

# 1 | **Satellite data as indicators of tree biomass growth and forest** 2 **dieback in a Mediterranean holm oak forest.**

## 3 4 **Abstract.**

- 5  
6 • **Context:** In the frame of climate change, decreased tree growth and enhanced  
7 mortality induced by hot and dry conditions are increasing in many forests  
8 around the world, and particularly in Mediterranean forests.
- 9 • **Aims:** Our aim was to estimate tree growth and mortality in a Mediterranean  
10 holm oak forest, using remote sensing data from MODIS.
- 11 • **Methods:** We monitored annual increases of aboveground biomass by measuring  
12 tree basal area, and we determined tree mortality by counting dead stems. We  
13 analyzed the relationships between forest growth and mortality with mean  
14 annual values of some MODIS products and meteorological data.
- 15 • **Results:** Mortality and increases of aboveground biomass correlated well with  
16 precipitation, September standardized precipitation/evapotranspiration indices  
17 (SPEI) and some MODIS products such as NDVI and enhanced vegetation  
18 index EVI. Other MODIS products such as gross primary production (GPP) and  
19 net photosynthesis, however, showed no clear relationship with tree mortality or  
20 measured increases of biomass.
- 21 • **Conclusion:** The MODIS products as proxies of ecosystemic productivity (gross  
22 primary productivity, net photosynthesis) were weakly correlated with biomass  
23 increase and did not reflect the mortality following the drought of autumn 2011.  
24 Nevertheless, NDVI and EVI were efficient indicators of forest productivity and  
25 dieback

26

27 *Keywords:* Forest productivity, Mediterranean forest, MODIS, remote sensing, SPEI  
28 indices, tree mortality.

29

30

31 **Introduction.**

32

33 Some forested ecosystems distributed in semi-arid and Mediterranean areas are  
34 seasonally exposed to water deficit and may be particularly vulnerable to even slight  
35 increases in water deficit, which can reduce tree growth (Barbeta et al. 2013; Ogaya and  
36 Peñuelas 2007), lower the condition of crowns (Carnicer et al. 2011; Galiano et al.  
37 2012) and increase tree mortality (Allen et al. 2010; Breshears et al. 2005; Peng et al.  
38 2011; Williams et al. 2012). Higher air temperatures are projected globally for the  
39 coming decades, and higher evapotranspiration rates induced by this increase in  
40 temperature and slight decreases in precipitation are expected in many areas, such as the  
41 Mediterranean Basin, subjected to seasonal drought (IPCC 2013). General circulation  
42 models project an average decrease of 15% in soil moisture over the next 50 years and a  
43 return period of extreme droughts 10 times shorter than in the twentieth century in these  
44 Mediterranean regions (Bates et al. 2008). Moreover, strong relationships between  
45 deficits in precipitation and subsequent occurrences of hot extremes have been widely  
46 observed (Mueller and Seneviratne 2012), and higher frequencies of heat waves  
47 coinciding with summer drought, higher evapotranspiration and the subsequent low  
48 availability of water are also expected for Mediterranean regions (Fischer and Schar,  
49 2010).

50 Holm oak (*Quercus ilex* L.) is a widespread and dominant tree species in sub-  
51 humid areas of the Mediterranean Basin. Many tall shrub species with lower growth  
52 rates but a higher resistance to drought are associated with holm oak forests (Peñuelas et  
53 al. 1998; Ogaya and Peñuelas 2003). Under future drier conditions, higher mortality  
54 rates and lower seed production and seedling survival of *Q. ilex* could drive a decrease  
55 in the distribution of this dominant species and favor the associated species that are  
56 more resistant to a low availability of water (Lloret et al. 2004; Ogaya and Peñuelas  
57 2007).

58 Monitoring the effects of climate change, particularly drought, on plant growth  
59 and mortality in various regions over time requires the use of remote-sensing techniques.  
60 Spectral indices from remote-sensing data are widely used to evaluate the structure and  
61 functioning of terrestrial ecosystems (Peñuelas and Filella 1998). The normalized  
62 difference vegetation index (NDVI), the most widely used remotely sensed index, is  
63 mainly used for estimating the fraction of the photosynthetically active radiation  
64 (FPAR) absorbed by the canopy (Tucker et al. 1985). The enhanced vegetation index  
65 (EVI) was developed to reduce the noise produced by soil background and atmospheric  
66 aerosols and to reduce the saturation of the reflectance signal at increasing levels of  
67 green biomass, which are commonly associated with the NDVI (Huete et al. 2002).  
68 Remote-sensing data can quantify the spatial variation in forest structure and growth  
69 (Waring et al. 2006) and stem volume (González Alonso et al. 2006). Both NDVI and  
70 EVI can provide good estimates of forest productivity but provide poor estimates of  
71 carbon uptake in dense evergreen forests such as those of the Mediterranean region,  
72 because these indices are largely insensitive to the short-term changes in CO<sub>2</sub> uptake  
73 that are caused by water deficit (Garbulsky et al. 2013).

74           The main objective of this work was to test the use of several MODIS products  
75 as tools for the detection and monitoring of biomass increase, forest decline and tree  
76 mortality in a typical Mediterranean forest and to assess the use of remote-sensing data  
77 from satellites as good indicators of forest productivity and dieback.

