Trachsel et al., 2012; Briffa et al., 1988). We used weighted averaging, where the weight of each series is determined by the amount of variance in site chronologies, explained by sunshine. In this case all proxies that correlate strongly with sunshine data receive a high weight, irrespective of how highly they correlate with each other. This approach ensures that all strong proxies are included (McCarroll et al., 2013). The mean chronology, constructed using weighted averaging, correlates with mean June–July sunshine hours at -0.54 ($n = 50$, $p < 0.0001$), more strongly than with simple averaging the site chronologies ($r = -0.44$). The equation for the linear model between BiH regional chronology and sunshine hours from Osijek is $Y = 271.424 - 11.592 \cdot X$ ($n = 50$, $F = 12.9$, $p < 0.001$), where Y represents the mean June–July sunshine hours and X are weighted TRW indices. Prediction skill and the stability of developed model were verified using a split-sample procedure (Table 3). The calibration-validation exercise indicated stability of the relationship over the two halves of the available instrumental data period. The similarity and strength of the derived calibration equations and verification tests of the two subset periods (Fig. 4) justify using the full period for developing the sunshine reconstruction. Additionally, the spatial strength of the weighted standardised chronology was tested using spatial correlation calculations in the KNMI Climate Explorer (van Oldenborgh, 1999). Our chronology correlates best with mean June–July Palmer Drought Severity Index (PDSI) for Europe, as a measure of soil moisture. Even though that solar radiation and sunshine hours vary significantly within the Carpathian-Balkan-Dinaric region (Niedźwiedź, 2012), we have calculated high correlation values in the region of Croatia ($0.6 < r < 0.5$, $p < 0.05$) and in the "triangle-like" area ($0.4 < r < 0.3$, $p < 0.05$) extending from Slovenia to Slovakia in the north and south to Greece (Fig. 3). This makes our regional chronology a valuable proxy for large-scale summer sunshine hours reconstruction.

3.3 Reconstruction and identification of extreme summers

Mean value of June–July sunshine hours in the period of available data is 268 h, with minimum value of 220 in the year of 1989 and maximum of 317 in 2000. The total range of measured mean June–July sunshine values over the entire instrumental period 1958–2007 is 96 h, but the reconstructed range over the same period is only 43; a reduction of 55 %. To avoid this bias we "scaled" the proxy series so that it has the same mean and variance as the climatic target data over the calibration period (Esper et al., 2005; McCarroll et al., 2013). After scaling, reconstruction produces a range of 80 h over the instrumental period, a loss of only 17 % comparing to the measured data. The threshold June–July sunshine values of the period 1660–2010 were computed at 247 h (1 SD) and 226 h (2 SD) for identification of less-sunny summers and at 289 h (1 SD) and 310 h (2 SD) for very sunny summers. With sunny weather thresholds we were able to reconstruct 5 (2 SD) and 55 (1 SD) very sunny summers, while with less-sunny thresholds we identified 6 (2 SD) and 58 (1 SD) summers with less-sunny weather (Table 4). In the period of available sunshine data (1958–2007), we were successful at identifying the very sunny summer of 2000 and the less-sunny summers of 1966, 1974, 1975 and 1983, while we were just beneath 1 SD threshold level for extreme years (by just 4 sunshine hours per month) in years 1959, 1968, 1969, 1986 and 1988. Sampled trees failed to respond to low June–July sunshine values in 1989 and 2004, and high sunshine values in 2006 and 2007.

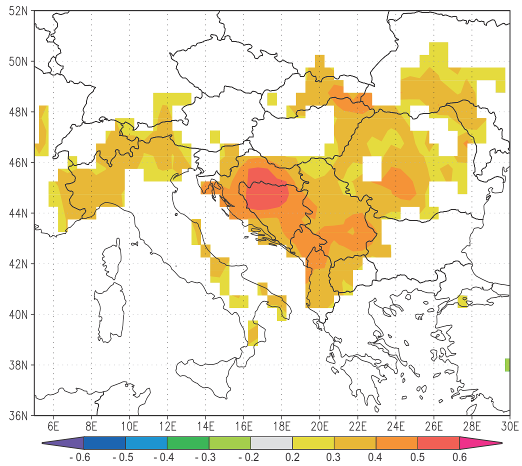


Fig. 3. Correlation values ($p < 0.05$) between weighted-TRW indices and mean June–July CRU Palmer Drought Severity Index (scPDSI), calculated in KNMI explorer (van Oldenborgh, 1999).

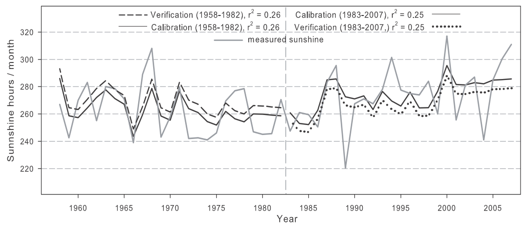


Fig. 4. Time series plots of measured (solid grey line) and reconstructed mean June–July sunshine hours for the calibration and verification periods of the split sample procedure (solid and dashed black line).

Table 3. Statistics of calibration/verification procedure between the *P. nigra* weighted mean chronology and mean June–July sunshine hours; RE – reduction of error; CE – coefficient of efficiency; r^2 – squared regression coefficient or explained variance.

	Calibration	Verification		
Period	r^2	r^2	RE	CE
1983–2007	0.25^a	0.26^b	0.38	0.15
1958–1982	0.26^b	0.25^a	0.34	0.17
1958–2007	0.29^c			

Stars denote significance ($^a = p < 0.05$, b $= p < 0.01$, $^c = p < 0.001$).

4 Discussion

4.1 Climate signal and reconstruction

Investigation of the climate signal in the *P. nigra* TRW chronologies is based on previously developed site chronologies for the north-western part of the Balkan Peninsula (Poljanšek et al., 2012). Each site chronology was compared to Bjelašnica climate data and sunshine data for Osijek area. Studies from the Alps report positive correlations with summer mean temperature (Rossi et al., 2007; Frank and Esper, 2005; Carrer et al., 2007), while sites from the Mediterranean area are more precipitation sensitive (Touchan et al., 2005). Variability of the radial growth of *P. nigra* from the mountainous western part of the Balkan Peninsula can be explained with the amount of summer sunshine hours, because June–July sunshine can be indirectly connected to moisture stress. So far, there are no results on cambium activity of *P. nigra* from BiH, but we can assume that the June–July period is the most important part of the growing season for tree ring formation (Gričar and Čufar, 2008).

Although significantly positive, the precipitation signal in the TRW is not as strong as the sunshine signal. Natural *P. nigra* stands on mountainous sites are found on south facing slopes (Bussotti, 2002), where the trees with maximised climate signal can be expected. Soils on these sites have quite high infiltration rates in summer and much lower rates during the wet seasons (Cerdà, 1997). During spring trees access water, available in the shallow soil layers, while during summer drought, when the highest response to moisture stress would be expected, *P. nigra* trees conduct hydraulic lift and access deep water source (Penuelas and Pilella, 2003). They also have efficient drought-response of needle tracheids (Cochard et al., 2004) and possibly similar to *P. sylvestris*, water storage in the stem and branches (Waring et al., 1979). Furthermore, precipitation is locally distributed and therefore weather station data does not show the actual amount of precipitation at the sites. Annual precipitation along western part of Dinaric mountain chain reaches amounts of 2000 mm or more, for example, in year 1900, Bjelašnica station recorded 3157 mm of precipitation. One of the reasons for the high amount of precipitation is the Dinaric Mountains, which acts as a climatic barrier between Mediterranean and continental climate, similar to the Pirin Mountains in southwest Bulgaria which spatially mark a transition between the Mediterranean and temperate climate zones (Grunewald et al., 2009). All these factors contribute to relatively low correlation between mean monthly precipitation and tree-ring indices in BiH, whereas an increasing influence of precipitation on tree-growth is observed towards the interior of the Balkan Peninsula in Romania (Levanič et al., 2012) and in the Central Europe in the Vienna basin region (Strumia et al., 1997), where *P. nigra* reacts more strongly to July rainfall. Similar results have also been reported from Turkey, where *P. nigra* responds positively to summer precipitation and not to temperature (Sevgi and Akkemik, 2007). In contrast to the relatively uniform response to a single climatic factor, a combined response of *P. nigra* to precipitation and temperature has been reported from Albania and Spain. In Albania, a significant negative response to June, July and August temperatures

Table 4. List of years with extreme summers, aligned from the years with the highest standard deviation (SD) from the mean to years, closer to mean value. Event years in bold are common to results from other studies, see Table 5.

Sunny summers	
2 SD	**1742**, **1908**, **1945**, **1695**, **1931**
1 SD	**1725**, **1696**, 1929, **1950**, **1697**, 1947, 1865, 2000, **1802**, 1944, **1806**, **1782**, **1808**, **1694**, **1830**, 1958, 1854, **1948**, 1909, 1891, **1803**, 1773, 1788, 1932, **1707**, **1825**, 1933, 1893, 1779, 1869, 1702, 1957, 1698, 1875, 1840, **1807**, 1907, 1703, 1952, 1741, 1763, 1666, **1784**, 1755, **1726**, **1789**, 1785, 1863, 1922, 1868, 1769, **1874**, **1946**, 1665, **1720**
Less-sunny summers	
2 SD	**1899**, **1843**, **1810**, **1815**, **1712**, 1966
1 SD	1818, 1816, 1814, 1799, 1736, **1772**, 1985, 1838, 1984, 1885, 1926, **1845**, **1871**, 1821, **1914**, 1681, 1682, 1683, **1692**, 1819, **1714**, **1833**, 1879, **1975**, **1691**, 1680, **1913**, **1876**, 1837, **1693**, 1897, **1915**, 1900, 1713, **1832**, **1846**, **1844**, 1898, 1820, 1886, 1974, 1978, 1684, 1722, **1783**, 1902, 1679, 1813, 1826, 1738, **1970**, 1983, 2009, **1729**, **1912**, **1927**, 1780, 1936

and positive response to June precipitation on the tree radial growth has been observed (Levanič and Toromani, 2010). In Spain, the standardised precipitation-evapotranspiration index is recognised as the main climatic driver of *P. nigra* radial growth (Martín-Benito et al., 2012), although the trees are still sensitive to July and August temperature and precipitation (Martín-Benito et al., 2010a). Beside significant correlations between summer climate factors and TRW indices in BiH, we also discovered a positive correlation ($r = 0.35$, $p < 0.01$) with spring temperatures as well (Fig. 2). Spring (January to March) temperatures have no direct influence on cambium activity, but their positive influence on radial growth can be explained through early start of cambium activity in warm March and with water availability at the beginning of the growing period. Mild and wet winters over the western part of the Balkan Peninsula are connected to negative North Atlantic Oscillation (NAO) phases (López-Moreno et al., 2011; Vicente-Serrano and López-Moreno, 2005). In negative NAO winters, the western Balkans experience anomalously cyclonic circulation and enhanced precipitation and therefore sufficient soil recharge which has a positive influence on a wider radial increment of *P. nigra*.

When testing the ability of the linear model to reconstruct June–July sunshine hours, decreased sensitivity of radial growth to summer sunshine between 1977 and 1985 was noticed (Fig. 4). In this period trees have complacent rings, giving an impression of very little climatic influence on annual tree growth. According to Mariotti and Dell'Aquila (2012), this period from the end of the 1960s to the beginning of the 1990s was characterised by outstanding decadal variations of summer sunshine values and therefore temperatures over the entire Mediterranean region, with maximum of the precipitation trends in the 1960s (Xoplaki et al., 2006). The summer of 1976 was the coolest summer of the second half of the twentieth century over the northeastern Mediterranean, while this same summer was one of the hottest and driest in the United Kingdom (Xoplaki et al., 2003a). Mediterranean summer temperature anomalies were also very well reflected in BiH, where the coolest summer was recorded in 1974 and the warmest summers in 1994, 1998 and 2000. The trend for the period 1950 to 1960 is $-1.15\,^{\circ}$C per decade, whereas a trend of $0.5\,^{\circ}$C per decade was recorded for the period between 1980 and 1999 (Xoplaki et al., 2003b). There is also a clear tendency for wetter summers between 1967 and 1985 over the Balkan region, when compared to previous decades (Blade et al., 2011). In our research we identified summer 2000 as sunny and 1974 as less-sunny (Table 4). Also, from the period of wetter summers 1967–1985, we identified 7 out of 19 summers as less-sunny (1970, 1974, 1975, 1978 and 1983–1985). Regional processes and feedbacks modulate the influence of large scale anomalies during summer over the Mediterranean. Mariotti and Dell'Aquilla (2012) have shown that these processes may involve cloud cover, land surface modifications and include positive soil moisture-precipitation and soil moisture-temperature feedback. Many regional processes that were modified due to increased summer NAO could mask the significant relationships among precipitation, temperature and tree growth. These processes can have a profound impact on tree growth, since incoming solar radiation and moderate heat flux are supporting factors for growth (Weitzenkamp et al., 2007). Changes in incoming solar radiation due to increased cloud cover could weaken the temperature and precipitation growth relationships of *P. nigra* by having a direct effect on gross primary production. Identification of significant processes is beyond the scope of this article but should be addressed in future studies.

4.2 Identification of extreme summer events

In our reconstruction there is a noticeable period from the beginning of the reconstruction in 1660 until 1695 (Fig. 5). This period is part of the Late Maunder Minimum (Luterbacher et al., 2001) and it signifies the climax of the so-called "Little Ice Age" in which Europe experienced predominant cooling (Xoplaki et al., 2001) and marked climate variability (Luterbacher et al., 2000). Summers in western and central Europe were wetter and slightly cooler than they are today due to a weaker Azores high (Luterbacher et al., 2001). During "Little Ice Age", the period 1725–1775 was warm and sunny in northern Norway (Young et al., 2010), while in BiH we noticed sunny period from 1695–1790 (Fig. 5). The coldest decade of the millennium over the Northern Hemisphere was in 1691–1700 (Jones et al., 1998). This partly

Table 5. Records of reconstructed sunny/less-sunny summers based on TRW from BiH, with standard deviations (SD) and their comparison with other related available documentary sources.

Sunny	Less-sunny	SD	Historical event	Reference
	1975	1	Slovakia: wet in June–August	Büntgen et al. (2010b)
	1970	1	Slovakia: wet in June–August	Büntgen et al. (2010b)
1950		1	Italy, south area: one of the hottest summers	Camuffo et al. (2010)
1948		1	Slovakia: dry spell from March–August	Büntgen et al. (2010b)
1946		1	SW Romania: year of great famine	Levanič et al. (2012)
1945		2	Driest years in Bulgaria during the 20th century (1945 and 2000)	Koleva and Alexandrov (2008)
1931		2	Warm period in Bulgaria	Trouet et al. (2012)
	1927	1	Slovakia: wet from March–August	Büntgen et al. (2010b)
	1912–1915	1	Taal eruption, Indonesia in 1911	Mastin and Witter (2000)
1908		2	Anatolia: major drought and famine event	Akkemik et al. (2005)
	1899	2	Etna eruption: central explosion in July	Bonaccorso et al. (2004)
	1876	1	Czech Lands: downpours in summer with local floods	Büntgen et al. (2010b)
1874		1	Province of Ankara, Turkey: a devastating drought	Touchan et al. (2007)
	1871	1	Czech Lands: 3 weeks of rain in July–August	Büntgen et al. (2010b)
	1844–1846	1	Etna eruption in 1842 and 1843, clouds in 1844–1846	Bonaccorso et al. (2004)
	1843	2	Etna eruption in 1842 and 1843, clouds in 1844–1846	Bonaccorso et al. (2004)
	1832–1833	1	Etna eruptions in 1831 caused clouds in 1832–1833	Bonaccorso et al. (2004)
1830		1	Slovenia: great heat and drought in July and August	Ogrin (2002)
1825		1	Slovakia: dry and warm April; long-lasting drought before late July; Czech Lands: very dry in July	Büntgen et al. (2010b)
	1815	2	Volcano Tambora explosion, Indonesia in April	Xoplaki et al. (2001), Boers (1995)
	1810	2	Large stratospheric eruption in 1809 of a volcano in the tropics	Cole-Dai et al. (2009)
1806–1808		1	Slovakia: dry and warm in May–August	Büntgen et al. (2010b)
1802–1803		1	Serbia: the lack of rain from May until October	Xoplaki et al. (2001)
1789		1	Slovakia: great drought in May–June	Büntgen et al. (2010b)
1782, 1784		1	Romania: extremely dry years	Levanič et al. (2012)
	1783	1	Eruption of Laki in southern Iceland	Grattan and Pyatt (1999)
1782		1	Slovakia: hot two weeks in June, warmth continuing in July–August	Büntgen et al. (2010b)
	1772	1	Czech Lands: rainy June	Büntgen et al. (2010b)
1742		2	Anatolia: extremely dry year	Akkemik et al. (2005)
	1729	1	SE Romania: extremely wet year	Levanič et al. (2012)
1725, 1726		1	SE Romania: drought in 1725 Anatolia: 2-yr long major drought	Levanič et al. (2012) Touchan et al. (2007)
1720		1	Mediterranean: one of the hottest summers	Camuffo et al. (2010)
	1712	2	Greece: drought, bad harvest, high prices, famine	Xoplaki et al. (2001)
	1712–1714	2	Awu eruption on December, 1711 in Indonesia	Clor et al. (2005)
1707		1	Anatolia: dry year	Akkemik et al. (2005)
1696, 1697		1	Anatolia: dry years	Akkemik et al. (2005)
1695		2	Cold summer, famine in England, Ireland	Lindgrén and Neumann (1981)
	1691–1694	1	Crete: bad harvest, famine, high prices olive-oil	Xoplaki et al. (2001)
	1691–1693	1	Northern Hemisphere: The coldest decade 1691–1700 of the millennium	Jones et al. (1998)

fits to our results, as the years of 1679–1684 and 1691–1693 were recognised as years with less-sunny summers. But afterwards, our reconstruction shows the period of 1694–1698 as years with sunny summers and even more; the summer of 1695 was recognised as the fourth sunniest summer in our reconstruction (Table 4). In the northern and continental part of Europe, this year was extremely cold and wet (Lindgrén and Neumann, 1981), while in Aegean sea area drought in the autumn destroyed harvest (Xoplaki et al., 2001). This long dry period from the late autumn of November 1695 to January–February of 1696 resulted from anticyclone conditions prevailing over central, eastern and south-eastern Europe, which prevented crossing of low-pressure systems towards the Balkans (Xoplaki et al., 2001). This, dominant atmospheric circulation pattern between the British Isles and Balkan Peninsula, has been also recorded by a summer reconstruction from north-eastern Mediterranean (Trouet et al., 2012). On a smaller scale, our results support this strong and consistent anti-phase relationship, which suggests that the summer NAO pattern is the main driving force of the teleconnection between summer temperatures in south-eastern versus north-western Europe (Trouet et al., 2012). We support this idea with identification of extremes (Table 4). In general, summers with low values of sunshine hours are related to oscillation patterns from continental Europe and regions north of BiH; e.g. 1975, 1970, 1927, 1876, 1871 and

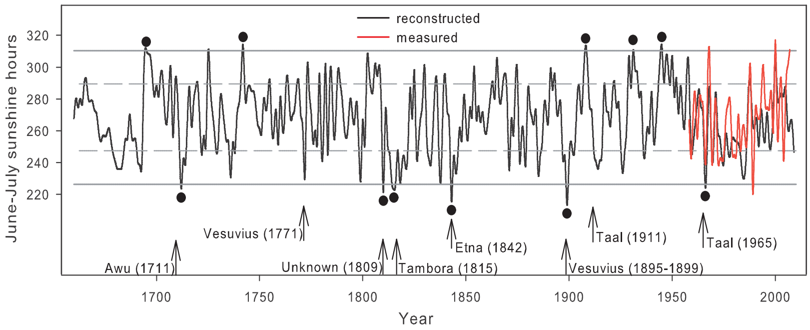


Fig. 5. Reconstructed (black line) and measured (shorter red line) mean June–July sunshine hours. Solid grey lines delineate two, while dashed grey lines represent one standard deviation from the mean, calculated over the reconstructed period 1660–2010. Black dots mark identified extreme summers and arrows indicate larger volcano eruptions; Awu (Clor et al., 2005), Vesuvius (Scandone et al., 2008), unknown and Tambora (Cole-Dai et al., 2009), Etna (Bonaccorso et al., 2004) and Taal (Mastin and Witter, 2000).

1772. On the other hand, sunny summers are more related to oscillations from the south-eastern and continental part of Balkan Peninsula; e.g. 1945, 1931, 1802, 1784 and 1729, or south-eastern/eastern Mediterranean; e.g. 1950, 1908, 1874, 1742, 1725, 1726, 1720, 1707 etc. (Table 5). The BiH area proved to be a good area for further extreme climatic events investigations, as it is located in the transition zone between Mediterranean and continental influence, therefore the trees react to climatic extremes from both zones. This could be the reason why we have many common summer climatic events with Slovakia, and on the other hand years when growth seasons were different between these two regions. For example, cold and wet conditions in the spring of 1725 prevailed over Slovakia and later during the summer, extensive anomalous low-pressure conditions, extending from northern to central Europe, have been connected with disastrous floods in Slovakia (Brázdil et al., 2008), while BiH and Romania (Levanič et al., 2012) were influenced by the hot, sunny summer weather from the eastern Mediterranean, similar to Anatolia and Syria (Touchan et al., 2007). After severe and snowy winter 1725/1726 in Slovakia (Brázdil et al., 2008), summer drought extended from Turkey (Touchan et al., 2007) and influenced both; BiH and Slovakia area (Brázdil et al., 2008).

Special awareness must be made when identifying extreme years and their possible causes. With mean June–July sunshine hours, we explain 21 % of the variability of the TRW indices. Aside to negative summer sunshine correlation values, there is also a positive correlation between TRW indices and spring temperatures (Fig. 2). This means that extremely cold winters could affect the cambium and limit its activity (Jyske et al., 2012). In such years TRW could be narrower, despite the possible good growth conditions later in the summer. Therefore, it is important to verify newly identified extreme climatic events (Table 5). One such case is the winter 1782. This winter is reported to be harsh and cold in Greece, with Lake Karla freezing and the destruction of olive and fruit trees, death of animals; for BiH plague and the deaths of people are mentioned (Xoplaki et al., 2001). Later in that year, drought events during the summer season extended north to Slovakia (Büntgen et al., 2010a), east to Romania (Levanič et al., 2012) and to the western Black Sea region of Turkey (Akkemik et al., 2005). The summer of 1782 was also recognised in our reconstruction as a year with high moisture stress during the growing season. The next example happened in the period of existing instrumental data in BiH. Winter of 1928/1929 was characterised as extremely cold in Slovakia (Büntgen et al., 2011) and as the winter when sea froze in the Venice lagoon (Winchester, 1930). The measured mean January–March temperature in 1929 for Sarajevo-Bjelave was, according to Federal Hydrometeorological Institute of BiH, −20 °C, while the long-term average (1889–2009) is −11 °C. In the following summer season mean temperature did not differ from long-term mean, but our reconstruction showed summer with above average sunshine hours (Table 4).

In search for explanations for less-sunny summer events, we also reviewed the influence of natural forcing on climate of the western part of Balkan Peninsula. The years with surprisingly low summer sunshine values matched well with years of major volcanic eruption, similar to strong volcanic forcing system in the North (McCarroll et al., 2013). This impact can be seen in abrupt change in the same growth year, lagged by one year, or as a prolonged effect, due to the influence of volcanic eruptions and sulphate loadings and consequently on tree-growth (Breitenmoser et al., 2012). We noticed the importance of strength, location and the length of volcano eruption, as well as the season of activity (Mastin and Witter, 2000). In the years of 1666, 1695 and 1698 Kuwae volcano erupted in the southwest Pacific (Briffa et al., 1998). While years 1666 and 1695 are both the dates of the eruption, our study identifies them as sunny. This indicates that western part of Balkan Peninsula was not influenced by volcanic eruptions from south-western Pacific. On the other hand, Tambora explosion in Indonesia (1815), whose eruption is counted as the largest historically documented eruption of the modern (instrumental) era (Briffa et al., 1998), is recorded in our tree ring series as the fourth summer with the lowest sunshine values in the reconstruction period. After Tambora, eruptions of Raung and Ijen, also from Indonesia, took place in the year 1817 (Mastin and Witter, 2000). Our reconstruction describes the period of 1813–1821, with exception of 1817, as summers with a low number of sunshine hours. This decade is also counted as probably the coolest in the last 500 yr (Cole-Dai et al., 2009). We can consider that one massive eruption has influence on more growth periods, like Taal volcanic eruption from Philippines in the 1911 (Mastin and Witter, 2000), which seems to have affected tree growth in BiH in the following 4 yr (1912–1915). We observed the same results in the years after Krakatoa eruption in 1883 (Rampino and Self, 1982). Closer to BiH an eruption of volcano Vesuvius (Italy) happened in May, 1771 and lasted for a whole month (Scandone et al., 2008). Its influence is not recorded in the same year, but the following summer had low value of sunshine hours (Table 4). Influence of longer volcanic eruptions on tree-growth is seen in the long Vesuvius eruption, starting in July, 1895 and lasting till September, 1899, being active for more than 1500 days (Scandone et al., 2008). Vesuvius is located southwest from BiH, but as there is in the beginning of the growing season a north–northeasterly flow over the eastern Mediterranean area (Kostopoulou and Jones, 2007), volcanic dust was transported towards the Dinaric mountains. This explains why we identified following years 1897–1900 and 1902 as less-sunny (1 SD) and 1899 as year with extremely low amount of sunshine (Table 4). With volcanic eruptions, we connected all summers with sunshine values below 2 SD; Vesuvius in 1899 (Scandone et al., 2008), Etna (Italy) in 1843 (Bonaccorso et al., 2004), unknown in 1810 and Tambora in 1815 (Cole-Dai et al., 2009), Awu (Indonesia) in 1712 (Clor et al., 2005) and Taal in 1966 (Mastin and Witter, 2000). The results of this research open many new fields of potential future investigations. But for a more detailed examination of the discovered BiH extreme summer sunshine events and their connection to volcanic eruptions, further inquiries with applications of data on sulphur loadings, power of eruption and its length should be addressed. Further, special investigation on available documentary archives with an emphasis on the whole region of the western Balkans is needed. Especially for those events which may be limited to the BiH area only and are not confirmed by documentary sources from outside the BiH.

5 Conclusions

We conclude that summer mean June–July sunshine hours from Osijek station (Croatia) are the most appropriate proxy for the moisture stress, which influences the radial growth of *P. nigra* in mountainous sites in the Bosnia and Herzegovina area. With application of the z-score method and weighted mean calculation, one reliable regional chronology, as a representative for the whole western part of Balkan Peninsula, was calculated. With values of 2 SD for identifying extreme climatic events, we discovered 5 extremely sunny (1742, 1908, 1945, 1695, 1931) and 6 summers with extremely low values of sunshine hours (1899, 1843, 1810, 1815, 1712, 1966). All identified 6 summers with the lowest number of sunshine hours from BiH area are connected to volcanic eruptions in the past. Major part of other less-sunny summer events overlap with reported events from regions north of the Balkan Peninsula, while sunny summer events are more related to events from inner, continental part of Balkan Peninsula or Mediterranean area. Besides climate forcing of moisture stress, impact of volcanic eruptions have been connected and their influence discussed, but for detailed explanation of the relation between moisture stress and sunshine values, more thorough identification of these relationships, including multispecies tree ring network and/or isotope analysis, should be addressed in the future.

Acknowledgements. We would like to express our special thanks to Dalibor Ballian from the Faculty of Forestry, Sarajevo for providing us with strong field support and for making this study possible. We are also grateful to forestry personnel from Bosansko Grahovo, Konjuh, Konjic, Prusac, Šipovo, rangers from Perućica National Park, and to the Federal Hydrometeorological Institute of Bosnia and Herzegovina for supplying us with the meteorological data used in this study. We thank Maarten de Groot for advice on statistical analysis of the data. We also thank Špela Jagodic and Robert Krajnc for their valuable assistance in the field and laboratory. A warm thanks to reviewers for their constructive suggestions that helped us improve the paper. This work was supported by the Slovenian Research Agency through the program and research group "Forest, biology, ecology and technology" P4-0107, a doctoral study grant from Simon Poljanšek and EUFORINNO project (European Forest Research and Innovation, Grant Agreement No. 315982); EU 7th Frame Work Programme – REGPOT 6/2012-12/2015.

Edited by: J. Luterbacher

References

Akkemik, Ü., Dağdeviren, N., and Aras, A.: A preliminary reconstruction (A.D. 1635–2000) of spring precipitation using oak tree rings in the western Black Sea region of Turkey, Int. J. Biometeorol., 49, 297–302, doi:10.1007/s00484-004-0249-8, 2005.

Alavi, G.: The impact of soil moisture on stem growth of spruce forest during a 22-year period, Forest Ecol. Manag., 166, 17–33, doi:10.1016/s0378-1127(01)00661-2, 2002.

Arking, A., Chou, M., Dah, M., and Ridgway, W. L.: On estimating the effect of clouds on atmospheric absorption based on flux observations above and below cloud level, Geophys. Res. Lett., 23, 829–832, doi:10.1029/96gl00775, 1996.

Auer, I., Böhm, R., Jurkovic, A., Lipa, W., Orlik, A., Potzmann, R., Schöner, W., Ungersböck, M., Matulla, C., Briffa, K., Jones, P., Efthymiadis, D., Brunetti, M., Nanni, T., Maugeri, M., Mercalli, L., Mestre, O., Moisselin, J.-M., Begert, M., Müller-Westermeier, G., Kveton, V., Bochnicek, O., Stastny, P., Lapin, M., Szalai, S., Szentimrey, T., Cegnar, T., Dolinar, M., Gajic-Capka, M., Zaninovic, K., Majstorovic, Z., and Nieplova, E.: HISTALP – historical instrumental climatological surface time series of the Greater Alpine Region, Int. J. Climatol., 27, 17–46, doi:10.1002/joc.1377, 2007.

Blade, I., Liebmann, B., Fortuny, D., and Van Oldenborgh, G. J.: Observed and simulated impacts of summer NAO in Europe: implications for projected drying in the Mediterranean region, Clim. Dynam., 39, 709–727, doi:10.1007/s00382-011-1195-x, 2011.

Boers, B. D. J.: Mount Tambora in 1815: A Volcanic Eruption in Indonesia and Its Aftermath, Indonesia, 60, 37–60, doi:10.2307/3351140, 1995.

Bonaccorso, A., Calvari, S., Coltelli, M., Negro, C. D., and Falsaperla, S.: Mt. Etna: volcano laboratory, American geophysical union, Washington DC, 2004.

Brázdil, R., Kiss, A., Luterbacher, J., and Valášek, H.: Weather patterns in eastern Slovakia 1717–1730, based on records from the Breslau meteorological network, Int. J. Climatol., 28, 1639–1651, doi:10.1002/joc.1667, 2008.

Breitenmoser, P., Beer, J., Brönnimann, S., Frank, D., Steinhilber, F., and Wanner, H.: Solar and volcanic fingerprints in tree-ring chronologies over the past 2000 years, Palaeogeogr. Palaeocl., 313–314, 127–139, doi:10.1016/j.palaeo.2011.10.014, 2012.

Briffa, K. R. and Jones, P. D.: Basic chronology statistics and assessment, in: Methods of dendrochronology: applications in the environmental sciences, edited by: Cook, E. R. and Kairiukstis, L. A., Kluwer academic publishers, Dordrecht, Boston, London, 137–152, 1990.

Briffa, K. R., Jones, P. D., and Schweingruber, F. H.: Summer temperature patterns over Europe: A reconstruction from 1750 A.D. based on maximum latewood density indices of conifers, Quaternary Res., 30, 36–52, doi:10.1016/0033-5894(88)90086-5, 1988.

Briffa, K. R., Jones, P. D., Schweingruber, F. H., and Osborn, T. J.: Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years, Nature, 393, 450–455, 1998.

Brus, R.: Drevesne vrste na slovenskem (Tree species on slovenian area; in Slovenian), Mladinska založba, Ljubljana, 2004.

Büntgen, U., Brázdil, R., Dobrovolný, P., Trnka, M., and Kyncl, T.: Five centuries of Southern Moravian drought variations revealed from living and historic tree rings, Theor. Appl. Climatol., 105, 1–14, doi:10.1007/s00704-010-0381-9, 2010a.

Büntgen, U., Brázdil, R., Frank, D., and Esper, J.: Three centuries of Slovakian drought dynamics, Clim. Dynam., 35, 315–329, doi:10.1007/s00382-009-0563-2, 2010b.

Büntgen, U., Brázdil, R., Heussner, K.-U., Hofmann, J., Kontic, R., Kyncl, T., Pfister, C., Chromá, K., and Tegel, W.: Combined dendro-documentary evidence of Central European hydroclimatic springtime extremes over the last millennium, Quaternary Sci. Rev., 30, 3947–3959, doi:10.1016/j.quascirev.2011.10.010, 2011.

Bussotti, F.: *Pinus nigra*, in: Pines of silvicultural importance, C.A.B. International, CABI Publishing, 266–286, 2002.

Camuffo, D., Bertolin, C., Barriendos, M., Dominguez-Castro, F., Cocheo, C., Enzi, S., Sghedoni, M., della Valle, A., Garnier, E., Alcoforado, M. J., Xoplaki, E., Luterbacher, J., Diodato, N., Maugeri, M., Nunes, M. F., and Rodriguez, R.: 500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations, Climatic Change, 101, 169–199, doi:10.1007/s10584-010-9815-8, 2010.

Carrer, M., Nola, P., Eduard, J. L., Motta, R., and Urbinati, C.: Regional variability of climate-growth relationships in *Pinus cembra* high elevation forests in the Alps, J. Ecol., 95, 1072–1083, doi:10.1111/j.1365-2745.2007.01281.x, 2007.

Cerdà, A.: Seasonal changes of the infiltration rates in a Mediterranean scrubland on limestone, J. Hydrol., 198, 209–225, doi:10.1016/s0022-1694(96)03295-7, 1997.

Chubarova, N. Y., Prilepsky, N. G., Rublev, A. N., and Riebau, A. R.: Chapter 11 A Mega-Fire Event in Central Russia: Fire Weather, Radiative, and Optical Properties of the Atmosphere, and Consequences for Subboreal Forest Plants, in: Developments in Environmental Science, edited by: Bytnerowicz, A., Arbaugh, M. J., Riebau, A. R., and Christian, A., Elsevier, 247–264, 2008.

Clor, L. E., Fischer, T. P., Hilton, D. R., Sharp, Z. D., and Hartono, U.: Volatile and N isotope chemistry of the Molucca Sea collision zone: Tracing source components along the Sangihe Arc, Indonesia, Geochem. Geophy. Geosy., 6, Q03J14, doi:10.1029/2004gc000825, 2005.

Cochard, H., Froux, F., Mayr, S., and Coutand, C.: Xylem Wall Collapse in Water-Stressed Pine Needles, Plant Physiol., 134, 401–408, doi:10.1104/pp.103.028357, 2004.

Cole-Dai, J., Ferris, D., Lanciki, A., Savarino, J., Baroni, M., and Thiemens, M. H.: Cold decade (AD 1810–1819) caused by Tambora (1815) and another (1809) stratospheric volcanic eruption, Geophys. Res. Lett., 36, L22703, doi:10.1029/2009gl040882, 2009.

Cook, E. R. and Briffa, K. R.: A comparison of some tree-ring standardization methods, in: Methods of Dendrochronology: Applications in the Environmental Sciences, edited by: Cook, E. R. and Kairiukstis, L. A., Kluwer Academic Publishers, Dordrecht, Boston, London, 153–162, 1990.

Cook, E. R., Meko, D. M., Stahle, D. W., and Cleaveland, M. K.: Drought Reconstructions for the Continental United States, J. Climate, 12, 1145–1162, doi:10.1175/1520-0442(1999)012<1145:drftcu>2.0.co;2, 1999.

Esper, J., Frank, D. C., Wilson, R. J. S., and Briffa, K. R.: Effect of scaling and regression on reconstructed temperature amplitude for the past millennium, Geophys. Res. Lett., 32, L07711, doi:10.1029/2004gl021236, 2005.

Frank, D. and Esper, J.: Characterization and climate response patterns of a high-elevation, multi-species tree-ring network in the European Alps, Dendrochronologia, 22, 107–121, 2005.

Fritts, H. C.: Tree rings and climate, Academic Press, London, New York, San Francisco, 567 pp., 1976.

García-Suárez, A. M., Butler, C. J., and Baillie, M. G. L.: Climate signal in tree-ring chronologies in a temperate climate: A multi-species approach, Dendrochronologia, 27, 183–198, doi:10.1016/j.dendro.2009.05.003, 2009.

Grattan, J. P. and Pyatt, F. B.: Volcanic eruptions dry fogs and the European palaeoenvironmental record: localised phenomena or hemispheric impacts?, Global Planet. Change, 21, 173–179, doi:10.1016/s0921-8181(99)00013-2, 1999.

Gričar, J. and Čufar, K.: Seasonal dynamics of phloem and xylem formation in silver fir and Norway spruce as affected by drought, Russ. J. Plant Phyl., 55, 538–543, doi:10.1134/s102144370804016x, 2008.

Grunewald, K., Scheithauer, J., Monget, J.-M., and Brown, D.: Characterisation of contemporary local climate change in the mountains of southwest Bulgaria, Climatic Change, 95, 535–549, doi:10.1007/s10584-008-9508-8, 2009.

Hafner, P., Robertson, I., McCarroll, D., Loader, N., Gagen, M., Bale, R., Jungner, H., Sonninen, E., Hilasvuori, E., and Levanič, T.: Climate signals in the ring widths and stable carbon, hydrogen and oxygen isotopic composition of *Larix decidua*; growing at the forest limit in the southeastern European Alps, Trees-Struct. Funct., 25, 1141–1154, doi:10.1007/s00468-011-0589-z, 2011.

Handler, P.: The effect of volcanic aerosols on global climate, J. Volcanol. Geoth. Res., 37, 233–249, doi:10.1016/0377-0273(89)90081-4, 1989.

Hughes, M. K., Kuniholm, P. I., Eischeid, J. K., Garfin, G., Griggs, C. B., and Latini, C.: Aegean tree-ring signature years explained, Tree-Ring Res., 57, 67–73, 2001.

Hughes, P. D.: Little Ice Age glaciers in the Balkans: low altitude glaciation enabled by cooler temperatures and local topoclimatic controls, Earth Surf. Proc. Land., 35, 229–241, doi:10.1002/esp.1916, 2010.

IPCC: IPCC 2001: Climate change 2001: the scientific basis. Contribution of working group 1 to the third assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, New York, 881, 2001.

IPCC: Climate Change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp., 2007.

Jones, P. D., Briffa, K. R., Barnett, T. P., and Tett, S. F. B.: High-resolution palaeoclimatic records for the last millennium: interpretation, integration and comparison with General Circulation Model control-run temperatures, Holocene, 8, 455–471, doi:10.1191/095968398667194956, 1998.

Jyske, T., Manner, M., Mäkinen, H., Nöjd, P., Peltola, H., and Repo, T.: The effects of artificial soil frost on cambial activity and xylem formation in Norway spruce, Trees, 26, 405–419, doi:10.1007/s00468-011-0601-7, 2012.

Kanji, G. K.: 100 statistical tests, Sage, London, 1993.

Kertész, Á. and Mika, J.: Aridification – Climate change in South-Eastern Europe, Phys. Chem. Earth Pt. A, 24, 913–920, doi:10.1016/s1464-1895(99)00135-0, 1999.

Koleva, E. and Alexandrov, V.: Drought in the Bulgarian low regions during the 20th century, Theor. Appl. Climatol., 92, 113–120, doi:10.1007/s00704-007-0297-1, 2008.

Kostopoulou, E. and Jones, P. D.: Comprehensive analysis of the climate variability in the eastern Mediterranean. Part I: map-pattern classification, Int. J. Climatol., 27, 1189–1214, doi:10.1002/joc.1467, 2007.

Kuniholm, P. I. and Striker, C. L.: Dendrochronological Investigations in the Aegean and Neighboring Regions, 1977–1982, J. Field Archaeol., 10, 411–420, 1983.