78

79

## 80 **Material and methods.**

81

### 82 *Study site.*

83 The study area was a valley (Vall dels Torners) in the Prades Mountains, Catalonia, in  
84 northeastern Spain (Fig. 1). This valley is populated by a natural holm oak (*Q. ilex* L.)  
85 forest (41°21' N, 1°2' E) at an altitude of 750-1050 m a.s.l. The soil is a Dystric  
86 Cambisol over Paleozoic schist, ranging in depth from 35 to 100 cm. The average  
87 annual temperature is 11.8 °C, and the average annual rainfall is 659 mm (data from  
88 1975 to 2012). Summer drought is pronounced and usually lasts for three months. The  
89 vegetation is a very dense multi-stem forest (16 616 stems ha<sup>-1</sup>) dominated by *Q. ilex* L.  
90 (8633 stems ha<sup>-1</sup>), *Phillyrea latifolia* L. (3600 stems ha<sup>-1</sup>) and *Arbutus unedo* L. (2200  
91 stems ha<sup>-1</sup>), with an abundance of other evergreen species well adapted to dry conditions  
92 such as *Erica arborea* L., *Juniperus oxycedrus* L., *Cistus albidus* L. and occasional  
93 individuals of deciduous species such as *Sorbus torminalis* (L.) Crantz and *Acer*  
94 *monspessulanum* L. This forest has not been perturbed for 65 years, and the maximum  
95 height of the dominant species is approximately 6-10 m. Biomass increment and  
96 mortality rate of these species were annually measured as described in Barbeta et al.  
97 2013, from 1999 to 2012.

### 98 *Climate data.*

99 An automated meteorological station installed at the study site has monitored  
100 temperature, photosynthetically active radiation, humidity and precipitation since late  
101 1998. We estimated temperature and rainfall for years prior to 1998 with data from  
102 another meteorological station located at Poblet Monastery, 5.6 km northeast of our  
103 study area and at 510 m a.s.l. The meteorological data from the Poblet station was  
104 collected from late 1974 to July 2002, so we had climatic data for the period from  
105 August 1998 to July 2002 from both meteorological stations. We calculated the linear  
106 relationships between temperature ( $R^2=0.97$ ) and rainfall ( $R^2=0.75$ ) at these two stations  
107 for this period to estimate the climatic data at the study site from 1975. We thus had  
108 continuous climate data of the study site from 1975 to 2012.

109

#### 110 *Defoliation and mortality.*

111 Defoliation and mortality were recorded in 2011. 40 dominant *Q. ilex* trees, 40  
112 dominant *P. latifolia* and 40 dominant *A. unedo* shrubs were randomly selected across  
113 the study site in early spring 2011. The intensity of canopy defoliation by herbivores  
114 was estimated assessing the remaining petioles of consumed leaves at the end of July  
115 2011. Canopy defoliation produced by summer drought conditions was thereafter  
116 estimated, in the same trees, assessing the brown color of dead leaves at the end of  
117 October 2011(Fig. 2). In both cases, we visually determined the percentage of defoliated  
118 or dead leaves in each tree, and later we calculated the mean value for all tree canopies.  
119 Eleven categories were established to measure the percentage of defoliation in each tree:  
120 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% (mortality), as  
121 described in Ogaya and Peñuelas 2004.

122

#### 123 *Remote-sensing data.*

124 Remote-sensing data from 2000 to 2012 were obtained from sensors of the Moderate  
125 Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites.  
126 The Terra satellite orbits Earth from north to south in the morning, and the Aqua  
127 satellite orbits from south to north in the afternoon. We used the normalized difference  
128 vegetation index (NDVI) and the enhanced vegetation index (EVI), obtained from the  
129 16-day Terra MOD13Q1 and 16-day Aqua MYD13Q1 products, combined in series  
130 with 8-day data based on 20 selected 250 m x 250 m pixels. We selected the pixels  
131 across the distribution of holm oak forest in the valley (Fig. 1). We later calculated the  
132 mean values of the 20 selected pixels to estimate the average values of these indices for  
133 the entire holm oak forest in the valley.

134 We also used data for gross primary production (GPP) and net photosynthesis  
135 (PsnNet) obtained from the 8-day Terra MOD17A2 product, net primary production  
136 (NPP) obtained from the annual Terra MOD17A3 product, leaf area index (LAI) and  
137 FPAR obtained from the 8-day Aqua MYD15A2 product and the quotient ( $R_{858}/R_{1240}$ )  
138 between the reflectances at 858 nm (reference) and 1240 nm (water absorption) from  
139 the 8-day Terra MOD09A1 product. All MODIS products were collected from 2000 to  
140 2010 from a 1 x 1 km pixel centered in the study area, except NDVI and EVI data, that  
141 were collected in the 20 selected 250 x 250 pixels. Mean annual values of the remotely  
142 sensed indices were calculated as annual integrations for each of the growing seasons  
143 covered by the NDVI, EVI, GPP, PsnNet, LAI, FPAR and  $R_{858}/R_{1240}$  data, whereas  
144 NPP data were directly collected annually.

145

#### 146 *Data analysis.*

147 The climate data (1975-2012) allowed us to calculate the standardized precipitation  
148 evapotranspiration index (SPEI) (Vicente-Serrano et al. 2010), an index based on the

149 difference between precipitation and potential evapotranspiration. Evapotranspiration  
150 can be very important for determining variability in soil moisture, a key factor in plant-  
151 water relations, The inclusion of potential evapotranspiration (PET) in the calculation of  
152 the SPEI only affects the index when PET differs from average conditions, for example  
153 under scenarios of global change (Vicente-Serrano et al. 2010). We selected September  
154 SPEI indices for the comparison of the 2011 summer drought to those of previous years;  
155 we used SPEI 3 and SPEI 6 indices (with data from three and six months before  
156 September, respectively). We selected September SPEI 6 and December SPEI 12  
157 indices for the statistical analyses of the other variables.

158         General linear models were constructed to examine the relationships of tree  
159 mortality rates and increases in aboveground biomass with the changes of air  
160 temperatures, rainfall and September SPEI 6 and December SPEI 12 indices during the  
161 study period (1975-2012). Other general linear models examined the relationships of  
162 tree mortality rates and increases in aboveground biomass with mean annual values of  
163 NDVI, EVI, GPP, PsnNet and NPP. We have shown linear regressions because they  
164 were the relationships that fit better with all the variables studied. All linear models  
165 were constructed with the StatView software package (SAS Institute Inc., Cary, North  
166 Carolina, USA).

167         Two redundancy analyses (RDAs) were performed to assess the relationships of  
168 the physical data on biomass increase and tree mortality. This linear method was chosen  
169 after performing a detrended correspondence analysis, which indicated that the length of  
170 the gradient was short (Lepš and Šmilauer 2003). The physical variables were used as  
171 *species (sensu* Canoco) and were centered and standardized, because the data differed in  
172 scale of measurement. The significance of the first axis was tested using 499

173 permutations (Lepš and Šmilauer 2003). The biplots show the first two axes and are  
174 displayed with CanoDraw. Ordination was performed using Canoco for Windows 4.5.

175

176

## 177 **Results.**

178

### 179 *Climate data.*

180 Mean annual temperature ranged from 10.7 °C in 1984 to 13.1 °C in 2011, and total  
181 annual precipitation ranged from 376 mm in 2005 to 984 mm in 1996 (Fig. 3). During  
182 this period (1975-2012), mean annual air temperature increased by approximately  
183 1.5 °C ( $R^2=0.42$ ,  $P<0.001$ ) (Fig. 3). This increase was due to the strong increases of  
184 2.86 °C in spring and 2.22 °C in summer temperatures ( $R^2=0.58$ ,  $P<0.001$ ; and  $R^2=0.40$ ,  
185  $P<0.001$ , respectively) ( $P<0.001$ ), while autumn and winter temperatures did not  
186 change. Precipitation, however, was quite variable, and annual precipitation decreased  
187 only slightly from 1975 to 2011 (Fig. 4). SPEI indices calculated in September were  
188 often negative during the later years, with a clear continuous decrease of both SPEI 3  
189 and SPEI 6 indices since 1990 (Fig. 5). Both the September SPEI 3 and SPEI 6 indices  
190 were lowest in 2011, when high temperatures coincided with the maximum number of  
191 days with no rainfall (133 days with rainfall under 10 mm) and when tree mortality  
192 occurred.

193

### 194 *Defoliation and mortality.*

195 *Q. ilex* was the only species with significant defoliation by herbivores. For instance,  
196 there was a heavy infestation by the caterpillar of the moth *Catocala nymphagoga* (Esp.)  
197 during late spring, that consumed an average 15% of *Q. ilex* leaves, all young leaves



198 just flushed in the previous one or two months. By the end of October 2011, just after  
199 the long period of hot and dry conditions, *Q. ilex* trees had lost an average 14% of their  
200 leaves, and few trees were completely defoliated and had dead stems. *Q. ilex* thus lost,  
201 on average, 29% of their leaves. The other dominant species suffered less defoliation,  
202 which was due only to drought: *A. unedo* shrubs lost approximately 6% of their leaves,  
203 and *P. latifolia* shrubs lost only approximately 1% of their leaves.

204

205 *Remote sensing data.*

206 NDVI values showed an annual pattern with high values during winter, a decrease  
207 during spring, the lowest values during late spring and early summer and a final  
208 increase during late summer and autumn (Fig. 6). EVI values had an inverse annual  
209 pattern, with maximum values during late spring and early summer and minimum  
210 values during winter (Fig. 6).

211 The maximum mean annual NDVI (0.80) occurred in 2003, and the maximum  
212 mean annual EVI (0.38) occurred in 2008, when annual precipitation was highest (926  
213 mm in 2003 and 837 mm in 2008). The minimum mean annual NDVI and EVI (0.74  
214 and 0.33, respectively) occurred in late autumn and winter 2011, during the period of  
215 high tree mortality. NDVI values remained low during late 2011 and early 2012 and did  
216 not exhibit the typical winter recovery. They began to increase slightly during spring  
217 2012 and reached typical values only at the end of 2012 (Fig. 6). EVI values were low  
218 during late 2011 and early 2012, as is usual during winter, but were lower than normal  
219 after the drought of autumn 2011 and recovered to typical values during spring 2012  
220 (Fig. 6). Increases in BAI and aboveground biomass correlated well with mean annual  
221 NDVI and EVI values, the sum of spring and autumn mean temperatures, annual

222 precipitation, spring precipitation, the sum of spring and summer precipitation, and  
223 September SPEI 6 and SPEI 12 indices (Table 1).

224 GPP and PsnNet values had a different annual pattern, with low values during  
225 winter, maximum values during spring, a decrease during summer, another increase in  
226 autumn (albeit with lower values than in spring) and a final decrease during late autumn  
227 and winter (Fig. 7). GPP and PsnNet values in 2011 were higher than the mean values  
228 of the period 2000-2010, except during the severe drought in September and October,  
229 but GPP and PsnNet values completely recovered in late autumn (Fig. 7).

230 The canonical axis (RDA axis 1) explained 46.4% of the total variance in the  
231 analysis of biomass increase, and the overall model was significant ( $P=0.01$ ) (Fig. 8).  
232 The canonical axis (RDA axis 1) explained 25.1% of the total variance in the analysis of  
233 tree mortality, and the overall model was significant ( $P=0.01$ ) (Fig. 9). As shown in  
234 Figs. 8 and 9, a group of variables (NDVI, EVI, LAI, FPAR,  $R_{850}/R_{1240}$ , annual rainfall,  
235 spring and spring-summer rainfall and September SPEI 6 and December SPEI 12  
236 indices) correlated well with increases in aboveground biomass and with tree mortality  
237 rates. In contrast, other variables (GPP, PsnNet and summer rainfall) were not clearly  
238 correlated with increased biomass or tree mortality rates. Mean annual temperature was  
239 negatively correlated with increased biomass and positively correlated with tree  
240 mortality rates (Figs. 8 and 9).