Leal, S., Eamus, D., Grabner, M., Wimmer, R., and Cherubini, P.: Tree rings of *Pinus nigra* from the Vienna basin region (Austria) show evidence of change in climatic sensitivity in the late 20th century, Can. J. Forest Res., 38, 744–759, doi:10.1139/x07-189, 2008.

Lebourgeois, F.: Climatic signals in earlywood, latewood and total ring width of Corsican pine from western France, Ann. For. Sci., 57, 155–164, 2000.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., Hannides, C., Lange, M., Tanarhte, M., Tyrlis, E., and Xoplaki, E.: Climate change and impacts in the Eastern Mediterranean and the Middle East, Climatic Change, 114, 667–687, doi:10.1007/s10584-012-0418-4, 2012.

Levanič, T. and Toromani, E.: Austrian pine (*Pinus nigra* Arnold.) tree-ring width chronology from northeast Albania-preliminary results, TRACE, Otočec, Slovenia, 2010.

Levanič, T., Popa, I., Poljanšek, S., and Nechita, C.: A 323-year long reconstruction of drought for SW Romania based on black pine (*Pinus nigra*) tree-ring widths, Int. J. Biometeorol., Online ISSN: 1432-1254, 1–12, doi:10.1007/s00484-012-0596-9, 2012.

Lindgrén, S. and Neumann, J.: The cold and wet year 1695 – a contemporary German account, Climatic Change, 3, 173–187, doi:10.1007/bf00154435, 1981.

Ljungqvist, F. C.: A new reconstruction of temperature variability in the extra-tropical northern hemisphere during the last two millennia, Geogr. Ann. A, 92, 339–351, doi:10.1111/j.1468-0459.2010.00399.x, 2010.

López-Moreno, J. I., Vicente-Serrano, S. M., Morán-Tejeda, E., Lorenzo-Lacruz, J., Zabalza, J., Kenawy, A. E., and Beniston, M.: Influence of Winter North Atlantic Oscillation Index (NAO) on Climate and Snow Accumulation in the Mediterranean Mountains, in: Hydrological, Socioeconomic and Ecological Impacts of the North Atlantic Oscillation in the Mediterranean Region, edited by: Vicente-Serrano, S. M. and Trigo, R. M., Advances in Global Change Research, Springer Netherlands, 73–89, 2011.

Luterbacher, J., Rickli, R., Tinguely, C., Xoplaki, E., Schüpbach, E., Dietrich, D., Hüsler, J., Ambühl, M., Pfister, C., Beeli, P., Dietrich, U., Dannecker, A., Davies, T. D., Jones, P. D., Slonosky, V., Ogilvie, A. E. J., Maheras, P., Kolyva-Machera, F., Martin-Vide, J., Barriendos, M., Alcoforado, M. J., Nunes, M. F., Jónsson, T., Glaser, R., Jacobeit, J., Beck, C., Philipp, A., Beyer, U., Kaas, E., Schmith, T., Bärring, L., Jönsson, P., Rácz, L., and Wanner, H.: Monthly mean pressure reconstruction for the Late Maunder Minimum Period (AD 1675–1715), Int. J. Climatol., 20, 1049–1066, doi:10.1002/1097-0088(200008)20:10<1049::aid-joc521>3.0.co;2-6, 2000.

Luterbacher, J., Rickli, R., Xoplaki, E., Tinguely, C., Beck, C., Pfister, C., and Wanner, H.: The Late Maunder Minimum (1675–1715) – A Key Period for Studying Decadal Scale Climatic Change in Europe, Climatic Change, 49, 441–462, 2001.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., and Wanner, H.: European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500, Science, 303, 1499–1503, doi:10.1126/science.1093877, 2004.

Luterbacher, J., García-Herrera, R., Akcer-On, S., Allan, R., Alvarez-Castro, M.-C., Benito, G., Booth, J., Büntgen, U., Cagatay, N., Colombaroli, D., Davis, B., Esper, J., Felis, T., Fleitmann, D., Frank, D., Gallego, D., Garcia-Bustamante, E., Glaser, R., Gonzalez-Rouco, F. J., Goosse, H., Kiefer, T., Macklin, M. G., Manning, S. W., Montagna, P., Newman, L., Power, M. J., Rath, V., Ribera, P., Riemann, D., Roberts, N., Sicre, M.-A., Silenzi, S., Tinner, W., Tzedakis, P. C., Valero-Garcés, B., van der Schrier, G., Vannière, B., Vogt, S., Wanner, H., Werner, J.

P., Willett, G., Williams, M. H., Xoplaki, E., Zerefos, C. S., and Zorita, E.: 2 – A Review of 2000 Years of Paleoclimatic Evidence in the Mediterranean, in: The Climate of the Mediterranean Region, edited by: Lionello, P., Elsevier, Oxford, 87–185, 2012.

Mariotti, A. and Dell'Aquila, A.: Decadal climate variability in the Mediterranean region: roles of large-scale forcings and regional processes, Clim. Dynam., 38, 1129–1145, 2012.

Martín-Benito, D., del Río, M., and Cañellas, I.: Black pine (*Pinus nigra* Arn.) growth divergence along a latitudinal gradient in Western Mediterranean mountains, Ann. For. Sci., 67, p. 401, doi:10.1051/forest/2009121, 2010a.

Martín-Benito, D., Del Río, M., Heinrich, I., Helle, G., and Cañellas, I.: Response of climate-growth relationships and water use efficiency to thinning in a *Pinus nigra* afforestation, Forest Ecol. Manag., 259, 967–975, doi:10.1016/j.foreco.2009.12.001, 2010b.

Martín-Benito, D., Kint, V., del Río, M., Muys, B., and Cañellas, I.: Growth responses of West-Mediterranean *Pinus nigra* to climate change are modulated by competition and productivity: Past trends and future perspectives, Forest Ecol. Manag., 262, 1030–1040, doi:10.1016/j.foreco.2011.05.038, 2011.

Martín-Benito, D., Beeckman, H., and Cañellas, I.: Influence of drought on tree rings and tracheid features of *Pinus nigra* and *Pinus sylvestris* in a mesic Mediterranean forest, Eur. J. For. Res., Online ISSN: 1612-4677, 1–13, doi:10.1007/s10342-012-0652-3, 2012.

Mastin, L. G. and Witter, J. B.: The hazards of eruptions through lakes and seawater, J. Volcanol. Geoth. Res., 97, 195–214, doi:10.1016/s0377-0273(99)00174-2, 2000.

McCarroll, D., Jalkanen, R., Hicks, S., Tuovinen, M., Gagen, M., Pawellek, F., Eckstein, D., Schmitt, U., Autio, J., and Heikkinen, O.: Multiproxy dendroclimatology: a pilot study in northern Finland, Holocene, 13, 829–838, doi:10.1191/0959683603hl668rp, 2003.

McCarroll, D., Loader, N. J., Jalkanen, R., Gagen, M. H., Grudd, H., Gunnarson, B. E., Kirchhefer, A. J., Friedrich, M., Linderholm, H. W., Lindholm, M., Boettger, T., Los, S. O., Remmele, S., Kononov, Y. M., Yamazaki, Y. H., Young, G. H. F., and Zorita, E.: A 1200-year multi-proxy record of tree growth and summer temperature at the northern pine forest limit of Europe, Holocene, in press, 2013.

Meehl, G. A. and Tebaldi, C.: More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century, Science, 305, 994–997, doi:10.1126/science.1098704, 2004.

Moosmüller, H., Chakrabarty, R. K., and Arnott, W. P.: Aerosol light absorption and its measurement: A review, J. Quant. Spectrosc. Ra., 110, 844–878, doi:10.1016/j.jqsrt.2009.02.035, 2009.

Nicault, A., Alleaume, S., Brewer, S., Carrer, M., Nola, P., and Guiot, J.: Mediterranean drought fluctuation during the last 500 years based on tree-ring data, Clim. Dynam., 31, 227–245, doi:10.1007/s00382-007-0349-3, 2008.

Niedźwiedź, T.: Climate, in: Recent Landform Evolution, edited by: Lóczy, D., Stankoviansky, M., and Kotarba, A., Springer Geography, Springer Netherlands, 19–29, 2012.

Ogrin, D.: Dry and wet years in Submediterranean Slovenia from the 14th to the mid-19th century, Acta Univ. Palacki. Olomuc., Fac. Rerum Nat., Geogr., 37, 8–11, 2002.

Ogrin, D.: Tree rings and climate in submediterranean Slovenia, TRACE 2005, 2005.

Panayotov, M., Bebi, P., Trouet, V., and Yurukov, S.: Climate signal in tree-ring chronologies of *Pinus peuce* and *Pinus heldreichii*; from the Pirin Mountains in Bulgaria, Trees-Struct. Funct., 24, 479–490, doi:10.1007/s00468-010-0416-y, 2010.

Penuelas, J. and Pilella, I.: Deuterium labelling of roots provides evidence of deep water access and hydraulic lift by *Pinus nigra* in a Mediterranean forest of NE Spain, Environ. Exp. Bot., 49, 201–208, doi:10.1016/S0098-8472(02)00070-9, 2003.

Poljanšek, S., Ballian, D., Nagel, T. A., and Levanič, T.: A 435-Year-Long European Black Pine (*Pinus nigra*) Chronology for the Central-Western Balkan Region, Tree-Ring Res., 68, 31–44, doi:10.3959/2011-7.1, 2012.

Popa, I. and Kern, Z.: Long-term summer temperature reconstruction inferred from tree-ring records from the Eastern Carpathians, Clim. Dynam., 32, 1107–1117, doi:10.1007/s00382-008-0439-x, 2009.

Rampino, M. R. and Self, S.: Historic eruptions of Tambora (1815), Krakatau (1883), and Agung (1963), their stratospheric aerosols, and climatic impact, Quaternary Res., 18, 127–143, doi:10.1016/0033-5894(82)90065-5, 1982.

Rossi, S., Deslauriers, A., Anfodillo, T., and Carraro, V.: Evidence of threshold temperatures for xylogenesis in conifers at high altitudes, Oecologia, 152, 1–12, doi:10.1007/s00442-006-0625-7, 2007.

Satheesh, S. K. and Krishna Moorthy, K.: Radiative effects of natural aerosols: A review, Atmos. Environ., 39, 2089–2110, doi:10.1016/j.atmosenv.2004.12.029, 2005.

Scandone, R., Giacomelli, L., and Speranza, F. F.: Persistent activity and violent strombolian eruptions at Vesuvius between 1631 and 1944, J. Volcanol. Geoth. Res., 170, 167–180, doi:10.1016/j.jvolgeores.2007.09.014, 2008.

Seim, A., Treydte, K., Büntgen, U., Esper, J., Fonti, P., Haska, H., Herzig, F., Tegel, W., and Faust, D.: Exploring the potential of *Pinus heldreichii* Christ. for long-term climate reconstruction in Albania, TRACE, Otočec, Slovenia, 75–82, 2010.

Seim, A., Büntgen, U., Fonti, P., Haska, H., Herzig, F., Tegel, W., Trouet, V., and Treydte, K.: Climate sensitivity of a millennium-long pine chronology from Albania, Clim. Res., 51, 217–228, doi:10.3354/cr01076, 2012.

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M., Jaeger, E. B., Lehner, I., Orlowsky, B., and Teuling, A. J.: Investigating soil moisture–climate interactions in a changing climate: A review, Earth-Sci. Rev., 99, 125–161, doi:10.1016/j.earscirev.2010.02.004, 2010.

Sevgi, O. and Akkemik, U.: A dendroecological study on *Pinus nigra* Arn. at different altitudes of northern slopes of Kazdaglari, Turkey, J. Environ. Biol., India, 28, 73–75, 2007.

Stahle, D. W., Cleaveland, M. K., and Cerveny, R. S.: Tree-ring reconstructed sunshine duration over central USA, Int. J. Climatol., 11, 285–295, doi:10.1002/joc.3370110305, 1991.

Strumia, G., Wimmer, R., and Grabner, M.: Dendroclimatic sensitivity of *Pinus nigra* Arnold in Austria, Dendrochronologia, 15, 129–137, 1997.

Suehrcke, H.: On the relationship between duration of sunshine and solar radiation on the earth's surface: Ångström's equation revisited, Sol. Energy, 68, 417–425, doi:10.1016/s0038-092x(00)00004-9, 2000.

Touchan, R., Garfin, G. M., Meko, D. M., Funkhouser, G., Erkan, N., Hughes, M. K., and Wallin, B. S.: Preliminary reconstructions of spring precipitation in southwestern Turkey from tree-ring width, Int. J. Climatol., 23, 157–171, 2003.

Touchan, R., Xoplaki, E., Funkhouser, G., Luterbacher, J., Hughes, M. K., Erkan, N., Akkemik, U., and Stephan, J.: Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation, Clim. Dynam., 25, 75–98, 2005.

Touchan, R., Akkemik, Ü., Hughes, M. K., and Erkan, N.: May–June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings, Quaternary Res., 68, 196–202, doi:10.1016/j.yqres.2007.07.001, 2007.

Trachsel, M., Kamenik, C., Grosjean, M., McCarroll, D., Moberg, A., Brázdil, R., Büntgen, U., Dobrovolný, P., Esper, J., Frank, D. C., Friedrich, M., Glaser, R., Larocque-Tobler, I., Nicolussi, K., and Riemann, D.: Multi-archive summer temperature reconstruction for the European Alps, AD 1053–1996, Quaternary Sci. Rev., 46, 66–79, doi:10.1016/j.quascirev.2012.04.021, 2012.

Trouet, V., Panayotov, M., Ivanova, A., and Frank, D.: A pan-European summer teleconnection mode recorded by a new temperature reconstruction from the northeastern Mediterranean (ad 1768–2008), Holocene, 22, 887–898, doi:10.1177/0959683611434225, 2012.

van Oldenborgh, G. J.: KNMI Climate explorer, Koninklijk Netherlands Meteorologisch Institut (KNMI), 1999.

Vicente-Serrano, S. M. and López-Moreno, J. I.: Hydrological response to different time scales of climatological drought: an evaluation of the Standardized Precipitation Index in a mountainous Mediterranean basin, Hydrol. Earth Syst. Sci., 9, 523–533, doi:10.5194/hess-9-523-2005, 2005.

Vidaković, M.: Conifers: morphology and variation, Grafički zavod Hrvatske, Zagreb, 754 pp., 1991.

Waring, R. H., Whitehead, D., and Jarvis, P. G.: The contribution of stored water to transpiration in Scots pine, Plant Cell Environ., 2, 309–317, doi:10.1111/j.1365-3040.1979.tb00085.x, 1979.

Weitzenkamp, B., Schneider, C., Kilian, R., Spiecker, H., and Kahle, H. P.: Regional climate tree growth at Gran Campo Nevado, Chilean Patagonia, Geophys. Res. Abstr., 9, 2007.

Wigley, T. M. L., Briffa, K. R., and Jones, P. D.: On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology, J. Clim. Appl. Meteorol., 23, 201–213, 1984.

Wimmer, R., Strumia, G., and Holawe, F.: Use of false rings in Austrian pine to reconstruct early growing season precipitation, Can. J. For. Res., 30, 1691–1697, 2000.

Winchester, L.: The abnormal weather of 1929, Geography, 15, 579–585, 1930.

Xoplaki, E., Maheras, P., and Luterbacher, J.: Variability of Climate in Meridional Balkans during the Periods 1675–1715 and 1780–1830 and its Impact on Human Life, Climatic Change, 48, 581–615, doi:10.1023/a:1005616424463, 2001.

Xoplaki, E., González Rouco, J. F., Gyalistras, D., Luterbacher, J., Rickli, R., and Wanner, H.: Interannual summer air temperature variability over Greece and its connection to the large-scale atmospheric circulation and Mediterranean SSTs 1950–1999, Clim. Dynam., 20, 537–554, doi:10.1007/s00382-002-0291-3, 2003a.

Xoplaki, E., Gonzalez-Rouco, F. J., Luterbacher, J., and Wanner, H.: Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs, Clim. Dynam., 20, 723–739, 2003b.

Xoplaki, E., Luterbacher, J., and Gonzalez-Rouco, F. J.: Mediterranean summer temperature and winter precipitation, large-scale dynamics, trends, Il Nuovo Cimento, 29, 45–54, 2006.

Young, G. H. F., McCarroll, D., Loader, N. J., and Kirchhefer, A. J.: A 500-year record of summer near-ground solar radiation from tree-ring stable carbon isotopes, Holocene, 20, 315–324, doi:10.1177/0959683609351902, 2010.

Zupan Hajna, N.: Dinaric karst: Geography and geology, in: Encyclopedia of Caves, 2nd Edn., edited by: White, B. W. and Culver, C. D., Elsevier, Oxford, 2012.

2.4 PARAMETRI BRANIK DREVES *Pinus nigra* (Arnold) IN NJIHOV KLIMATSKI SIGNAL

Poljanšek S., Levanič T. 2012. Parametri branik dreves Pinus nigra (Arnold) in njihov klimatski signal. Zbornik gozdarstva in lesarstva, 98: 15-25

Predstavljamo prvo analizo klimatskega signala v branikah črnega bora (*P. nigra* Arnold) s pomočjo metode odboja modrega spektra. Izbrana drevesa so rastla na Kojniku. Z ekstrakcijo smole in skeniranjem so bili 5 mm debeli vzorci pripravljeni za analizo. Izmerili smo širino celotne branike ter širino in gostoto ranega ter kasnega lesa. Za odstranitev starostnega trenda in drugih ne-klimatskih faktorjev smo merjene časovne serije standardizirali s kubičnim zlepkom. Pri meritvah gostot smo značilne korelacije izračunali med padavinami obdobja maj-junij ter gostoto ranega lesa ($r = 0,64$, $p<0,001$), medtem ko gostota kasnega lesa korelira najbolje s povprečno temperaturo obdobja junij-avgust ($r = 0,42$, $p<0,01$). Pri merjenju širin je bila najvišja korelacija izračunana med širino celotne branike in povprečno temperaturo obdobja junij-avgust ($r = -0,62$, $p<0,001$).

Zbornik gozdarstva in lesarstva 98 (2012), s. 15 - 25

GDK: 811.4:553+563:111:174.7 Pinus nigra(045)=111
Prispelo / *Received*: 03. 12. 2012
Sprejeto / *Accepted*: 28. 12. 2012

Izvirni znanstveni članek
Original scientific paper

MULTIPLE TREE-RING PARAMETERS FROM *Pinus nigra* (ARNOLD) AND THEIR CLIMATE SIGNAL

Simon POLJANŠEK[1], Tom LEVANIČ[2]

Abstract

The first exploration of climate signal in tree-rings of Black pine (*P. nigra* Arnold), using minimum blue intensity method, is presented. Sampled trees were growing on site Kojnik (Slovenia). For resin extraction and scanning, 5 mm thick cores were prepared. Whole tree-ring widths were measured, as well as the width and density of early- and latewood. To remove age trend and influence of non-climatic factors, raw measurements were standardized using spline function. In density measurements, highly significant correlation values were calculated between May-June summed precipitation and earlywood density ($r = 0.64$, $p<0.001$), while maximum latewood density correlates the best with mean June-August temperature ($r = 0.42$, $p<0.01$). In width measurements, the highest correlation was calculated between tree-ring width and mean June-August temperature ($r = -0.62$, $p<0.001$).

Key words: minimum blue intensity, Black pine, Kojnik, sub-Mediterranean, drought, response, density

PARAMETRI BRANIK DREVES Pinus nigra (Arnold) *IN NJIHOV KLIMATSKI SIGNAL*

Izvleček

Predstavljamo prvo analizo klimatskega signala v branikah črnega bora (P. nigra Arnold*) s pomočjo metode odboja modrega spektra. Izbrana drevesa so rastla na Kojniku. Iz vzorcev debeline 5 mm smo ekstrahirali smolo in jih optično skenirali. Izmerili smo širino celotne branike ter širino in gostoto ranega ter kasnega lesa. Za odstranitev starostnega trenda in drugih ne-klimatskih faktorjev smo merjene časovne serije standardizirali s kubičnim zlepkom. Pri meritvah gostot smo značilne korelacije izračunali med padavinami obdobja maj-junij ter gostoto ranega lesa (r = 0.64, p<0.001), medtem ko je gostota kasnega lesa v najboljši korelaciji s povprečno temperaturo obdobja junij-avgust (r = 0.42, p<0.01). Pri merjenju širin je bila najvišja korelacija med širino celotne branike in povprečno temperaturo obdobja junij-avgust (r = -0.62, p<0.001).*

Ključne besede: metoda odboja modrega spektra, črni bor, Kojnik, sub-mediteran, suša, odziv, gostota

INTRODUCTION
UVOD

Morphological properties of newly developed xylem cells, which define tree-ring characteristics, are influenced by the length of growing season, the growth and speed-rate of cell division and environmental factors (Gričar and Čufar, 2008; Levanič, 1993). The influence of climate on tree growth can be studied using measurements of various tree-ring characteristics; whole tree-ring width (TRW), early / latewood width (EWW / LWW), and tree-ring density. Densitometry is a process in which we obtain measurements of wood density within the tree-ring (Fritts, 1976). Density characteristics of conifer tree-rings were originally studied using X-rays (Parker et al., 1980; Parker et al., 1976; Polge, 1963; Schweingruber et al., 1978), although X-rays had been used even earlier in various qualitative wood evaluation examinations (Tomazello et al., 2008). X-ray densitometry is expensive and it requests under the right angle oriented fibres (Schweingruber et al., 1978), so efforts have been made to develop alternative paleoclimate proxies, which are as reliable as the X-ray densitometry, but can be applied more readily and efficiently. Method of minimum blue intensity, also named minimum blue reflection (MBR), requires no specific equipment other than a Soxhlet extractor, high-quality colour scanner, a personal computer and an appropriate software (McCarroll et al., 2002). Developers assessed the suitability of multiband digital images (RGB) of Scots pine (*Pinus sylvestris* L.) laths as a surrogate for X-ray densitometry. The blue channel proved to correlate most strongly ($r = -0.96$) with maximum latewood density (MXD), measured using optical Walesch 2002 microdensitometer (McCarrol et al., 2002). Intensity of this channel is sensitive to the amount of lignin present; when illuminated by short-wavelength light, the lignin absorbs most of the energy and the light energy absorbed by lignin declines as wavelength increases (McCarroll et al., 2002). However,

[1] S. P., univ. dipl. inž. gozd., Gozdarski inštitut Slovenije, Večna pot 2, 1000 Ljubljana, simon.poljansek@gozdis.si
[2] doc. dr. T. L., univ. dipl. inž. gozd., Gozdarski inštitut Slovenije, Večna pot 2, 1000 Ljubljana, tom.levanic@gozdis.si

the measured tree-ring density represents only the proxy for wood density; these values have not been calibrated.

With densitometry, scientists discovered, at some sites, even stronger relationship between climate and tree-ring density than between climate and tree-ring widths (Cown and Parker, 1978; Levanič et al., 2008; Schweingruber et al., 1978). This is the case of researching on more moist, complacent sites, where the rings may be wide and the widths may exhibit much less variability than wood density characteristics, or in the high latitudes, where MXD is a better indicator of summer temperature than tree-ring width (Kirdyanov et al., 2007). In areas of little width variation, dendroecology may be possible only because of the greater variability in density measurements (Fritts and Swetnam, 1998). In reconstructing climate, some report that it is the MXD that has proved to be the best surrogate for climate (Campbell et al., 2007; McCarroll et al., 2002), while other claim that tree-ring parameters beside TRW reveal little additional potential (Esper et al., 2006). Blue intensity was introduced and tested on *P. sylvestris*, but for a general usage it needs to be tested on other paleoclimatologically important conifers. One of them is *P. nigra* (Arnold) (Levanič et al., 2012; Nicault et al., 2008). X-ray densitometry on *P. nigra* in Spain revealed small MXD inter-series correlations and thus a lower common variance; furthermore, MXD on *P. nigra* does not correlate significantly with climate from previous or current year of growth (Dorado Liñán et al., 2012). Testing MBR on Atlas cedar (*Cedrus atlantica*) showed that MXD contains low common variance and weak climatic signal, comparing to TRW, but it was the minimum density (earlywood density), which seems to provide additional information on past precipitation (Esper et al., 2006). For this reason, climate signal in density of *P. nigra* tree-ring parameters was tested and results compared to width measurements of earlywood, latewood and total tree-rings.

The aims of this study are to:

- Explore potential of minimum blue reflectance (MBR) on *P. nigra* in Slovenian sub-Mediterranean region,
- identify climate signal in tree-ring parameters, and to
- compare climate signal in multiple tree-ring parameters

MATERIALS AND METHODS
MATERIALI IN METODE

SPECIES SELECTION, SITE DESCRIPTION AND CLIMATE DATA
IZBIRA DREVESNE VRSTE, OPIS RASTIŠČA IN KLIMATSKI PODATKI

P. nigra is a widespread species in the Mediterranean area and it grows on a wide altitudinal range from 500 to 2,000 m a.s.l. (Vidaković, 1991). In Slovenia, *P. nigra* is widely dispersed and can be found on southern slopes of the Kolpa River valley, in the Iška gorge, above the Gorenja Trebuša valley, on the slopes of Jerebica and Mangart, above the Tolminka and in some parts of the Karavanke Mts (Brus, 2004), as well as in the Kras region, where the barren karst areas were afforested with *P. nigra* in the late 18th century (Kranjc, 2009). It can grow on extreme sites, where missing rings (Wilmking et al., 2012) can occur (Figure 2). Trees, growing on extreme sites, are suitable for investigation of climatological questions related to tree growth (Fritts, 1976). Trees were sampled in a stand on Kojnik hill (780 m a.s.l.) in sub-Mediterranean Slovenia. The term 'sub-Mediterranean Slovenia' denotes the south-west region of Slovenia, which lies under the Alpi-

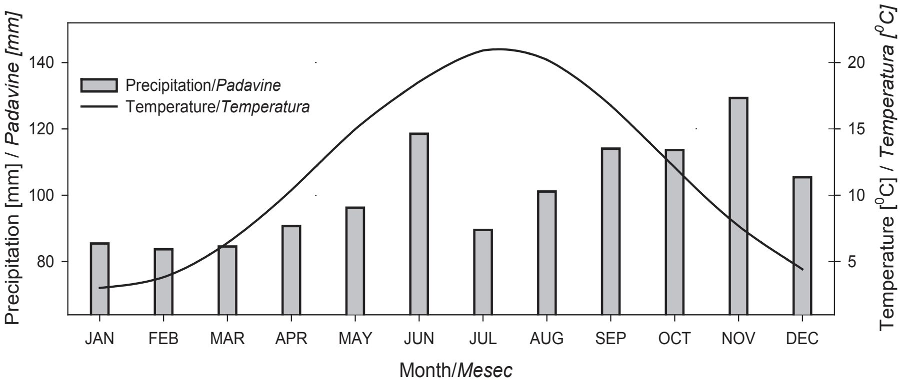


Fig. 1: Long-term average of temperatures and precipitation on monthly basis at Kubed weather station

Slika 1: Dolgoletno merjeno povprečje mesečnih vrednosti temperature in padavin postaje Kubed ne-Dinaric barrier and opens towards the Adriatic Sea, from which the forests grow under the influence of Mediterranean climate (Ogrin, 2005), although there is no strong seasonality in rainfall distribution (Šraj et al., 2008). The area is characterized by its deficit in humidity, owing to the prevailing karst features of the surface, high temperatures and frequent droughts in the summer months of July and August, causing higher potential evapotranspiration than precipitation in July and August (Ogrin, 2005). Climate influence on *P. nigra* from the sub-Mediterranean region has already been investigated (Ogrin, 1989; 1992; 2005; Srebotnjak, 1997), using different climate stations. In our case, the Kubed weather station (available data range from 1950 to 1990), supplied by the Slovenian Environment Agency, was used (Figure 1).

SAMPLE PREPARATION AND MEASUREMENTS
PRIPRAVA VZORCEV IN MERITVE

This investigation was aimed at testing blue reflectance on *P. nigra*, and for this purpose only ten trees were sampled, using 5 mm increment borer. From 1.3 m height, two cores from the opposite sites of the stem were taken perpendicular to the slope, to avoid compression wood, which would influence density measurements. Fresh cores were marked on a side with wood burning pen (pyrography) and put into Soxhlet apparatus to extract resin. Resin extraction was done at the Biotechnical Faculty, Department of Wood Science and Technology. Cores in Soxhlet were treated with 3 liquids in three cycles, each time for 24 hours: first with mixture of n-hexane / ethanol 100 % (2:1 ratio), second 100 % ethanol and third with 100 % distilled water. Our method was modified from originally suggested 30-40 hours of refluxing in ethanol (Campbell et al., 2011). After the laboratory procedure, cores were relocated to the dendrochronological laboratory of the Department of Yield and Silviculture at the Slovenian Forestry Institute. Samples were air dried, fixed on holders and sanded with progressively smoother sanding paper, until high polish surface was achieved. Sample scanning was carried out at the University of Swansea, Geography Department Laboratory, on Epson Expression 1680 flatbed Pro Series scanner. For the blue reflectance measurement, a colour card with steps of known blue intensity is used to remove age and power intensity effect of scanner bulbs and to ensure comparability of blue intensity values measured at different times or with different equipment (Campbell et al., 2011). We used Monaco EZ-colour card (monr2004:08-01 version 2) for light calibration. Originally, 1000 dpi scanning was suggested (Campbell et al., 2011), although even at the modest scanning resolution used, the technique yielded reliable results (McCarroll et al., 2002). But results on *P. abies* showed more pronounced latewood peaks at 1200 dpi (Babst et al., 2009), and as there were some thoughts on using 1200 dpi on very narrow rings of climatically sensitive trees (Babst et al., 2009), we decided to use 1600 dpi. Scanning resolution affec-

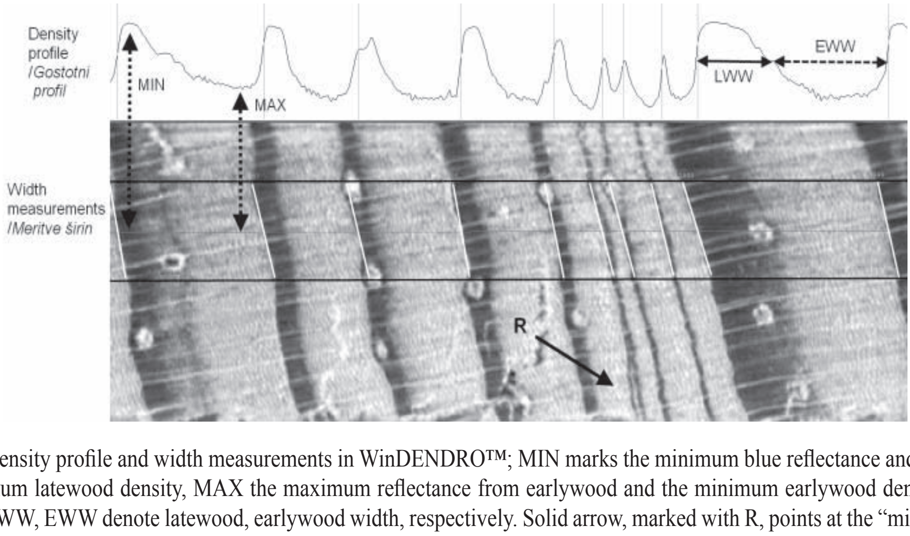


Fig. 2: Density profile and width measurements in WinDENDRO™; MIN marks the minimum blue reflectance and the maximum latewood density, MAX the maximum reflectance from earlywood and the minimum earlywood density, while LWW, EWW denote latewood, earlywood width, respectively. Solid arrow, marked with R, points at the "missing ring"

Slika 2: Gostotni profil in meritve širin branik v programu WinDENDRO™; MIN označuje minimalni odboj modrega spektra svetlobe in hkrati točko maksimalne gostote kasnega lesa, MAX označuje maksimalni odboj modre svetlobe od ranega lesa oziroma minimalno gostoto ranega lesa, medtem ko LWW in EWW označujeta širino kasnega in ranega lesa, v tem zaporedju. Polna puščica, označena s črko R, označuje mesto izklinjene branike ts the density results. This is noticeable if the scanning resolution is increased to 2600 dpi, which is above the hardware resolution of the device, then there is a strong shift towards less intensity and the peaks of the latewood even reached a BR of zero (Babst et al., 2009). Samples were saved as 24-bit colour images in TIFF (Tagged Information File Format). Produced images were analysed using commercially available software WinDENDRO™ for Densities software (www.regentinstruments.com). Brighter part of the image is found in the earlywood, where less dense wood is placed and the light reflectance is higher, while the darker part is in latewood, where MXD is (Figure 2). Values of MBR actually represent amount of light reflected from the sample. From this point on, MAX / MIN will denote the intensity of the light, reflected from the sample; MAX represents maximum amount of reflected light (regularly in earlywood) and MIN minimum amount of reflected light (regularly in latewood). MIN values are, therefore, a proxy record for MXD. The WinDENDRO™ for Densities software enables measuring widths and densities of earlywood, latewood and whole tree-ring. The width of each annual ring was measured to the nearest 0.01 mm and the border between early and latewood was set at 50 % of the density profile.

STATISTICAL ANALYSIS
STATISTIČNA ANALIZA

Crossdating and synchronization of tree-ring time-series was done in PAST-4™ software (www.sciem.com), using visual comparison and statistical coefficients t_{BP} (Baillie and Pilcher, 1973) and GLK% (Eckstein and Bauch, 1969). GLK% measures the year-to-year agreement between the interval trends of two time series, based upon the sign of agreement and expressed as percentage. Coefficient t_{BP} determines the correlation between two time series. To remove long-term trends (Cook, 1985), all individual proxy series were standardized using 67 % cubic smoothing spline (Cedilnik, 1991) with a 50 % frequency cut-off and all basic statistical parameters of proxies were calculated in ARSTAN for Windows, version 4.1d, program provided by Cook and Krusic, Lamonth-Doherty Earth Observatory, Columbia University (http://www.ldeo.columbia.edu/trl). Each year's proxy value was divided by the year's value of the fitted curve to give a dimensionless index with a mean of 1. This was done to remove non-climatic trends due to the tree age, size and the effects of stand dynamics (Cook and Kairiukstis, 1990). MIN has low values of autocorrelation and, for this reason, some authors do not apply standardization to raw chronologies (Kirdyanov et al., 2007), while others use negative exponential or linear equation (Campbell et al., 2007). 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 the outliers. This way standardized chronology was produced (Cook, 1985; Cook and Kairiukstis, 1990). Expressed population signal (EPS) and sensitivity analysis were also calculated; A series with EPS threshold of at least 0.85 (Briffa and Jones, 1990) and 0.2 of mean sensitivity (Speer, 2010) is normally regarded as a series that is sensitive enough for climate reconstruction. Sensitivity is a measure of a relative difference in proxy value between two adjacent tree-rings; the values of mean sensitivity range from 0, where there is no difference to 2, where a zero value occurs next to a nonzero one in the time sequence (Fritts, 1976). Finally, the Pearson correlation coefficient (r value) was calculated between climate data and proxy data.

RESULTS
REZULTATI

STANDARDIZED CHRONOLOGIES
STANDARDNE KRONOLOGIJE

Selected trees were from 51 to 95 years old, with an average of 86 years (Table 1). The terminal-ring was formed in the year 2011, while the oldest tree-ring was dated in the year 1917. Variability of tree-ring parameters, measured in standard deviation (SD), was the highest in LWW (0.57). Very similar SD values were in TRW, EWW and MIN (from 0.34 to 0.35). Average sensitivity reached threshold values in all series, except MAX; the highest was calculated in latewood widths (average 0.45) and the lowest in MAX reflectance (average 0.06).

In the standardization process, the abnormal standardized values at the end of TRW, LWW and EWW chronology were observed in trees 2, 3, 4, 7, 8 and 10. Unusually high values of the years 2010 and 2011 are the mathematical fault; In the process of dividing measured values with expected values of below 0.5 mm, the function of dividing transforms into multiplying, causing higher than measured values. Other problems of the so-called end-effect in standardization and how to avoid them are beyond the scope of this paper and are described elsewhere (Esper et al., 2006; Melvin and Briffa, 2008). As

Table 1: General statistics of whole tree-ring width (TRW), earlywood width (EWW), latewood width (EWW), maximum reflectance (MAX) and minimum reflectance (MIN) standardized (STD) chronologies, with data on standard deviation (SD), mean sensitivity (MS) and autocorrelation coefficient (AC) for each of the individual standardized tree-ring indices and the mean

Preglednica 1: Statistični kazalci standardnih (STD) kronologij celotne širine branik (TRW), širine ranega lesa (EWW), kasnega lesa (LWW), maksimalnega odboja (MAX) in minimalnega odboja (MIN), s podatki o standardnem odklonu (SD), srednji stopnji občutljivosti (MS) in avtokorelacijskem količniku (AC) za vsako od individualnih oziroma za povprečno standardno kronologijo (mean)

STD chronology of:			TRW	EWW	LWW	MAX	MIN
n	Period/*Obdobje*	Years / *Leta*	SD/MS/AC	SD/MS/AC	SD/MS/AC	SD/MS/AC	SD/MS/AC
1	1961-2011	51	0.25/0.27/0.22	0.26/0.28/0.16	0.39/0.47/0.08	0.08/0.08/0.09	0.27/0.23/0.18
2	1925-2011	87	0.35/0.29/0.49	0.35/0.28/0.52	0.45/0.43/0.32	0.06/0.05/0.17	0.36/0.26/0.44
3	1925-2011	87	0.33/0.25/0.45	0.33/0.25/0.37	1.33/0.45/0.51	0.09/0.08/0.28	0.24/0.24/0.15
4	1919-2011	93	0.36/0.31/0.45	0.32/0.29/0.35	0.53/0.44/0.43	0.06/0.05/0.22	0.31/0.24/0.39
5	1917-2011	95	0.39/0.33/0.60	0.38/0.35/0.53	0.51/0.47/0.48	0.08/0.06/0.43	0.39/0.27/0.41
6	1922-2011	90	0.37/0.32/0.46	0.36/0.34/0.32	0.48/0.41/0.47	0.09/0.08/0.19	0.29/0.23/0.40
7	1921-2011	91	0.37/0.31/0.40	0.35/0.31/0.34	0.49/0.45/0.30	0.07/0.07/0.32	0.45/0.31/0.49
8	1920-2011	92	0.40/0.31/0.53	0.39/0.30/0.51	0.50/0.45/0.40	0.06/0.05/0.13	0.51/0.31/0.62
9	1924-2011	88	0.33/0.28/0.41	0.34/0.29/0.41	0.49/0.48/0.25	0.06/0.05/0.26	0.28/0.25/0.20
10	1925-2011	87	0.39/0.29/0.50	0.38/0.29/0.50	0.51/0.43/0.39	0.08/0.06/0.40	0.27/0.22/0.39
Mean/*Povprečje*			0.35/0.29/0.45	0.35/0.30/0.40	0.57/0.45/0.36	0.07/0.06/0.25	0.34/0.26/0.37
EPS ≥ 0.85			1937	1937	1940	1967	1951
inter-series correlation / *inter-korelacija*			0.477	0.458	0.357	0.309	0.275

there are no climate data from the Kubed weather station after 1990, we simply removed the years 2010 and 2011. For climate influence analysis, only the part of chronologies, where EPS is higher or equal to 0.85, and without the years after 1990, was used. Observing the plotted raw chronologies of TRW, EWW and LWW (Figure 3), the highest variability among width parameters is noticed in LWW, and in density in MIN. The lowest variability in standardized chronologies is noticed in MAX, this is confirmed by the mean value of SD (Table 1).