241

242

## 243 **Discussion.**

244

245 The dry conditions increased stem mortality and decreased tree growth in the holm oak  
246 forest (Barbeta et al. 2013; Ogaya and Peñuelas 2007). The constant increase in spring

247 and summer temperatures during 1975-2012 led to higher vapor-pressure deficits, and  
248 the September SPEI 3 and September SPEI 6 indices had negative values during the  
249 most recent years, particularly in September 2011. The atmospheric moisture demand is  
250 the primary mechanism by which high temperatures influence drought-sensitive tree  
251 populations (Liu et al. 2013), and this is consistent with our negative relationship  
252 between mean annual temperature and biomass increase and with our positive  
253 relationship between mean annual temperature and tree mortality rates. As expected,  
254 higher precipitation induced larger increases in biomass, with the exception of summer  
255 rainfall. The negative relationship between summer rainfall and increased biomass must  
256 be due to other climatic circumstances more conducive to tree growth, such as annual  
257 rainfall or September SPEI indices, because summer rainfall was always low.

258         The mortality of autumn 2011 coincided with a heavy infestation of *C.*  
259 *nymphagoga* during late spring 2011 that consumed a large proportion of recently  
260 flushed leaves. After recent droughts in Catalonia, particularly in summer 1994 when  
261 80% of *Q. ilex* individuals in some areas had lost all their foliage (Lloret and Siscart  
262 1995), a high percentage of *Q. ilex* trees resprouted from the base of the trunk, the upper  
263 branches of the canopy or both after the mortality induced by the extremely dry  
264 conditions (Espelta et al. 1999). The percentage of resprouting *Q. ilex* trees after the  
265 autumn 2011 mortality in our study forest, though, was negligible. The deterioration in  
266 the condition of the crown in *Q. ilex* soon after autumn 2011 was clearly associated with  
267 lower carbon reserves, and defoliated trees generally had less stored non-structural  
268 carbohydrates than did healthy trees (Rosas et al. 2013). For these reasons, carbon  
269 starvation induced by the continuous increase of temperatures during dry periods may  
270 be a key factor of forest dieback at our study site.

271 MODIS provides a large variety of remote sensing indices widely used in  
272 ecophysiological studies for determining plant activity and ecosystemic productivity  
273 (Peñuelas and Filella 1998). In our holm oak forest, the correlation between the  
274  $R_{858}/R_{1240}$  ratio and biomass increase and the negative relationship with tree mortality  
275 rates may be due to the importance of water availability in determining tree growth in  
276 this Mediterranean ecosystem. Other indices such as LAI and FPAR were also  
277 positively correlated with biomass increase and negatively correlated with tree mortality,  
278 because FPAR depends on the total amount of leaves in the canopies. A decrease in the  
279 total amount of leaves remaining in the canopies of this forest was observed in *Q. ilex*  
280 under simulated drought conditions (Ogaya and Peñuelas 2006). NDVI and EVI indices  
281 were also well correlated with biomass increase, as has been observed in many other  
282 works (Gamon et al. 1995). High correlations between stem growth and EVI values  
283 have also been observed in this forest (Garbulsky et al. 2013). Despite their seasonal  
284 variability, the lowest NDVI and EVI values occurred in late autumn 2011 (when tree  
285 mortality occurred) and did not recover typical values until late spring 2012 (soon after  
286 the flush of new leaves), showing again that NDVI and EVI indices are good indicators  
287 of crown condition and forest dieback. In contrast, annual GPP, PsnNet and NPP values  
288 were poorly correlated with biomass increase or tree mortality rates, and seasonal GPP  
289 and PsnNet values did not significantly decrease during the period of tree mortality and  
290 subsequent months. This result was unexpected because these algorithms are  
291 specifically designed to directly estimate ecosystemic productivity.

292 In conclusion, the continuing increase of temperatures in this Mediterranean  
293 ecosystem has been correlated with lower growth rates and higher forest dieback. Some  
294 remote-sensing indices, such as NDVI and EVI, were good indices for estimating  
295 annual productivity and for determining the occurrence of forest dieback, whereas other

296 indices such as GPP, PsnNet and NPP were less useful for estimating productivity or for  
297 detecting tree mortality, at least in the holm oak forest studied.

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299

300 **Acknowledgments.**

301

302 We are grateful to DARP (Generalitat de Catalunya), X. Buqueras and A. Vallvey for  
303 permission and assistance to conduct this research in the Poblet Holm Oak Forest.

304

305

306 **Funding.**

307 This research was financially supported by the Spanish Government projects  
308 **CGL2013-48074-P** and Consolider-Ingenio MONTES CSD2008-00040, by the  
309 Catalan government project **SGR2014-274** and by the ERC Synergy project SyG-  
310 2013-610028 IMBALANCE-P.

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439 Gangodagamage C, Cai M, McDowell NG (2012) Temperature as a potent driver of  
440 regional forest drought stress and tree mortality. Nature Clim Change. DOI:  
441 10.1038/nclimate1693.  
442

443 **Tables.**

444

445 Table 1. Coefficients of determination ( $R^2$ ) of the linear relationships of biomass  
446 increase and mortality with spectral indices and meteorological variables. (N.S. means  
447 not significant).

448

	Biomass Increase	Mortality
NDVI	0.64	0.43
EVI	0.55	0.35
GPP	N.S.	N.S.
PsnNet	N.S.	N.S.

449

Annual precipitation	0.53	0.24
Spring precipitation	0.44	0.31
Spring + Summer precipitation	0.41	0.34
Mean annual temperature	N.S.	0.33
Spring + Autumn temperature	0.16	0.38
September SPEI 6	0.30	0.31
December SPEI 12	0.45	0.27

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454 **Figure captions.**

455

456 Figure 1. Study site with the land-cover types obtained from the “Land Cover Map of  
457 Catalonia” (CREAF 2009) (modified legend). The study site is depicted by a red square  
458 in the map of Europe. The 20 selected pixels of NDVI and EVI values are framed in  
459 black. The other values were calculated in 1 x 1 km pixel, centered in the middle of  
460 these pixels, and covering the area of 16 depicted pixels.

461

462 Figure 2. Photographs showing the mortality in the studied forest during early autumn  
463 2011 and the same forest with healthy trees in autumn 2010.

464

465 Figure 3. Mean annual temperature and annual precipitation at the study site. The  
466 straight lines represent the linear relationships of an increase of air temperatures and a  
467 decrease of rainfall during the 36 years that meteorological data were collected. N.S.  
468 means not significant. Each point indicates the mean value of 1 year.

469

470 Figure 4. Monthly data of air temperatures and precipitation during 2011 (black points)  
471 compared to the average data during 1975-2010 (white points and grey columns). Each  
472 point and column indicates the mean value of 1 month. Error bars indicate the standard  
473 errors of the means for 1975-2010.

474

475 Figure 5. Values of September standardized precipitation evapotranspiration index  
476 (SPEI) for 1975-2012. SPEI 3 is calculated with meteorological data during the three  
477 months before September (included), and SPEI 6 is calculated with data during the six  
478 months before September (included).

479

480 Figure 6. Monthly variations of the normalized difference vegetation index (NDVI) and  
481 the enhanced vegetation index (EVI) in 2011 and 2012 (black points) compared to the  
482 average of 2000-2010 (white points). Each point indicates the mean value of 1 month.  
483 Error bars indicate the standard errors of the means for 2000-2010.

484

485 Figure 7. Monthly variations of gross primary production (GPP) and net photosynthesis  
486 (PsnNet) in 2011 (black points) compared to the average of 2000-2010 (white points).  
487 Error bars indicate the standard errors of the means for 2000-2010.

488

489 Figure 8. RDA biplot representing the relationships of the physical data on biomass  
490 increase. Abbreviations: “temp” is mean annual temperature, “spring-summer” is the  
491 sum of spring and summer rainfall and “SPEI 6” and “SPEI 12” are the September SPEI  
492 6 and December SPEI 12 indices, respectively.

493

494 Figure 9. RDA biplot representing the relationships of the physical data on mortality.  
495 Abbreviations: “temp” is mean annual temperature, “spring-summer” is the sum of  
496 spring and summer rainfall and “SPEI 6” and “SPEI 12” are the September SPEI 6 and  
497 December SPEI 12 indices, respectively.

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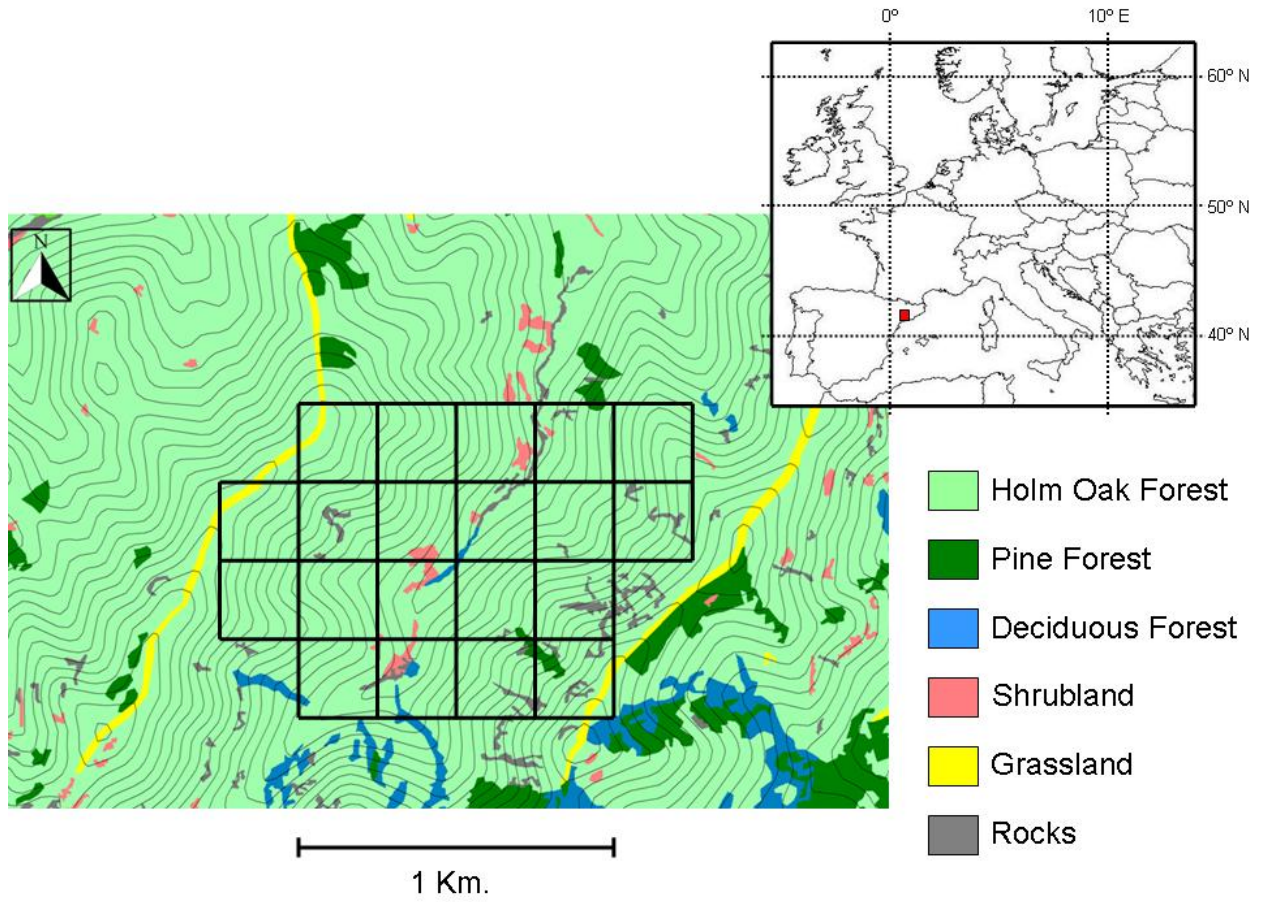
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510 Fig. 1  
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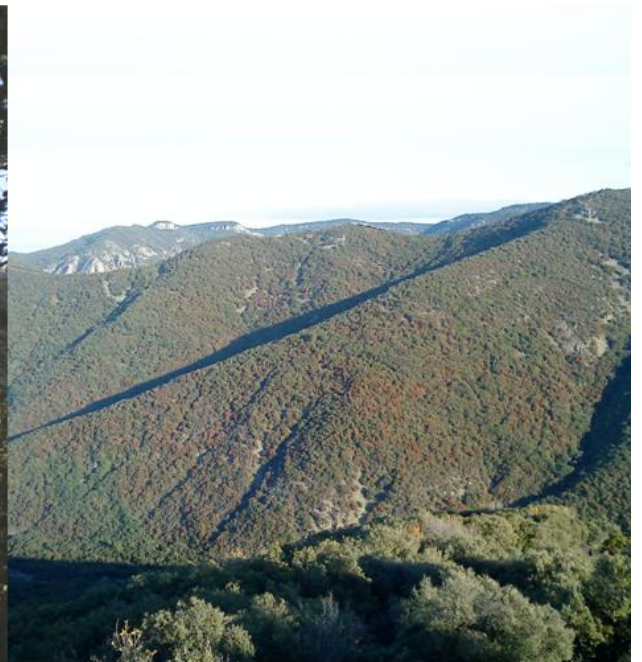
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**Autumn 2010**