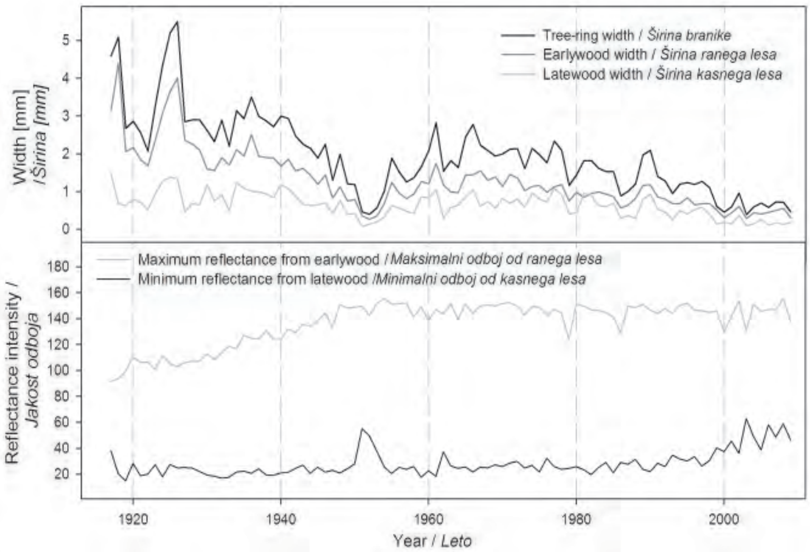


Fig. 3: Raw chronologies of whole tree-ring width, earlywood and latewood in the upper part of the figure, with maximum and minimum blue reflectance in the lower part of the figure

Slika 3: Osnovne kronologije širin branik, širin ranega ter kasnega lesa v zgornjem delu slike in maksimalnega ter minimalnega odboja v spodnjem delu slike

CLIMATE-TREE GROWTH RELATIONSHIP

ODNOS MED KLIMO IN RASTJO DREVES

Widths of tree-ring parameters (TRW, EWW, LWW) are positively correlated with March temperature and July, August precipitation, and negatively with summer temperatures from July, August and September (Figure 4). This relationship is even stronger, if months are combined into periods. The highest correlation between width parameters and climate is with June-August mean temperature and the highest individually is found between LWW and August temperature (r = -0.60, p<0.001). Precipitation has positive influence on all width parameters in current summer period May-August, with the highest correlations between LWW and August precipitation (r = 0.44). For the previous growth year, significant correlations with precipitation were found in EWW; May (r =

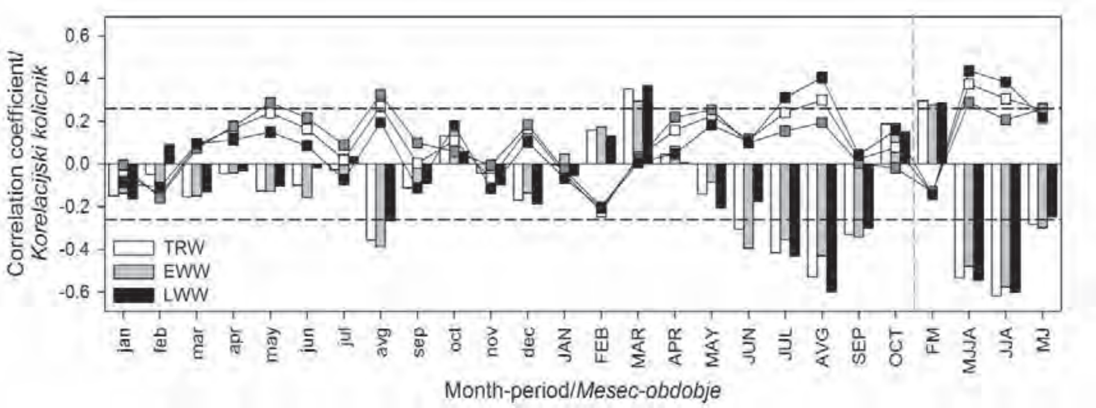


Fig. 4: Correlation coefficients between tree ring width (TRW), earlywood width (EWW), latewood width (LWW) and the climate data; temperatures (columns) and precipitation (lines). Significance is presented with dashed line (r = 0.26, p=0.05 %). Values are presented for previous and current years by months and periods (FM; February-March, MJJA; May-August, JJA; June-August, and MJ; May-June)

Slika 4: Korelacijski koeficienti med širino branike (TRW), širino ranega (EWW) ter kasnega lesa (LWW) in klimo; temperaturo (stolpci) ter padavinami (črte). Statistična značilnost je predstavljena s črtkano črto (r = 0,26, p=0,05 %). Vrednosti so predstavljene za preteklo in tekoče leto z meseci ter periodami (FM; februar-marec, MJJA; maj-avgust, JJA; junij-avgust, in MJ; maj-junij)

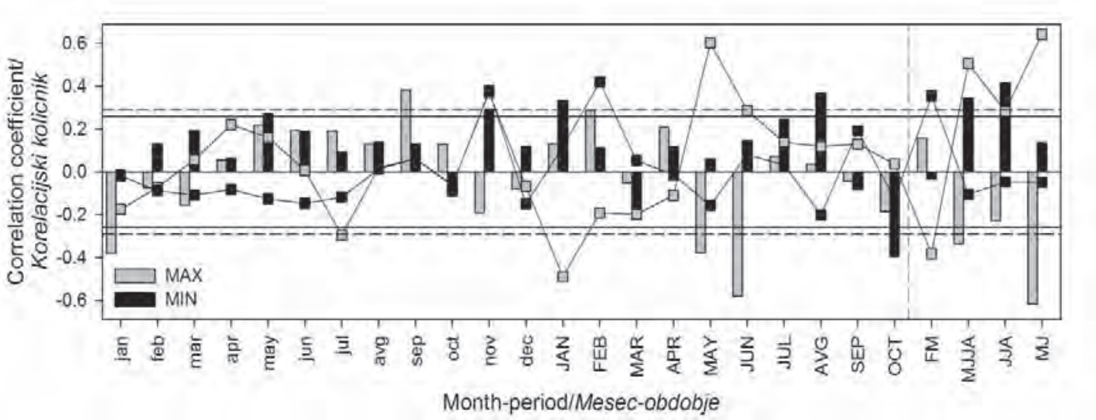


Fig. 5: Correlation coefficients between earlywood density (MAX), latewood density (MIN) and the climate data; temperatures (columns) and precipitation (lines). Significance is presented with solid line (r = 0.29, p=0.05 %) for latewood (MIN) and with dashed line (r = 0.26, p=0.05 %) for earlywood (MAX). Values are presented for previous and current years by months and periods (FM; February-March, MJJA; May-August, JJA; June-August, and MJ; May-June)

Slika 5: Korelacijski koeficienti med gostoto ranega lesa (MAX) in kasnega lesa (MIN) ter klimo; temperaturo (stolpci) ter padavinami (črte). Statistična značilnost koeficientov korelacij za gostoto kasnega lesa (MIN) je predstavljena s črtkano črto (r = 0.29, p=0.05 %), s polno črto (r = 0.26, p=0.05 %) pa statistična značilnost ranega lesa (MAX). Vrednosti so predstavljene za preteklo in tekoče leto z meseci ter periodami (FM; februar-marec, MJJA; maj-avgust, JJA; junij-avgust, in MJ; maj-junij)

0.29) and August (r = 0.33) (Figure 4). In the density measurements, the strongest correlations were found between MAX and June (r = -0.58) or May-June temperature (r = -0.62), and precipitation from May (r = 0.60) and May-June period (r = 0.64) (Figure 5). Also, seasonalized precipitation from May-August period significantly correlates with MAX, but this goes more on the account of combining significant May and June precipitation influence with insignificant influence of July and August precipitation. Correlation coefficients between MIN and climate are not that strong – we found the highest correlation with mean June-August temperature, r = 0.42 (Figure 5). While TRW, EWW and LWW have uniform, negative or positive correlation values with temperatures and precipitation (Figure 4), the MAX and MIN have, in the majority of months or periods, opposite values (Figure 5). In measuring the widths, high summer temperatures have a negative influence on the tree-ring, early- and latewood widths, while spring temperatures exert a positive influence. In measuring densities, summer temperatures correlate negatively with MAX (proxy for earlywood density) and positively with MIN (proxy for latewood density). The higher the summer temperatures, the denser the latewood and earlywood.

DISSCUSION
RAZPRAVA

In this short investigation, MBR was used on 5 mm thick cores. Originally, this method was applied on 10 or 12 mm wide cores (McCarroll et al., 2002). Whether there is a difference in success of resin removal between 5 mm cores and thin laths, cut out of 10 mm cores, (Campbell et al., 2011), further tests should be done. In the process of sanding cores, differences in latewood colour between roughly, medium and smoothly sanded samples were noticed. None of the sample surface was burned due to the heat between the sample and the circulating sanding paper, but this influence could be avoided using the core-microtome (Gärtner and Nievergelt, 2010). We are aware that influence of coloured heartwood on reflectance readings is also unknown, so further investigations should be carried out in this direction, as previously suggested by Babst et al. (2009).

Age trend and stand influence were removed from raw chronologies using standardization. In all chronologies, except in MAX, an unusually great growth decline in the 1950-1954 period is observed (Figure 3). The reason could be a forest fire, as the majority of the trees had similar response. Forest fire already influenced forest in this area in the past (Jurc, 2001). With the length of 95 years, we have developed twice as long *P. nigra* site chronology, compared to previously published *P. nigra* chronology from sub-Mediterranean Slovenia (Ogrin, 2005), but shorter than developed chronologies from the Divača Komen area (Srebotnjak, 1997). To test reliability of the newly developed Kojnik site chronology, we compared it to the available chronologies, archived at the Slovenian Forestry Institute, Department for Yield and Silviculture. We obtained good results comparing Kojnik chronology to *P. nigra* chronology from a Croatian site with 7.3 t_{BP} / 68.9 GLK% (Poljanšek and Levanič, unpublished data), Šipovo and Krivaja chronology from BiH with t_{BP} > 3 / GLK% > 57 (Poljanšek S. et al., 2012), and *P. heldreichii* chronology from BiH t_{BP} > 4.2 / GLK% 69.7 (Poljanšek and Levanič, unpublished data). These results confirm transect from BiH over Croatia towards Slovenia, but for further investigations, a denser dendrochronological network is needed.

All tree-ring parameter chronologies have low EPS values in the beginning of the chronologies (Table 1), which could be the influence of a ''juvenile effect''. Juvenile wood is relatively thin-walled lignified xylem tissue, which is low in density and is formed in young trees or in tissues located near the stem apex (Fritts, 1976). Its influence is well known for the first 50–100 years in *P. nigra* tree-ring width, density and stable isotope series (Dorado Liñán et al., 2012), but if trees grow on extreme sites, this juvenile period is shorter (Fritts, 1976). One of the possible reasons for weak signal in MIN could be the influence of the resin ducts, but it is difficult to address influence of resin ducts on MIN variations, as the relatively large intra-tree density variations have been also reported for species, with less resin ducts as *P. nigra,* like balsam fir (*Abies balsamea*) (Koga and Zhang, 2004) and Norway spruce (*Picea abies*) (Jyske, 2008). In *A. balsamea*, they discovered that wood density characteristics show remarkably smaller variations, compared to ring width and its components, and that the intra-tree variations in ring width and wood density components are much larger than inter-tree variations (Koga and Zhang, 2004). This is also confirmed by our measurements of MIN and MAX, as their SD values are lower than in width measurements (Table 1). Low inter-series correlation could also be the result of various other factors, such as thinning, crown position, growth rate, fertilization (Jyske, 2008), high between-tree genetic variation (Jyske, 2008), or drought response of individual trees (Martinez-Meier et al., 2008).

CLIMATE AND TREE-GROWTH

KLIMA IN RAST DREVES

Climate signal in radial increments of *P. nigra* from sub-Mediterranean Slovenia has been previously studied in flysch and karst areas (Ogrin, 2005) and in the Divača Komen karst region (Srebotnjak, 1997). Stimulating effect of above average temperatures at the beginning of the growth period is reported; winter: r = 0.50; spring: r= 0.29; March: r = 0.55 (Ogrin, 2005). From Kojnik site, we also report on significant correlations for spring (r = 0.30, p<0.05), and March temperatures (r = 0.35, p<0.05). The negative impact on *P. nigra* radial growth of the above-average temperatures in summer (r = -0.39) and during the entire growth period from April through September (r = -0.48) is clear (Ogrin, 2005). We have significantly strong correlation with mean June-August temperature (r = -0.62, p<0.001), while correlation with mean temperature from growth season is the same as previously published (Ogrin, 2005); –0.49 (p<0.001). When mean monthly temperatures exceed values of 20^{o}C, negative influence of above average temperatures is expected, as this is approximately the temperature for the optimum growth of trees in the moderate vegetation zone (Fritts, 1976). High temperatures are associated with moisture stress, higher evapotranspiration and, if there is absence of precipitation, also with water deficit in photosynthesis (Fritts, 1976). Current year growth is also affected by climate from the previous year(s) (Cook and Kairiukstis, 1990). While Ogrin (2005) reports on negative influence of previous year autumn temperatures (September: r = -0.29; October: r = -0.30; November: r = -0.35), we calculated significant influence only for the August temperature (r = -0.39, p<0.01). Higher autumn temperatures can prolong the formation of tissues, which use up the nutrition reserve prepared for the growth in spring (Fritts, 1976). These results are also observed in Spain, where variables based on ring width correlate well with the previous summer to autumn temperatures (Dorado Liñán et al., 2012). The density response to temperatures is seen in the early summer period for MAX (May; r = -0.38 and June; r = -0.58, both p<0.01) and in the late summer period for MIN (r = -0.42, p<0.01). According to the known mechanisms of tree-ring formation and hypotheses of environmental control of tracheid production and maturation, latewood cells are produced, enlarged and thickened during the second part of a growing season (Kirdyanov et al., 2007). In correlation values of MIN, progressively higher influence of temperatures from May till August is observed (Figure 5), but the only significant month is August (r = -0.37, p<0.05), or from June-August period (r = -0.42, p<0.01). This result is not in accordance with a study from Spain, where they report that MXD (measured with X-ray densitometry) does not correlate significantly with climate neither in the previous nor current year of growth (Dorado Liñán et al., 2012).

Precipitation influence on width parameters in our study is less involved than temperature influence. From the Divača Komen Karst, response function recognized June precipitation as significantly influencing TRW, EWW and LWW of *P. nigra* (Srebotnjak, 1997), while Ogrin (2005) reports on correlation coefficients between TRW and precipitation- July: r = 0.30; September: r = 0.39; summer: r = 0.32; growth period: r = 0.37; and annual amount of precipitation: r = 0.34. Similar coefficients are calculated in our study, as TRW correlates with summed summer (May-August) precipitation (r = 0.38, p<0.01), and whole growing season (April-September) precipitation (r = 0.35, p<0.01). In previous research (Ogrin, 1989), when same locations of sampling trees were used, but with the climate stations Kubed and Kozina, higher correlations between TRW and total precipitation in growth period were discovered (r = 0.64), and with temperatures: March (r = 0.41), May (r = -0.36) and August (r = -0.37). In our investigation, the highest correlation with precipitation was found between MAX and May-June summed precipitation (r = 0.64, p<0.001). This result is similar to climate signal investigation in *C. atlantica* from Morocco, where the highest correlations were found between MAX and precipitation sums October-September (r = -0.54) and December-July (r = -0.55) (Esper et al., 2006). In the event of reconstructing May-June precipitation using our MAX measurements, there would be a problem; although this is the strongest correlation discovered in our investigation, it would be in a disagreement with the 0.20 sensitivity threshold principle (Speer, 2010). Reduced signal strength statistics of MAX was also discovered in *C. atlantica* (Esper et al., 2006). Our results show some significant correlations between MIN and climate data (Figure 5). To statistically improve climatic signal in *P. nigra* MIN chronologies, two approaches have been used so far: (1) where two proxies have the same dominant climate control, their combination enhances climatic signal and combining can be used to increase calibration correlation coefficients (Gagen et al*., 2006;* Stahle et al., 1991) and (2) climatic signal can be maximised with removing the relationship between MXD and TRW out of the maximum density series (Kirdyanov et al., 2007). We have not tested these two approaches, as this topics goes beyond the scope of this paper. However, for the future use of MBR method on the samples from the Balkan region, these two methods need to be taken into account as well as ecophysiological background of the tree-ring formation (which is also not discussed here). In particular, lignification of cell walls plays an important role in the climate-growth relationship as it influences the ring density (Gindl et al., 2000) and hence MBR readings.

CONCLUSIONS
ZAKLJUČKI

With the introduction of the Minimum blue reflectance (blue intensity) method on *P. nigra*, we tested the climate signal embedded in tree-ring density. We discovered that latewood density (MIN) contains less strong climate signal than TRW, but the earlywood density (MAX) shows equal or stronger climate signal. The strongest correlation coefficient within density measurements was found between summed May-June precipitation and MAX ($r = 0.64$, $p<0.001$) and in width measurements between TRW and mean June-August temperature ($r = -0.62$, $p<0.001$). Our results of climate signal in *P. nigra* width parameters of tree-rings are similar to previously published results, with no great differences observed.

SUMMARY
POVZETEK

Na lastnosti branik, kot so širina celotne branike (TRW), širina ranega (EWW) in kasnega lesa (LWW) ter gostota ranega (MAX) in kasnega lesa (MIN), deluje več dejavnikov (Gričar in Čufar, 2008; Levanič, 1993). Z meritvami naštetih lastnosti branik lahko preučujemo vpliv klime na rast dreves. Raziskovalci so opazili, da ima MIN močnejši klimatski signal kot samo TRW (Cown in Parker, 1978; Levanič in sod., 2008; Schweingruber in sod., 1978). Sprva so gostotne profile branik merili s pomočjo rentgenskih žarkov, vendar je ta metoda draga in zahtevna (Schweingruber in sod., 1978). Za cenejšo pripravo vzorcev in pridobivanje rezultatov, primerljivih po metodi rentgenskih žarkov, so odkrili metodo odboja modrega spektra (Campbell in sod., 2011; McCarroll in sod., 2002), ki za svoje delovanje ne potrebuje nič drugega kot Soxhlet, kakovosten optični čitalec in osebni računalnik. Vrednost odboja svetlobe modrega spektra bo največja v ranem lesu, ki je svetlejši, najmanj odboja pa v kasnem lesu, ki je temnejši. Zaradi tega se MAX uporablja za oznako gostote ranega in MIN kasnega lesa. Prvi rezultati uporabe te metode opozarjajo, da vse iglaste drevesne vrste v MIN ne vsebujejo močnega klimatskega signala ter da je MAX tista, ki si zasluži pozornost (Esper in sod., 2006). Zato je pomembno, da preverimo drevesne vrste, ki dokazano vsebujejo klimatski signal v TRW, kot na primer črni bor (*Pinus nigra* Arnold) (Levanič in sod., 2012; Nicault in sod., 2008). Prve raziskave MIN na *P. nigra* iz Španije so pokazale, da se gostota, merjena z rentgenskimi žarki, ne odziva na klimatsko variabilnost (Dorado Liñán in sod., 2012). Toda ker črni bor raste na ekstremnih rastiščih in ima jasno izražen rani ter kasni les in je tudi predmet že mnogih uspešnih raziskav (Levanič in sod., 2012; Ogrin, 2005; Poljanšek in sod., 2012), smo želeli novo metodo merjenja gostote preskusiti na tej vrsti.

Izbrana drevesa so rastla v sestoju na apnenčasti podlagi na hribu Kojnik (780 m n.m.v.). Ta lokacija je bila izbrana na podlagi našega predvidevanja, da imajo drevesa s takega rastišča v parametrih branik klimatski signal. Območje je pod vplivom submediteranske klime (slika 1), vendar brez stroge periodičnosti v padavinskem režimu (Šraj in sod., 2008). Visoke temperature in pogoste poletne suše povzročajo višjo potencialno transpiracijo, kot je količina padavin v juliju in avgustu (Ogrin, 2005). Za potrebe analize vpliva klime na rast dreves smo uporabili vremensko postajo Kubed. Izbrana drevesa so bila vzorčena s 5 mm prirastnim svedrom, čeprav se po originalni metodi uporabljajo 10 ali 12 mm debeli vzorci (McCarroll in sod., 2002). Vzorci so bili vstavljeni v Soxhlet, kjer smo jih očistili smole. Aparat Soxhlet predstavlja povezavo bučke, iz katere s pomočjo gretja izhlapeva alkohol, ki se v povratnem hladilniku utekočini in steka v ekstraktor. Vzorci ležijo v ekstraktorju, kjer jih preliva alkohol, ki topi smolo. Ob doseženem zgornjem nivoju se alkohol prek cevke, imenovane natega, prelije nazaj v bučko in postopek se ponovi. Sledilo je sušenje, brušenje ter skeniranje vzorcev. Ob brušenju z vedno bolj finim brusnim papirjem smo opazili postopno vidno izboljšanje kakovosti površine vzorcev in prepoznali nevarnost, da se zaradi povečanega trenja med brusnim papirjem in vzorcem površina lesa prekomerno segreje, pri čemer prihaja do zažiganja površine lesa ter spremembe barve lesa. V prihodnje bi lahko vpliv brušenja odpravili z uporabo mikrotoma za prirastne vzorce (Gärtner in Nievergelt, 2010). Pred uporabo skenirne naprave smo njeno luč umerili z barvno lestvico. Zaradi boljše vidljivosti ozkih branik smo vzorce skenirali s 1600 dpi, čeprav je priporočljiva natančnost 1200 dpi (Babst in sod., 2009). Za merjenje parametrov branik smo uporabili program WinDENDRO™. Merili smo

širino celotne branike ter širino in gostoto ranega ter kasnega lesa. Izmerjene časovne serije smo standardizirali s pomočjo kubičnih zlepkov (Cedilnik, 1991). To je s polinomom tretje stopnje določena krivulja, ki je zvezno odvedljiva in je približek pričakovani rasti dreves, brez vplivov okolja. Od celotne dolžine izračunanih standardnih kronologij (slika 3) smo za korelacijsko analizo s klimo uporabili le tisti del kronologij, ki je dosegel mejno vrednost EPS-količnika. Ta določa del kronologije, ki ima značilen skupen signal, primeren za analize vplivnih dejavnikov (Briffa in Jones, 1990). Ta vrednost je bila prva dosežena pri TRW v letu 1937, najkasneje pa pri MAX, šele v letu 1967 (preglednica 1). Slab skupen signal lahko pripišemo individualni rasti dreves v njihovem juvenilnem obdobju (Dorado Liñán in sod., 2012) in fiziološkim lastnostim lesa iz tega obdobja. Slabše ujemanje med drevesi v parametrih MIN in MAX bi lahko bile tudi posledice dejavnikov, kot so redčenja, lastnosti krošenj, genetske variabilnosti med drevesi (Jyske, 2008) ali individualnih odzivov dreves na sušne razmere (Martinez-Meier in sod., 2008).

Ugotovili smo pozitivno korelacijo med TRW, EWW ter LWW in marčevskimi temperaturami ter padavinami v juliju in avgustu, ter negativni vpliv julijskih, avgustovskih ter septembrskih temperatur (slika 4). Rezultati korelacij med padavinami oziroma temperaturami ter parametri širin so skladni s predhodnimi objavami raziskav rasti *P. nigra* z območja sub-mediteranske Slovenije (Ogrin, 1989; 2005; Srebotnjak, 1997). Poleg značilnih korelacij s klimatskimi parametri tekočega leta smo, podobno kot v Španiji (Dorado Liñán in sod., 2012), identificirali tudi značilne vplive klime predhodnega leta (slika 4). Višje poznopoletne temperature lahko vplivajo na podaljšano rast tkiv in porabo zalog hranil, prihranjenih za začetek prihodnje rastne sezone (Fritts, 1976). Na splošno so poletne padavine pozitivno korelirale z vsemi parametri širin, medtem ko je korelacija z gostoto slabše izražena. Najvišja korelacija med MIN in klimo je bila s povprečno temperaturo obdobja junij-avgust ($r = 0.42$), medtem ko je imela MAX še višjo korelacijo s količino padavin maj-junij ($r = 0.64$) (slika 5). Podobno največjo korelacijo med padavinami in gostoto ranega lesa so našli na cedri (Esper in sod., 2006); največja izračunana korelacija je bila med MAX in padavinami iz obdobja maj-junij. Pogoste dolgotrajne suše in vročinski valovi so lahko vzrok, da smo kljub slabi odzivnosti gostote branik *P. nigra* na klimo (Dorado Liñán in sod., 2012) lahko potrdili povezavo med MIN in povprečno temperaturo v obdobju junij-avgust (slika 5).

Z uporabo metode odboja modrega spektra smo preskušali vsebnost klimatskega signala v branikah dreves *P. nigra*. Odkrili smo, da gostota kasnega lesa (MIN) ne vsebuje tako močnega klimatskega signala kot širina celotne branike (TRW), je pa bil največji količnik izračunan med gostoto ranega lesa (MAX) in padavinami obdobja maj-junij ($r = 0,64$, $p<0,001$). Ker je gostota branik manj pod vplivom lokalnih dejavnikov kot TRW (Levanič in sod., 2008), klimatski signal pa se lahko s posameznimi metodami še izboljša (Gagen in sod., 2006; Stahle in sod., 1991), bi lahko več prihodnjih raziskav namenili za preskus rekonstrukcij pretekle klime iz MAX.

ACKNOWLEDGEMENTS
ZAHVALE

The authors would like to express warm thanks to Damjan Vatovec, Slovenian Forestry Service, for field support, Miha Humar for using Soxhlet during resin extraction, and Miha Demšar from the Slovenian Environmen Agency for providing us with meteorological data. Special thanks also to the team of dendrochronologists from the Swansea University; Danny McCarroll, Neil J. Loader, Iain Robertson and Giles H. F. Young for their help in the laboratory. This investigation was financed by student grant of Simon Poljanšek and EUFORINNO project (European Forest Research and Innovation, Grant Agreement No. 315982); EU 7th Frame Work Program – REGPOT 6/2012-12/2015.

REFERENCES
VIRI

Babst F., Frank D., Büntgen U., Nievergelt D., Esper J. 2009. Effect of sample preparation and scanning resolution on the Blue Reflectance of *Picea abies*. TRACE- Tree Rings in Archaeology, Climatology and Ecology, 7: 188-195.

Baillie M. G. L., Pilcher J. R. 1973. A simple cross-dating programme for tree-ring research. Tree-Ring Bulletin, 33: 7-14.

Briffa K. R., Jones P. D. 1990. Basic chronology statistics and assessment. V: Methods of dendrochronology: applications in the environmental sciences. Cook E. R. in sod. (ur.). (Methods of dendrochronology: applications in the environmental sciences, Dordrecht, Boston, London, Kluwer academic publishers: 137-152

Brus R. 2004. Drevesne vrste na slovenskem (Tree species on slovenian area; in slovenian). (ur.) Ljubljana, Mladinska založba: 399 str.

Campbell R., McCarroll D., Loader N. J., Grudd H., Robertson I. in sod. 2007. Blue intensity in *Pinus sylvestris* tree-rings: developing a new palaeoclimate proxy. The Holocene, 17, 6: 821-828.

Campbell R., McCarroll D., Robertson I., Loader N. J., Grudd H. in sod. 2011. Blue Intensity In *Pinus sylvestris* Tree Rings: A Manual for A New Palaeoclimate Proxy. Tree-Ring Research, 67, 2: 127-134.

Cedilnik A. 1991. Aproksimacija rastnih funkcij s kubičnimi zlepki. Zbornik gozdarstva in lesarstva, 37: 117-123.

Cook E. R. 1985. Time series analysis approach to tree ring standardization: Dissertation. (University of Arizona). Tucson: 171 str.

Cown D. J., Parker M. L. 1978. Comparison of annual ring density profiles in hardwoods and softwoods by X-ray densitometry. Canadian Journal of Forest Research, 8, 4: 442-449.

Dorado Liñán I., Gutiérrez E., Heinrich I., Andreu-Hayles L., Muntán E. in sod. 2012. Age effects and climate response in trees: a multi-proxy tree-ring test in old-growth life stages. European Journal of Forest Research, 131, 4: 933-944.

Eckstein D., Bauch J. 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. Forstwissenschaftliches Centralblatt, 88, 4: 230-250

Esper J., Büntgen U., Frank D., Nievergelt D., Nievergelt D. in sod. 2006. Multiple tree-ring parameters from Atlas cedar (Morocco) and their climatic signal. Tree rings in archaeology, Climatology, and Ecology (TRACE), 4: 46-55.

Fritts H. C. 1976. Tree rings and climate. (ur.) London, New York, San Francisco, Academic Press: 567 str.

Fritts H. C., Swetnam T. W. 1998. Dendroecology: A tool for evaluating variations in past and present forest environments. V: Advances in ecological research. Begon M. in sod. (ur.). Advances in ecological research, 111-154.

Gagen M., McCarroll D., Edouard J.-L. 2006. Combining Ring Width, Density and Stable Carbon Isotope Proxies to Enhance the Climate Signal in Tree-Rings: An Example from the Southern French Alps. Climatic Change, 78, 2: 363-379.

Gärtner H., Nievergelt D. 2010. The core-microtome: A new tool for surface preparation on cores and time series analysis of varying cell parameters. Dendrochronologia, 28, 2: 85-92.

Gindl W., Grabner M., Wimmer R. 2000. The influence of temperature on latewood lignin content in treeline Norway spruce compared with maximum density and ring width. Trees - Structure and Function, 14: 409-414.

Gričar J., Čufar K. 2008. Seasonal dynamics of phloem and xylem formation in silver fir and Norway spruce as affected by drought. Russian Journal of Plant Physiology, 55, 4: 538-543.

Jurc M. 2001. Vpliv požarov na entomofavno - predvsem subkortikalno, v monokulturah črnega bora (*Pinus nigra* ARN.) na slovenskem Krasu. Zbornik gozdarstva in lesarstva, 66: 25.

Jyske T. 2008. The effects of thinning and fertilisation on wood and tracheid properties of Norway spruce (*Picea abies*)—the results of long-term experiments: (University of Helsinki). Helsinki: 59 str.

Kirdyanov A., Vaganov E., Hughes M. 2007. Separating the climatic signal from tree-ring width and maximum latewood density records. Trees - Structure and Function, 21, 1: 37-44.

Koga S., Zhang S. Y. 2004. Inter-tree and intra-tree variations in ring width and wood density components in balsam fir (*Abies balsamea*). Wood Science and Technology, 38, 2: 149-162.

Kranjc A. 2009. History of Deforestation and Reforestation in the Dinaric Karst. Geographical Research, 47, 1: 15-23.

Levanič T. 1993. Effects of hydromelioration on diameter growth and increment of black alder, ash and oak in Slovene Prekmurje. Zbornik gozdarstva in lesarstva, 42: 7-65.

Levanič T., Gričar J., Gagen M., Jalkanen R., Loader N. in sod. 2008. The climate sensitivity of Norway spruce (*Picea abies* (L.) Karst.) in the southeastern European Alps. Trees - Structure and Function, 23, 1: 169-180.

Levanič T., Popa I., Poljanšek S., Nechita C. 2012. A 323-year long reconstruction of drought for SW Romania based on black pine (*Pinus nigra*) tree-ring widths. International Journal of Biometeorology, 1-12.

Martinez-Meier A., Sanchez L., Pastorino M., Gallo L., Rozenberg P. 2008. What is hot in tree rings? The wood density of surviving Douglas-firs to the 2003 drought and heat wave. Forest Ecology and Management, 256, 4: 837-843.

McCarroll D., Pettigrew E., Luckman A., Guibal F., Edouard J. L. 2002. Blue Reflectance Provides a Surrogate for Latewood Density of High-Latitude Pine Tree Rings. Arctic, Antarctic, and Alpine Research, 34, 4: 450-453.

Melvin T. M., Briffa K. R. 2008. A "signal-free" approach to dendroclimatic standardisation. Dendrochronologia, 26, 2: 71-86.

Nicault A., Alleaume S., Brewer S., Carrer M., Nola P. in sod. 2008. Mediterranean drought fluctuation during the last 500 years based on tree-ring data. Climate Dynamics, 31, 2: 227-245.

Ogrin D. 1989. Vpliv padavinskih in temperaturnih razmer na širino letnic črnih borov (*Pinus nigra*) v submediteranski Sloveniji. Dela, 6: 10.

Ogrin D. 1992. Vpliv padavin in temperatur na debelinski prirast črnih borov in hrastov gradnov v Koprskem primorju in na Krasu. Annales : anali Koprskega primorja in bližnjih pokrajin = annali del Litorale capodistriano e delle regioni vicine, 2, 2: 9.

Ogrin D. 2005. Tree rings and climate in submediterranean Slovenia. TRACE 2005,

Parker M. L., Bunce H. W. F., Smith J. H. G. 1976. The use of X-ray densitometry to measure the effects of air-pollution on tree growth near Kitimat, British Columbia. (Internationale Tagung uber die Luftverunreinigung und Forstwirtschaft, IUFRO (ur.) Marianske Lazne, Tschechoslowakei., Tagungsbericht: 185-204 str.

Polge H. 1963. Une nouvelle methode de determination de la texture du bois: l'analyse densitometrique de cliches radiographiques. Annales des Sciences Forestieres, 20, 4: 531-581.

Poljanšek S., Ballian D., Nagel T. A., Levanič T. 2012. A 435-Year-Long European Black Pine (*Pinus nigra*) Chronology for the Central-Western Balkan Region. Tree-Ring Research, 68, 1: 31-44.

Schweingruber F. H., Fritts H. C., Bräker O. U., Drew L. G., Schär E. 1978. The X-ray technique as applied to dendrochronology. Tree Ring Bulletin, 38: 61-91.

Speer J. H. 2010. Fundamentals of tree-ring research. (ur.) The University of Arizona Press.: 324 str.

Srebotnjak K. 1997. Dendroekološka analiza črnega bora (*Pinus nigra* Arnold) na Divaško Komenskem Krasu: (Univerza v Ljubljani). Ljubljana: 80 str.

Stahle D. W., Cleaveland M. K., Cerveny R. S. 1991. Tree-ring reconstructed sunshine duration over central USA. International Journal of Climatology, 11, 3: 285-295.

Šraj M., Brilly M., Mikoš M. 2008. Rainfall interception by two deciduous Mediterranean forests of contrasting stature in Slovenia. Agricultural and Forest Meteorology, 148, 1: 121-134.

Tomazello M., Brazolin S., Chagas M. P., Oliveira J. T. S., Ballarin A. W. 2008. Application of x-ray techique in nondestructive evaluation of eucalypt wood. Ciencia y tecnologia, 10, 2: 139-149.

Vidaković M. 1991. Conifers: morphology and variation. (ur.) Zagreb, Grafički zavod Hrvatske: 754 str.

Wilmking M., Hallinger M., Van Bogaert R., Kyncl T., Babst F. in sod. 2012. Continuously missing outer rings in woody plants at their distributional margins. Dendrochronologia, 30, 3: 213-222..

3 RAZPRAVA IN SKLEPI

3.1 RAZPRAVA

3.1.1 Lokalne kronologije BiH

Območje zahodnega dela Balkanskega polotoka med Albanijo in Slovenijo je predstavljalo regijo brez sistematično izdelane dendrokronološke mreže. Prevladujoči del neraziskanega območja leži na območju BiH, zato smo se osredotočili na vzorčenje v tej državi. Za vzorčenje izbrana drevesa so rasla na sedmih različnih lokacijah v območju Dinarskega gorstva. Z našo prvo postavljeno hipotezo smo želeli preveriti, ali se lokalne kronologije črnega bora z različnih rastišč, nadmorskih višin in matičnih podlag med seboj ujemajo. Izbrana stara drevesa so rasla posamično ali v redkih sestojih na rastiščih s plitvimi in odcednimi tlemi, velikim nagibom ter večinoma južno ekspozicijo. S tem izborom rastišč smo se v največji možni meri izognili vplivu sestojnih dejavnikov ter poskrbeli, da so zaporedja širin branik vsebovala predvsem klimatski signal (Fritts, 1976). Ugotovili smo, da se izdelane lokalne kronologije območja BiH medsebojno dobro ujemajo. Najboljše ujemanje je med lokacijama Prusac in Konjuh, najmanjše pa med Krivajo in Šatorjem (Poljanšek in sod., 2012a), vendar sta bili obe lokalni kronologiji zadržani v vzorcu zaradi dobrega ujemanja z drugimi lokalnimi kronologijami. Z izdelavo medsebojno ujemajočih se lokalnih kronologij območja zahodnega dela Balkanskega polotoka je bila vzpostavljena mreža lokalnih kronologij širin branik črnega bora (Poljanšek in sod., 2012a). Medsebojno ujemajoče lokalne kronologije potrjujejo skupen klimatski signal, na podlagi katerega je bila razvita prva regionalna kronologija črnega bora za območje BiH. S tem je dopolnjen manjkajoči del mozaika v dendrokronološki mreži Balkanskega polotoka. Prva hipoteza, da se lokalne kronologije črnega bora z različnih rastišč, nadmorskih višin in matičnih podlag med seboj ujemajo, je zato potrjena (Poljanšek in sod., 2012a).

Poleg vzorčenja dreves črnega bora iz njegovega osrednjega dela areala na zahodnem delu Balkanskega polotoka smo dodatno vzorčili tudi na dveh robnih lokacijah njegove razširjenosti na Balkanskem polotoku (slika 4). Severovzhodna lokacija je od sklenjenega areala ločeno rastišče črnega bora v celinskem delu Balkanskega polotoka in leži v jugozahodnem delu Romunije (Levanič in sod., 2012). Druga lokacija pa leži na severozahodnem delu razširjenosti na Balkanskem polotoku, to je na območju submediteranske Slovenije (Poljanšek in Levanič, 2012a). Sedem lokalnih kronologij osrednjega območja razširjenosti na Balkanskem polotoku in iz njih izpeljano regionalno kronologijo smo zato lahko primerjali z lokalnima kronologijama dveh robnih območij. Novo izdelana regionalna kronologija črnega bora osrednjega območja areala z Balkanskega polotoka se dobro ujema z lokalno kronologijo severovzhodnega roba razširjenosti (Romunija) s t_{BP} 7,9 in GLK% 66; koeficient t_{BP} pa je slabši ob primerjavi regionalne kronologije s kronologijo severozahodnega roba razširjenosti (Slovenija), tudi zaradi krajše dolžine lokalne kronologije (t_{BP} 2,1 in GLK% 59). Malce bolje se lokalna kronologija iz submediteranske Slovenije ujema z lokalnima kronologijama iz osrednjega območja areala; Krivaja in Šipovo (pri obeh velja $t_{BP} > 2,7$ in GLK% > 57), ter z internetno objavljenima kronologijama iz Ravno Borja (NOAA, 2012) (t_{BP} 3,1 in GLK % 62) ter (t_{BP} 3,5 in GLK % 66) z območja najbolj severnega dela areala naravne razširjenosti črnega bora, to je okolice Dunaja (Wimmer in Grabner, 1998).

Medtem ko se kljub velikim razdaljam med lokacijami vzorčenja naštete kronologije razmeroma dobra ujemajo, pa ujemanja med lokalnima kronologijama severovzhodnega in severozahodnega robnega območja praktično ni. Razlog za to so verjetno različne prevladujoče klimatske razmere. Na severozahodni lokaciji prevladujejo submediteranske razmere, medtem ko je za severovzhodno lokacijo značilna celinska klima z le manjšim submediteranskim vplivom (Levanič in sod., 2012). Razlog je lahko tudi v izjemnih vplivih lokalnih dejavnikov na rast dreves in s tem zabrisani klimatski signal širšega območja. Eden izmed takih primerov je bil odkrit na lokaciji Šator, v osrednjem delu areala. Z vzorčenjem debelinskega prirastka tamkajšnjih dreves smo odkrili sedemletni upad prirastka, ki je izhajal iz dogodka leta 1929 (Poljanšek in sod., 2012a). Dejavnik, ki bi lahko povzročil tak odziv dreves, je gozdni požar oziroma z njim povezan ekstremni sušni stres. Ta bi lahko povzročil izredno izgubo več setov iglic ali pa celotne zelene krošnje, zaradi česar je bil proces fotosinteze skoraj ustavljen. Ali je res prišlo v letu 1929 do odpada vseh iglic, bi lahko preverili z metodo sledenja sledi iglic, ki retrospektivno ugotavlja življenjsko dobo iglic terminalnega poganjka (Jalkanen in sod., 2000; Poljanšek in sod., 2011, priloga F).

Slika 4: Lokacije vzorčenja lokalnih kronologiji: Kojnik (KOJ) v Sloveniji za vzorčenje širin branik in gostote lesa ter vzorčenje samo širin branik v Băile Herculane (BaH) v Romuniji in v BiH: Šator (SAT), Šipovo (SIP), Prusac (PRU), Blace (BLA), Peručica (PER), Konjuh (KON) in Krivaja (KRI). Lokacija vremenske postaje v Osijeku je označena z belim kvadratom (avtor slike: Tom Levanič).

Figure 4: Locations of sampling for local chronologies: Kojnik (KOJ) in Slovenia for sampling tree-ring widths and density measurements, and sampling for tree-ring widths only in Băile Herculane (BaH) in Romania and in BiH: Šator (SAT), Šipovo (SIP), Prusac (PRU), Blace (BLA), Peručica (PER), Konjuh (KON) and Krivaja (KRI). Location of the Osijek weather station is marked with white square (author: Tom Levanič).

3.1.2 Ujemanje regionalnih kronologij

Iz sedmih lokalnih kronologij osrednjega območja areala na Balkanskem polotoku je bila izračunana regionalna kronologija BiH. Za potrditev klimatskega signala širšega območja Balkanskega polotoka je bila nova regionalna kronologija s parametroma t_{BP} in GLK% primerjana z objavljenimi kronologijami iz sosednjih območij (Poljanšek in sod., 2012a). Med sabo smo primerjali le objavljene kronologije črnih borov, ker je odziv na klimo vrstno specifičen (García-Suárez in sod., 2009). Kronologije, uporabljene v primerjavi, so na voljo v mednarodni dendrokronološki podatkovni banki ITRDB (NOAA, 2012) ter v arhivu Gozdarskega inštituta Slovenije, oddelka za prirastoslovje in gojenje gozdov.

Ugotovili smo, da se regionalna kronologija črnega bora iz njegovega osrednjega območja na Balkanskem polotoku odlično ujema s tistimi iz južnega dela areala, t.j. Črne gore, Albanije in Grčije, s skrajno severnega robu območja razširjenosti črnega bora- Avstrije (Poljanšek in sod., 2012a) ter severovzhodne točke razširjenosti - jugozahodne Romunije (Levanič in sod., 2012). Ujemanje z regionalnimi kronologijami sosednjih območij, predvsem s transekta Avstrija-Grčija, potrjuje drugo hipotezo o ujemanju regionalne kronologije črnega bora zahodnega dela Balkanskega polotoka z regionalnimi kronologijami sosednjih območij. Na tem mestu lahko opozorimo, da ima dendrokronološka mreža še vedno praznine na območju Srbije, Hrvaške, Makedonije ter Kosova, zato bi lahko tem območjem posvetili naše nadaljnje delo in tako zgostili dendrokronološko mrežo.

3.1.3 Klimatski signal v gostoti ranega in kasnega lesa ter širini branike

Meritev gostot branik je bila opravljena po metodi modrega odboja (McCarroll in sod. 2002). Analiza je prvo testiranje metode modrega odboja na črnem boru, zato je bila testno uporabljena samo na eni lokaciji (Poljanšek in Levanič, 2012a). Izbrana lokacija leži na severozahodnem robu razširjenosti črnega bora na Balkanskem polotoku in je dovolj ekstremno rastišče, kjer so zaradi vpliva submediteranske klime dobre korelacijske povezave med širino branik in klimatskim dejavnikom (Ogrin, 1989 in 2005). Postavljena četrta hipoteza pravi, da na širino branik črnega bora z ekstremnih rastišč vplivajo zgodnje poletne temperature in padavine, medtem ko na maksimalno gostoto kasnega lesa vplivajo pozno poletne temperature in padavine. Na vzorčenih borih je bil analiziran vpliv klime na širino in gostoto ranega ter kasnega lesa. Močni odziv širin branik na količino padavin obdobja maj-avgust je bolj posledica odziva širin kasnega lesa na padavine. Viden je jasen odziv širin kasnega lesa na julijske in avgustovske padavine, zato je na padavine teh dveh mesecev odzivna tudi širina celotne branike. Podobno je v odzivu na temperature, saj je večji del variabilnosti širin branike vezan na variabilnost širin kasnega lesa. Kljub temu lahko del četrte hipoteze o vplivu zgodnje poletnih temperatur in padavin na širino branik zavrnemo. Na širino branik, predvsem pa na širino kasnega lesa, ne vplivajo temperature in padavine zgodnjega poletja, temveč padavine in temperature mesecev julij in avgust, torej sredina oziroma konec poletja (Poljanšek in Levanič, 2012a).

V drugem delu četrte hipoteze smo predpostavili, da na maksimalno gostoto kasnega lesa v braniki vplivajo pozno poletne temperature in padavine, vendar smo z rezultati odkrili, da na maksimalno gostoto kasnega lesa najbolj vplivajo februarske padavine, medtem ko je med poletnimi temperaturami značilen le vpliv avgustovskih temperatur. Del četrte hipoteze o vplivu pozno poletnih temperatur na gostoto kasnega lesa je potrjen, o vplivu pozno poletnih padavin pa zavrnjen, čeprav korelacijske vrednosti izkazujejo določen vpliv avgustovskih padavin na gostoto kasnega lesa, vendar je ta vpliv neznačilen. Ob preučevanju klimatskega signala v gostoti ranega lesa sta bila odkrita značilna temperaturni in padavinski signal zgodnje poletnega obdobja maj-junij (Poljanšek in Levanič, 2012a).

Poleg iskanja obdobja, v katerem imajo temperature in padavine največ vpliva na izbrane parametre branik, smo preučili tudi jakost tega vpliva. Zanimalo nas je, ali je klimatski signal v maksimalni gostoti kasnega lesa bolj izrazit kot v širini branik, k primerjavi pa smo dodali še klimatski signal v gostoti ranega lesa. Najmočnejša klimatska signala sta bila odkrita v gostoti ranega lesa ter v širini branik. Izbrani klimatski signal v gostoti ranega lesa je sicer močnejši, kot je v širini branik, vendar razlika statistično ni značilna. Najmočnejši klimatski signal v gostoti kasnega lesa izraža vpliv temperatur obdobja junij-avgust, vendar njegova jakost ni bolj izrazita, kot je močan klimatski signal v širini branik. Ker smo v tretji hipotezi postavili trditev, da je klimatski signal v maksimalni gostoti kasnega lesa bolj izrazit kot v širini branike, smo to hipotezo zavrnili. Razlog za šibkejši klimatski signal v gostoti kasnega lesa bi lahko iskali v ne dovolj ekstremnem rastišču. Mogoče kljub vsem okoljskim omejitvam izbrano rastišče ne pomeni tako ekstremnih razmer za rast črnega bora. Avtorji metode modrega odboja (McCarroll in sod., 2002) so opozorili, da mora biti metoda testirana na več drevesnih vrstah in na več različnih rastiščih. Rezultati doktorske disertacije so začetek uporabe te metode na črnem boru in veljajo le za območje submediteranske Slovenije oziroma za severozahodni rob areala črnega bora na Balkanskem polotoku (Poljanšek in Levanič, 2013). Zaradi rastiščne in vrstne pestrosti iglavcev na Balkanskem polotoku imamo namen raziskave razširiti še na druga rastišča vzhodnega in notranjega dela Balkanskega polotoka.

Del četrte hipoteze, da na širino branik črnega bora z ekstremnih rastišč vplivajo zgodnje poletne temperature in padavine, je bil preverjen tudi na drevesih s severovzhodnega roba in osrednjega dela areala na Balkanskem polotoku. Izračuni korelacijskih vrednosti med letnim debelinskim prirastkom črnega bora in klimatskima dejavnikoma z zahodnega dela Balkanskega polotoka potrjujejo, da je klimatski signal v širinah branik zaradi prepletanja vplivov mediteranske, gorske in kontinentalne klime tega območja (Zupan Hajna, 2012) veliko bolj kompleksen kot v Alpah, kjer je za debelinsko rast najbolj omejujoč dejavnik temperatura (Frank in Esper, 2005; npr. Carrer in sod., 2007; Levanič in sod., 2008), ali na območju vzhodnega in južnega mediteranskega bazena, kjer so ta dejavnik padavine (npr. Touchan in sod., 2005; Touchan in sod., 2008). Ker se topli in vlažni veter iznad Jadranskega morja nad Dinaridi dviga in trči v hladni zrak, so orografske padavine obilne (Zupan Hajna, 2012). Količine padavin nad najvišjimi vrhovi znašajo od 3.000 do 5.000 mm letno. Medtem ko je količina padavin na Dinarskem gorstvu ena izmed največjih v Evropi, dosega količina padavin na letni ravni v celinskem delu polotoka, na severovzhodnem robu areala črnega bora, le 630 mm (Jones in Harris 2008; Levanič in sod., 2012) in je podobna tisti z območja Dunaja (Wimmer in sod., 2000). Na območjih z manjšo količino padavin je zato pogosteje zaslediti sušni stres dreves kot na območjih z večjimi količinami padavin.

Črni bor ima, podobno kot rdeči, mnogo kompenzacijskih mehanizmov za odziv na sušne razmere. Mednje lahko štejemo npr. skladiščenje vode v vejah in steblu, črpanje razpoložljive vode iz velikih globin ter preprečevanje transpiracije iz iglic (Waring in sod., 1979; Penuelas in Pilella, 2003; Cochard in sod., 2004). Vse to pomaga boru preživeti močnejše oziroma daljše sušno obdobje, hkrati pa zabriše jasen odziv širin branik na padavinski režim. Debelinska rast dreves črnega bora iz osrednjega dela areala ima približno enako močno korelacijo tako s poletnimi padavinami kot s temperaturo (Poljanšek in sod., 2012b). Optimalno temperaturno območje za fotosintezo je odvisno od drevesne vrste, rastišča, sončnega obsevanja, razpoložljive talne vlage in drugih dejavnikov, vendar pa naj bi bila optimalna temperatura za drevesa zmernega pasu na splošno okoli 20 ^{0}C (Fritts, 1976). Med povprečnimi poletnimi temperaturami zraka z visokogorskih rastišč zahodnega dela Balkanskega polotoka in debelinsko rastjo črnega bora smo izračunali negativne korelacije (Poljanšek in sod., 2012b), ker pa so izmerjene povprečne poletne temperature na gorskih lokacijah Dinarskega gorstva le okoli 14 ^{0}C ($T_{povprečna\ junij\text{-}julij}$, postaja Čemerno, 1300 m n.m.v.), neposredno negativnega vpliva na širino branik nismo znali pojasniti. V odnosu med klimo, rastiščem in debelinsko rastjo dreves gre za kompleksen sistem prepletanja vplivov sončnega obsevanja, opoldanskega upada fotosinteze, najnižjih, povprečnih in najvišjih dnevnih temperatur, količin padavin ter razpoložljive vlage v tleh, nezanemarljivi pa niso tudi odzivi dreves v času sušnih razmer. Zato smo padavinski in temperaturni signal območja osrednjega areala črnega bora (Poljanšek in sod., 2012b) pojasnili z variabilnostjo sončnega obsevanja, ki tudi neposredno vpliva na fotosintezo (Stahle in sod., 1991), in potrdili število ur sončnega obsevanja kot nadomestni kazalnik za sušni stres in s tem najvplivnejši dejavnik na širino branik črnega bora iz BiH (Poljanšek in sod., 2013).

Za območje osrednjega dela areala je bila tako odkrita značilna povezava med širino branik in urami sončnega obsevanja iz obdobja junij-julij z vremenske postaje Osijek (slika 4). Bolj izrazit padavinski signal je bil odkrit v celinskem delu Balkanskega polotoka, v severovzhodnem robu areala črnega bora. Tu je bil sušni stres opredeljen s trimesečnim standardiziranim padavinskim indeksom obdobja junij-avgust (Levanič in sod., 2012). Pri tem je bil odkrit jasen vpliv julijskih padavin, in ker je julij sredi poletja, je četrta hipoteza s trditvijo, da na širino branik črnega bora z ekstremnih rastišč vplivajo zgodnje poletne temperature in padavine, zavrnjena. Ta hipoteza je zavrnjena tudi za območje zahodnega dela Balkanskega polotoka, saj je za območje BiH preverjeni klimatski signal potrdil negativno (pozitivno) korelacijo med širino branik in temperaturami (padavinami) celotnega poletja (maj-avgust) (Poljanšek S. in sod., 2012b). Glede na del četrte hipoteze in uporabe sončnega obsevanja kot najbolj omejujočega dejavnika pa jo lahko potrdimo, saj je trajanje sončnega obsevanja mesecev junij-julij, kot obdobja zgodnjega poletja, najbolj vplivalo na širino branik (Poljanšek in sod., 2013).

V raziskavi vpliva klime na širino branik dreves črnega bora iz osrednjega in severovzhodnega robnega dela areala širine ranega in kasnega lesa niso bile izmerjene. S tovrstno analizo bi lahko preverili, ali vsebuje širina kasnega lesa več variabilnosti kot celotna širina branike in močnejši klimatski signal. Do sedaj tudi še ni bilo raziskav sezonske dinamike nastanka lesa pri črnem boru z Balkanskega polotoka, zato ni znano, kateri klimatski dejavniki in na kakšen način vplivajo na posamezne procese nastanka lesa. Veliko informacij bi lahko pridobili tudi s preučevanjem letnega poteka prilagoditve fotosinteze ekološkim razmeram. Zaradi vsega naštetega bi bilo smiselno opravljati kombinirane raziskave znotraj letne in več letne dinamike debelinske rasti ter meritve temperaturne in svetlobne kompenzacijske ter saturacijske točke fotosinteze.

3.1.4 Stabilnost klimatskega signala v času

Pred izračunom rekonstruiranih vrednosti klimatskega dejavnika je treba preučiti stabilnost signala v času. V širini branik črnega bora z zahodnega dela Balkanskega polotoka smo izračunali signal trajanja sončnega obsevanja. Vendar pa dolžina podatkovnega seta sončnega obsevanja za območje severnega dela Balkanskega polotoka (Osijek, Hrvaška), kakor tudi prekratki seti temperaturnih ter padavinskih podatkov iz submediteranskega dela Slovenije, ne omogočajo izračuna večletne drseče korelacije. Za preskus šeste hipoteze o stabilnosti klimatskega signala v času smo namesto sončnega obsevanja zato uporabili korelacijsko povezavo med širinami branik črnega bora iz osrednjega dela areala in padavinami oziroma temperaturami poletnega obdobja (Poljanšek in sod., 2012b). Z drsečo korelacijo odkrita slabša odzivnost širin branik na temperature in padavine se je pokazala v obdobju okoli leta 1980 (Poljanšek in sod., 2012b). Poleg drseče korelacije je slabši odziv širin branik prikazala tudi grafična slika testa dveh linearnih modelov, kjer so v posameznih obdobjih opazna neskladja med merjenimi in napovedanimi vrednostmi sončnega obsevanja (Poljanšek in sod., 2013). Stabilnost signala je bila preverjena tudi na severovzhodnem robu razširjenosti črnega bora. Tu uporabljena drseča korelacija potrjuje v obdobju 1960-1980 nižje korelacije med padavinskim indeksom in širino branik (Levanič in sod., 2012).

V literaturi je zaslediti več možnih razlogov za slabši odziv širin branik na klimo. Raziskava vpliva kislega dežja in onesnaženosti zraka z emisijami nitratov iz industrijskih območij na debelinski prirastek jelke (*Abies alba* Mill.) in smreke v Nemčiji je pokazala jasno zmanjšan odziv debelinskega prirastka na temperaturo iz omenjenega obdobja. Kot razlog za to je podana posledica pozitivnega vpliva nitratov na debelinski prirastek in s tem zmanjšanega vpliva klime (Wilson in Elling, 2004).

Po drugi strani Seim s sodelavci (2012) v raziskavi za območje Albanije opozarja na možnost slabše kvalitete merjenih klimatskih podatkov oziroma na njihovo nezanesljivost. Vendar pa je podrobnejša analiza klimatskih podatkov z zahodnega dela Balkanskega polotoka pokazala, da je obdobje opaženega slabšega klimatskega signala v širinah branik črnega bora (Poljanšek in sod., 2013) predvsem posledica desetletnih sprememb, tako v vrednostih sončnega obsevanja kot v izmerjenih temperaturah nad severovzhodnim delom Sredozemlja (Xoplaki in sod., 2003; Mariotti in Dell'Aquila, 2012). Črni bor je imel okoli leta 1960 za kratek čas šibkejši odziv na klimo, ki je posledica večje oblačnosti, večjega števila ciklonov ter večje količine padavin (Xoplaki in sod., 2006) in s tem manjše ekstremnosti, za rast omejujočih dejavnikov. Kot kaže, so drevesa v tem času debelinsko priraščala v skladu z rastiščnim indeksom in ne toliko z omejujočim dejavnikom klime. Kljub temu šeste hipoteze, da se signal ne spreminja, statistično ne moremo zavrniti, ker stabilnost klimatskega signala v širinah branik dreves s severovzhodnega roba in osrednjega dela areala nikoli ni padla pod mejo statistične značilnosti. Stabilnost odziva debelinske rasti črnega bora na klimatske dejavnike bi v prihodnje lahko primerjali še z odzivi drugih drevesnih vrst, z merjenjem odziva višinskih prirastkov ali pa z merjenjem drugih parametrov branik, kot so gostota in širina ranega ter kasnega lesa ali pa izotopska sestava.

3.1.5 Rekonstrukcija klimatskega dejavnika

Na območju osrednjega dela areala črnega bora na Balkanskem polotoku smo potrdili odziv širin branik na število ur sončnega obsevanja (Poljanšek in sod., 2013), na severovzhodnem robu razširjenosti pa na širino branik značilni vpliv sušnega indeksa (Levanič in sod., 2012). Kronologiji za omenjeni območji presegata dolžino izmerjenih klimatskih dejavnikov, kar skupaj z značilnim linearnim modelom omogoča rekonstrukcijo. Prekratka kronologija širin branik črnega bora z njegove severozahodne lokacije, submediteranskega dela Slovenije, rekonstrukcije ne omogoča. Sestoji črnega bora tega območja so nastali konec 19. stoletja s pogozditvijo, zato starejših borov od 200 let na tej lokaciji ni. Veliko starejša drevesa in drevesa avtohtonega porekla so bila vzorčena na območju zahodnega dela Balkanskega polotoka - na območju BiH (Poljanšek in sod., 2013) ter v celinskem delu polotoka - v jugozahodnem delu Romunije (Levanič in sod., 2012). V BiH je bilo do leta 1660 izračunano preteklo trajanje poletnega sončnega obsevanja, na območju Romunije pa padavinski indeks do leta 1688. Z izdelanima rekonstrukcijama številom ur sončnega obsevanje zahodnega oziroma padavinskega indeksa celinskega dela Balkanskega polotoka je potrjena peta hipoteza, da regionalna kronologija omogoča rekonstrukcijo na širino branik najbolj vplivnega vremenskega dejavnika. Izdelana 435-letna kronologija črnega bora za osrednji del areala na zahodnem delu Balkanskega polotoka ni tako dolga, kot je 677-letna izdelana kronologija za najsevernejši del naravnega areala črnega bora (Wimmer in Grabner, 1998). Razloge za to bi lahko iskali v manjši ekstremnosti rastišč zahodnega dela Balkanskega polotoka, kjer je črni bor kljub bolj sušnim rastiščem zaradi orografskih padavin dobro preskrbljen z vodo. Razvite kronologije širin branik črnega bora se lahko z vzorčenjem starih lesenih objektov, ob upoštevanju zadostne globine vzorca ter vrednosti EPS količnika, še podaljšajo (Hughes in sod., 2001).

Z rekonstrukcijo klimatskega dejavnika in identifikacijo preteklih značilnih let se lahko preveri obstoj skupnih značilnih let med zahodnim in celinskim delom Balkanskega polotoka. Ob upoštevanju EPS koeficienta 0,80 kot mejno vrednost smo v celinskem delu Balkanskega polotoka rekonstruirali sušni indeks ter prepoznali značilna poletja vse do leta 1688. Prepoznana najbolj sušna poletja so bila 1725, 1748, 1782, 1784 in 1830, najmanj pa 1729, 1770 in 1884 (Levanič in sod., 2012). Medtem so bila, za zahodni del Balkanskega polotoka, odkrita poletja z največjim številom ur sončnega obsevanja v letu 1695, 1742, 1908, 1931 in 1945 ter z najmanjšim leta 1712, 1810, 1815, 1843, 1899 in 1966 (Poljanšek in sod., 2013). Največ skupnih značilnih poletij je bilo v letih s slabšimi razmerami za debelinsko rast, t.j. malo padavin v celinskem delu ter veliko število ur sončnega obsevanja v zahodnem delu Balkanskega polotoka (1725, 1782, 1784 in 1830). Od značilnih let, ugodnih za rast, je skupno le leto 1729. Posebej poudarjamo dejstvo, da so vsa za rast najbolj ugodna značilna leta na območju zahodnega dela Balkanskega polotoka povezana z vulkanskimi izbruhi (Poljanšek in sod., 2013). Velika količina vulkanskega prahu, izbruhanega v stratosfero, povzroči močan albedo oziroma odboj sončnega sevanja, kar pomeni za drevesa manj obsevanja in s tem manjši sušni stres (Breitenmoser in sod., 2012). Poletja z značilno nizkim trajanjem sončnega obsevanja so bila tako pojasnjena z izbruhi vulkanov iz širšega območja Indonezije (vulkana Awu in Tambora), Filipinov (Taal) in vulkanov iz Italije (Vezuv in Etna).

Da osrednji del areala črnega bora leži na robnem območju vplivov klime z jugovzhodnega dela Sredozemlja in kontinentalne iz centralnega dela Evrope, je potrjeno s skupnimi značilnimi leti med našo rekonstrukcijo in drugimi objavljenimi iz obrobnih regij (Poljanšek in sod., 2013). Ugotovitve o vplivu klime iz sosednjih regij so skladne s predhodnimi temperaturnimi rekonstrukcijami za območje vzhodnega dela Balkanskega polotoka (Trouet in sod., 2012). V obeh raziskavah so bila manj sončna oziroma hladnejša poletja skupna z značilnimi poletji iz regij severno-severozahodno od Balkanskega polotoka, medtem ko so bila bolj sončna oziroma vroča poletja skupna z značilnimi poletji jugovzhodnega oziroma vzhodnega Sredozemlja in celinskega dela Balkanskega polotoka (Trouet in sod., 2012; Poljanšek in sod., 2013).

3.2 SKLEPI

Prej dendrokronološko neraziskano območje zahodnega dela Balkanskega polotoka ima zdaj sistematično razvito mrežo lokalnih kronologij širin branik črnega bora. Kronologije so bile izdelane na podlagi merjenja vzorčenih debelinskih prirastkov dreves črnega bora, rastočih v osrednjem delu in dodatno z dveh robnih lokacij areala na Balkanskem polotoku. Iz medsebojno ujemajočih se lokalnih kronologij osrednjega dela areala je bila za območje zahodnega dela Balkanskega polotoka izračunana prva regionalna kronologija širin branik črnega bora. Ta kronologija se ujema z regionalnimi kronologijami sosednjih območij, kar dokazuje obstoj skupnega klimatskega vpliva na širšem območju Balkanskega polotoka.

Na severozahodnem robu razširjenosti črnega bora na Balkanskem polotoku smo poleg širin branik izmerili tudi njihovo gostoto. Na širino branik dreves črnega bora z ekstremnega rastišča submediteranskega dela Slovenije najbolj vplivajo temperature zraka celotnega poletja (najbolj pa meseca avgusta) in padavine poznega poletja, medtem ko na maksimalno gostoto kasnega lesa v braniki vplivajo temperature meseca avgusta in padavine meseca februarja. Februarske padavine bi lahko povezali z debelino snežne odeje, ki v začetku rastne sezone, v običajno sušnem mesecu marcu, zagotavlja dovolj talne vlage za začetek rasti. Vpliv klime na gostoto ranega lesa in širino branik je podobno močan, največji vpliv na minimalno gostoto ranega lesa pa imajo temperature in padavine obdobja maj-junij. Nižje vrednosti korelacijskih koeficientov med širino branik in klimatskima dejavnikoma temperaturo in padavinami so bile izračunane v osrednjem delu razširjenosti črnega bora na Balkanskem polotoku. Variabilnost širin branik dreves črnega bora z območja Dinarskega gorstva je bila najbolje pojasnjena s trajanjem sončnega obsevanja. Njegova variabilnost je v posredni povezavi z variabilnostjo temperature in padavin, hkrati pa ima v času rastne sezone neposreden vpliv na proces fotosinteze.

Glede na načelo, da dejavniki, ki so na širino branik delovali v preteklosti, delujejo tudi v sedanjosti, bi moral biti vpliv sončnega obsevanja na širino branik stalen. Vendar je posredna preverba stabilnosti klimatskega signala v širinah branik dreves iz celinskega in zahodnega dela Balkanskega polotoka pokazala rahlo oslabljen signal v krajšem obdobju druge polovice 20. stoletja. Klimatski signal je stabilen od začetka dostopnih vremenskih podatkov do poznih 60 let, kasneje pa je bolj šibek.

Kot razlog za ta pojav podajamo spremembe v vzorcih ciklonov, katerih smer poteka čez centralni del Jadranskega morja in ki so bili po letu 1970 močnejši in številčnejši. Tako so vplivali na povečan padavinski režim nad zahodnim delom Balkanskega polotoka in posledično zmanjšali sušni stres dreves v poletnem času ter oslabeli odziv širin branik črnega bora na klimo. Sklepamo lahko, da branike enakomernih širin, nastale v tem omejenem časovnem obdobju, izkazujejo debelinsko rast, ki je skladna z lokalnim rastiščnim indeksom in starostjo dreves. Kljub vsemu je klimatski signal vedno statistično značilen, zato se lahko uporabi v procesu rekonstrukcije.

Rekonstruirana sta bila dva klimatska dejavnika; za severovzhodni rob razširjenosti črnega bora oziroma za celinski del Balkanskega polotoka je bil rekonstruiran padavinski indeks, za osrednji del razširjenosti pa so bile izračunane pretekle vrednosti sončnega obsevanja. Rekonstrukciji veljata za območje zahodnega in osrednjega dela Balkanskega polotoka. Z izračunano regionalno kronologijo širin branik črnega bora za območje zahodnega dela Balkanskega polotoka je bilo rekonstruirano sončno obsevanje vse do leta 1660. Ob tem so bila tudi identificirana značilna poletja tega območja. Z njihovo primerjavo z objavljenimi raziskavami na drugih drevesnih vrstah iz sosednjih regij smo odkrili več skupnih, izjemnih klimatskih dogodkov. Identificirana značilna poletja z velikim številom ur sončnega obsevanja centralno-zahodnega dela Balkanskega polotoka so bila povezana s sistemom oscilacij v jugovzhodnem/vzhodnem delu Sredozemlja, poletja z značilnim krajšim trajanjem sončnega obsevanja pa s poletji iz območij severno od centralnega dela Balkanskega polotoka. Poletja z izjemno nizkim trajanjem sončnega obsevanja so bila skladna z izbranimi vulkanskimi izbruhi iz Italije, Indonezije ter Filipinov.

Z identificiranimi skupnimi značilnimi leti, ujemanjem regionalne kronologije širin branik dreves črnega bora iz osrednjega območja areala z lokalno kronologijo iz severovzhodnega roba območja razširjenosti na Balkanskem polotoku ter s prostorsko analizo klimatskega signala v sistemu KNMI Explorer je potrjeno, da novo izdelana dendrokronološka mreža širin branik črnega bora pokriva skupno območje zahodnega in celinskega dela Balkanskega polotoka.

4 POVZETEK

4.1 POVZETEK

Dendrokronologija je veda, ki preučuje časovna zaporedja vrednosti različnih parametrov branik in njihovo odvisnost od več različnih dejavnikov okolja ter pridobljena znanja uporablja v različnih procesih. Poleg klime vplivajo na širino branik še drugi, za raziskavo moteči dejavniki (Cook, 1985), zato se v procesu standardizacije njihov vpliv v najboljši možni meri odstrani z izbiro prave regresijske krivulje (Fritts, 1976). Pri tem se izračunata standardna kronologija in kronologija ostankov. Za nadaljnje delo je bila izbrana standardna kronologija, saj vsebuje več variabilnosti kot kronologija ostankov in se zato bolje prilagaja variabilnosti klime. Značilni klimatski signal lahko pričakujemo v širinah branik dreves, rastočih na ekstremnih rastiščih (Fritts, 1976). Za vsako vzorčeno lokacijo se izdela ena lokalna kronologija, več medsebojno ujemajočih se lokalnih kronologij pa sestavlja dendrokronološko mrežo.

Kronologija z značilnim klimatskim signalom, katere dolžina sega v obdobje pred instrumentalnimi meritvami, omogoča rekonstrukcijo klimatskih dejavnikov. Pred rekonstrukcijo izbranega klimatskega dejavnika se preverijo še značilnost linearnega modela (Fritts, 1976; Cook in sod., 1999) ter stabilnost klimatskega signala v času. Medtem ko so dendroklimatološke raziskave že dobro razširjene po južnem delu Balkanskega polotoka (npr. Sarris in sod., 2007; Panayotov in sod., 2009; Levanič in Toromani E., 2010), pa tovrstnih raziskav na območju zahodnega dela Balkanskega polotoka še ni (slika 3). Črni bor (*Pinus nigra* Arnold) je primeren za raziskave vpliva klime na debelinsko rast dreves z zahodnega dela Balkanskega polotoka, saj je to območje njegov osrednji del areala na Balkanskem polotoku (slika 2). Hkrati dosega 800 let starosti (Wimmer in Grabner, 1998), raste na ekstremnih rastiščih (slika 1) in je odziven na variabilnost klime (npr. Leal in sod., 2008).

Odziv rasti črnega bora na klimo zahodnega dela Balkanskega polotoka še ni raziskan, prav tako ni znana pretekla variabilnost klime tega območja. Zato so bili v tej doktorski disertaciji postavljeni naslednji cilji: 1) Z izdelavo lokalnih kronologij širin branik črnega bora z različnih rastišč, nadmorskih višin in matičnih podlag vzpostaviti dendrokronološko mrežo zahodnega dela Balkanskega polotoka ter sestaviti regionalno kronologijo črnega bora za Bosno in Hercegovino (BiH). 2) Preveriti, ali se nova regionalna kronologija črnega bora zahodnega dela Balkanskega polotoka ujema z regionalnimi kronologijami sosednjih območij. 3) Preveriti, ali je klimatski signal v maksimalni gostoti kasnega lesa bolj izrazit kot v širini branik, ter 4) preučiti, kateri klimatski dejavnik najbolj vpliva na širino in kateri na gostoto branik. 5) Z izračunano regionalno kronologijo črnega bora želimo v obdobje pred instrumentalnimi meritvami rekonstruirati na širino branik najvplivnejši klimatski dejavnik ter 6) preveriti, ali se odziv črnega bora na klimo skozi čas spreminja.

Drevesa črnega bora so bila vzorčena na sedmih lokacijah osrednjega dela areala na Balkanskem polotoku ter z dveh robnih lokacij (slika 4). Izbrane lokacije osrednjega dela areala ležijo na območju Dinarskega gorstva v državi BiH, robna lokacija s severovzhodnega dela areala leži v jugozahodnem delu Romunije, točka vzorčenja s severozahodnega roba razširjenosti črnega bora na Balkanskem polotoku pa v submediteranskem delu Slovenije. Izbrana drevesa z lokacij osrednjega dela in severovzhodnega roba areala na Balkanskem polotoku so rastla posamično, v severozahodni točki roba areala pa v sestoju. Z izborom ekstremnih rastiščih s strmim naklonom, plitvimi tlemi in različno geološko podlago (apnenec, dolomit in serpentinit) je bila zajeta raznovrstnost ekstremnih rastišč. S prirastnim svedrom so bili iz starih in nepoškodovanih dreves odvzeti izvrtki. Na podlagi merjenja branik so bile izdelane lokalne kronologije širin branik za vsako lokacijo posebej, v primeru lokacije iz submediteranske Slovenije pa smo merili tudi gostoto ranega in kasnega lesa. Preverba medsebojnega ujemanja lokalnih kronologij širin branik iz osrednjega dela areala na Balkanskem polotoku je razkrila slabše ujemanje le med kronologijama Šator in Krivaja (Poljanšek in sod., 2012a). S preverbo skladnosti med kronologijami po statističnih kazalnikih t_{BP} in GLK % (Eckstein in Bauch, 1969; Baille in Pilcher, 1973) večjega neujemanja med izdelanimi lokalnimi kronologijami nismo odkrili, zato so bile vse vključene v dendrokronološko mrežo zahodnega dela Balkanskega polotoka. S preprostim izračunom povprečja, kjer ima vsaka lokalna kronologija osrednjega območja enako težo, smo iz sedmih lokalnih kronologij izračunali eno regionalno kronologijo črnega bora zahodnega dela Balkanskega polotoka. Z medsebojnim ujemanjem lokalnih kronologij in izdelavo regionalne je potrjena prva hipoteza.

Različne drevesne vrste se odzivajo na različne klimatske parametre (García-Suárez in sod., 2009), zato je bila za potrditev njene pravilne izdelave regionalna kronologija črnega bora primerjana le z drugimi regionalnimi kronologijami črnega bora. Regionalne kronologije so bile pridobljene iz mednarodne internetne baze (NOAA, 2012). Regionalna kronologija zahodnega dela Balkanskega polotoka se najbolje ujema s kronologijami iz regij južneje od centralnega dela areala črnega bora (območje držav Črne gore, Albanije in Grčije) ter dobro s kronologijami s severnega (Avstrije) ter severovzhodnega roba areala črnega bora (Romunije) (Poljanšek in sod., 2012a). Ujemanje regionalne kronologije s sosednjimi je potrdilo drugo hipotezo.

Vpliv klimatskih dejavnikov na širino branik je bil preverjen v osrednjem delu areala črnega bora na Balkanskem polotoku in na njegovem severovzhodnem robu (Levanič in sod., 2012; Poljanšek in sod., 2013), vpliv klime na gostoto branik pa le v severozahodnem robu areala (Poljanšek in Levanič, 2012a). Na širino branik črnega bora s severovzhodnega roba razširjenosti najbolj vpliva padavinski indeks obdobja junij-avgust, iz osrednjega dela areala pa sušni stres, izražen kot trajanje sončnega obsevanja mesecev junij-julij. Primerjava klimatskih signalov v širini in gostoti branik dreves s severozahodne lokacije je pokazala, da na gostoto ranega lesa najbolj vplivajo temperature in padavine obdobja maj-junij, na širino branik pa povprečna poletna temperatura. Pri tem je bil izračunan močnejši klimatski signal v gostoti ranega lesa kot v širini branik, vendar s statistično neznačilno razliko. Hkrati je bilo potrjeno, da je signal v gostoti kasnega lesa značilno šibkejši kot v širini branik (Poljanšek in Levanič, 2012a). Tretja hipoteza trdi, da je klimatski signal v maksimalni gostoti kasnega lesa bolj izrazit kot v širini branik, zato je zavrnjena.

Na širino branik dreves črnega bora s severozahodnega roba areala ne vplivajo le temperature in padavine zgodnjega, temveč celotnega poletja, zato je del četrte hipoteze o vplivu zgodnje poletne klime na širino branik zavrnjen. Drugi del četrte hipoteze pravi, da na maksimalno gostoto kasnega lesa v braniki vplivajo pozno poletne temperature in padavine, vendar smo z rezultati odkrili, da nanjo vplivajo februarske padavine, medtem ko je vpliv poletnih temperatur komaj značilen oz. viden le v avgustovskih temperaturah (Poljanšek in Levanič, 2012a). Del hipoteze o vplivu pozno poletnih temperatur na gostoto kasnega lesa je potrjen, del o vplivu pozno poletnih padavin pa zavrnjen.

Del četrte hipoteze o vplivu klime na širino branik je bil preverjen tudi v osrednjem delu areala in na njegovem severovzhodnem robu. Na slednji lokaciji je bil odkrit jasen vpliv julijskih padavin (Levanič in sod., 2012), in ker je julij sredi poletja, je četrta hipoteza zavrnjena. Četrta hipoteza je zavrnjena tudi na območju osrednjega dela areala, saj je za to območje preverjeni klimatski signal potrdil negativno (pozitivno) korelacijo med širino branik in temperaturami (padavinami) celotnega poletja (maj-avgust) in ne samo zgodnjega dela (Poljanšek in sod., 2012b).

Dolžina tistega dela kronologije s severozahodnega roba razširjenosti črnega bora na Balkanskem polotoku, ki je po kriteriju kazalnika EPS primerna za rekonstrukcijo, ni daljša, kot je dolžina razpoložljivih klimatskih podatkov, zato s te lokacije rekonstrukcija ni mogoča. Lokalna kronologija iz severovzhodnega in regionalna iz osrednjega dela areala pa omogočata rekonstrukciji, s čimer potrjujeta peto hipotezo. Vzporedno z izračunom preteklih vrednosti klime se lahko preveri še območje vplivnosti klimatskega dejavnika. Prostorska korelacija med kronologijo in izbranim klimatskim dejavnikom definira območje, za katero veljata izračunani rekonstrukciji. Kronologiji skupaj pokrivata območje zahodnega in osrednjega dela Balkanskega polotoka, kar je tudi skladno z rezultatom preverbe ujemanja s sosednjimi regionalnimi kronologijami.

Za rekonstrukcijo preteklih vrednosti je bila uporabljena statistično značilna korelacija med kronologijo in sušnim indeksom celinskega dela oziroma številom ur sončnega obsevanja v severnem delu Balkanskega polotoka. Linearni model je bil izračunan iz linearne regresije med standardno kronologijo in merjenima klimatskima dejavnikoma. V celinskem delu Balkanskega polotoka je linearni model z lokalno kronologijo rekonstruiral variabilnost preteklega padavinskega indeksa do leta 1688, medtem ko so bile ure sončnega obsevanja v zahodnem delu Balkanskega polotoka izračunane do leta 1660. Značilna leta, ki so se od drugih razlikovala po izredno dobrih ali izredno slabih razmerah za debelinsko rast, so bila identificirana z dvema različnima metodama - metodo centilov (Levanič in sod., 2012) in metodo standardnega odklona od povprečne vrednosti (Poljanšek in sod., 2013). Identificirana značilna leta so bila primerjana z drugimi objavljenimi nenavadnimi dogodki iz sosednjih regij; sušami, poplavami, hladnimi poletji in celo vulkanskimi izbruhi Etne in Vezuva ter vulkanov otočja Indonezije in Filipinov.

Primerjava z objavljenimi značilnimi leti iz drugih regionalnih kronologij je odkrila, da osrednji del areala črnega bora, ki leži na območju BiH, tvori robno območje dveh klimatskih vplivov. Prepoznana, za rast ugodna poletja se ujemajo z značilnimi leti z območja severno od BiH, medtem ko se za rast neugodna poletja ujemajo s tistimi iz južnega oziroma jugovzhodnega dela Sredozemlja (Poljanšek in sod., 2013). Pri tem so bila potrjena tudi skupna značilna leta med območjema osrednjega in severovzhodnega dela areala (Levanič in sod., 2012; Poljanšek in sod., 2013).

Stabilnost klimatskega signala v času je bila preverjena z izvedbo drseče korelacije in s pregledom skladnosti med izmerjenimi in izračunanimi vrednostmi. V obeh klimatskih signalih, padavinskega indeksa in sončnega obsevanja, je opaženo obdobje slabšega odziva na klimo. Za območje severovzhodnega robu je test stabilnosti s 30-letno drsečo korelacijo odkril šibkejši padavinski signal v obdobju 1950-1970, vendar je signal kljub temu ves čas značilen (Levanič in sod., 2012). V osrednjem delu areala črnega bora je pri preskusu linearnega modela za rekonstrukcijo opazen šibkejši signal sončnega obsevanja. V letih okoli konca 1960-ih je skladnost gibanja med širino branik in količino ur sončnega obsevanja nekoliko zabrisana. Kot možen razlog za obe slabši stabilnosti signala na območju zahodnega in celinskega dela Balkanskega polotoka je podana razlaga o bolj pogostih ciklonih nad območjem Jadranskega morja iz omenjene periode. Poletja so bila zato bolj oblačna, hladnejša in predvsem bolj deževna kot v dolgoletnem povprečju. Zadnja, šesta hipoteza o stalnosti odziva črnega bora na klimo je tako delno potrjena; obstaja obdobje slabšega odziva na klimo, a ker je odziv stalno statistično značilen, hipoteze ne moremo zavrniti.