**Autumn 2011**



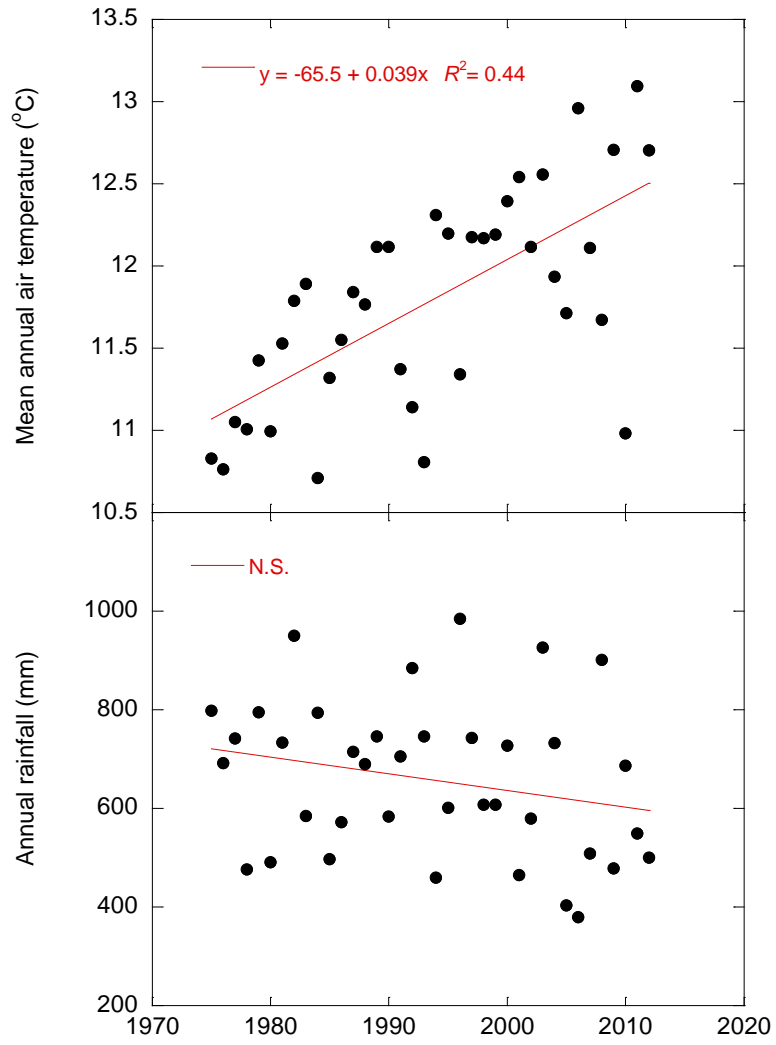
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526 Fig. 2