4.2 SUMMARY

Dendrochronology investigates the time series of tree-ring proxies and the influence of environmental factors on the radial tree-growth and uses this knowledge in different fields. Beside climate, there are many other factors, which are influencing tree-ring widths (Cook, 1985), and as they represent disruption in our investigation they are removed from the measured time series in the process of standardization (Fritts, 1976). As a result, standard and residual chronologies are calculated. Standard chronology was chosen for further calculations as it contains more low-frequency signal than residual and it better fits to the climate variability. Significant climate signal can be expected in the tree-ring widths of the trees, growing on extreme sites (Fritts, 1976). For each of the sampled site, one local chronology is developed. More well-matched site chronologies form dendrochronological network. Chronology with significant climate signal and the length, longer than measured climate data, enables reconstruction of the climate factors into the past. Before reconstructing climate factor, significance of the linear model (Fritts, 1976; Cook *et al*., 1999) and the time stability of climate signal are investigated. While there are many investigations available for the southern part of Balkan Peninsula (e.g. Sarris *et* al., 2007; Panayotov *et al*., 2009; Levanič & Toromani E., 2010), investigations from the western part of the Balkan Peninsula are still absent. Black pine (*Pinus nigra* Arnold) is suitable for dendroclimatological investigation of the western part of the Balkan Peninsula, as this area represents the central part of its distribution in the Balkans (Figure 2), reaches ages of 800 years (Wimmer & Grabner, 1998), grows on extreme sites (Figure 1) and is responsive to climate variability (e.g. Leal *et al*., 2008).

Influence of climate on radial tree growth of black pine in the western part of Balkan Peninsula is unknown, the same as the past variability of the climate from this area. For this reason, goals from this doctoral dissertation were set to: 1) To develop dendrochronological network for the western part of Balkan Peninsula with calculation of local black pine tree-ring width chronologies from different sites, elevations, bedrocks, and to calculate the regional black pine chronology for Bosnia and Herzegovina. 2) To compare newly developed regional black pine chronology for the western Balkans to other regional black pine chronologies from the neighbouring countries. 3) To check if climate signal embedded in the maximum latewood density is stronger than signal from tree-ring

width. 4) To investigate, which climate factor most strongly influences tree-ring density and widths. 5) With calculated regional black pine chronology, we would like to reconstruct the most growth-limiting climate factor into the period of pre-instrumental climate data. 6) To check the time-stability of black pine response to climate.

In order to develop dendrochronological tree-ring widths network, trees from seven sites were sampled in central part of distribution on the Balkan Peninsula and on one site each in its north-eastern and north-western edges (Figure 4). Chosen sites in the central part of distribution are found in Bosnia and Herzegovina (BiH) and are distributed over the Dinaric Mountains. Extreme sites had steep slopes, shallow soil and different bedrock (limestone, dolomite, serpentine). This way, the diversity of extreme sites was captured. With increment borer, two increments from the opposite sides of the trunk were taken from old and healthy trees. In BiH, one local chronology was developed for each chosen site and compared to other local chronologies. The lowest matching coefficients were discovered between the sites Šator and Krivaja, but they were kept in investigation, since both match significantly with other chronologies. No other problems were found with tBP and GLK% coefficients (Eckstein and Bauch, 1969; Baille and Pilcher, 1973); for this reason, all local chronologies were chosen for development of the dendrochronological network from the western part of the Balkan Peninsula. In this way, the first hypothesis was confirmed. In order to compare our new results to the regional chronologies from neighbouring regions, BiH regional chronology was calculated with simple mean calculation, where each local chronology had the same weight.

Different tree species response to different climate factors (García-Suárez *et al*., 2009), and for this reason, BiH regional tree-ring width chronology was compared only to other black pine regional chronologies, published in international tree-ring data bank (NOAA, 2012), or available in the archives of the Slovenian Forestry Institute. The best match to BiH chronology was found with regional chronologies from southern (Montenegro, Albania, and Greece), eastern (Romania) and northern (Austria) regions (Poljanšek *et al*., 2012a). These results confirmed the second hypothesis; newly developed regional black pine chronology for the western part of Balkan Peninsula matches to other regional black pine chronologies from the neighbouring countries.

In the central part of the black pine distribution, as well as on the north-eastern and north-western margins, the influence of climate factors on tree-ring width was investigated (Levanič *et al*., 2012; Poljanšek *et al*., 2013). On the north-western margin, tree-ring density was also measured (Poljanšek and Levanič, 2012). With correlation analysis and linear model, climate signal in tree-ring widths and in early/latewood density was confirmed. The highest influence on the tree-ring widths of black pine on its north-eastern margin had drought stress, measured through standardized precipitation index of the June-August period, while in central part of its distribution, in the area of BiH, the highest correlation between climate and tree-ring width was calculated with moisture stress, as linked to June-July sunshine hours. Precipitation index and moisture stress are both under the direct influence of precipitation, temperatures and sunshine hours. Drought and/or moisture stress can be used as the function of temperatures, precipitation and sunshine hours, therefore we used precipitation index and sunshine hours as a proxy for growth limiting factor. Comparison of the climate signal in the tree-ring widths and in the tree-ring density from the north-western margin showed that average May-June precipitation and temperatures have the strongest influence on the earlywood density, and average summer temperatures on tree-ring widths. It is confirmed that climate signal in earlywood density is stronger than in tree-ring widths, but not significantly. Also, the signal in latewood density is significantly weaker than the signal in tree-ring widths (Poljanšek & Levanič, 2012). This does not support the third hypothesis, which claims that climate signal, embedded in the maximum latewood density, is stronger than the signal from tree-ring widths.

Early summer temperatures and precipitation do not have the strongest influence on the whole tree-ring width from north-western part, but the temperatures and precipitation from the whole June-August summer season certainly do. Part of the fourth hypothesis is thus rejected. Second part of the fourth hypothesis asserted that late summer climate has an impact on latewood density. We discovered that this statement was incorrect in the relationship between latewood density and precipitation, as the greatest impact is exerted by February precipitation. But it was confirmed in part of late summer temperatures influencing the latewood density, as the August temperature exerts the greatest impact on latewood density. Climate influence on tree ring widths was also investigated in the central part and on the north-eastern margin. On this margin, clear influence of July precipitation is seen (Levanič *et al.*, 2012) and since month July represents the middle of the summer, the fourth hypothesis is rejected. It is also rejected for the western part of the Balkan Peninsula, as for this particular area climate signal showed negative (positive) correlation between tree-ring widths and temperatures (precipitation) of the whole summer period (May-August) and not only of its early part (Poljanšek *et al.*, 2012b).

The length of chronology from the north-western margin, with EPS values appropriate for reconstruction, is shorter than available climate dataset, so there is no climate reconstruction for this area. Statistically significant correlation between local chronology and standardized precipitation index in north-eastern margin, and between regional chronology and sunshine hours in central part of distribution, enable reconstructions of the past variability of the climate factors. This confirms the fifth hypothesis. Parallel to reconstruction, spatial correlation analysis of climate signals can be tested. Together, precipitation index and sunshine hours signal cover the area of western and continental part of the Balkan Peninsula. This result is also confirmed with matching neighbouring chronologies. For the reconstruction of past climate variability, statistically significant correlation between chronology and precipitation index of the continental part of the Balkan Peninsula, and summer sunshine hours from the northern part of Balkan Peninsula, was used. For the western part of Balkan Peninsula, z-scored values of chronology and measured climate data were used. On the north-eastern margin we reconstructed standardized precipitation index till 1688, while in the central area of distribution, sunshine hours were reconstructed till 1660.

Extreme years with unusually good or bad growth conditions for radial increments were identified using two different methods; percentiles (Levanič *et al.*, 2012) and standard deviation (Poljanšek *et al.*, 2013). The identified extreme years were compared to other published extreme events; droughts, floods, cool summers, and volcanic eruptions of Etna and Vesuvius, as well as volcanoes from Indonesia and Philippines. Central part of distribution of the black pine, which is located in the BiH area, represents the margin of two influences. In comparison to the extreme years from other regional chronologies, we discovered that identified summers with good growth conditions coincide with cool summers from the north, while less good growth seasons were associated with dry years from the southern or south-eastern Mediterranean. Common years between the western and continental parts of the Balkan Peninsula were also noted (Poljanšek *et al*., 2013). Stability of the climate signal was tested using running correlation and with comparison between the measured and with linear model calculated values. In both climate signals, the period of less strong climate influence was noticed. On the north-eastern margin, this was tested using the 30-year running correlation (Levanič *et al*., 2012). The climate signal is stable and significant through time, but weaker in the 1950-1970 period. In the central part of distribution, weaker sunshine signal was discovered only in the process of testing the linear model, as there was lower consistency between tree-ring widths and sunshine hours at the end of the 1960s. In literature overview, many possible explanations were found, but we connected the weaker climate signal in the western part of Balkans Peninsula to cyclone divergence, as from this specific period summers were wetter and cloudier than usual. Climate signal was in certain period weaker than usual, but always significant, therefore the last, sixth hypothesis, simply cannot be rejected.

5 VIRI

Accetto M. 1979. Obnova, rast in razvoj sestojev črnega bora (*Pinus nigra* Arnold) na dolomitsko-apnenčastih rastiščih zahodne Bosne. Zbornik gozdarstva in lesarstva, 274-351

Accetto M. 1980. Rast bora *Pinus heldreichii* Christ. na planini Prenj v Bosni in Hercegovini. Doktorska disertacija. Univerza v Ljubljani, Ljubljana.

Amodei T., Guibal F., Fady B. 2012. Relationships between climate and radial growth in black pine (*Pinus nigra*; Arnold ssp. *salzmannii* (Dunal) Franco) from the south of France. Annals of Forest Science, 1-7

Andreu L., Gutiérrez E., Macias M., Ribas M., Bosch O., Camarero J. J. 2007. Climate increases regional tree-growth variability in Iberian pine forests. Global Change Biology, 13, 4: 804-815

Auer I., Böhm R., Jurkovic A., Lipa W., Orlik A., Potzmann R., Schöner W., Ungersböck M., Matulla C., Briffa K., Jones P., Efthymiadis D., Brunetti M., Nanni T., Maugeri M., Mercalli L., Mestre O., Moisselin J. M., Begert M., Müller-Westermeier G., Kveton V., Bochnicek O., Stastny P., Lapin M., Szalai S., Szentimrey T., Cegnar T., Dolinar M., Gajic-Capka M., Zaninovic K., Majstorovic Z., Nieplova E. 2007. HISTALP—historical instrumental climatological surface time series of the Greater Alpine Region. International Journal of Climatology, 27, 1: 17-46

Baillie M. G. L., Pilcher J. R. 1973. A simple cross-dating programme for tree-ring research. Tree-Ring Bulletin, 33, 7-14

Breitenmoser P., Beer J., Brönnimann S., Frank D., Steinhilber F., Wanner H. 2012. Solar and volcanic fingerprints in tree-ring chronologies over the past 2000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 313–314: 127-139

Briffa K. R., Jones P. D. 1990. Basic chronology statistics and assessment. V: Methods of dendrochronology: applications in the environmental sciences. Cook E. R. in Kairiukstis L.A.. (ur.). V: Methods of dendrochronology: applications in the environmental sciences, Dordrecht, Boston, London, Kluwer academic publishers: 137-152

Briffa K. R., Jones P. D., Bartholin T., Eckstein D., Schweingruber F. H., Karlen W., Zetterberg P., Eronen M.. 1992. Fennoscandian summers from A.D. 500: Temperature changes on short and long timescales. Climate Dynamics, 7, 111-119

Briffa K. R., Jones P. D., Pilcher J. R., Hughes M. K. 1988. Reconstructing summer temperatures in northern Fennoscandinavia back to A.D. 1700 using tree-ring data from Scots pine. Arctic and Alpine Research, 20, 4: 385-394

Briffa K. R., Osborn T. J., Schweingruber F. H., Harris I. C., Jones P. D., Shiyatov S. G., Vaganov E. A.. 2001. Low-frequency temperature variations from a northern tree ring density network. Journal of Geophysical Research, 106, D3: 2929-2941

Brus R. 2004. Drevesne vrste na slovenskem. Ljubljana, Mladinska založba: 399 str.

Bunn A. G. 2010. Statistical and visual crossdating in R using the dplR library. Dendrochronologia, 28, 4: 251-258

Büntgen U., Frank D., Liebhold A., Johnson D., Carrer M., Urbinati C., Grabner M., Nicolussi K., Levanič T., Esper J. 2009. Three centuries of insect outbreaks across the European Alps. New Phytologist, 182: 929-941

Büntgen U., Frank D., Schmidhalter M., Neuwirth B., Seifert M., Esper J. 2006. Growth/climate response shift in a long subalpine spruce chronology. Trees - Structure and Function, 20, 1: 99-110

Campbell R., McCarroll D., Loader N. J., Grudd H., Robertson I., Jalkanen R. 2007. Blue intensity in *Pinus sylvestris* tree-rings: developing a new palaeoclimate proxy. The Holocene, 17, 6: 821-828

Camuffo D., Bertolin C., Barriendos M., Dominguez-Castro F., Cocheo C., Enzi S., Sghedoni M., della Valle A., Garnier E., Alcoforado M. J., Xoplaki E., Luterbacher J., Diodato N., Maugeri M., Nunes M. F., Rodriguez R. 2010. 500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations. Climatic Change, 101, 1/2: 169-199

Carrer M., Nola P., Eduard J. L., Motta R., Urbinati C. 2007. Regional variability of climate–growth relationships in *Pinus cembra* high elevation forests in the Alps. Journal of Ecology, 95, 5: 1072-1083

Cochard H., Froux F., Mayr S., Coutand C. 2004. Xylem Wall Collapse in Water-Stressed Pine Needles. Plant Physiology, 134, 1: 401-408

Cook E. R. 1985. Time series analysis approach to tree ring standardization: Dissertation. (University of Arizona). Tucson: 171 str.

Cook E. R., Meko D. M., Stahle D. W., Cleaveland M. K. 1999. Drought Reconstructions for the Continental United States. Journal of Climate, 12, 4: 1145-1162

Coppola A., Leonelli G., Salvatore M. C., Pelfini M., Baroni C. 2012. Tree-ring based June–July mean temperature variations since the Little Ice Age in the Adamello-Presanella Group (Italian Central Alps). Climate of the Past- Discussions, 8, 4: 3871-3900

Cown D. J., Parker M. L. 1978. Comparison of annual ring density profiles in hardwoods and softwoods by X-ray densitometry. Canadian Journal of Forest Research, 8, 4: 442-449

Dean W. Jr., Anderson R. 1974. Application of some correlation coefficient techniques to time-series analysis. Journal of the International Association for Mathematical Geology, 6, 4: 363-372

Di Filippo A., Biondi F., Čufar K., De Luis M., Grabner M., Maugeri M., Presutti Saba E., Schirone B., Piovesan G. 2007. Bioclimatology of beech (*Fagus sylvatica* L.) in the Eastern Alps: spatial and altitudinal climatic signals identified through a tree-ring network. Journal of Biogeography, 34, 11: 1873-1892

Eckstein D., Bauch J. 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. Forstwissenschaftliches Centralblatt, 88, 4: 230-250

Esper J., Cook E. R., Schweingruber F. H. 2002. Low-Frequency Signals in Long Tree-Ring Chronologies for Reconstructing Past Temperature Variability. Science, 295, 5563: 2250-2253

EUFORGEN. 2013. Distribution map of *Pinus nigra* Arnold. (http://www.euforgen.org/fileadmin/www.euforgen.org/Documents/Maps/PDF/Pinus_nigra.pdf) (15. 1. 2013)

Frank D., Esper J. 2005. Characterization and climate response patterns of a high-elevation, multi-species tree-ring network in the European Alps. Dendrochronologia, 22, 107-121

Fritts H. C. 1976. Tree rings and climate. (ur.). London, New York, San Francisco, Academic Press: 567 str.

Fritts H. C., Blasing T. J., Hayden B. P., Kutzbach J. E. 1971. Multivariate techniques for specifying tree growth and climate relationships for reconstructing anomalies in paleoclimate. Journal of Applied Meteorology, 10, 5: 845-864

García-Suárez A. M., Butler C. J., Baillie M. G. L. 2009. Climate signal in tree-ring chronologies in a temperate climate: A multi-species approach. Dendrochronologia, 27, 3: 183-198

Gričar J., Čufar K. 2008. Seasonal dynamics of phloem and xylem formation in silver fir and Norway spruce as affected by drought. Russian Journal of Plant Physiology, 55, 4: 538-543

Grissino-Mayer H. D. 2003. A Manual and Tutorial for the Proper Use of an Increment Borer. Tree-Ring Research, 59, 2: 63-79

Hafner P., Levanič T. 2009. Stable carbon isotopes in Norway spruce (*Picea abies* (L.) Karst.) tree-rings at two sites in Slovenia. Zbornik gozdarstva in lesarstva, 88: 43-52

Hughes M. K., Kuniholm P. I., Eischeid J. K., Garfin G., Griggs C. B., Christine L. 2001. Aegean tree-ring signature years explained. Tree-Ring Research, 57, 1: 67-73

Jalkanen R., Aalto T., Kurkela T. 2000. Needle trace method. Forestry studies, 34: 75-78.

Jones P., Harris I. 2008. CRU Time Series (TS) high resolution gridded datasets. University of East Anglia Climatic Research Unit (CRU), NCAS British Atmospheric Data Centre. (http://badc.nerc.ac.uk/view/badc.nerc.ac.uk_ATOM_dataent_1256223773328276) (15. 1. 2013).

Jyske T. 2008. The effects of thinning and fertilisation on wood and tracheid properties of Norway spruce (*Picea abies*) - the results of long-term experiments: (University of Helsinki). Helsinki: 59 str.

Kaennel M., Schweingruber F.H. 1995. Multilingual Glossary of Dendrochronology. Paul Haupt Verlag. Berne, Stuttgart, Vienna: 467 str.

Kern Z., Popa I. 2007. Climate-growth relationship of tree species from a mixed stand of Apuseni Mts., Romania. Dendrochronologia, 24, 2-3: 109-115

Kern Z., Popa I., Varga Z., Széles É. 2009. Degraded temperature sensitivity of a stone pine chronology explained by dendrochemical evidences. Dendrochronologia, 27, 2: 121-128

Krusic P. J., Cook E. R. 2007. ARSTAN for Windows, version 4.1d. Lamonth-Doherty Earth Observatory, Columbia University. (http://www.ldeo.columbia.edu/trl) (15. 1. 2013)

Kuniholm P. I. 1981. International tree-ring data bank. *Pinus nigra*, Ravno Borje, Bosnia and Hercegovina. V: NOAA. 2012. International tree-ring data bank. National climatic data center, National oceanic and atmospheric administration. (http://www.ncdc.noaa.gov/paleo/treering.html) (15. 1. 2013).

Kuniholm P. I., Striker C. L. 1983. Dendrochronological Investigations in the Aegean and Neighboring Regions, 1977-1982. Journal of Field Archaeology, 10, 4: 411-420

Leal S., Eamus D., Grabner M., Wimmer R., Cherubini P. 2008. Tree rings of *Pinus nigra* from the Vienna basin region (Austria) show evidence of change in climatic sensitivity in the late 20th century. Canadian Journal of Forest Research, 38, 4: 744-759

Lebourgeois F. 2000. Climatic signals in earlywood, latewood and total ring width of Corsican pine from western France. Annals of Forest Science, 57, 2: 155-164

Levanič T. 1996. Dendrokronološka in dendroekološka analiza propadajočih vladajočih in sovladajočih jelk (*Abies alba* Mill.) v dinarsko fitogeografski regiji. Doktorska disertacija. Univerza v Ljubljani. Ljubljana: 167 str.

Levanič T. 2005. Vpliv klime na debelinsko rast macesna (*Larix decidua* Mill.) na zgornji gozdni meji v JV Alpah = Effect of climate on growth of European larch (*Larix decidua* Mill.) at the upper timberline in the SE Alps. Zbornik gozdarstva in lesarstva, 78, 29-55

Levanič T. 2007. ATRICS - a new system for image acquisition in dendrochronology. Tree Ring Research, 63, 2: 117-122

Levanič T., Gričar J., Gagen M., Jalkanen R., Loader N., McCarroll D., Oven P., Robertson, I. 2008. The climate sensitivity of Norway spruce (*Picea abies* (L.) Karst.) in the southeastern European Alps. Trees - Structure and Function, 23, 1: 169-180

Levanič T., Oven P. 2002. Prirastne in anatomske značilnosti rdečega bora (*Pinus sylvestris* L.), izpostavljenega solem za posipanje cestišč. Zbornik gozdarstva in lesarstva, 69, 237-258

Levanič T., Toromani E. 2010. Austrian pine (*Pinus nigra* Arnold.) tree-ring width chronology from northeast Albania-preliminary results. 2010. Levanič T. in sod. (ur.). Otočec, Slovenia, Helmholtz-zentrum Potsdam, Deutsches Geoforschungszentrum: 5 str.

Levanič T., Popa I., Poljanšek S., Nechita C. 2012. A 323-year long reconstruction of drought for SW Romania based on black pine (*Pinus nigra*) tree-ring widths. International Journal of Biometeorology, 1-12

Lindholm M., Jalkanen R., Salminen H. 2009. High-frequency reconstruction of mid-summer temperature from annual height increment of Scots pine at the northern timberline since 1846. Dendrochronologia, 27, 2: 113-119

Ljungqvist F. C. 2010. A new reconstruction of temperature variability in the extra-tropical northern hemisphere during the last two millennia. Geografiska Annaler: Series A, Physical Geography, 92, 3: 339-351

Luterbacher J., García-Herrera R., Akcer-On S., Allan R., Alvarez-Castro M.-C., Benito G., Booth J., Büntgen U., Cagatay N., Colombaroli D., Davis B., Esper J., Felis T., Fleitmann D., Frank D., Gallego D., Garcia-Bustamante E., Glaser R., Gonzalez-Rouco F. J., Goosse H., Kiefer T., Macklin M. G., Manning S. W., Montagna P., Newman L., Power M. J., Rath V., Ribera P., Riemann D., Roberts N., Sicre M. A., Silenzi S., Tinner W., Tzedakis P. C., Valero-Garcés B., van der Schrier G., Vannière Boris., Vogt S., Wanner H., Werner J. P., Willett G., Williams M. H., Xoplaki E., Zerefos C. S., Zorita E. 2012. A Review of 2000 Years of Paleoclimatic Evidence in the Mediterranean. V: The Climate of the Mediterranean Region. Lionello P. (ur.). Oxford, Elsevier: 87-185

Luterbacher J., Schmutz C., Gyalistras D., Xoplaki E., Wanner H. 1999. Reconstruction of monthly NAO and EU indices back to AD 1675. Geophysical Research Letters, 26, 17: 2745-2748

Mäkinen H., Nöjd P., Kahle H.-P., Neumann U., Tveite B., Mielikainen K., Rohle H., Spiecker H. 2003. Large-scale climatic variability and radial increment variation of (*Picea abies* (L.) Karst. in central and northern Europe. Trees - Structure and Function, 17, 2: 173-184

Mäkinen H., Seo J.-W., Nöjd P., Schmitt U., Jalkanen R. 2008. Seasonal dynamics of wood formation: a comparison between pinning, microcoring and dendrometer measurements. European Journal of Forest Research, 127, 3: 235-245

Mariotti A., Dell'Aquila A. 2012. Decadal climate variability in the Mediterranean region: roles of large-scale forcings and regional processes. Climate Dynamics, 38, 5-6: 1129-1145

Martin-Benito D., Kint V., del Río M., Muys B., Cañellas I. 2011. Growth responses of West-Mediterranean *Pinus nigra* to climate change are modulated by competition and productivity: Past trends and future perspectives. Forest Ecology and Management, 262, 6: 1030-1040

McCarroll D., Jalkanen R., Hicks S., Tuovinen M., Gagen M., Pawellek F., Eckstein D., Schmitt U., Autio J., Heikkinen O. 2003. Multiproxy dendroclimatology: a pilot study in northern Finland. The Holocene, 13, 6: 829-838

McCarroll D., Loader N. J. 2005. Isotopes in tree rings. V: Isotopes in palaeoenvironmental research (developments in paleoenvironmental research). Leng M. J. (ur.). Dordrecht, Springer: 67-116

McCarroll D., Loader N. J., Jalkanen R., Gagen M. H., Grudd H., Gunnarson B. E., Kirchhefer A. J., Friedrich M., Linderholm H. W., Lindholm M., Boettger T., Los S. O., Remmele S., Kononov Y. M., Yamazaki Y. M., Young G. H. F., Zorita E. 2012. A 1200-year multi-proxy record of tree growth and summer temperature at the northern pine forest limit of Europe. the Holocene, in press.

McCarroll D., Pettigrew E., Luckman A., Guibal F., Edouard J. L. 2002. Blue Reflectance Provides a Surrogate for Latewood Density of High-Latitude Pine Tree Rings. Arctic, Antarctic, and Alpine Research, 34, 4: 450-453

NOAA. 2012. International tree-ring data bank. National climatic data center, National oceanic and atmospheric administration.
(http://www.ncdc.noaa.gov/paleo/treering.html) (15. 1. 2013).

Ogrin D. 1989. Vpliv padavinskih in temperaturnih razmer na širino letnic črnih borov (*Pinus nigra*) v submediteranski Sloveniji. Annales : anali Koprskega primorja in bližnjih pokrajin = annali del Litorale capodistriano e delle regioni vicine, 6: 163-173

Ogrin D. 2005. Tree rings and climate in submediterranean Slovenia. 2006. Heinrich I, Gärtner H, Monbaron M, Schleser G (ur.). TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 4: Proceedings of the DENDROSYMPOSIUM 2005, April 21st – 23rd 2005, Fribourg, Switzerland. 61: 77 – 83

Oldenborgh van, G.J. 1999. KNMI Climate explorer. Koninklijk Netherlands Meteorologisch Institut (KNMI).
(http://climexp.knmi.nl/start.cgi?someone@somewhere) (15. 1. 2013).

Panayotov M., Bebi P., F. K., Yurukov S. 2009. *Pinus peuce* and *Pinus heldreichii* tree rings as a key to past mountain climate in Southeastern Europe. TRACE- Tree Rings in Archaeology, Climatology and Ecology, Vol. 7: 71-77

Pauling A., Luterbacher J., Casty C., Wanner H. 2006. Five hundred years of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation. Climate Dynamics, 26, 4: 387-405

Penuelas J., Pilella I. 2003. Deuterium labelling of roots provides evidence of deep water access and hydraulic lift by *Pinus nigra* in a Mediterranean forest of NE Spain. Environmental and Experimental Botany, 49, 3: 201-208

Poljanšek S., Levanič T. 2012a. Parametri branik dreves Pinus nigra (Arnold) in njihov klimatski signal. Zbornik gozdarstva in lesarstva, 98: 15-25

Poljanšek S., Levanič T. 2012b. Pripomoček pri prirastnem svedru: patentna prijava: P-201200251. Ljubljana, Urad republike Slovenije za intelektualno lastnino: 7 str.

Poljanšek S., Ballian D., Nagel T. A., Levanič T. 2012a. A 435-Year-Long European Black Pine (*Pinus nigra*) Chronology for the Central-Western Balkan Region. Tree-Ring Research, 68, 1: 31-44

Poljanšek S., Ceglar A., Levanič T. 2012b. Long term January-March and May-August temperature reconstructions from tree-ring records from Bosnia and Herzegovina. Climate of the Past- Discussions, 8, 5: 4401-4442

Poljanšek S., Ceglar A., Levanič T. 2013. Long-term summer sunshine/moisture stress reconstruction from tree-ring widths from Bosnia and Herzegovina. Climate of the Past, 9, 27-40

Poljanšek S., Jagodic Š., Levanič T. 2010. Primerjava programov za standardizacijo časovnih vrst v dendrokronologiji. Zbornik gozdarstva in lesarstva, 93, 11-22

Poljanšek S., Oven P., Jalkanen R., Levanič T. 2011. Metoda preučevanja sledi iglic terminalnega poganjka. Zbornik gozdarstva in lesarstva, 96, 3: 9

Popa I., Kern Z. 2009. Long-term summer temperature reconstruction inferred from tree-ring records from the Eastern Carpathians. Climate Dynamics, 32, 7: 1107-1117

Regent. 2013. WinDendro program. Regent instruments. (http://www.regent.qc.ca/products/dendro/DENDRO.html) (15. 1. 2013).

Rolland C. 1993. Tree-Ring and climate relationship for *Abies alba* in the internal Alps. Tree Ring Bulletin, 53, 1-11

Sarris D., Christodoulakis D., Körner C. 2007. Recent decline in precipitation and tree growth in the eastern Mediterranean. Global Change Biology, 13, 6: 1187-1200

Schweingruber F. H., Briffa K. R., Nogler P. 1993. A tree-ring densitometric transect from Alaska to Labrador. Comparison of ring-width and maximum-latewood-density chronologies in the conifer belt of northern North America. International Journal of Biometeorology, 37, 3: 151-169

Schweingruber F. H., Eckstein D., Serre-Bachet F., Bräker O. U. 1990. Identification, presentation and interpretation of event years and pointer years in dendrochronology. Dendrochronologia, 8, 9-38

Schweingruber F. H. 1983. Der Jahrring: Standort, Methodik, Zeit und Klima in der Dendrochronologie. (ur.). Bern, Stuttgart, Verlag Paul Haupt: 234 str.

Schweingruber F. H., Fritts H. C., Bräker O. U., Drew L. G., Schär E. 1978. The X-ray technique as applied to dendrochronology. Tree Ring Bulletin, 38, 61-91

Sciem. 2013. PAST-4; Personal Analysis System for Treering Research. (http://www.sciem.com) (15. 1. 2013).

Seim A., Büntgen U., Fonti P., Haska H., Herzig F., Tegel W., Trouet V., Treydte K. 2012. Climate sensitivity of a millennium-long pine chronology from Albania. Climate Research, 51, 3: 217-228

Shumilov O. I., Kasatkina E. A., Lukina N. V., Kirtsideli I. Y., Kanatjev A. G. 2007. Paleoclimatic potential of the northernmost juniper trees in Europe. Dendrochronologia, 24, 2–3: 123-130

Stahle D. W., Cleaveland M. K., Cerveny R. S. 1991. Tree-ring reconstructed sunshine duration over central USA. International Journal of Climatology, 11, 3: 285-295

Strumia G., Wimmer R., Grabner M. 1997. Dendroclimatic sensitivity of *Pinus nigra* Arnold in Austria. Dendrochronologia, 15, 129-137

Touchan R., Anchukaitis K., Meko D., Sabir M., Attalah S., Aloui, A. 2010. Spatiotemporal drought variability in northwestern Africa over the last nine centuries. Climate Dynamics, 37, 237-252

Touchan R., Meko D. M., Aloui A. 2008. Precipitation reconstruction for Northwestern Tunisia from tree rings. Journal of Arid Environments, 72, 10: 1887-1896

Touchan R., Xoplaki E., Funkhouser G., Luterbacher J., Hughes M. K., Erkan N., Akkemik U., Stephan J. 2005. Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. Climate Dynamics, 25, 25: 75-98

Trachsel M., Kamenik C., Grosjean M., McCarroll D., Moberg A., Brázdil R., Büntgen U., Dobrovolný P., Esper J., Frank D. C., Friedrich M., Glaser R., Larocque-Tobler I., Nicolussi K., Riemann D. 2012. Multi-archive summer temperature reconstruction for the European Alps, AD 1053–1996. Quaternary Science Reviews, 46: 66-79

Trouet V., Panayotov M., Ivanova A., Frank D. 2012. A pan-European summer teleconnection mode recorded by a new temperature reconstruction from the northeastern Mediterranean (ad 1768–2008). The Holocene, 22, 8: 887-898

Vidaković M. 1991. Conifers: morphology and variation. (ur.). Zagreb, Grafički zavod Hrvatske: 754 str.

Waring R. H., Whitehead D., Jarvis P. G. 1979. The contribution of stored water to transpiration in Scots pine. Plant, Cell & Environment, 2, 4: 309-317

Wigley T. M. L., Briffa K. R., Jones P. D. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. Journal of Climate and Applied Meteorology, 23, 201-213

Wilmking M., Hallinger M., Van Bogaert R., Kyncl T., Babst F., Hahne W., Juday G. P., de Luis M., Novak K., Völlm C. 2012. Continuously missing outer rings in woody plants at their distributional margins. Dendrochronologia, 30, 3: 213-222

Wilson R., Elling W. 2004. Temporal instability in tree-growth/climate response in the Lower Bavarian Forest region: implications for dendroclimatic reconstruction. Trees - Structure and Function, 18, 1: 19-28

Wimmer R. 2002. Wood anatomical features in tree-rings as indicators of environmental change. Dendrochronologia, 20, 1-2: 21-36

Wimmer R., Grabner M. 1998. Dendrochronologie – heute, Standardchronologien in Österreich als Basis für die dendrochronologische Datierung. Archäologie Österreichs, 9, 79-85

Wimmer R., Strumia G., Holawe F. 2000. Use of false rings in Austrian pine to reconstruct early growing season precipitation. Canadian Journal of Forest Research, 30, 11: 1691-1697

Xoplaki E., González-Rouco J., Gyalistras D., Luterbacher J., Rickli R., Wanner H. 2003. Interannual summer air temperature variability over Greece and its connection to the large-scale atmospheric circulation and Mediterranean SSTs 1950-1999. Climate Dynamics, 20, 5: 537-554

Xoplaki, E., Luterbacher, J., gonzalez-Rouco, F.J., 2006. Mediterranean summer temperature and winter precipitation, large-scale dynamics, trends. Il Nuovo Cimento 29(1), 45-54

Young G. H. F., McCarroll D., Loader N. J., Kirchhefer A. J. 2010. A 500-year record of summer near-ground solar radiation from tree-ring stable carbon isotopes. The Holocene, 20, 3: 315-324

Zupan Hajna N. 2012. Dinaric karst: Geography and geology. V: Encyclopedia of Caves. Blaine White W., C. Culver David. (ur.). Oxford, Elsevier: 195-203.

ZAHVALA

Hvala mojima staršema in bratu za večletno spodbudo pri študiju ter Miši za zanimanje za moje delo, hkrati pa tudi za razumevanje mojih odsotnosti v času terenskih vzorčenj in izobraževanj v tujini.

Predvsem gre zahvala mojemu mentorju Tomu Levaniču za usmerjanje dela pri raziskovanju ter komisiji za njeno delo. Hvala tudi sodelavcem z Gozdarskega inštituta Slovenije, zlasti pa z Oddelka za prirastoslovje in gojenje gozdov: Matjažu Čatru, Poloni Hafner, Špeli Jagodic, Robertu Krajncu in Jožici Gričar, hkrati tudi članici komisije. Oni vedo, kako vztrajen in vedoželjen karakter imam.

Hvala vsem raziskovalcem in gozdarjem iz dežel, kjer je potekalo terensko delo, predvsem pa dr. Daliborju Ballianu za sodelovanje na terenu in vse kontakte s področja Bosne in Hercegovine (Konjic, Bosansko Grahovo, Šipovo, Prusačka rijeka, Peručica) ter dr. Ionelu Popa in Constantinu Nechiti za sodelovanje pri izdelavi romunske kronologije črnega bora.

Zahvaljujem se tudi znanstvenikom in strokovnjakom, ki so mi ponudili oporo pri razvijanju idej in razpravi rezultatov (*I would like to express my warmest thanks to the researchers and scientistswho supported me in various ways during my PhD study*): dr. Ramzi Touchan, dr. Risto Jalkanen, m.sc. Mauri Timonen, dr. Markus Lindholm, dr. Samuli Helama, dr. Oleg I. Shumilov in dr. Elena A. Kasatkina, dr. Fritz Schweingruber, dr. Danny McCarroll, dr. Iian Robertson, dr. Neil J. Loader in dr. Giles H.F. Young.

Hvala tudi Agenciji za raziskovalno dejavnost republike Slovenije (ARRS), da je podprla moje usposabljanje v okviru projekta »*Vpliv klimatskih sprememb na trajnost, stabilnost in biodiverziteto sestojev bukve in črnega bora na Balkanu*«, programski skupini P4-0107 »Gozdna biologija, ekologija in tehnologija«, tekočim projektom na Gozdarskem inštitutu Slovenije, agenciji Ad-futura, ki je omogočila izobraževanje na finskem inštitutu METLA v Rovaniemiju, ter projektu Euforinno za izobraževanje na Swansea University, Wales (VB).

Hvala vsem za nepozabna doživetja, izkušnje ter pridobljeno znanje.

Priloga A

Dovoljenje za uporabo članka iz revije **Tree-ring Research**

Tree-Ring Research
(A Publication of the Tree-Ring Society)
Lab. of Tree-Ring Research
105 W. Stadium, Bldg. #58
University of Arizona
Tucson, AZ 85721 USA
Phone: 1-520-621-1608
FAX: 1-520-621-8229

17 September 2012

Simon Poljanšek
Slovenian Forestry Institute,
Večna pot 2
1000 Ljubljana
Slovenia

Dear Mr. Poljanšek:

This letter provides permission for you to include your paper, "A 435-Year-Long European Black Pine (*Pinus nigra*) Chronology for the Central-Western Balkan Region" by Poljanšek, S., Ballian, D., Nagel, T. A., and Levanič, T. (Tree-Ring Research, 68:31-44, 2012), in your dissertation. You must provide proper credit to the source of the paper with complete bibliographic citation.

Best regards,

Steven W. Leavitt

Priloga B

Dovoljenje za uporabo članka iz revije **Climate of the Past**

Copyright for manuscript, published by Copernicus Publications on behalf of the European Geosciences Union (EGU) in the journal Climate of the Past and its discussion forum Climate of the Past Discussions whose original manuscript was received from 10 December 2007 on:

Copyright <u>on any article is retained by the author(s)</u>.
Authors grant Copernicus Publications a license to publish the article and identify itself as the original publisher.
Authors grant Copernicus Publications commercial rights to produce hardcopy volumes of the journal for sale to libraries and individuals.
Authors grant any third party the right to use the article freely as long as its original authors and citation details are identified.

The article and any associated published material is distributed under the Creative Commons Attribution 3.0 License:
Creative Commons Attribution 3.0 License
Anyone is free:

- **to Share —** to copy, distribute and transmit the work
- **to Remix —** to adapt the work

Under the following conditions:

- **Attribution.** The original authors must be given credit.

For any reuse or distribution, it must be made clear to others what the license terms of this work are. Any of these conditions can be waived if the copyright holders give permission. Nothing in this license impairs or restricts the author's moral rights.

From: *http://www.climate-of-the-past.net/general_information/license_and_copyright.html*
Date: 11.1.2013

Priloga C

Dovoljenje za uporabo članka iz revije **International Journal of Biometeorology**

SPRINGER LICENSE
TERMS AND CONDITIONS
Jan 16, 2013

This is a License Agreement between Simon Poljanšek ("You") and Springer ("Springer") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by Springer, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	3070841102993
License date	Jan 16, 2013
Licensed content publisher	Springer
Licensed content publication	International Journal of Biometeorology
Licensed content title	A 323-year long reconstruction of drought for SW Romania based on black pine (Pinus Nigra) tree-ring widths
Licensed content author	Tom Levanič
Licensed content date	Jan 1, 2012
Type of Use	Thesis/Dissertation
Portion	Full text
Number of copies	1
Author of this Springer article	Yes and you are the sole author of the new work
Title of your thesis / dissertation	DENDROCHRONOLOGY OF BLACK PINE (Pinus nigra Arnold) ON THE WESTERN PART OF BALKAN PENINSULA
Expected completion date	Apr 2013
Estimated size(pages)	110
Total	0.00 EUR

Terms and Conditions

Introduction
The publisher for this copyrighted material is Springer Science + Business Media. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your Rightslink account and that are available at any time at http://myaccount.copyright.com).

Limited License

With reference to your request to reprint in your thesis material on which Springer Science and Business Media control the copyright, permission is granted, free of charge, for the use indicated in your enquiry.

Licenses are for one-time use only with a maximum distribution equal to the number that you identified in the licensing process.

This License includes use in an electronic form, provided its password protected or on the university's intranet or repository, including UMI (according to the definition at the Sherpa website: http://www.sherpa.ac.uk/romeo/). For any other electronic use, please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com).

The material can only be used for the purpose of defending your thesis, and with a maximum of 100 extra copies in paper.