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535 Fig. 3

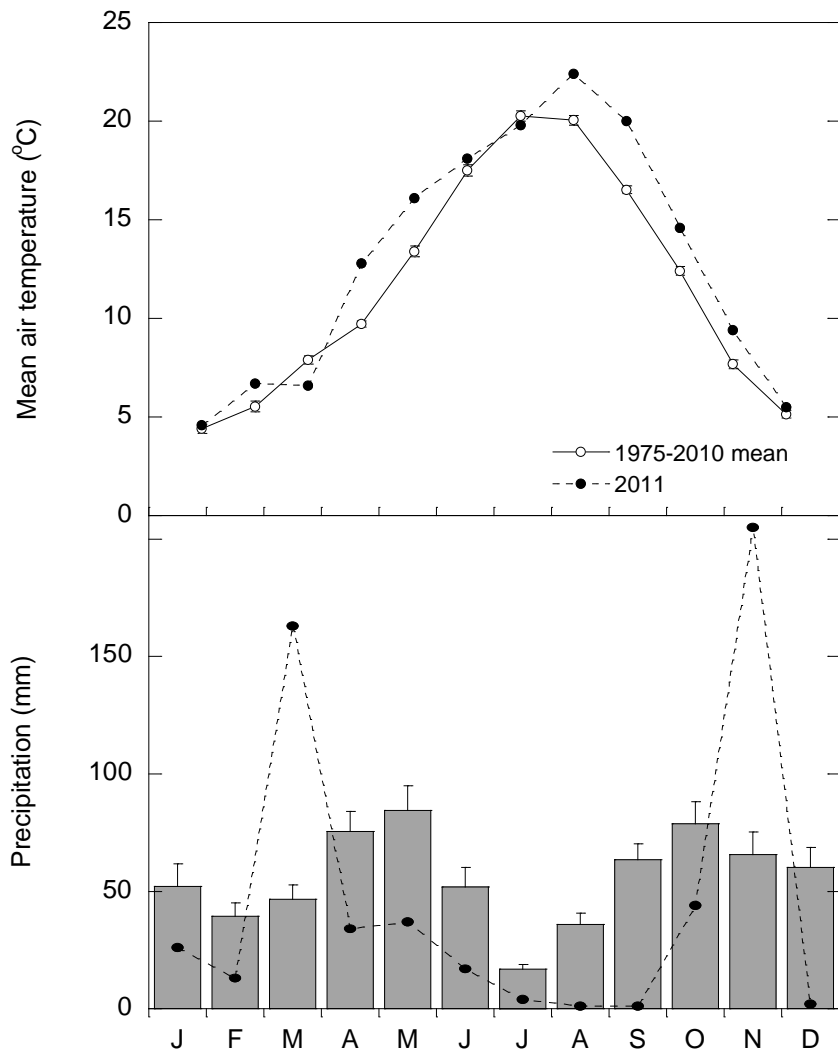


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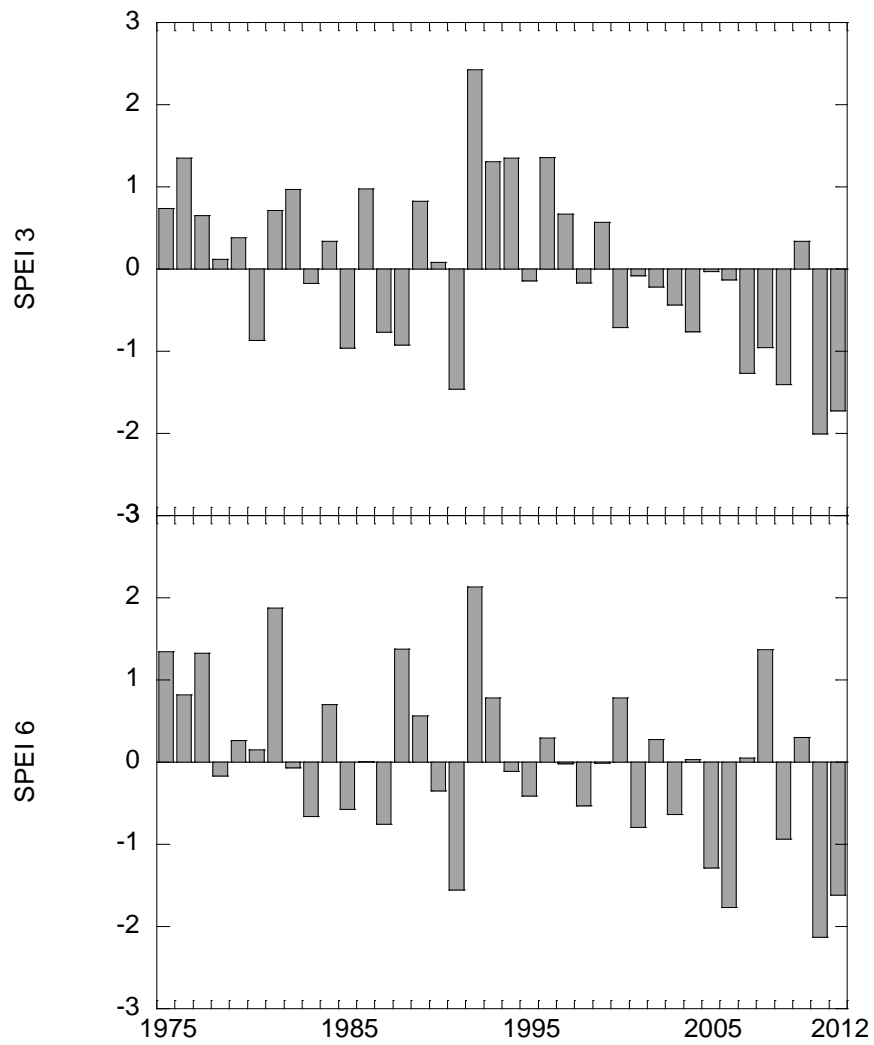
541 Fig. 4