Although Springer holds copyright to the material and is entitled to negotiate on rights, this license is only valid, provided permission is also obtained from the (co) author (address is given with the article/chapter) and provided it concerns original material which does not carry references to other sources (if material in question appears with credit to another source, authorization from that source is required as well).

Permission free of charge on this occasion does not prejudice any rights we might have to charge for reproduction of our copyrighted material in the future.

Altering/Modifying Material: Not Permitted
You may not alter or modify the material in any manner. Abbreviations, additions, deletions and/or any other alterations shall be made only with prior written authorization of the author(s) and/or Springer Science + Business Media. (Please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com)

Reservation of Rights
Springer Science + Business Media reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction, (ii) these terms and conditions and (iii) CCC's Billing and Payment terms and conditions.

Copyright Notice:Disclaimer
You must include the following copyright and permission notice in connection with any reproduction of the licensed material: "Springer and the original publisher /journal title, volume, year of publication, page, chapter/article title, name(s) of author(s), figure number(s), original copyright notice) is given to the publication in which the material was originally published, by adding; with kind permission from Springer Science and Business Media"

Warranties: None

Example 1: Springer Science + Business Media makes no representations or warranties with respect to the licensed material.
Example 2: Springer Science + Business Media makes no representations or warranties with respect to the licensed material and adopts on its own behalf the limitations and disclaimers established by CCC on its behalf in its Billing and Payment terms and conditions for this licensing transaction.

Indemnity
You hereby indemnify and agree to hold harmless Springer Science + Business Media and CCC, and their respective officers, directors, employees and agents, from and against any and all claims arising out of your use of the licensed material other than as specifically authorized pursuant to this license.

No Transfer of License
This license is personal to you and may not be sublicensed, assigned, or transferred by you to any other person without Springer Science + Business Media's written permission.

No Amendment Except in Writing
This license may not be amended except in a writing signed by both parties (or, in the case of Springer Science + Business Media, by CCC on Springer Science + Business Media's behalf).

Objection to Contrary Terms
Springer Science + Business Media hereby objects to any terms contained in any purchase order, acknowledgment, check endorsement or other writing prepared by you, which terms are inconsistent with these terms and conditions or CCC's Billing and Payment terms and conditions. These terms and conditions, together with CCC's Billing and Payment terms and conditions (which are incorporated herein), comprise the entire agreement between you and Springer Science + Business Media (and CCC) concerning this licensing transaction. In the event of any conflict between your obligations established by these terms and conditions and those established by CCC's Billing and Payment terms and conditions, these terms and conditions shall control.

Jurisdiction
All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in The Netherlands, in accordance with Dutch law, and to be conducted under the Rules of the 'Netherlands Arbitrage Instituut' (Netherlands Institute of Arbitration).***OR:***

All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in the Federal Republic of Germany, in accordance with German law.

Priloga D

Zahteva za podelitev patenta; Pripomoček pri prirastnem svedru

1

Gozdarski inštitut Slovenije

Pripomoček pri prirastnem svedru

Predloženi izum se nanaša na prirastni sveder za pridobivanje vzorcev rasti dreves za dendrokronološke raziskave, zlasti na strojno gnani prirastni sveder, ki je prednostno gnan s pomočjo ročnega električnega pogonskega stroja.

Znani ročni prirastni sveder obsega cevasto zasnovano steblo svedra, ki je na svojem prostem koncu zasnovano s kvadratnim nastavkom za sprejem ročaja. Ročaj se na omenjenem steblu svedra položajno pričvrsti s pomočjo zaskočke, ki sede v ustrezen izrez na prostem koncu stebla svedra. Sestavljeni prirastni sveder se v smeri gibanja urinega kazalca ročno privije v drevo in se ga v nasprotni smeri izvije iz drevesa. Za privijanje prirastnega svedra se pogosto uporablja tudi električni pogonski stroj, pri čemer je v takšnem primeru potrebno ročaj ločiti od stebla svedra in ga s pomočjo vmesnika vpeti v vpenjalno glavo električnega pogonskega stroja. Pri tovrstnem delu pa se pojavijo težave, saj električni pogonski stroj marsikdaj ne zmore priviti prirastnega svedra dovolj globoko v drevo. Še večja težava pa se pojavi pri izvijanju svedra, saj je omenjeni vmesnik zgolj nataknjen na steblo svedra, zaradi česar stebla svedra ni mogoče sočasno vrteti in izvleči iz drevesa. Zato je potrebno električni pogonski stroj odklopiti od stebla svedra in nanj natakniti ročaj, nakar se steblo svedra ročno odvije iz drevesa. Pri tem je delo dokaj oteženo, pogoste pa so tudi poškodbe zveze med ročajem in steblom svedra.

Naloga predloženega izuma je ustvariti pripomoček pri prirastnem svedru, s katerim so odpravljene pomanjkljivosti znanih rešitev.

Zastavljena naloga je po izumu rešena z značilnostmi, podanimi v značilnostnem delu 1. patentnega zahtevka. Podrobnosti so razkrite v podzahtevkih.

Izum je v nadaljevanju podrobneje opisan na osnovi neobveznega izvedbenega primera in s sklicevanjem na priloženo skico, kjer kaže

sl. 1 pripomoček prirastnega svedra po izumu v tridimenzionalnem pogledu,
sl. 2 prirastni sveder za uporabo s pripomočkom po izumu.

Pripomoček prirastnega svedra po izumu je zasnovan kot valjasta skodela 1, katere dnu 2 je z njene zunanje strani soosno prigrajen priključni nastavek 3 za povezavo z neprikazanim električnim pogonskim strojem. Dalje je omenjenemu dnu 2 skodele 1 z njene notranje strani soosno prigrajen valjast nastavek 4 za povezavo s steblom 5 svedra (na sl. prikazan s črtkano črto). Stena 6 omenjene skodele 1 je v smeri proč od dna 2 zasnovana z diametralno nasproti ležečima si ovalnima izrezoma 7, 8. Pri tem sta omenjena izreza 7, 8 zasnovana tako, da je njuna daljša središčnica približno vzporedna dnu 2. Nadalje je vsakokraten izrez 7, 8 na svojem prvem vzdolžnem koncu zasnovan tako, da poteka po celotni višini omenjene stene 6, medtem ko nasprotni konec omenjenega izreza 7, 8 tvori neke vrste žep 9 v omenjeni steni 6. Omenjeni vsakokratni žep 9 je tako na strani, obrnjeni proč od omenjenega dna 2, zamejen z mostičem 9a. Po predloženem izumu je predvideno, da so izmere omenjenega izreza 7, 8 v celoti prirejene ročaju 5a stebla 5 svedra, tako da lahko izrez 7, 8 brez težav sprejme ročaj 5a.

V nadaljevanju je za boljše razumevanje izuma opisan sicer po sebi znani prirastni sveder. Slednji sestoji iz cevastega stebla 5, na katerega prvem koncu je zasnovan vrtalni odsek 10 in na katerega nasprotnem koncu je zasnovan štirikotni nastavek 11 za sprejem ročaja 5a. Omenjeno steblo 5 je na ročaju 5a položajno držano s pomočjo zasukljive zaskočke 12, ki aretirno sodeluje s krožnim utorom 13 na štirikotnem nastavku 11, ki štrli iz ročaja 5a.

3

Pri delu s prirastnim svedrom se pripomoček po izumu s pomočjo priključnega nastavka 3 poveže z električnim pogonskim strojem (na sl. ni prikazan); omenjeni nastavek 3 se na primer pritrdi v vpenjalno glavo električnega pogonskega stroja. Zatem se sestavljeni prirastni sveder natakne na omenjeni valjasti nastavek 4 na način, da se omenjeno votlo steblo 5 s štirikotnim nastavkom 11 nasloni na dno 2 omenjene skodele 1. Ročaj 5a prirastnega svedra se pri tem potisne v izrez 7, 8 na mestu, ki poteka po celotni višini omenjene stene 6 skodele 1. Zatem se na po sebi znan način zavrta v drevo, iz katerega je potrebno vzeti prirastni vzorec. Pripomoček po izumu pri tem s steno 6 izreza 7, 8 deluje na vsakokratni krak ročaja 5a in ga vrti, skupaj s steblom 5, s katerim sta oblikosklepno povezana, v smeri gibanja urinega kazalca. Če električni pogonski stroj ne zmore več vrteti svedra, se omenjeni električni pogonski stroj sname s priključnega nastavka 3, nakar se prirastni sveder ročno zavrti do zahtevane globine. Ko je dosežena zadostna globina izvrtine, bodisi s pomočjo električnega pogonskega stroja bodisi ročno, se električni pogonski stroj, seveda če se s pomočjo le-tega doseže zahtevano globino izvrtine, sname s priključnega nastavka 3. Zatem se prirastni sveder za približno pol do enega obrata ročno zavrti v nasprotni smeri, s čimer se izvrtani prirastni vzorec loči od debla drevesa, nakar se s pomočjo ustrezne odvzemne priprave, ki je po sebi znana in zato ni podrobneje prikazana in opisana, odvzame iskani prirastni vzorec.

Temu sledi ponovna priključitev električnega pogonskega stroja na omenjeni priključni nastavek 3 in zasuk prirastnega svedra, tako da se vsakokratni krak ročaja 5a znajde v omenjenem žepu 9 vsakokratnega izreza 7, 8. Zatem se s pomočjo električnega pogonskega stroja in vrtenjem v smeri, ki je nasprotna gibanju urinega kazalca, prirastni sveder izvleče iz vrtine v drevesu. Pri tem je potrebno tako električni pogonski stroj kot tudi prirastni sveder s sorazmerno veliko silo vleči iz omenjene vrtine v drevesu. Kot omenjeno zgoraj se vsakokratni krak ročaja 5a sedaj nahaja v omenjenem žepu 9 vsakokratnega izreza 7, 8, pri čemer se ob vlečenju prirastnega svedra iz vrtine kraka ročaja 5a naslanjata na omenjeni mostič 9a. S tem se prepreči neželeno snetje električnega pogonskega stroja s pripomočka po izumu.

Gozdarski inštitut Slovenije

Za:

Patentni zahtevki

1. Pripomoček pri prirastnem svedru za pridobivanje vzorcev rasti dreves za dendrokronološke raziskave, zlasti pri strojno gnanem prirastnem svedru, ki je prednostno gnan s pomočjo ročnega električnega pogonskega stroja, ***značilen po tem***, da je zasnovan kot valjasta skodela (1) z dnom (2) in steno (6), pri čemer je dnu (2) na zunanji strani soosno prigrajen priključni nastavek (3) za povezavo z električnim pogonskim strojem, na notranji strani pa valjast nastavek (4) za povezavo s steblom (5) svedra, in pri čemer je omenjena stena (6) v smeri proč od dna (2) zasnovana z diametralno nasproti ležečima si ovalnima izrezoma (7, 8).

2. Pripomoček pri prirastnem svedru po zahtevku 1, ***značilen po tem***, da je daljša središčnica omenjenih izrezov (7, 8) približno vzporedna dnu (2).

3. Pripomoček pri prirastnem svedru po zahtevkih 1 in 2, ***značilen po tem***, da vsakokraten izrez (7, 8) na svojem prvem vzdolžnem koncu poteka po celotni višini omenjene stene (6).

4. Pripomoček pri prirastnem svedru po zahtevkih 1 in 2, ***značilen po tem***, da omenjeni izrez (7, 8) na svojem drugem vzdolžnem koncu tvori žep (9) v omenjeni steni (6), ki je tako na strani, obrnjeni proč od omenjenega dna (2), zamejen z mostičem (9a).

5. Pripomoček pri prirastnem svedru po kateremkoli od predhodnih zahtevkov, ***značilen po tem***, da so izmere omenjenega izreza (7, 8) v celoti prirejene za sprejem ročaja (5a) prirastnega svedra

Gozdarski inštitut Slovenije
Za:

P2120803.odt

Povzetek

Predloženi izum se nanaša na pripomoček pri prirastnem svedru za pridobivanje vzorcev rasti dreves za dendrokronološke raziskave, zlasti pri strojno gnanem prirastnem svedru, ki je prednostno gnan s pomočjo ročnega električnega pogonskega stroja. Po predloženem izumu je predvideno, da je omenjeni pripomoček zasnovan kot valjasta skodela (1) z dnom (2) in steno (6), pri čemer je dnu (2) na zunanji strani soosno prigrajen priključni nastavek (3) za povezavo z električnim pogonskim strojem, na notranji strani pa valjast nastavek (4) za povezavo s steblom (5) svedra, in pri čemer je omenjena stena (6) v smeri proč od dna (2) zasnovana z diametralno nasproti ležečima si ovalnima izrezoma (7, 8).

(Fig. 1)

1/1

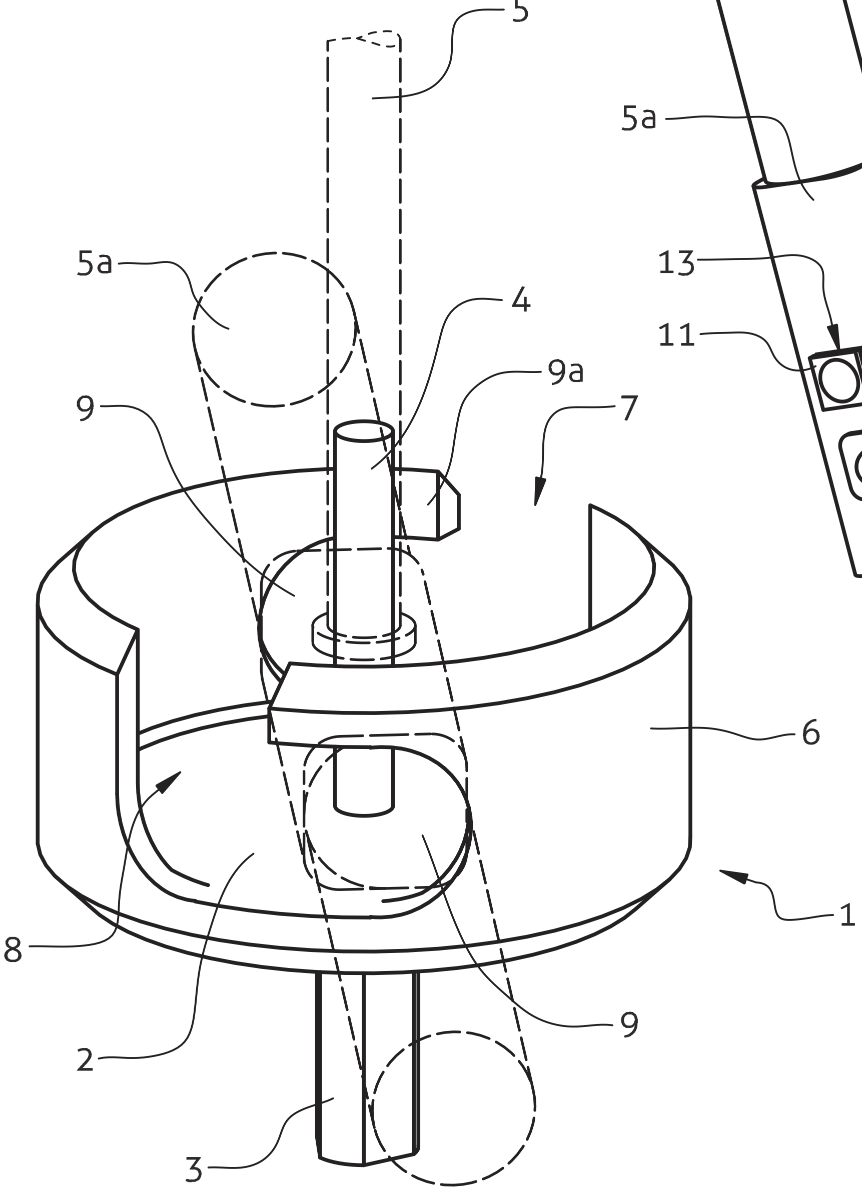


FIG. 1

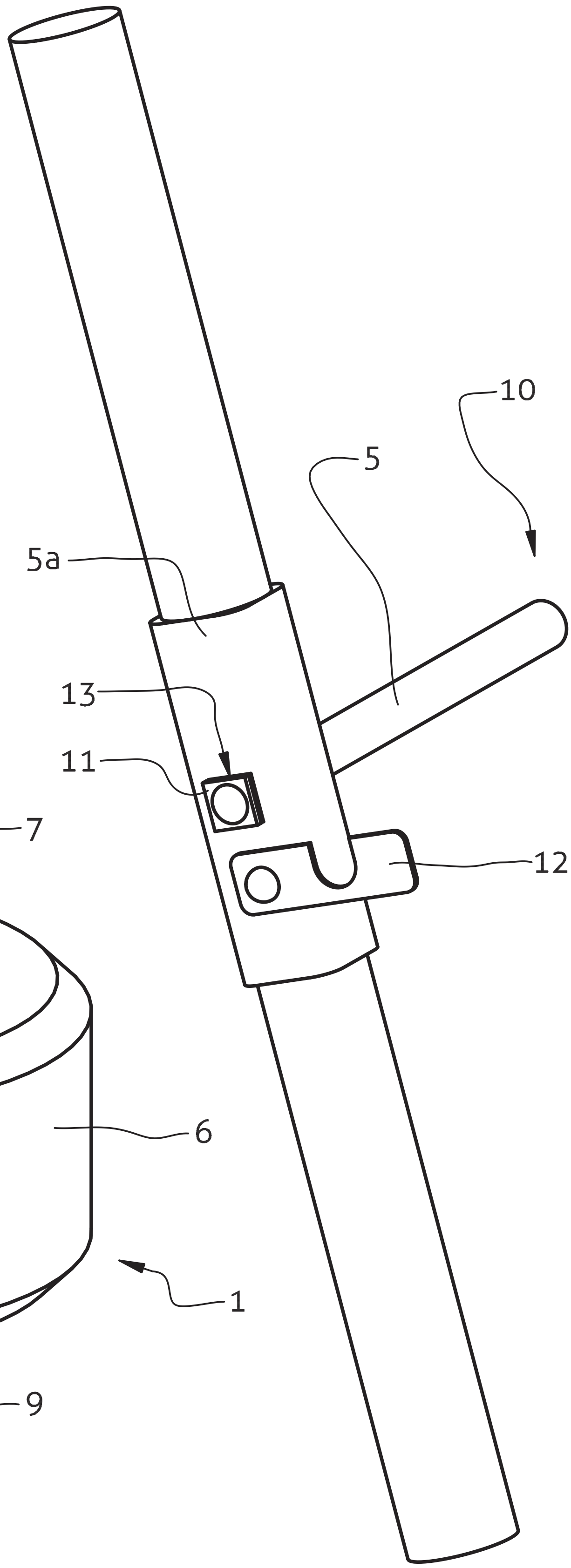


FIG. 2

Priloga E

Članek Primerjava programov za standardizacijo časovnih vrst v dendrokronologiji

Zbornik gozdarstva in lesarstva 93 (2010), s. 11–22

GDK: 56.241(045)=163.6
UDK: 630*56:004.42(045)=163.6
Prispelo / *Received:* 06.05.2010
Sprejeto / *Accepted:* 03.09.2010

Izvirni znanstveni članek
Original scientific paper

Primerjava programov za standardizacijo časovnih vrst v dendrokronologiji

Simon POLJANŠEK[1], Špela JAGODIC[2], Tom LEVANIČ[3]

Izvleček

Za standardizacijo zaporedij širin branik je v uporabi več programov, mi smo primerjali dva - najbolj razširjeni in znani program ARSTAN in pred kratkim predstavljeno knjižnico za standardizacijo dendrokronoloških podatkov dplR, narejeno za statistični program R. Oba programa sta brezplačna, ARSTAN je namenski program za standardizacijo zaporedij širin branik, medtem ko je program R, v okviru katerega deluje knjižnica dplR, namenjen tudi drugim analizam in prikazom podatkov. Uporabili smo različne teste in preverili, ali so med kronologijami širin branik, kakor jih izračunata ARSTAN in dplR, statistično značilne razlike in ali so standardizirane kronologije, narejene s knjižnico dplR, enako uporabne za preučevanje ekoloških in klimatoloških vprašanj, kot so kronologije, narejene s programom ARSTAN. ARSTAN za izračun kronologije ponudi uporabniku listo ukazov, medtem ko dplR zahteva pisne ukaze in ne ponuja izbire. Pri primerjavi rezultatov smo ugotovili, da razlike med izračuni primerjanih programov niso statistično značilne - programa pri osnovnih statističnih parametrih ponudita enake rezultate za povprečne širine branik in standardne odklone ter z razliko na drugem decimalnem mestu za rezultate občutljivosti in avtokorelacijskega koeficienta. Korelacija med standardiziranima kronologijama znaša 0,9773, med kronologijama ostankov pa 0,9776, grafično so razlike prav tako maloštevilne in majhne. Ker se programa razlikujeta le po delovnem okolju, je odločitev o izbiri programa prepuščena uporabniku.

Ključne besede: dendrokronologija, računalniški program, ARSTAN, dplR, kronologija širin branik

Comparison of two programs for standardisation of time-series data in dendrochronology

Abstract

Several freeware programs are available for calculation of chronologies. In this paper, we compared two of these programs; the well known ARSTAN and the newly introduced library for standardization dendrochronological data dplR, made for statistical program R. Both are free. ARSTAN is specific and produces chronologies from tree-ring width by standardization, while dplR is a package within the statistical programming environment R, which is able to analyze and present results of other analysis. For comparison of chronologies, made in these two programs, we used different tests. ARSTAN provides many options for calculating chronologies, whereas dplR demands written orders and offers no choices. Differences between built chronologies from these two programs are not statistically significant – programs produce same results comparing basic statistical analysis for average tree-ring widths and standard deviations, but for results of sensitivity and autocorrelation coefficient, there is a difference on a second decimal place. Correlation between standardized chronologies is 0.9773, while between residual chronologies it reaches 0.9776; graphically, the differences are also small and low numbered. As the true difference between the programs lies merely in the working environment, it is for users to decide, which program suit them best.

Key words: *dendrochronology, computer program, ARSTAN, dplR, chronology tree-ring width*

1 Uvod

1 Introduction

Drevesa rastejo v naravnem okolju, zato na njihovo rast vplivajo številni dejavniki, kot so starost, klima, konkurenca med drevesi, tla itd. Navadno nas ne zanimajo vplivi vseh dejavnikov hkrati, zato so tisti dejavniki, ki jih ne preučujemo, moteči in jih v procesu raziskav skušamo odstraniti. To storimo s postopkom, ki se v dendrokronologiji imenuje standardizacija (ang. *standardization*). Standardizacija v dendrokronologiji temelji na združenem linearnem modelu rasti, ki ga je postavil Cook (COOK / KAIRIUKSTIS, 1989) in se glasi:

[1] S. P., Gozdarski inštitut Slovenije, Večna pot 2, SI-1000 Ljubljana, simon.poljansek@gozdis.si
[2] Š. J., Gozdarski inštitut Slovenije, Večna pot 2, SI-1000 Ljubljana Slovenija, spela.jagodic@gozdis.si
[3] doc.dr., T. L., Gozdarski inštitut Slovenije, Večna pot 2, SI-1000 Ljubljana, tom.levanic@gozdis.si

$$R_t = A_t + C_t + \delta D1_t + \delta D2_t + E_t,$$

pri tem je R_t opazovana časovna vrsta (zaporedje) širin branik, A_t trend v časovni vrsti, ki je odvisen od starosti drevesa, C_t so združeni klimatski vplivi na širino branike, δ binarni simbol, kjer vrednost 1 pomeni motnjo, 0 pa, da motnje, ki jo povzročajo lokalni okoljski dejavniki ($D1_t$) in širša okolica drevesa ($D2_t$), ni, medtem ko E_t ponazarja nepojasnjeni del variabilnosti širine branike.

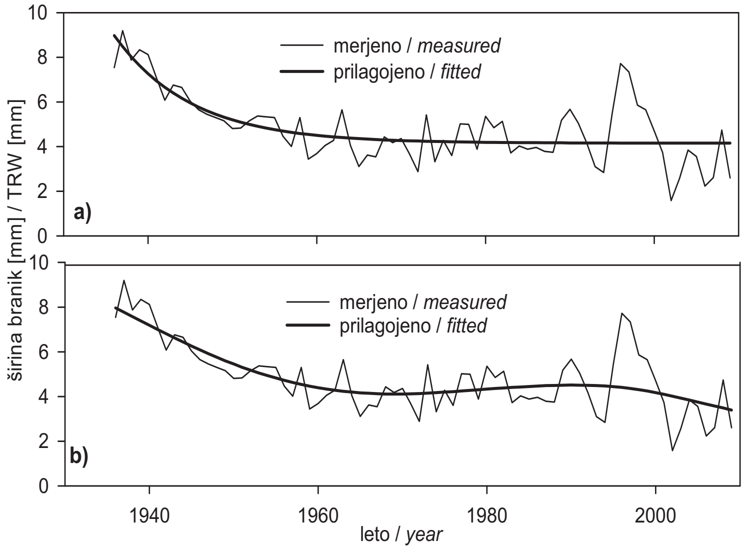
Standardizacija je računsko zahteven postopek, za katerega večinoma uporabljamo program ARSTAN (HOLMES/ADAMS/FRITTS, 1986), ki je v uporabi še od časov, ko ni bilo na voljo ustreznih programskih orodij za delo s časovnimi vrstami. V zadnjem času pa se pojavljajo programske knjižnice, ki tečejo v programih R (BUNN, 2008) in Matlab in opravljajo podobne funkcije kot program ARSTAN, le da tečejo v bolj modernem programskem okolju (npr. MS Windows). Postopek standardizacije zaporedij širin branik je, matematično gledano, analiza časovnih vrst. V našem primeru gre za postopek iskanja primerne regresijske funkcije in izračuna ostankov (ang. *residuals*) oziroma razmerij med prilagojenimi (pričakovanimi, ang. fitted values) in dejanskimi (izmerjenimi, ang. measured values) vrednostmi (LEVANIČ, 1996). Rezultat standardizacije so standardizirane (indeksirane) krivulje, ki so primerljive med drevesi različnih starosti in z različnih rastišč. Za standardizacijo v glavnem uporabljamo dva tipa regresijskih funkcij – toge in gibke. Toge regresijske funkcije (kot npr. linearna in modificirana negativna eksponentna) se navadno dokaj slabo prilagajajo merjenim podatkom, vendar so v primeru, ko je trend debelinske rasti enakomerno naraščajoč ali padajoč, primerne za standardizacijo širin branik (slika 1a).

Gibke regresijske funkcije, kot npr. kubični zlepki ali drseče sredine (slika 1b), so bistveno bolj fleksibilne in se dobro prilagajajo rasti dreves, tudi v zelo dinamičnih okoljskih in sestojnih razmerah, kjer so pogosta redčenja, vetrolomi, rast ob vrzelih, itd.

Standardizacija dendrokronoloških podatkov, kot jo poznamo danes, je bila pred uvedbo računalnikov težko izvedljiva, v primeru kubičnih zlepkov pa tudi nemogoča. Po letu 1960 so se tudi v civilni sferi pojavili prvi računalniki in različni programi (glej npr. BUNN, 2008), vendar smo šele v poznih 80-ih letih prejšnjega stoletja dobili prvi zares uporaben program za standardizacijo dendrokronoloških podatkov, imenovan ARSTAN. Ta še danes velja za de-facto standard in vsi programi ali knjižnice za standardizacijo dendrokronoloških podatkov se zgledujejo po njem, tudi knjižnica dplR, ki jo v tem prispevku želimo primerjati s programom ARSTAN.

Cilji prispevka so naslednji:

1. Opisati potek standardizacije zaporedij širin branik v ARSTANU in dplR, s poudarkom na izvedbi standardizacije v dplR.
2. Primerjati rezultate standardizacije zaporedij širin branik v programskih okoljih ARSTAN in dplR, tako z vizualnimi kot statističnimi metodami, in ovrednotiti morebitne razlike, ki so posledica razlik v algoritmih za izračunavanje standardiziranih kronologij.
3. Korelacijska analiza: ugotoviti, ali prihaja do statistično značilnih razlik pri izračunu korelacije kronologij s klimo.
4. Poudariti uporabnost programa R v dendrokronoloških analizah.



Slika 1: Merjene in prilagojene širine branik: (a) z modificirano negativno eksponentno funkcijo in (b) s kubičnim zlepkom
Figure 1: Measured tree-ring widths, fitted (a) with modified negative exponential function and (b) cubic smoothing spline

2 Materiali in metode

2 Materials and methods

2.1 Dendrokronološki podatki

2.1 Dendrochronological data

Za primerjavo programov ARSTAN in dplR smo iz dendrokronološke zbirke Oddelka za prirastoslovje in gojenje gozdov Gozdarskega inštituta Slovenije izbrali 10 preverjenih in sinhroniziranih zaporedij širin branik dobov (*Quercus robur*) iz Murske Šume, vzorčenih v letu 2009. Osnovni podatki o zaporedjih širin branik so predstavljeni v preglednici 1. Podatkovna datoteka je bila zapisana v obliki tekstovne datoteke tipa Tucson, ki ga bereta tako ARSTAN kot dplR.

podatki smo ovrednotili s parnim t-testom. Parni t-test je preskušanje razlik med parametri dveh vzorcev, gre torej za statistično testiranje razlik med dvema nizoma podatkov ali med dvema metodama na istem nizu podatkov (KOŠMELJ, 2007).

2.4 Splošno o programu ARSTAN

2.4 General information about ARSTAN

ARSTAN je prosto dostopen računalniški program, razvit s strani Edwarda R. Cooka (http://www.ldeo.columbia.edu/res/fac/trl/public/public-Software.html). Program standardizira zaporedja širin branik, ki so v principu časovne vrste, izračuna kronologije, jih grafično prikaže ter izpiše široko paleto statističnih kazalnikov

Preglednica 1: Osnovni podatki zaporedij širin branik vzorčnih hrastov

Table 1: Basic data of tree ring widths of sampled oaks

drevo / *series*	ime / *name*	prvo leto / *first year*	zadnje leto / *last year*	dolžina / *lenght*	povpr. širina branike / *mean ring width*
1	ms1-01	1945	2009	65	3,15
2	ms1-02	1938	2009	72	4,07
3	ms1-03	1936	2009	74	4,78
4	ms1-04	1935	2009	75	2,95
5	ms1-05	1943	2009	67	3,92
6	ms1-06	1941	2009	69	3,68
7	ms1-07	1935	2009	75	4,93
8	ms1-09	1937	2008	72	3,89
9	ms1-10	1937	2008	72	4,55
10	ms1-08	1933	2008	76	3,55

2.2 Meteorološki podatki

2.2 Meteorological data

Meteorološki podatkovni niz so sestavljali podatki o povprečnih mesečnih temperaturah in povprečnih mesečnih količinah padavin za Mursko Soboto za obdobje od leta 1951 do 2005. Podatke smo dobili na Agenciji Republike Slovenije za okolje (ARSO, 2009). Uporabili smo jih v analizi, kjer smo primerjali korelacije med klimatskimi podatki in residualnima kronologijama, narejenima v Arstanu in dplR.

2.3 Statistične analize

2.3 Statistical analysis

Razlike med rezultati izdelanih kronologij in korelacije med obema kronologijama in klimatskimi

vhodnih podatkov. Program je razmeroma zastarel, saj želene parametre obdelave določamo s pomočjo številskih ukazov, npr. tip standardizacije izberemo tako, da vtipkamo številko 4, nato pa izberemo funkcijo (glej sliko 3). Potek standardizacije spremljamo za vsako časovno vrsto posebej. Za izvedbo standardizacije imamo na voljo različne matematične funkcije (toge in gibke, tudi kubični zlepki) ter eno ali dvostopenjsko standardizacijo. Odločitev za eno ali dvostopenjsko standardizacijo temelji na ekspertni oceni in predhodni vizualni analizi časovnih vrst v enem od dendrokronoloških programov (npr. PAST-4). Po končanem postopku standardizacije dobimo kot rezultat datoteko, ki vsebuje 4 tipe kronologij širin branik (glej sliko 2) (LEVANIČ, 1996):

1. Osnovna kronologija (RAW) je enostavno povprečje nestandardiziranih zaporedij širin branik in vsebuje vse odzive rasti drevesa na okoljske dejavnike.

2. Standardizirana kronologija (STD) je aritmetična sredina standardiziranih podatkov. Standardizirane

vrednosti so izračunane kot razmerje med izmerjeno širino branik in prilagojeno vrednostjo (regresijsko funkcijo). Povprečje vrednosti količnikov za vse kronologije dreves je izračunano kot navadna aritmetična sredina ali pa kot robustna , tehtana aritmetična sredina, ki drugače upošteva vrednosti, ki se od povprečja preveč razlikujejo (ang: *outliers*).

3. Kronologija ostankov (RES) (ang. *residual chronology*) je robustno (vsaka vrednost ima enako težo) standardizirano povprečje ostankov avtoregresijskega modeliranja zaporedij širin branik. Osnova je kronologija STD, ki ji z metodo »čiščenja« (ang. *prewhiten*) odstranimo avtokorelacijo.

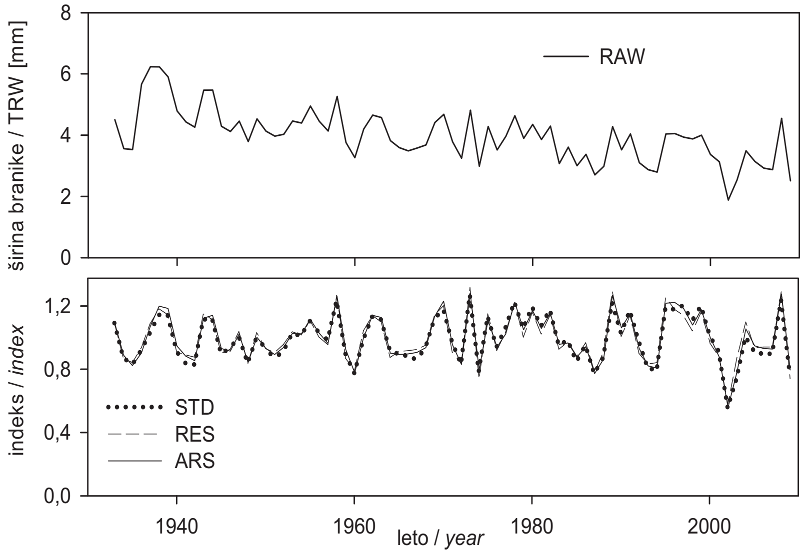
4. Četrto kronologijo tipa ARS dobimo tako, da z uporabo avtoregresijskega modeliranja v kronologijo RES dodamo povprečno stopnjo avtokorelacije analiziranih zaporedij širin branik. V tej kronologiji je jakost klimatskega signala podobno visoka kot v kronologiji RES (LEVANIČ, 2006).

V ARSTAN-u se rezultati med procesom izdelave kronologij prikazujejo grafično za vsako drevo posebej. Tako lahko za vsako drevo vizualno preverimo, kako se regresijska krivulja prilagaja podatkom. Proces lahko pri vsakem drevesu ustavimo, izberemo drugo funkcijo za standardizacijo, shranimo grafikon in nadaljujemo z analizo. Na koncu nam ARSTAN poleg izračuna kronologij v mapo shrani tudi obsežen izpis statističnih kazalnikov in različne podatke za nadaljnje analize. Vse datoteke se zapišejo v mapo, kjer sta program ARSTAN in datoteka s podatki. Ker je ARSTAN v svojem bistvu program, ki je bil razvit v operacijskem sistemu MS-DOS in zato ne pozna pridobitev okenskih operacijskih sistemov, naredi v direktoriju večje število datotek, v katerih so rezultati standardizacije. Tako npr. datoteka s končnico _tabs vsebuje vse 4 tipe kronologije, s končnico _raw ponazarja merjena zaporedja širin branik za izdelavo kronologij, _out pa prikaže izbrane specifikacije izdelane kronologije s statističnimi kazalniki za osnovne podatke ter kronologijo ostankov. Datoteka s končnico _ind1 vsebuje vrednosti standardiziranih kronologij posameznih dreves, _res vrednosti kronologije ostankov, _crv1 pa postreže z izračunanimi vrednostmi krivulje, ki smo jo izbrali za standardizacijo posameznih zaporedij širin branik. Za primerjavo med programom ARSTAN in dplR smo uporabili kronologiji STD in RES.

2.5 Standardizacija v ARSTAN-u (različica 4.1.D za Windows XP)

2.5 Standardization in ARSTAN (version 4.1.D for Windows XP)

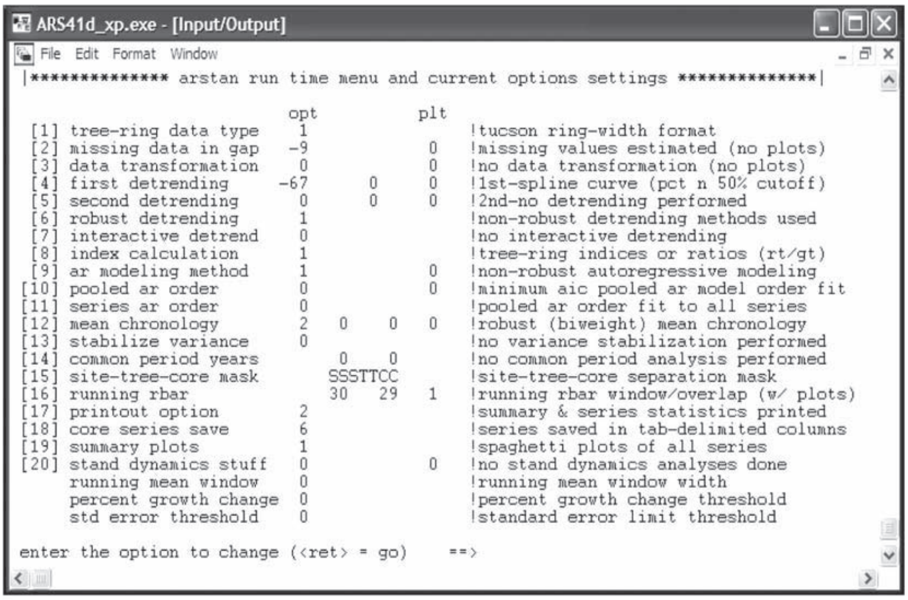
Programu najprej definiramo vir podatkov v standardnem formatu Tucson, nato se odpre meni (slika 3), prek katerega določamo parametre za izračun kronologije. Pod zaporedno št. 4 izberemo tip funkcije za prvo stopnjo standardizacije. Pod št. 12 izberemo način izračuna povprečij standardiziranih vrednosti kronologije. Pri št. 16 določamo izračun EPS (ang. expressed population signal, več glej: BRIFFA et al., 1990, povzeto po COOK / KAIRIUKSTIS 1990). V našem primeru smo izbrali kubični zlepek z dolžino, ki ustreza 67 % dolžine kronologije, s 50-odstotno ohranitvijo variabilnosti podatkov in z robustnim izračunavanjem aritmetične sredine izdelanih kronologij. Za izračun drsečega populacijskega signala (EPS) smo izbrali širino obdobja 30 let, s pomikom po 1 leto. Na koncu določanja parametrov definiramo še način prikaza



Slika 2: 4 tipi kronologij, dobljenih v programu ARSTAN – »surova« kronologija, samo povprečje zaporedij širin branik (RAW), standardna kronologija (STD), kronologija ostankov (RES) in avtoregresivna kronologija ARS

Figure 2: 4 types of chronologies, calculated in ARSTAN program – raw chronology, just an average of all tree-ring chronologies (RAW), standard chronology (STD), residual chronology (RES,) and autoregressive chronology ARS

rezultatov (točki 17 določimo vrednost 2; posebni grafi) ter način shranitve rezultatov (točki 18 določimo vrednost 6; tab datoteke).



Slika 3: Zapis v ARSTAN-u za izračun standardizirane časovne vrste
Figure 3: ARSTAN options for standardization measurement series

zapisov, ukazov, ki omogočajo opravljanje operacij. Ena izmed knjižnic je dplR (ang: *dendrochronology* program library in R), namenjen standardizaciji časovnih vrst v

2.6 dplR

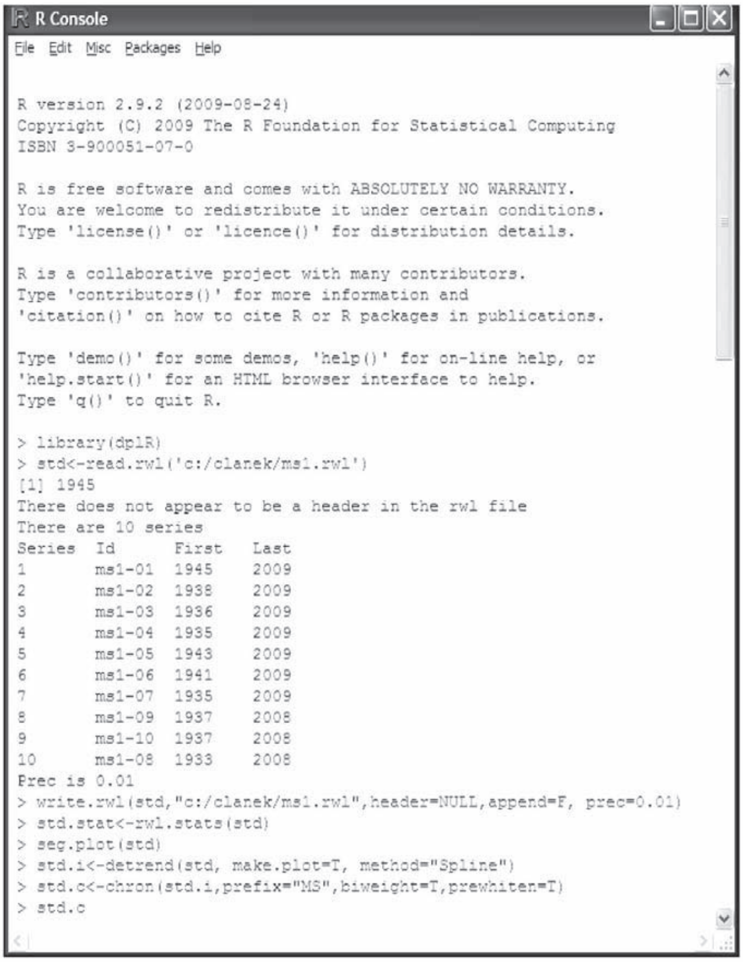
2.6 dplR

R (www.r-project.org) je brezplačno programsko okolje za statistične analize podatkov, njihovo grafično prikazovanje ter platforma za razvoj in implementacijo novih matematično-statističnih rešitev (R DEVELOPMENT CORE TEAM, 2009). Njegova prednost je fleksibilnost, ki se kaže v velikem številu paketov (statistične analize, računske operacije in grafični prikazi), ki jih kot knjižnico (ang: *library*) vključimo v R in rabijo različnim matematično-statističnim operacijam v R. Program je neodvisen od operacijskega sistema, zato deluje na vseh modernih operacijskih sistemih (Microsoft Windows, Mac OS, Linux). Prednost je tudi razvita komunikacija med drugimi uporabniki tega programa (spletna objava in reševanje težav). Slabost R je, da je obsežen in kompleksen program ter zato težaven za učenje, manjka pa mu tudi menijska struktura izbire ukazov (ni okenskega grafičnega vmesnika), zato moramo vsak ukaz pred izvedbo vtipkati. Ta problem rešimo s programskim urejevalnikom Tinn-R. To je brezplačen, preprost in učinkovit program, v katerem zapisane ukaze preprosto shranimo, kopiramo ali posredujemo drugim uporabnikom, kar zagotavlja ponovljivost analize. Tinn-R s pošiljanjem ukazov prek vrstic nadzoruje R. Program R in njegove knjižnice posodabljamo prek interneta. Knjižnica je zbirka dendrokronologiji. Knjižnico dplR uporabimo takrat, kadar želimo standardizirati zaporedja širin branik, a ne želimo uporabiti ARSTAN-a. Tako kot ARSTAN nam tudi dplR omogoča prilagoditev regresijske krivulje posameznemu drevesu in sestavo kronologije.

2.7 Standardizacija z dplR

2.7 Standardization with dplR

Knjižnica dplR deluje podobno kot ARSTAN, le da je na voljo manj ukazov za standardizacijo. Najprej poženemo program R, nato pa odpremo knjižnico dplR in določimo mesto, kjer so naši podatki, sledi branje tekstovne datoteke Tuscon, standardizacija ter izdelava kronologije (za celoten zapis glej sliko 4). Postopek standardizacije smo opravili enako kot v ARSTAN-u. Zaporedje širin branik smo standardizirali s kubičnimi zlepki s 67 % dolžine kronologije, s 50-odstotnim ohranjanjem variabilnosti podatkov ter z robustnim izračunavanjem aritmetične sredine izdelanih kronologij.



Slika 4: Delovno okolje v programu R

Figure 4: Working environment in program R

Standardizacijo v nasprotju z ARSTAN-om napravimo v dplR-ju v naslednjih korakih (slika 4).

1. Najprej odpremo knjižnico dplR z ukazom:

   library(dplR)

2. Nato določimo vir (ang. *data frame*) in značilnosti baze podatkov. V primeru je privzeto, da so naši podatki na lokalnem disku C in da se datoteka imenuje ms1.rwl. Funkcija *read.rwl* (ang. *rwl = ring width list*) omogoča branje standardne tekstovne datoteke tipa Tuscon.

   std<-read.rwl('c:/R/podatki/ms1.rwl')

3. Osnovne statistične kazalce zaporedij širin branik dobimo z ukazom rwl.stats, graf prekrivanja dolžine kronologij dreves pa z ukazom *seg.plot*.

   std.stat<-rwl.stats(std)

   seg.plot(std)

4. Funkcija detrend omogoča prikaz treh različnih prilagoditev (negativna eksponentna, kubični zlepki in linearna funkcija) za vsak posamezen primer (npr. vsako drevo), vendar v skupnem grafičnem programskem oknu. V našem primeru smo kronologije dreves standardizirali s kubičnimi zlepki (method="*Spline*") z ukazom *detrend*.

   std.i<-detrend(std, make.plot=T, method="Spline")

5. Z ukazom chron povprečimo standardizirane kronologije dreves (std.i) v skupno kronologijo std.c. Ukaz chron za izračun srednje vrednosti kronologij uporablja Tukeyevo robustno aritmetično sredino (*biweight=T*), pri kateri imajo ekstremne vrednosti (širine branik) drugačno težo (njihov vpliv na aritmetično sredino je zmanjšan). Z ukazom crn. plot kronologijo prikažemo na zaslonu. Ker želimo odstraniti vpliv avtokorelacije, uporabimo ukaz

»*prewhiten=T*«. Osnovne statistične parametre narejene kronologije nam prikaže *rwi.stats*.

```
std.c<-chron(std.i, biweight=T,prewhiten=T)
crn.plot(std.c)
std.stat.i<-rwi.stats(std.c,period="max")
```

Za izdelano kronologijo lahko izračunamo še naslednja kazalca:

1. Srednja mera občutljivosti[2] se, ko je rastni trend odstranjen, izračuna z izrazom *sens1* oziroma *sens2*, ko še obstaja.

```
sens1(std.i)
sens1(std.c)
sens2(std)
```

2. Za izračun avtokorelacijskih koeficientov[3] odpremo novo knjižnico.

```
library(FinTS)
acfms<-Acf(std.c$MSstd, na.action = na.pass, lag.max = 10)
acraw<-acf(std,na.action = na.pass)
library(stats)
pcfms<- pacf(std.c$MSstd, na.action = na.pass, lag max = 10)
```

Če želimo shraniti kronologijo, uporabimo ukaz *write.rwl*, ki kronologijo zapiše v standardnem Tucson formatu.

```
write.rwl(std,"c:/R/podatki/ms1.rwl",header=NULL,
append=F, prec=0.01)
```

3 Rezultati

3 Results

3.1 Opisna statistika merjenih širin branik

3.1 Descriptive statistics of measured tree rings

Tu primerjamo osnovno opisno statistiko, ki jo izračunata programa za isti nabor podatkov in za vsako drevo posebej. Rezultati so enaki pri zaokroževanju vrednosti na tri decimalna mesta pri izračunih povprečja in standardnega odklona, razlike pa obstajajo na tretjem decimalnem mestu pri izračunu občutljivosti ter že na drugem decimalnem mestu avtokorelacijskega koeficienta z zamikom 1 leta (preglednica 2).

3.2 Primerjava standardiziranih podatkov

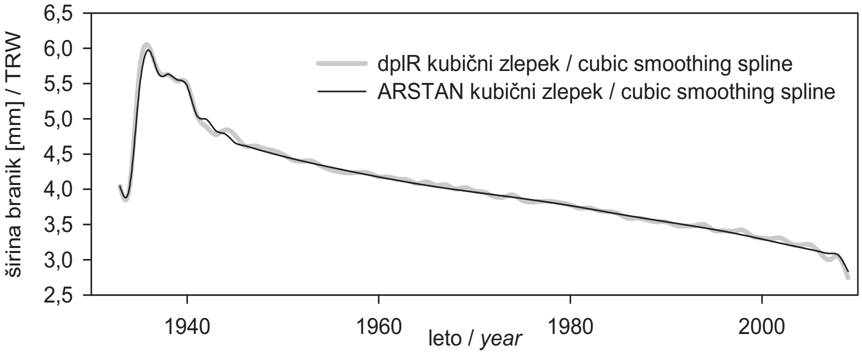
3.2 Comparison of standardized data

Tu med sabo primerjamo končne kronologije. Korelacija med standardiziranima kronologijama programa ARSTAN in dplR (slika 5) po metodi robustne ocene aritmetičnih sredin in očiščenja avtokorelacije znaša 0,9773. Aritmetična sredina indeksa pri ARSTAN-u znaša 0,989, pri dplR-ju je nekoliko višja - 0,994. Srednja mera občutljivosti je pri ARSTAN-u z 0,151 višja kot pri dplR 0,144 (preglednica 3).

Preglednica 2: Primerjava osnovnih statističnih parametrov zaporedij širin branik

Table 2: Comparison of basic statistical results of tree-ring widths

Zap.št./ *series*	obdobje / *period*	Dolžina/ *length*	povprečje/ *mean*		Std. odklon / *stdev*		Občutljivost / *sens*		ac(1) *ar1*	
			ARSTAN	dplR	ARSTAN	dplR	ARSTAN	dplR	ARSTAN	dplR
1	1945-2009	65	3,150	3,150	0,915	0,915	0,203	0,200	0,587	0,578
2	1938-2009	72	4,072	4,072	1,110	1,110	0,163	0,161	0,591	0,582
3	1936-2009	74	4,783	4,783	1,514	1,514	0,190	0,188	0,730	0,720
4	1935-2009	75	2,947	2,947	1,103	1,103	0,217	0,215	0,767	0,757
5	1943-2009	67	3,923	3,923	0,831	0,831	0,214	0,211	0,285	0,281
6	1941-2009	69	3,681	3,681	1,276	1,276	0,229	0,226	0,649	0,640
7	1935-2009	75	4,934	4,934	1,319	1,319	0,176	0,174	0,626	0,617
8	1937-2008	72	3,890	3,890	0,862	0,862	0,203	0,200	0,338	0,334
9	1937-2008	72	4,553	4,553	1,522	1,522	0,196	0,193	0,722	0,712
10	1933-2008	76	3,553	3,553	0,813	0,813	0,214	0,211	0,291	0,287



Slika 5: Povprečje kubičnih zlepkov, izdelanih v programih ARSTAN in dplR (korelacija=0,998)

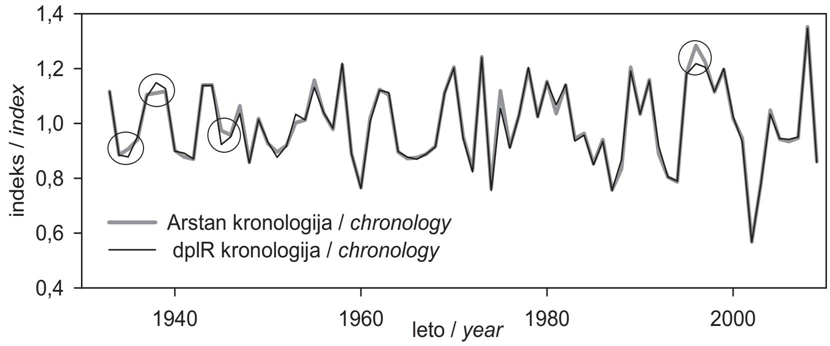
Figure 5: Average cubic spline calculated in programs ARSTAN and dplR (correlation=0.998)

Med kronologijama ostankov (RES) znaša korelacija 0,9776, aritmetična sredina indeksov pa je z 0,996 višja pri dplR kot pri ARSTAN-u 0,992 (preglednica 3). Povprečni avtokorelacijski koeficient z zamikom 1 leta za dplR znaša 0,001, za ARSTAN pa -0,144.

Preglednica 3: Primerjava statističnih parametrov kronologij, izdelanih v ARSTAN-u in dplR

Table 3: Comparison between statistical results of chronologies developed in ARSTAN and dplR

Kronologija / chronology	*Obdobje / period*	*Skupno / total*	*Indeks / index*		*Std. odklon / stdev*		*Občutljivost / sensitivity*		*ac(1) ar1*	
			Arstan	dplR	Arstan	dplR	Arstan	dplR	Arstan	dplR
STD	1933-2009	77	0,989	0,994	0,147	0,144	0,151	0,144	0,177	0,169
RES	1933-2009	77	0,992	0,996	0,148	0,140	0,169	0,150	-0,144	0,001

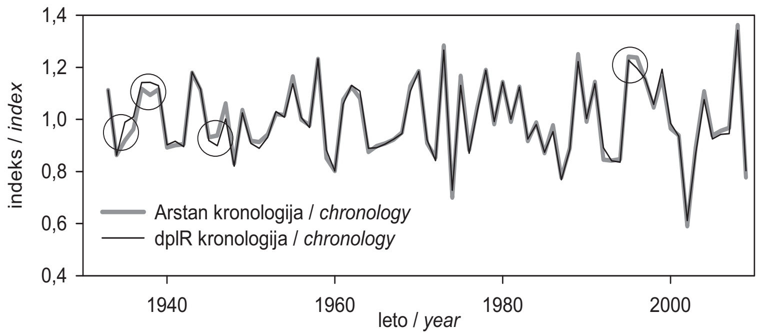


Slika 6: Primerjava kronologij STD, izdelanih v ARSTAN-u in dplR

Figure 6: Comparison of chronologies STD calculated in ARSTAN and dplR

Grafična primerjava standardiziranih (STD) kronologij, izračunanih v dplR in ARSTAN-u, je pokazala manjše razlike le na nekaterih mestih. Omenjene razlike smo na sliki označili s krožnico (slika 6). Ob primerjavi razlik na začetku kronologije ima ARSTAN manjše odklone merjenih vrednosti od regresijske funkcije, kot so odkloni pri programu dplR. V vmesnem obdobju kronologiji izkazujeta podobnost.

Podobne razlike so pri primerjavi kronologij ostankov (RES). Zopet so med kronologijama opazne nekoliko večje vrednosti razlik na začetku kronologije, ponovno so razlike poudarjene s krožnico (slika 7).



Slika 7: Primerjava kronologij RES, izračunanih v ARSTAN-u in dplR

Figure 7: Comparison of chronologies RES calculated in ARSTAN and dplR

3.3 Korelacija s klimo

3.3 Correlation with climate

V prejšnjih poglavjih smo preverjali, ali obstajajo med izračuni kronologije v ARSTAN-u in dplR kakršnekoli razlike. Tu smo želeli dodatno preveriti, ali kronologije, narejene v ARSTAN-u in dplR, dajo drugačne, statistično značilno različne korelacije s klimatskimi podatki (glej izsek iz podatkovne datoteke pod točko 1). V tem kontekstu niti ni pomembno, kakšne so posamezne korelacije med kronologijo in klimo, bistvene so morebitne razlike v višini in predznaku korelacij. V primerjavi smo uporabili kronologije ostankov, narejene v ARSTAN-u ali v dplR. Za primerjavo smo uporabili kar program R.

1. Najprej odpremo vir podatkov za klimo, naša datoteka je imenovana klima.txt. Podatki morajo biti zapisani na način »*tab delimited*«.

   klima<-read.table(file('C:/R/podatki/klima.txt'), dec=",", sep="\t", header = TRUE)

Datoteka v stolpcih od 2 do 26 vsebuje podatke o mesečni temperaturi in padavinah. Kronologiji, narejeni v ARSTAN-u in dplR sta v stolpcu 29 in 30.

Leto	Jan-T	Feb-T	Mar-T			Nov-P	Dec-P	ARSTAN	dplR
2005	-0,9	-3,3	3,1	…	…	112	86	0,94289	0,94491
2004	-1,6	1,3	4,3	…	…	73	47	1,04768	1,03373
2003	-3,3	-3,1	5,4	…	…	81	48	0,78155	0,78146
…	…	…	…	…	…	…	…	…	…
1952	-1,8	-2,1	2,1	…	…	38	67	0,91908	0,91732
1951	1,0	4,0	4,9	…	…	114	66	0,89573	0,87656

2. Korelacijo med kronologijo, izračunano v ARSTAN-u, in klimo.

   cor(klima[29],klima[2:26],use="pairwise.complete.obs", method='pearson')

3. Korelacijo med kronologijo, izračunano v dplR, in klimo.

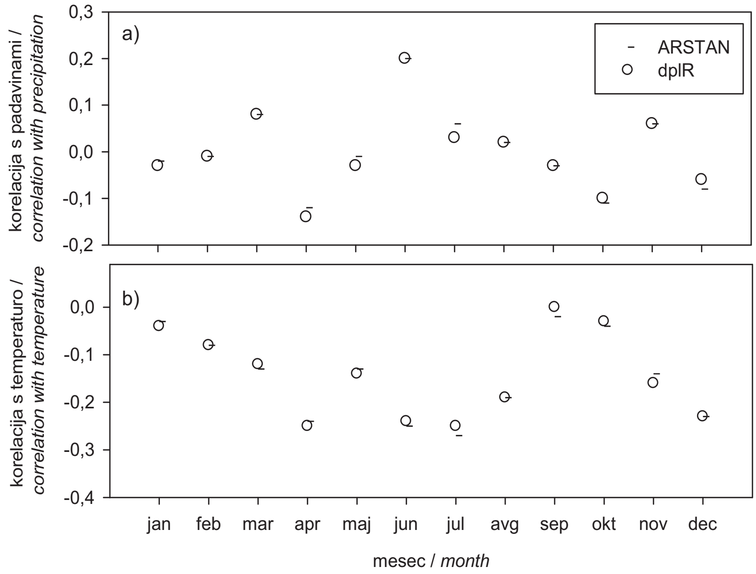
   cor(klima[30],klima[2:26],use="pairwise.complete.obs", method='pearson')

Korelacijo smo računali med podatki za povprečne mesečne temperature in mesečno količino padavin s standardiziranima kronologijama. Upoštevali smo le obdobje tistih let, za katero imamo na voljo meteorološke podatke. Pri primerjavi rezultatov korelacije širin branik glede na padavine (slika 8a) podaja ARSTAN višje pozitivne vrednosti kot dplR v mesecih januar, april, maj in julij, nižje oktobra in novembra, enake pa v preostalih mesecih. Glede na temperaturo (slika 8b) izkazuje ARSTAN-ov izračun bolj pozitivno odvisnost (oziroma manj negativno) kot dplR v mesecih januar, april, maj in november. Februarja, septembra in decembra podajata programa enako korelacijo. V preostalih mesecih izkazuje ARSTAN nekoliko nižje vrednosti. Vsota korelacij med ARSTAN-om in temperaturo znaša -1,75 in padavinami 0,04. Z dplR-jem pa -1,73 s temperaturo in -0,01 s padavinami. Povprečje korelacij znaša pri obeh programih med kronologijama in temperaturo -0,14 in med padavinami 0,00. Standardni odklon je pri vseh korelacijah enak - 0,09.

4 Zaključki

4 Conclusions

S parnim t-testom smo preverili vse razlike med rezultati kronologij in korelacij ter potrdili, da nobena razlika med programoma ni statistično značilna. To potrjuje pravilnost izračunov programa dplR v primerjavi z bolj uveljavljenim ARSTAN-om in dendrokronologom daje možnost izbire med ARSTAN-om in dplR.



Slika 8: Primerjava korelacije kronologije STD, izdelane v ARSTAN-u in dplR s padavinami (a) in temperaturami (b) po posameznih mesecih

Figure 8: Comparison of correlation between STD chronologies calculated in ARSTAN and dplR with temperature (a) and precipitation (b)

5 Razprava

5 Discussion

V članku smo primerjali enakost izračunov dveh programov, ARSTAN-a in dplR, za standardizacijo časovnih vrst v dendrokronologiji. V obeh programih smo kronologije izračunali na podoben način (da bi ohranili primerljivost), z uporabo kubičnih zlepkov s togostjo 67 % dolžine posameznega, standardiziranega zaporedja širin branik. Izračunani kronologiji se med sabo zelo malo razlikujeta, to dokazujejo visoke korelacije in dobro vizualno ujemanje med kronologijama ter neznačilne vrednosti t-testa. ARSTAN je za začetnika lažji, ker že vsebuje predlagane operacije in možnosti izdelave poročila, vendar mora biti uporabnik že seznanjen z načinom dela in razlago dobljenih rezultatov. Pri dplR (ki je knjižnica programa R) pa moramo na začetku vse ukaze zapisati ali jih kopirati iz drugih analiz sami. Vendar, ko imamo spisek ukazov enkrat narejen, ga lahko na preprost način v R-ju pregledujemo, sproti popravljamo, dopolnjujemo in posredujemo. V ARSTAN-u lahko med procesom izdelave kronologije zamenjamo tip krivulje, ne moremo pa se vračati v pretekla dejanja, temveč moramo začeti proces izpeljati do konca ali pa ga v celoti prekiniti. Pri dplR ni ovire, če želimo popraviti ukaz v preteklem dejanju, saj se prosto odločamo o izvajanju operacij, hkrati pa si ogledujemo rezultate (tabele, grafe). Izdelava enostavnih grafov je v R-ju preprosta, z višanjem zahtevnosti grafov pa se veča tudi zahtevnost izvedbe. Razlike v grafih primerjanih kronologij STD in RES lahko pripišemo računanju vrednosti na začetku in na koncu obdobij, zaradi drugačnega upoštevanja konca kronologij. Razlike se namreč pojavljajo prav v okolici začetka dolžine kronologije ter na koncu. Rezultati t-testov so pri vseh izračunanih kronologijah in koeficientih potrdili vizualno podobnost grafov izdelanih kronologij v knjižnici dplR ter v programu ARSTAN, zato lahko trdimo, da izdela dplR enako kakovostne in natančne rezultate kot že uveljavljeni ARSTAN. Ker se programa razlikujeta le po načinu opredelitve parametrov oziroma zapisu za izdelavo kronologije in predstavitvi rezultatov, naj se o dokončni izbiri programa odloči vsak uporabnik sam.

6 Summary

A tree's response to climate and other factors at radial growth can be studied by measuring tree-ring widths (TRW). TRW depends on various factors and holds information on growth for many years in the past (COOK, 1985). Chronologies, made out of raw data, are influenced by age trend and other disturbing factors. In order to remove these factors, we standardize chronologies. Process of standardization consists of finding a regression function that best fits the measured TRW and calculating

indices between them (LEVANIČ, 1996). The commonest functions are linear, modified negative exponential and cubic smoothing spline (Figure 1). For this study, a cubic smoothing spline with 50% frequency response and 67% length of chronology was chosen. Computer programs such as ARSTAN and dplR (dendrochronology program library in R) allow users to read Tuscon format files and perform a variety of functions or statistical analyses. In these two programs, we compared numerical and graphical results of site chronology, made for 10 pedunculate oaks (*Quercus robur*). In this article we describe standardization in both programs and compare results. One of the goals is also to introduce the usefulness of R.

ARSTAN is a free program, developed by Cook and Holmes (http://www.ldeo.columbia.edu/res/fac/trl/public/public-Software.html). It produces chronologies from tree-ring widths series by detrending and indexing (standardizing) the series, then applying a robust estimation of the value function to remove effects of endogenous stand disturbance (HOLMES/ADAMS/FRITTS, 1986). The program execution properties (settings) are chosen from a menu before starting standardization (Figure 3). When the process is completed, statistics of each measurement series before and after detrending can be seen. ARSTAN produces four chronologies: raw, STD, RES and ARSTAN (Figure 2). The basic (raw) chronology of TRW contains age trend and standardized (STD) is the detrended tree ring index series, combined into a mean value function of all series (as a robust estimation of arithmetic mean). The residual (RES) chronology is computed the same as STD, this time using the residual series from autoregressive modelling of the detrended measurement series. Robust estimation of the mean value function produces a chronology with a strong common signal and without persistence. The pooled model of autoregression is reincorporated in to the RES version to produce the ARSTAN chronology. ARSTAN creates statistical results of chronologies, eigenvalues and principal component analysis. Standardization and how the regression line is fitted to measurement series can be controlled for one tree at a time. We can stop calculation, choose other method and continue. For comparison between programs, we have chosen the STD and RES chronologies.

R (www.r-project.org) is a statistical programming environment for statistical analysis and graphical presentation of results. There are four features that make R preferred; first, R and its add-on packages (libraries) are free. Second, R community helps with posting questions and answers on the Internet. Third, all analyses in R are easily reproducible, and fourth, R operates on every modern computer platform (BUNN, 2008). Libraries are an essential part of the program, containing orders and enabling operations. One of them is the dendrochronology program library in R or short dplR, used for standardization measurement series (Figure 4). R demands from users written orders that can easily be re-called, but not if in the meanwhile the program is shut down. This problem is solved with commands, saved in Tinn-R. This is another free, simple and efficient program, in which we process, copy and reproduce analyses. STD and RES chronologies are made in dplR in many ways. Like ARSTAN, it enables the computation of regression functions for individual trees or all together, but it also shows fitting of the function to measurement series for one tree at a time. In our comparison, a correlation coefficient between temperature and precipitation with our chronology made in ARSTAN was calculated. This process was repeated with dplR and results were compared.

Results for basic statistics of tree-ring widths are equal at computing mean and standardized deviation. Differences are shown only at third decimal place of result for sensitivity and on second decimal place for autocorrelation coefficient (Table 2). Correlation between standardized chronologies is 0.9773, while between residual chronologies it reaches 0.9776. Graphical comparison shows little and small differences between chronologies. Differences are circled (Figures 6 and 7). When comparing the sum of correlation values between ARSTAN and temperature, the value is -1.75 (comparing to dplR with value -1.73). With correlation between STD chronology and precipitation, the sum of correlations is valued with 0.04 for ARSTAN and 0.01 for dplR (Figure 8).

All results were checked for significance with t-test and no difference was statistically significant. This result confirms that calculations made with dplR are equal to the ones made with ARSTAN. As both of the programs have their own advantages and disadvantages, user himself should be the one to decide which program to use, when in need to standardize dendrochronological data.

7 Viri

7 References

ARSO, 2009. Podatki za klimo (temperatura, količina padavin) za območje Murske Sobote.

BAILLIE, M.G.L. / PILCHER, J.R., 1973. A simple cross-dating program for tree-ring research. Tree-Ring Bulletin, 33, s. 7-14.

BIONDI F. / QEADAN F., 2008. Inequality in paleorecords. Ecology, 89 (4), 1056-1067 s.

BRIFFA / WIGLEY 1990, povzeto po COOK / KAIRIUKSTIS 1990

BUNN, A. G., 2008. A dendrochronology program library in R (dplR). -Dendrochronologia 26, s. 115-124.

COOK, E. R., 1985. Time series analysis approach to tree ring standardization. -Doktorska disertacija. Tucson, University of Arizona, Laboratory of Tree-Ring Research, s. 171.

COOK, E.R. / BRIFFA, K. / SHIYATOV, S. / MAZEPA, A. / Jones, P.D., 1990. Data analysis. v: COOK, E.R., KAIRIUKSTIS, L.A. (Eds), Methods of Dendrochronology: Applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, s. 97-162.

COOK, E.R. / KAIRIUKTSTIS. -L.A., 1989. Methods of dendrochronology (applications in the environment sciences). -Dordrecht, Boston, London, Kluwer academic publishers, 394 s.

EKSTEIN, D / BAUCH, J., 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. –Heidelberg, Forstwissenschaftliches Centralblatt. 88.1. s. 230-250.

FRITTS, H.C., 1976. Tree rings and climate. -Tucson, Univerza v Arizoni, s. 21.

HOLMES R.L., ADAMS R.K., FRITTS H.C., 1986. Users manual for computer program ARSTAN. Tree-ring Chronologies of Western North America, Laboratory of TreeRing Research, University of Arizona, s. 50-65.

KOŠMELJ, K., 2007. Uporabna statistika. -Ljubljana, Biotehniška fakulteta, oddelek za agronomijo, s. 120.

LEVANIČ T., 1996. Dendrokronološka in dendroekološka analiza propadajočih vladajočih in sovladajočih jelk (*Abies alba* Mill.) v dinarski fitogeografski regiji. Doktorska disertacija, samozal. 184 s.

LEVANIČ T., 2006. Vpliv klime na debelinsko rast macesna (*Larix decidua* Mill.) na zgornji gozdni meji v JV Alpah. ZbGL 78, s. 29-55.

LEVANIČ T., 2007. Atrics – a new system for image acquisition in dendrochronology. Tree-ring research. 63.2, s. 117-122.

R DEVELOPMENT CORE TEAM, 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing. -Vienna, Austria. http://www.R-project.org.

Priloga F

Članek Metoda preučevanja sledi iglic terminalnega poganjka

Zbornik gozdarstva in lesarstva 96 (2011), s. 3–12

GDK: 164.5:416.11:181.45(045)=163.6
Prispelo / *Received:* 13.01.2012
Sprejeto / *Accepted:* 14.02.2012

Pregledni znanstveni članek
Scientific review paper

Metoda preučevanja sledi iglic terminalnega poganjka

Simon POLJANŠEK[1] , Primož OVEN[2] , Risto JALKANEN[3] , Tom LEVANIČ[4]

Izvleček

Metoda preučevanja sledi iglic terminalnega poganjka, ali krajše metoda sledi iglic (ang.: *needle trace method*), retrospektivno beleži starost iglice v trenutku, ko odpade, ter preučuje vpliv okoljskih in biotskih dejavnikov na številne izpeljane podatke, ki temeljijo na ugotovljeni življenjski dobi iglice. Z izvedbo metode pridobimo podatke o dolžini višinskih prirastkov ter številu sledi iglic v posameznih branikah vseh višinskih prirastkov. Z izračunanimi kazalniki je mogoče oceniti fizično stanje krošnje preučevanega drevesa. Metoda je bila razvita na Finskem na rdečem boru (*Pinus sylvestris* L.), kmalu pa uporabljena tudi na drugih iglavcih. Uporablja se na področju dendrokronologije, gozdne ekologije, patologije in entomologije. V članku avtorji predstavljajo osnovno morfologijo sledi iglic, osnovno idejo metode in njeno uporabnost v okoljskih študijah ter izpeljane kazalnike, kot so relativno število sledi iglic ter zadrževanje, izguba, odmet, starost, dolgoživost, gostota, letni prirast števila in zaloga iglic.

Ključne besede: iglavec, rdeči bor, listni aparat, kazalnik, okolje, onesnaževanje, defoliacija

Needle trace method

Abstract

Needle trace method retrospectively records the needle age at the time of its fall-off and studies the influence of the environmental and biotic factors on needle proxies. Data on height increments and number of needle traces in tree-rings of individual growth shoot are collected. With needle proxies, the tree crown's physical condition is evaluated. The method was developed in Finland on Scots Pine (Pinus sylvestris L.) and soon used on many other conifers. Its application is in dendrochronology, forest ecology, pathology and entomology. In this paper, the structure of needle trace is described, background of the method, its usage and the needle proxies: relative number of needle traces, needle retention, needle loss, needle shed, needle age, needle longevity, needle density, needle production and needle pool.

Key words: *conifer, Scots Pine, crown, needle proxy, environment, pollution, defoliation*

1 Uvod

1 Introduction

Vsako pomlad zraste na obstoječih poganjkih borov (*Pinus* spp.), jelk (*Abies* spp.), smrek (*Picea* spp.) in drugih vednozelenih iglavcih nov poganjek z novim polnim setom iglic, jeseni pa povprečno en set najstarejših iglic odpade. Povprečno število hkrati obstoječih setov iglic na drevesu je vrstno značilno, odklon od povprečja pa je posledica odziva drevesa na okoljske dejavnike. Eden izmed kazalnikov stanja gozdov je osutost drevesnih krošenj. Delež manjkajočih asimilacijskih organov se najpogosteje ocenjuje okularno, kar je sicer slabost izbrane inventurne metode. Za natančnejše merjenje osutosti je bila na Finskem na rdečem boru (*Pinus sylvestris* L.) razvita metoda preučevanja sledi iglic terminalnega poganjka (JALKANEN / AALTO / KURKELA 1994a) (ang. *needle trace method* = NTM), kar lahko poslovenimo kot metoda sledi iglic. NTM omogoča pridobitev podatkov o življenjski dobi iglic pod terminalnim poganjkom. Dolgoživost iglic vzdolž debla in vej sta značilno povezani (JALKANEN *et al.* 2000), zato dobljeni izsledki s terminalnega (vrhnjega) poganjka veljajo za vso krošnjo. NTM je bila v Sloveniji uporabljena že dvakrat; prvič pri raziskavi vpliva redčenja na rast rdečega bora (JALKANEN / LEVANIČ 2001) in drugič pri primerjavi rasti navadne smreke (Picea abies L.) z dveh rastišč (LEVANIČ *et al.* 2006). Kljub temu NTM v slovenskih prispevkih še ni bila podrobno opisana. Namen tega prispevka je razložiti nastanek, morfologijo in dimenzije sledi iglic, opisati izvedbo metode, definirati osnovne in izpeljane kazalnike metode ter predstaviti njeno

[1] S.P., univ. dipl. inž., Gozdarski inštitut Slovenije, SI-1000 Ljubljana, Slovenija simon.poljansek@gozdis.si
[2] Prof.dr., P.O., UL, BF, odd. za lesarstvo, SI-1000 Ljubljana, primoz.oven@bf-uni.lj.si
[3] D.Sc., Ph.D., R.J., Finnish Forest Research Institute, FI-96301 Rovaniemi, Finland, risto.jalkanen@metla.fi
[4] Doc.dr.,T.L., Gozdarski inštitut Slovenije, SI-1000 Ljubljana, Slovenija, tom.levanic@gozdis.si

uporabo v raziskavah rasti in odzivnosti drevesnih vrst na okoljske dejavnike.

1.1 Morfologija in dimenzije sledi iglic

1.1 Morphology and dimensions of needle traces

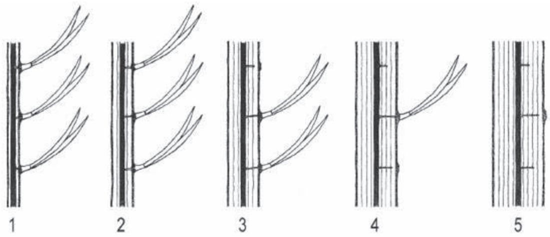
Za predstavnike *Abies*, *Cedrus*, *Larix*, *Picea*, *Pinus*, *Pseudotsuga* in *Tsuga* so značilni listi igličaste oblike. V nasprotju z luskastimi listi, ki so na primer značilni za araukarijevke (*Araucariaceae*), se pri iglastih listih pojavljata samo eden ali dva nerazvejena vaskularna pramena (MAUSETH 1988). Pramen prevodnih tkiv mnogih iglavcev vsebuje vaskularni kambij, ki proizvaja sekundarni floem, in le malo ali nič sekundarnega ksilema (MAUSETH 1988). Pramen prevodnih tkiv, ki poteka skozi ksilemske branike in povezuje notranjost iglice s prevodnim sistemom poganjka, predstavlja sled iglice (GIBSON 2010). Podobno sled v braniki imajo kratki poganjki borov (ang. *short shoot*). To so iglični ovoji, v katerih so iglice združene v skupine po 2 (npr. *P. sylvestris*, *P. nigra*), 3 (*P. ponderosa*, *P. radiata*), 4 (*P. quadrifolia*) ali 5 iglic (*P. cembra*, *P. longaeva*). Ti poganjki dodatno vključujejo še stržen, ki ga obdaja ksilem. Z izrazom sled iglic tako označujemo tudi sledi kratkih poganjkov, ki so vidne v lesu borov (Slika 1). Premer sledi iglic se

Slika 1: Mikrografija tangencialnega prereza sledi iglice pri rdečem boru (*Pinus sylvestris*) in makroskopska slika sledi iglice na prečnem prerezu dve leti starega poganjka; A označuje iglico in iglični ovoj, B sled iglice od skorje do stržena ter C stržen.

Figure 1: Micrograph of tangential section of needle trace in Scots Pine (Pinus sylvestris) and macroscopy of needle trace in cross-section of two years old shoot; A marks needle with needle fascicle, B needle trace from bark to pith, and C pith.

razlikuje med drevesnimi vrstami in med iglicami z različnih poganjkov istega osebka, ne pa med sledmi iglic z istega poganjka. Njihov premer je v sorazmerju z dolžino in težo suhe iglice, povezave z drugimi morfološkimi značilnostmi iglic (širina, debelina in morfologija) pa niso statistično značilne, zato preučevanje morfologije iglic prek njihovih sledi ni možno (PENSA / AALTO / JALKANEN 2004). V povprečju znaša premer sledi iglice pri rdečem boru 233±30 µm, navadni tisi (*Taxus baccata*) 141±19 µm, duglaziji (*Pseudotsuga menziesii*) 121±30 µm, navadni smreki (*Picea abies*) 80±18 µm ter sibirski jelki (*Abies sibirica*) 85±21 µm.

Pramen prevodnih tkiv se razteza od stržena poganjka skozi branike in skorjo poganjka do baze iglice. Ob odmrtju iglice celice abscizijskega tkiva prekinejo pretok snovi med iglico in deblom, zato se pecelj iglice oziroma steblo kratkega poganjka prelomi. Na tem mestu kambij ne proizvaja več parenhimskih celic, temveč začne proizvajati lesna vlakna poganjka. Zaradi tega sega sled iglice od stržena do mesta v braniki tistega leta, v katerem je bila iglica odvržena (Slika 2).



Slika 2: Razvoj od 1- do 5-letnega poganjka s sledmi iglic v radialnem prerezu; povzeto po: Jalkanen *et al.* (2000)

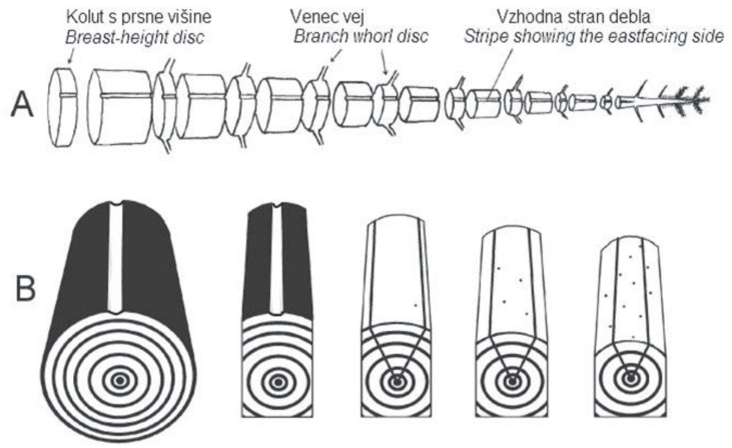
Figure 2: Development over five growing seasons of short shoots in radial vision; after: Jalkanen et al. (2000)

2 Opis metode

2 Method description

Za izvedbo metode je treba posekati drevo, zato jo uvrščamo med destruktivne raziskovalne metode. NTM se opravlja na vzhodni strani debla oziroma terminalnega poganjka, zato to smer na debelih posekanih dreves označimo z zarezo (Slika 3A). Vzhodna stran najbolje ponazarja variabilnost zadrževanja iglic (JALKANEN / AALTO / KURKELA 2000), zato štetje opravimo le na tem delu, število iglic celotnega oboda pa dobimo z izračunom. Po poseku drevesa najprej izmerimo višinske letne prirastke, sledi razrez stebla na letne višinske prirastke (Slika 3A). Iz sredine vsakega višinskega prirastka odrežemo kolut, na spodnji del zapišemo njegovo zaporedno številko in preštejemo branike. Število branik na teh kolutih se mora ujemati z zaporedno številko višinskega prirastka. Tudi skupno število višinskih prirastkov se mora ujemati s številom branik na kolutu s prsne višine. Dolžine kolutov upoštevamo pri kasnejših izračunih. Sledi iglic pričakujemo samo v prvih nekaj branikah od stržena navzven, zato lahko odstranimo branike, v katerih zagotovo ni sledi iglic. Sledi iglic so lahko s prostim očesom slabo vidne, zato jih iščemo s previdnim in postopnim rezanjem tangencialne ravnine branike oziroma vzorca, v radialni smeri od skorje proti strženu (Slika 3B). Sledi iglic štejemo v kasnem lesu vsake branike na površini vzorca, ki jo določata dolžina vzorca in ostri kot (npr. 50, 60 ali 70 stopinj) trikotnika, ki ga skiciramo na prečnem prerezu vzorca (Slika 3B).

Seštevek sledi iglic za posamezen poganjek (višinski prirastek) in posamezno braniko (leto) zapišemo v vnaprej pripravljeno tabelo (Slika 4), ki vsebuje tudi podatke o kotu trikotnika, letnem višinskem prirastku ter dolžini vzorca. Število proizvedenih iglic na vzorcu po celotnem obsegu izračunamo z upoštevanjem števila sledi iglic v najstarejši (prvi) braniki ter deležu obsega vzorca, vzetega v analizo. Ob upoštevanju kota trikotnika, dolžin vzorčenih poganjkov, višin letnih prirastkov ter naštetih sledi iglic dobimo z računskimi postopki različne kazalnike sledi iglic.



Slika 3: (A) Razrez debla na letne višinske prirastke, zareza označuje na vzhod obrnjeno stran debla (B) Del debla, označen z zarezo, izžagamo in ga uporabimo za nadaljnjo analizo. Sledi iglic se štejejo na tangencialni ravnini branike oz. vzorca; povzeto po Aalto in Jalkanen (1998).

Figure 3: (A) Cutting a stem into annual sections (bolts), cut points east. (B) Parts of disks with marked east side are additionally cut, inventory of needle traces using an arc surface is done on tangential side; after Aalto and Jalkanen (1998).

Zap. št. prirastka	Leto rasti	Višinski prirastek [cm]	Dolžina vzorca [mm]	Kot 1/360^0	Število sledi iglic v posamezni braniki												Število sledi iglic na vzorcu
					…	11	10	9	8	7	6	5	4	3	2	1	
1	2011	**25**	**95**	360												112	112
2	2010	**14**	**74**	360											85	85	85
3	2009	**19**	**99**	360										76	78	78	78
4	2008	**17**	**83**	360									62	65	68	68	68
5	2007	**20**	**95**	70								11	13	14	14	14	72
6	2006	**23**	**95**	70								8	10	12	12	12	61
7	2005	**22**	**86**	70									11	11	13	13	65
8	2004	**19**	**92**	70								3	8	8	10	10	50
9	2003	**21**	**90**	70								5	9	9	9	12	61
…																	
…																	
53	1959	**32**	**85**	70							1	6	8	12	12	12	61
54	1958	**25**	**87**	70								8	8	9	11	11	56
55	1957	**26**	**91**	70								5	9	12	12	13	66
56	1956	**26**	**80**	70							2	7	8	11	11	11	56
57	1955	**31**	**95**	70							1	5	5	9	13	14	72
58	1954	**28**	**92**	70								8	8	12	12	12	61
59	1953	**23**	**105**	70								7	9	11	11	13	66
60	1952	**24**	**98**	70							1	5	5	8	12	12	61

Slika 4: Primer preglednice s podatki o preštetih sledeh iglic v posameznih branikah in višinskih prirastkih, upoštevanem kotu trikotnika ter dolžini vzorca. Krepke številke označujejo podatke, pridobljene na terenu.

Figure 4: Example of table with data of counted needle traces in tree-rings and height increments, according to angle and length of the sample. Bold numbers characterize values, acquired in the field.

2.1 Izpeljani kazalniki

2.1 Calculated dendrochronological proxies

Na osnovi pridobljenih podatkov izračunamo kazalnike (JALKANEN / AALTO / KURKELA 2000; JALKANEN / LEVANIČ 2001), ki so pojasnjeni in prikazani v nadaljevanju (Slika 6). Predstavljeni kazalniki so:

- Relativno število sledi iglic (ang. relative number of needle traces),
- zadrževanje iglic (ang. annual needle retention),
- izguba iglic (ang. annual needle loss),
- odmet (ang. needle shed),
- starost iglic (ang. current age),
- dolgoživost iglic (ang. longevity, needle age),
- gostota iglic (ang. needle density),
- letni prirast iglic (ang. annual needle production) in
- zaloga iglic (ang. needle pool, tudi total number of needles).

Relativno število sledi iglic (p_r) je osnova vseh izračunov. Absolutno število sledi iglic v posamezni braniki izbranega poganjka primerjamo s številom iglic v prvi braniki. Relativno število sledi (1) izračunamo:

$$p_r = \frac{x_r}{x_1} 100, \qquad 1$$

pri čemer je p_r relativno število iglic (p) v izbrani braniki (r) letnega višinskega prirastka, x_r število sledi iglic (x) v braniki (r) in x_1 število sledi iglic v braniki prvega leta.

Zadrževanje iglic *(ANR)* ponazarja seštevek relativnih števil sledi iglic v izbrani braniki (2). Ta kazalnik nam pove skupen delež setov iglic, hkrati obstoječih na steblu v izbranem letu. Zadrževanje iglic ugotovimo:

$$ANR = \frac{\sum(p_b, p_{b+1,\dots}\, p_{b+n,})}{100}, \qquad 2$$

kjer *ANR* pomeni število starostnih razredov iglic izbranega leta, p_b delež obstoječih iglic na poganjku *b* v preučevanem letu, p_{b+1} delež obstoječih iglic v isti braniki, vendar na leto starejšem poganjku, itd. *(b)* je numerično zaporedje poganjkov, začenši od najmlajšega. Na sliki (Slika 5) je triletni poganjek z 2,66 razreda iglic v izbranem letu; prva dva razreda (letošnji in lanski poganjek) sta popolna, pri zadnjem razredu (predlanski poganjek) pa manjka 1/3 iglic, torej število starostnih razredov ni 3, temveč je ta ocena zmanjšana za 1/3 zadnjega razreda, skupaj torej 2 celoti in 2/3, oziroma 2,66 starostnega razreda v danem letu.

Izguba *(ANL_t)* seta iglic se izračuna kot razlika med dvema zaporednima starostnima razredoma (3). Število starostnih razredov prihodnjega leta (ANR_{t+1}) odštejemo od števila starostnih razredov v letu, ki ga preučujemo (ANR_t). Konstanta +1 pomeni povečanje števila obstoječih setov za en poln set iglic.

$$ANL_t = (ANR_t - ANR_{t+1}) + 1 \qquad 3$$

Odmet *(NS_t)* je kazalec relativne izgube iglic v letu *t*, izražen je kot razmerje med številom setov iglic dveh zaporednih let (NS_t , NS_{t+1}) (4). Vsako leto priraste nov set iglic, pričakovano pa je, da en set iglic odpade zaradi starosti. Ko je indeks 1, je zadrževanje v ravnovesju z odmetom, večja vrednost pomeni večji osip kot pridobitev novih iglic. V primeru (Slika 5B) vidimo, da v zadnjem setu ni odpadla ena iglica, zato odmet ni popoln, vrednost je tako manjša kot 1, torej 0,66 seta.

$$NS_t = \frac{NS_t}{NS_{t+1}} \qquad 4$$

Starost iglic ponazarja povprečno starost hkrati obstoječih iglic na tistih poganjkih, ki imajo v izbranem letu obstoječe iglice. Gre za tehtano aritmetično sredino, ki upošteva število iglic na različno starih poganjkih.

Dolgoživost *(NA)* je izračunana za poganjek, to je povprečna starost iglic na izbranem poganjku. Ob tem se leto, ko so iglice preživele v brstu poganjka, ne šteje. Za izračun povprečne starosti iglic je nujno oceniti dolžino časovne periode med odprtjem brsta (začetek rastne sezone) in rumenenjem najstarejših iglic (v jeseni). Povprečno starost iglic izračunamo (5):

$$NA = \frac{\sum_{r=1}^{n}(p_r - p_{r+1})\left[r - 1 + \frac{t}{12}\right]}{100} \qquad 5$$

NA ponazarja povprečno starost iglic, ki so zrasle v izbranem letu, p_r delež iglic *p* v braniki *r* in *t* število mesecev od začetka rasti brsta do rumenenja iglic (navadno 4 meseci). Dolgoživosti tistih iglic, ki so še pritrjene na poganjek, ni mogoče izračunati, zato izračun ne poda rezultatov za najmlajše poganjke, torej za vrh drevesa.

Gostota iglic *(ND)* - čeprav je gostota izraz množine česa na določeni površini, se tu uporablja kot oznaka števila sledi iglic (*x*) na dolžinski centimeter poganjka v prvem letu starosti. Pri izračunu sta pomembna dolžina vzorca (l_b) in kot trikotnika (α), ki označuje površino, na kateri štejemo sledi iglic (Slika 3C). Gostoto iglic izračunamo (6):

$$ND = \frac{360^{\circ} x}{\alpha \cdot l_b} \qquad 6$$

Letni prirast iglic je število vseh iglic na novem poganjku izbranega leta. Prirast dobimo z množenjem gostote iglic in dolžine višinskega prirastka v izbranem letu. V primeru A (Slika 5A) znaša letni prirast letošnjega in lanskega poganjka tri iglice.

Zaloga iglic *(ANN)* je seštevek vseh hkrati obstoječih iglic na steblu v izbranem letu. Seštevek zapišemo (7):

$$ANN = \sum\left(NN_{b,}NN_{b+1,\dots}\,NN_{b+n,}\right) \qquad 7$$

ANN ponazarja celotno število iglic v izbranem letu, NN_b število iglic na poganjku *b*, NN_{b+1} število iglic na leto starejšem poganjku (*b*+1), itd. Oznaka *b* predstavlja zaporedno številko vrhnjega poganjka, začetno številko ima najvišji poganjek. Na primeru (Slika 5C) je torej zaloga iglic 6; 3 iglice na poganjku v prvem letu starosti, 2 iglici na dve leti starem poganjku ter 1 iglica na tri leta starem poganjku.

3 Uporaba metode

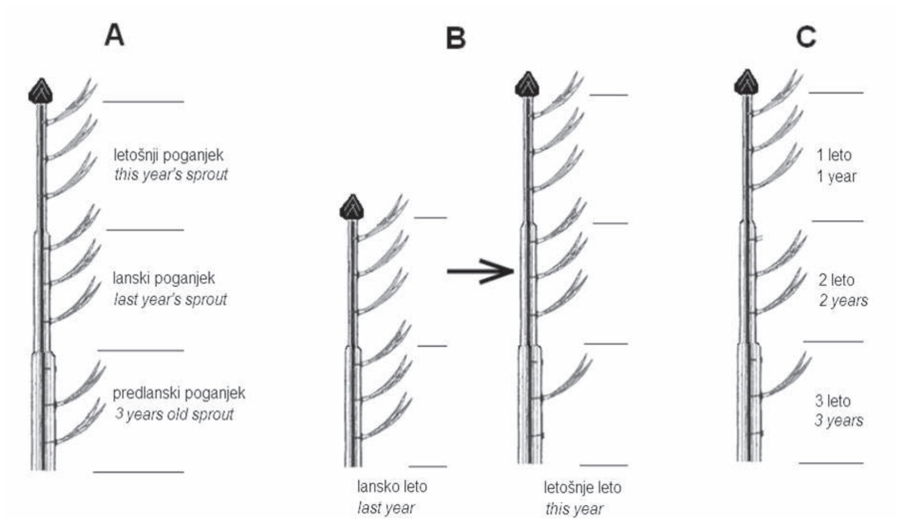
3 Method usage

Fiziologija dreves in odziv kazalnikov na okolje

Tree's physiology and response of needle proxies to environment

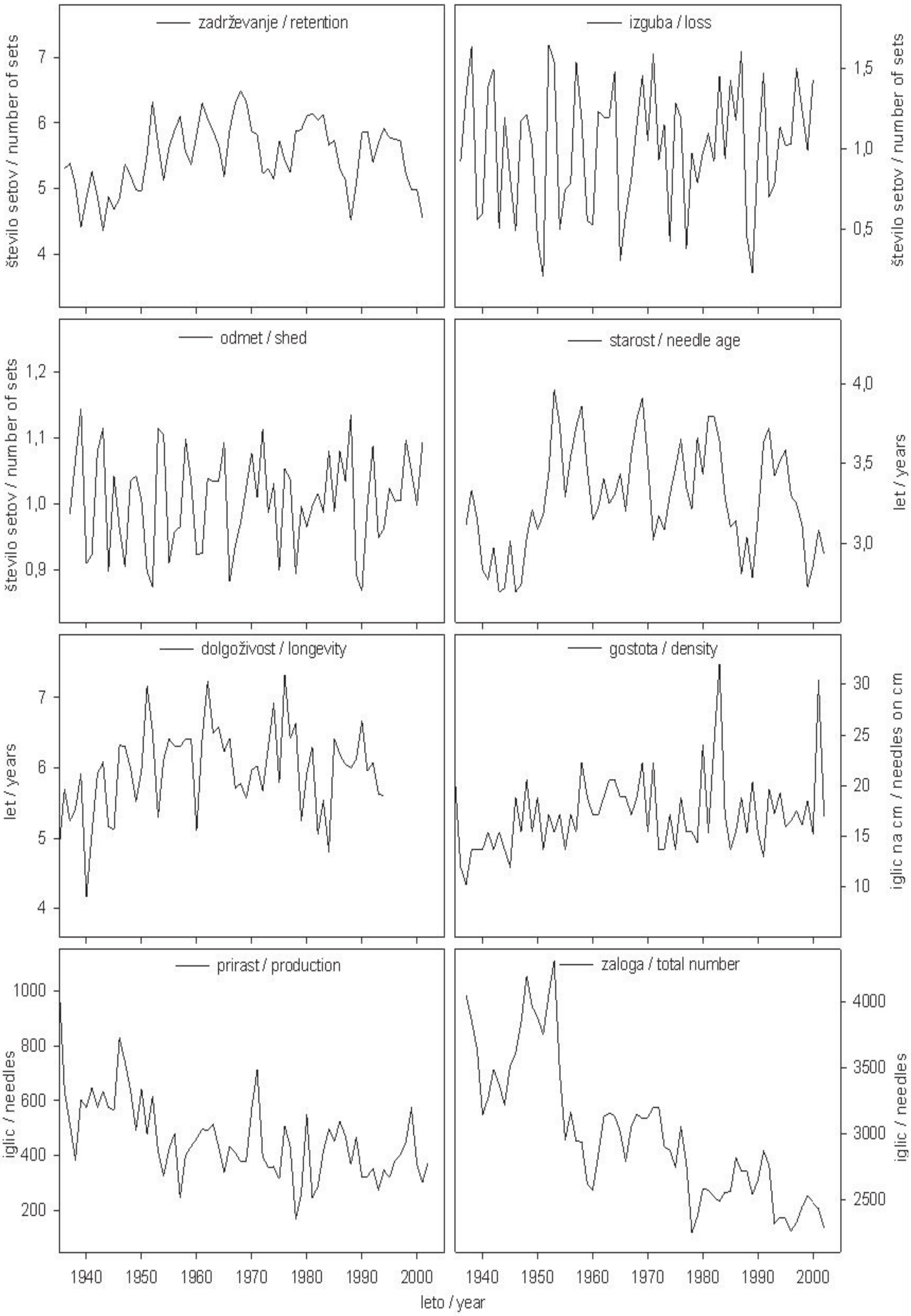
Rast dreves je v veliki meri odvisna od listnega aparata. Mlade iglice rdečega bora nimajo vpliva na višinsko rast poganjka, lahko pa pozitivno vplivajo na radialno rast v zadnjih dveh tretjinah rastne sezone. Iglice, starejše od 3 let, porabijo več energije za respiracijo, kot jo proizvedejo s fotosintezo, zato se na poganjkih ohranijo le v primeru ovirane asimilacije mlajših iglic, npr. zaradi okužbe (DRENKHAN / KURKELA / HANSO 2006).

Podobno velja za mladike navadne smreke, ki se jim rast, če odstranimo 70 % najmlajših iglic, zmanjša le za 30 % (BAUER *et al.* 2000). Mlajša drevesa rdečega bora imajo več kratkih poganjkov (igličnih ovojev) na steblu kot starejša, vendar je zadrževanje iglic, starih 3 in 4 leta, večje pri starejših drevesih. Razloge za to lahko iščemo v prevajanju vode, ki je pri rdečih borih najmočnejše pri drevesih starosti 15-20 let, pri starejših pa vodni potencial upade (PENSA / JALKANEN / SELLIN 2001). Na zadrževanje iglic vplivata poleg starosti dreves tudi nadmorska višina rastišč (POUTTU / DOBBERTIN 2000) ter zemljepisna širina. Zadrževalna sposobnost rdečega bora na severu Finske (68 °S) je 6 setov, na jugu (60 °S) pa le 3,4 seta (JALKANEN / AALTO / KURKELA 1995a), medtem ko iz Rusije (62 °S) poročajo o 4,6 seta in povprečni starosti iglice 3,7 leta (FEDORKOV 2002). Razlika je tudi v dolgoživosti iglic, ta je za dve leti daljša pri borih na Finskem (4 leta) kot v Estoniji (2 leti) (PENSA / JALKANEN 2005). Primerjava zadrževanja setov iglic med vrstama rdečega in rumenega bora (P. ponderosa) je bila opravljena na sušnem rastišču v Nemčiji (INSINNA *et al.* 2007). Vrsti sta se na okolje odzivali podobno s kazalniki letnega prirastka iglic (206/215), izgube (202/196) ter gostote iglic (6,8/7,8), razlike med rdečim in rumenim borom (v tem zaporedju) so bile značilne v starosti iglic (2,1/3,5), zadrževanju (2,6/3,7) in zalogi iglic (634/877). Pri uporabi metode na japonskem črnem (*Pinus thunbergii* Parl.) in japonskem rdečem boru (*Pinus densiflora* Sieb. et Zucc.) so našteli število obstoječih setov na vrhnjem poganjku 3,7 in 2,2 ter gostote iglic 9,4 in 7,4 v tem zaporedju



Slika 5: Letni prirastki poganjkov, obstoječe iglice in mesta odpadlih iglic (povzeto po AALTO / JALKANEN 1998). Za razlago kazalnikov glej besedilo.

Figure 5: Annual growth of long shoots, attached needles and empty spaces of fallen needles (after AALTO / JALKANEN 1998). For explanation of the needle proxies, see text.



Slika 6: Kronološki prikaz kazalnikov iglic izbrane smreke (*P. abies*)

Figure 6: Chronological introduction of needle proxies of a selected Spruce (P. abies)

(KONÔPKA / TSUKAHARA / JALKANEN 2000).

Na smreki so bile prve raziskave opravljene v Nemčiji in zatem na Češkem (SANDER / ECKSTEIN 2001). Pri tem sta avtorja Sander in Eckstein odkrila, da znaša povprečna letna produkcija iglic na terminalnem poganjku navadne smreke 355 iglic, gostota 13 iglic na dolžinski centimeter poganjka ter da je na poganjku vedno 6,5 seta iglic. Na vzorčeni češki lokaciji so spremljali tudi stanje zračne onesnaženosti, a značilen vpliv na listni aparat ni bil potrjen. Iz Slovenije izhajajo rezultati prve raziskave rasti smreke v neonesnaženem okolju (LEVANIČ *et al.* 2006). Izmerjena smreka je imela zadrževalno sposobnost 6,5 seta, povprečno starost iglic 6 let (4,3 -11), letno produkcijo 441 iglic ter 18 iglic/cm višinskega prirastka. V raziskavah rdečega bora so opazili tudi povezavo med letno produkcijo iglic in proizvodnjo peloda rdečega bora. Kazalnik produkcije iglic pojasni do 51 % variacije letne proizvodnje peloda. Na osnovi kalibracije med produkcijo iglic, peloda ter julijske povprečne temperature prejšnjega leta je omogočena rekonstrukcija preteklih letnih proizvodenj peloda (JALKANEN *et al.* 2008). Zabeleženih in preučenih je tudi več odzivov kazalnikov iglic na različne stopnje osvetljenosti in razpoložljivosti hranil (NIINEMETS / KULL 1995; SANDER / ECKSTEIN 2001). Rodovitnost tal vpliva na dolžino iglic, krajše so na rdečih borih, rastočih na nerodovitnih tleh (PENSA / SELLIN 2002). Počasna rast dreves in majhna koncentracija hranil v iglicah ne povzročata nujno večjega zadrževanja iglic in s tem daljšega zadrževanja hranil (PENSA / JALKANEN / LIBLIK 2007b). Ena izmed prilagoditev rastlin na sušne razmere je zmanjšanje listne površine, tj. števila iglic in s tem transpiracijske površine, dodatno obstaja povezava med premerom sledi iglic rdečega bora in gostoto listnih rež, ki vpliva na transpiracijo (PENSA / AALTO / JALKANEN 2004). Rdeči in rumeni bor imata podoben odziv nekaterih kazalnikov listnega aparata (izguba, skupno število, zadrževanje) na jesenske padavine, razlike pa so pri odzivu na poletne padavine, ki imajo večji vpliv na druge kazalnike rdečega bora (INSINNA / JALKANEN / GÖTZ 2007). Na dolžino iglic in na debelinsko rast črnega bora negativno vpliva poletna suša (LEBOURGEOIS *et al.* 1998). V primerjavi s padavinami ima temperatura manjši vpliv na iglične kazalnike raziskanih vrst. Negativen vpliv na zadrževanje iglic rdečega bora na jugu Finske ima dolžina rastne sezone, izražena kot termalna vsota (mejna vrednost +5 °C), zadrževanje iglic pa se kaže kot periodično z dolžino cikla 6-12 let (JALKANEN / AALTO / KURKELA 1995b). Spremenljiva dolgoživost iglic rdečega bora pomaga kompenzirati manjšo produkcijo iglic. Glede na spremembo v klimi, od leta 1990 dalje, so se povečali produkcija iglic ter višinski in debelinski prirastek (PENSA / SEPP / JALKANEN 2006). Kazalniki iglic pa ne pokažejo vedno odziva na okolje. Tako niso pokazali razlik v vrednostih kazalnikov iglic med sestojema rdečega bora iz onesnaženega in neonesnaženega območja, se pa je s povečanim prirastkom rdeči bor odzval na zračno onesnaževanje v Estoniji (termoelektrarna in kemične tovarne) (PENSA / LIBLIK / JALKANEN 2004).

Kombinacije z drugimi metodami

Combination with other methods

Povezovanje NTM in dendrokronologije lahko pomaga pri razumevanju sprememb v priraščanju dreves, ki jih lahko napačno ali celo ne zmoremo pojasniti z uporabo samo ene metode. NTM je bila prvič uspešno uporabljena za potrditev zabeleženih okužb rdečega bora s švedskim osipom borovih iglic (*Lopbodermella sulcigena* (Rostr.) v. Hohn.) (JALKANEN / AALTO / KURKELA 1994b). Analiza rezultatov NTM je prav tako izključila vpliv vremenskih dejavnikov na upad prirastka rdečega bora v centralni Finski v letih 1960-1985 in potrdila napad rjave borove grizlice (*Neodiprion sertifer* G.) v letih 1961 in 1981-82 (FERRETTI *et al.* 2002). Podobno lahko retrospektivno z NTM in s primerjavo debelinskih prirastkov spremljamo posledice objedanja gosenic borovega pedica (*Bupalus piniaria* L.). Največji vpliv na rast dreves rdečega bora na Škotskem je imela gostota pedicev v tekočem in predhodnem letu. Radialni in volumenski prirastek sta se v obdobju 2-3 let po vrhu številčnosti pedicev zmanjšala za največ 50 %. V tem času je bila rast močno pozitivno povezana z zadrževanjem iglic (ARMOUR / STRAW / DAY 2003). V primeru preučevanja defoliacije so NTM uporabili tudi na sitki (WILLIAMS / STRAW / DAY 2003), kjer so ugotovili, da se za 33-38 % zmanjšano zadrževanje iglic ujema z 10-letno periodo izbruha napadov grizlice Gilpinia hercyniae, pri čemer so najhuje napadene najmlajše iglice. Defoliacija v času prenamnožitve je povzročila upad v višinskem, radialnem in volumskem prirastku za 24–49 %, 30–59 % in 32–56 % (v tem zaporedju).

4 Zaključek

4 Conclusion

Metoda sledi iglic (NTM) preučuje starosti iglic, zapisane v branikah posameznih višinskih prirastkov vrhnjega poganjka. Od prvih raziskav rdečega bora (KURKELA / JALKANEN 1990) se je uspešno zastavljena metoda hitro razvila in bila uporabljena tudi na drugih vrstah (SANDER / ECKSTEIN 1994; KONÔPKA / TSUKAHARA / JALKANEN 2000; INSINNA *et al.* 2007). NTM se praviloma opravlja na vzhodni strani drevesa, a se navkljub temu načelu v literaturi pojavi tudi izvedba metode na severni strani (PENSA / AALTO / JALKANEN 2004). Rezultate NTM so v Švici primerjali z rezultati okularnih ocen osutosti gozdnih inventur in ugotovili, da se ocene metod ujemajo v dveh tretjinah letnih podatkov (POUTTU / DOBBERTIN 2000). Uporabnost metode potrjuje tudi analiza sestoja sitke v Walesu, kjer je metoda prepoznala umetno povzročeno 75-odstotno defoliacijo vrhnjega poganjka (WILLIAMS / STRAW / DAY 2003). Čeprav so rezultati merjene osutosti NTM in okularnih ocen popisov skladni, se naj NTM zaradi destruktivnega pristopa, težav pri iskanju letnih višinskih prirastkov drevesa ter beleženjem izpadlih branik ne bi uporabljala kot nadomestilo gozdnih inventur (POUTTU / DOBBERTIN 2000). Poleg tega je uporaba metode na drugih družinah iglavcev (poleg borov) omejena z vidljivostjo sledi iglic. Manjša ko je sled iglic v lesu, bolj je oteženo štetje sledi in obratno. Sled igličnega ovoja pri borih je velika, pri smreki pa je iglica krajša in vedno sama pritrjena na poganjek. Podoben primer so sibirska jelka, tisa in duglazija (PENSA / AALTO / JALKANEN 2004). Kot za pomoč pri lažjem iskanju sledi iglic je bil razvit način sledenja sledi iglic s peskanjem (ang: sandblasting) branik v smeri od strženi proti skorji (SANDER / ECKSTEIN 1994). Ta sistem je bolj zahteven in zaradi tega manj uporabljen. Pri zelo tankih branikah sta natančno strganje branik in štetje sledi zahtevna, težavo pa povzročajo tudi nejasno vidni letni višinski prirastki. Venci smreke so lahko nejasno izraženi, med dvema vencema se lahko pojavljajo tudi posamezne, dimenzijsko močne veje, podobne tistim v vencih. Te motijo pri določevanju vejnih vencev na odraslih drevesih in s tem pri meritvah višinskih prirastkov. Metoda je časovno potratna, vendar preprosta in ne zahteva specifičnih ter dragih orodij. Vzorčimo in preučujemo lahko tudi odmrla ali subfosilna drevesa, če je le njihova sredica trdna. Tako so npr. ugotovili raznolikost gostot iglic skozi čas in drugih kazalnikov za 4.000 let v preteklost (JALKANEN 1998). Prve raziskave z NTM so bile usmerjene k preučevanju lastnosti krošenj in starosti iglic, kmalu pa so pomagale pri preučevanju vpliva okužb gliv (JALKANEN / AALTO / KURKELA 1994a; BAUER *et al.* 2000), preteklih napadov žuželk (ARMOUR / STRAW / DAY 2003; WILLIAMS / STRAW / DAY 2003) in gojitvenih ukrepov (JALKANEN / LEVANIČ 2001). Najnovejše raziskave prihajajo s področij vplivanja stanja okolja (PENSA / LIBLIK / JALKANEN 2004), v prihodnosti pa lahko pričakujemo predvsem raziskave odvisnosti listnega aparata od klime in s klimo povezanih sprememb (PENSA / SEPP / JALKANEN 2006).

5 Summary

Every year, evergreen conifers add one needle set and every year on average one needle set falls down. The number of needle sets is influenced with environmental conditions and, to some degree, varies through years. Loss of needles can be estimated with visual forestry inventory methods, but such techniques are not reliable. To solve this problem, needle trace method (NTM) was invented. It is based on the examination of length and location of the needle traces embedded in stem wood (Figure 1). The age of every needle, at the time of its fall off, is discovered through counting the tree-rings in which the individual needle trace is seen (Figure 2). The exact age of each needle or short shoot (in pines, two or more needles grouped in one fascicle) can be estimated. The method enables us to retrospectively detect influence of a factor, which had the greatest influence on the tree foliar system. Originally, it was introduced on Scots Pine (*Pinus sylvestris* L.) in Finland in the late 1980's (KURKELA / JALKANEN 1990) and since then it's been applied on many other species (KONÔPKA / TSUKAHARA / JALKANEN 2000; PENSA / AALTO / JALKANEN 2004; INSINNA *et al.* 2007). The method has already been used in Slovenia in research of thinning influence on Scots Pine at Smlednik (JALKANEN / LEVANIČ 2001) and of growth parameters in Norway Spruce (Picea abies L.) on Pokljuka (LEVANIČ *et al.* 2006), but has never been explained in details.

Each needle or short shoot is in the first year of long shoot growth attached to the pith of the long shoot (stem). With radial growth of long shoot, the needle moves away from the pith (GIBSON 2010). In between, there is a radial increment from current year and the bark. To keep the connection with the vascular system of the stem, meristem tissue has to produce cells of conductive tissue. These cells create needle trace, which extends from needle through the annual increment(s) to the pith. After needle loss, radial increment eventually overgrows conductive tissue or needle trace (Figure 2). There is a connection between width of needle trace and needle length (PENSA / AALTO / JALKANEN 2004).

In order to obtain NTM data, the sampled tree has to be felled. The method is used on eastern side, so a longitudinal cut is made to mark the position. This side shows the highest amount of variability of needle traces. The stem is cut into sections equalling annual shoots, but omitting the branch whorls (Figure 3A). The innermost tree rings, examined ring by ring using an arc surface and a fixed angle, reveal the location and number of the needle traces (Figure 3B). Once the needle trace data have been obtained (Figure 4), chronologies of needle proxies can be produced (AALTO / JALKANEN 1998) for a single-tree or a stand (normally 5 to 10 trees) as follows: **Relative number of needle traces** compares numbers of needle traces in the following annual rings to the needle traces in the first ring, all from the same growth shoot. **Needle retention** describes how many needle sets are present on the main stem in a given year, **needle loss** how many sets are shed per year and **needle shed** relative number of lost needle sets. **Needle age** is able to produce chronology for mean age of needle classes. Separately, the NTM calculates the average age of fallen needles at any shoot; **longevity**. The number of needles in different annual shoots in a given year is called **needle pool** and the **needle production** is normal annual needle production that reveals the number of needles produced in the leader shoot. The number of needles per centimetre on the long shoot gives **needle density**. Additionally, data on height and radial increment are obtained.

Results of the needle proxies can be used in order to investigate response of trees to the climate conditions (INSINNA / JALKANEN / GÖTZ 2007; PENSA /

JALKANEN / LIBLIK 2007a), silvicultural influence (JALKANEN / LEVANIČ 2001) or environmental conditions, such as fungi attacks (JALKANEN / AALTO / KURKELA 1994a) and insects epidemics (FERRETTI *et al.* 2002; WILLIAMS / STRAW / DAY 2003). NTM has gradually extended our understanding to the whole-tree needle history of various conifer species. Future work may well concentrate more on using NTM in climate change and forest health studies (JALKANEN / AALTO / KURKELA 2000).

6 Viri

6 References

AALTO, T. / JALKANEN, R., 1998. Neulasjälkimenetelmä. The needle trace method.- Rovaniemi, Finnish Forest Research Institute, Research Papers 681,

ARMOUR, H. / STRAW, N. / DAY, K., 2003. Interactions between growth, herbivory and long-term foliar dynamics of Scots pine.- Trees - Structure and Function 17, 1: 70-80.

BAUER / HELMUT / PLATTNER / KARIN / VOLGGER / WALTRAUD, 2000. Photosynthesis in Norway spruce seedlings infected by the needle rust *Chrysomyxa rhododendri*.- Oxford, ROYAUME-UNI, Oxford University Press, 6 p.

DRENKHAN, R. / KURKELA, T. / HANSO, M., 2006. The relationship between the needle age and the growth rate in Scots pine (*Pinus sylvestris*): a retrospective analysis by needle trace method (NTM).- European Journal of Forest Research 125, 4: 397-405.

FEDORKOV, A. L., 2002. Retrospective Assessment of the Parameters of Needle Retention in Scotch Pine.- Russian Journal of Ecology 33, 6: 452-454.

FERRETTI, M. / INNES, J. L. / JALKANEN, R. / SAURER, M. / SCHÄFFER, J. / SPIECKER, H. / WILPERT, K. V., 2002. Air pollution and environmental chemistry - what role for tree-ring studies?- Dendrochronologia 20, 1-2: 159-174.

GIBSON, P., 2010. Botany. An introduction to plant biology, 4th edn.- Annals of Botany 105, 5: viii-ix.

INSINNA, P. / JALKANEN, R. / GÖTZ, B., 2007. Climate impact on 100-year old foliage chronologies of Scots pine and Ponderosa pine in the northeast lowlands of Brandenburg, Germany.- Silva Fennica 41, 4: 16.

INSINNA, P. A. / GÖTZ, B. / JALKANEN, R. / AAS, G., 2007. One-hundred-year foliage comparison of *Pinus ponderosa* and **Pinus sylvestris** under dry growing conditions in Brandenburg, Germany.- Scandinavian Journal of Forest Research 22, 2: 149 - 159.

JALKANEN, R., 1998. Needle traces-less known organs of conifer stems as environmental indicators.- The 4th Pacific Regional Wood Anatomy Conference. Kwangju, Korea, IAWA Journal. 19.

JALKANEN, R. / AALTO, T. / KURKELA, T., 1994a. The use of needle-trace method (NTM) in retrospectively detecting *Lophodermella* needle-cast epidemic.- European Journal of Forest Pathology 24, 6-7: 376-385.

JALKANEN, R. / AALTO, T. / KURKELA, T., 1994b. The use of needle-trace method (NTM) in retrospectively detecting *Lophodermella* needle-cast epidemic. (Cover story).- European Journal of Forest Pathology 24, 6/7: 376-385.

JALKANEN, R. / AALTO, T. / KURKELA, T., 1995a. Development of needle retention in Scots pine (*Pinus sylvestris*) in 1957-1991 in northern and southern Finland.- Trees - Structure and Function 10: 125-133.

JALKANEN, R. / AALTO, T. / KURKELA, T., 1995b. Development of needle retention in Scots pine (*Pinus sylvestris*) in 1957–1991 in northern and southern Finland.- Trees - Structure and Function 10, 2: 125-133.

JALKANEN, R. / AALTO, T. / KURKELA, T., 2000. Needle trace method.- Forestry studies 34.

JALKANEN, R. / AALTO, T. / OJANEN, M. / VAINIO, E., 2000. Needle trace method and crown thinning (defoliation) in pines. Final report. EU-project 97.60.SF.005.0.- Pori, Rovaniemi, Finnish For. Res. Inst., Univ. Turku,

JALKANEN, R. / HICKS, S. / AALTO, T. / SALMINEN, H., 2008. Past Pollen Production Reconstructed from Needle Production in *Pinus sylvestris* at the Northern Timberline: a Tool for Evaluating Palaeoclimate Reconstructions.- Silva Fennica 42, 4: 499-513.

JALKANEN, R. / LEVANIČ, T., 2001. Growth and needle parameter responses of *Pinus sylvestris* after release from suppression.- Dendrochronologia 19, 2: 189-196.

KONÔPKA, B. / TSUKAHARA, H. / JALKANEN, R., 2000. A comparison of needle retention on Japanese black pine and Japanese red pine.- Journal of Forest Research 5, 3: 175-180.

KURKELA, T. / JALKANEN, R., 1990. Revealing past needle retention in *Pinus* spp.- Scand. J. For. Res. 5, 4: 481-485.

LEBOURGEOIS, F. / LÉVY, G. / AUSSENAC, G. / CLERC, B. / WILLM, F., 1998. Influence of soil drying on leaf water potential, photosynthesis, stomatal conductance and growth in two black pine varieties.- Ann. For. Sci. 55, 3: 287-299.

LEVANIČ, T. / JALKANEN, R. / GRIČAR, J. / GAGEN, M. / OVEN, P., 2006. Use of different growth parameters of Norway spruce (*Picea abies* (L.) Karst.) to study tree response to climate = Uporabnost različnih rastnih parametrov navadne smreke (*Picea abies* (L.) Karst.) za študij odziva dreves na klimo.- ZbGL 80: 97-109.

MAUSETH, J. D., 1988. Plant anatomy.- Menlo Park, California, Benjamin/Cummings

NIINEMETS, Ü. / KULL, O., 1995. Effects of light availability and tree size on the architecture of assimilative surface in the canopy of *Picea abies*: variation in needle morphology.- Tree Physiology 15, 5: 307-315.

PENSA, M. / AALTO, T. / JALKANEN, R., 2004. Variation in needle-trace diameter in respect of needle morphology in five conifer species.- Trees - Structure and Function 18, 3: 307-311.

PENSA, M. / JALKANEN, R., 2005. Variation in needle longevity is related to needle-fascicle production rate in *Pinus sylvestris*.- Tree Physiology 25, 10: 1265-1271.

PENSA, M. / JALKANEN, R. / LIBLIK, V., 2007a. Variation in Scots pine needle longevity and nutrient conservation in different habitats and latitudes.- Can. J. For. Res.-Rev. Can. Rech. For. 37, 9: 1599-1604.

PENSA, M. / JALKANEN, R. / LIBLIK, V., 2007b. Variation in Scots pine needle longevity and nutrient conservation in different habitats and latitudes.- Canadian Journal of Forest Research 37: 1599-1604.

PENSA, M. / JALKANEN, R. / SELLIN, A., 2001. Age-dependent Changes in Needle-fascicle Dynamics of *Pinus sylvestris* (L.).- Scandinavian Journal of Forest Research 16, 4: 379-384.

PENSA, M. / LIBLIK, V. / JALKANEN, R., 2004. Temporal Changes in the State of a Pine Stand in a Bog Affected by Air Pollution in Northeast Estonia.- Water, Air, & Soil Pollution 159, 1: 87-99.

PENSA, M. / SELLIN, A., 2002. Needle longevity of Scots pine in relation to foliar nitrogen content, specific leaf area, and shoot growth in different forest types.- Canadian Journal of Forest Research 32: 1225-1231.

PENSA, M. / SEPP, M. / JALKANEN, R., 2006. Connections between climatic variables and the growth and needle dynamics of Scots pine (*Pinus sylvestris* L.) in Estonia and Lapland.- International Journal of Biometeorology 50, 4: 205-214.

POUTTU, A. / DOBBERTIN, M., 2000. Needle-retention and density patterns in *Pinus sylvestris* in the Rhone Valley of Switzerland: comparing results of the needle-trace method with visual defoliation assessments.- Canadian Journal of Forest Research 30, 12: 10.

SANDER, C. / ECKSTEIN, D., 1994. Reconstruction of the foliation of *Picea abies* by means of needle traces.- Scandinavian Journal of Forest Research 9, 1: 311 - 315.

SANDER, C. / ECKSTEIN, D., 2001. Foliation of spruce in the Giant Mts. and its coherence with growth and climate over the last 100 years.- Ann. For. Sci. 58, 2: 155-164.

WILLIAMS, D. T. / STRAW, N. A. / DAY, K. R., 2003. Defoliation of Sitka spruce by the European spruce sawfly, *Gilpinia hercyniae* (Hartig): a retrospective analysis using the needle trace method.- Agricultural and Forest Entomology 5, 3: 235-245.