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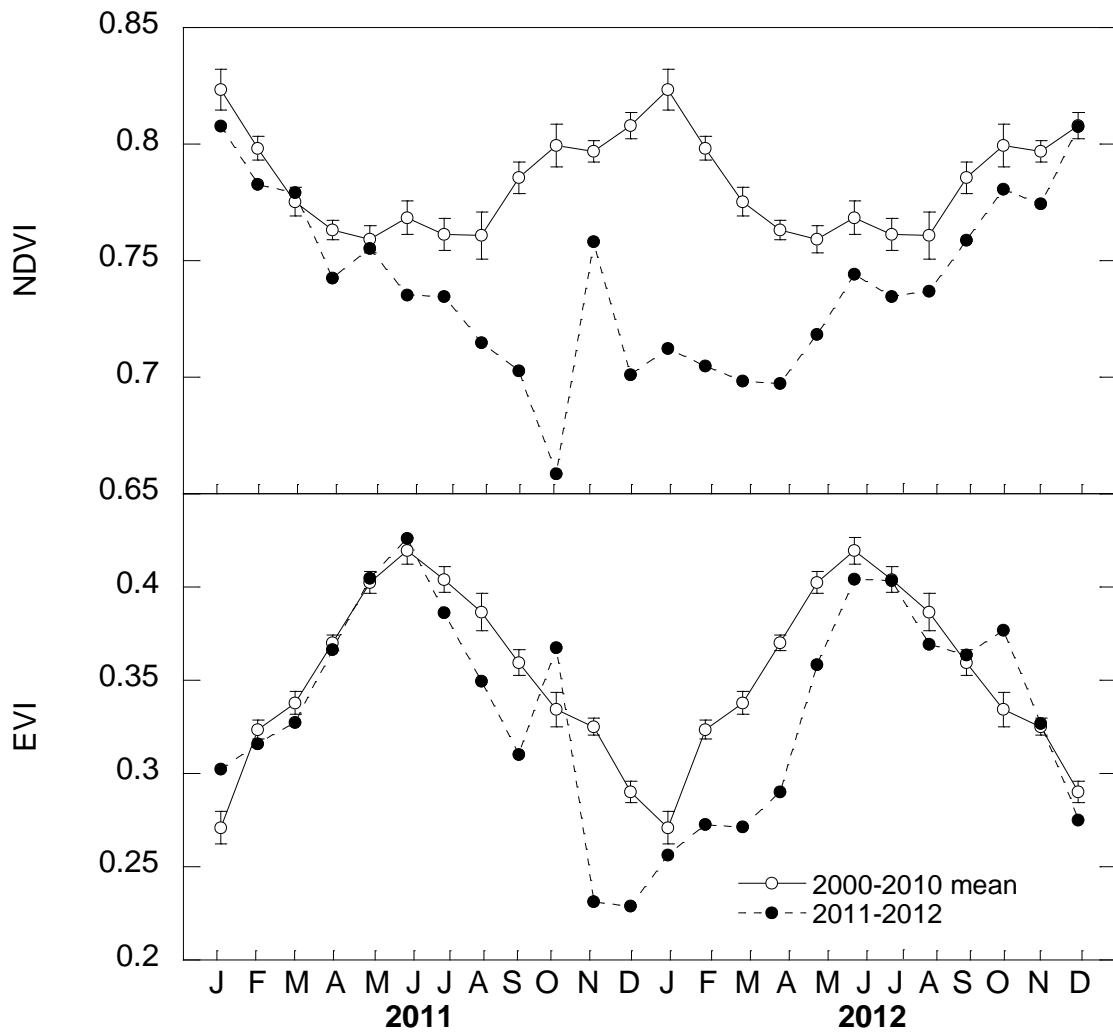
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547 Fig. 5

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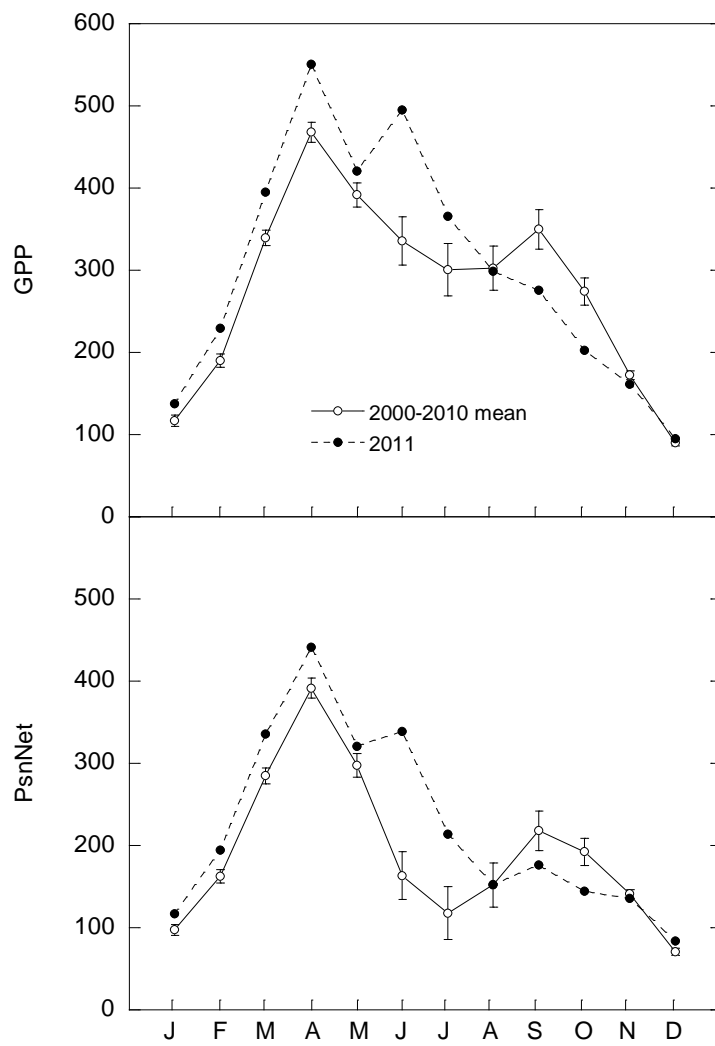
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Fig. 6

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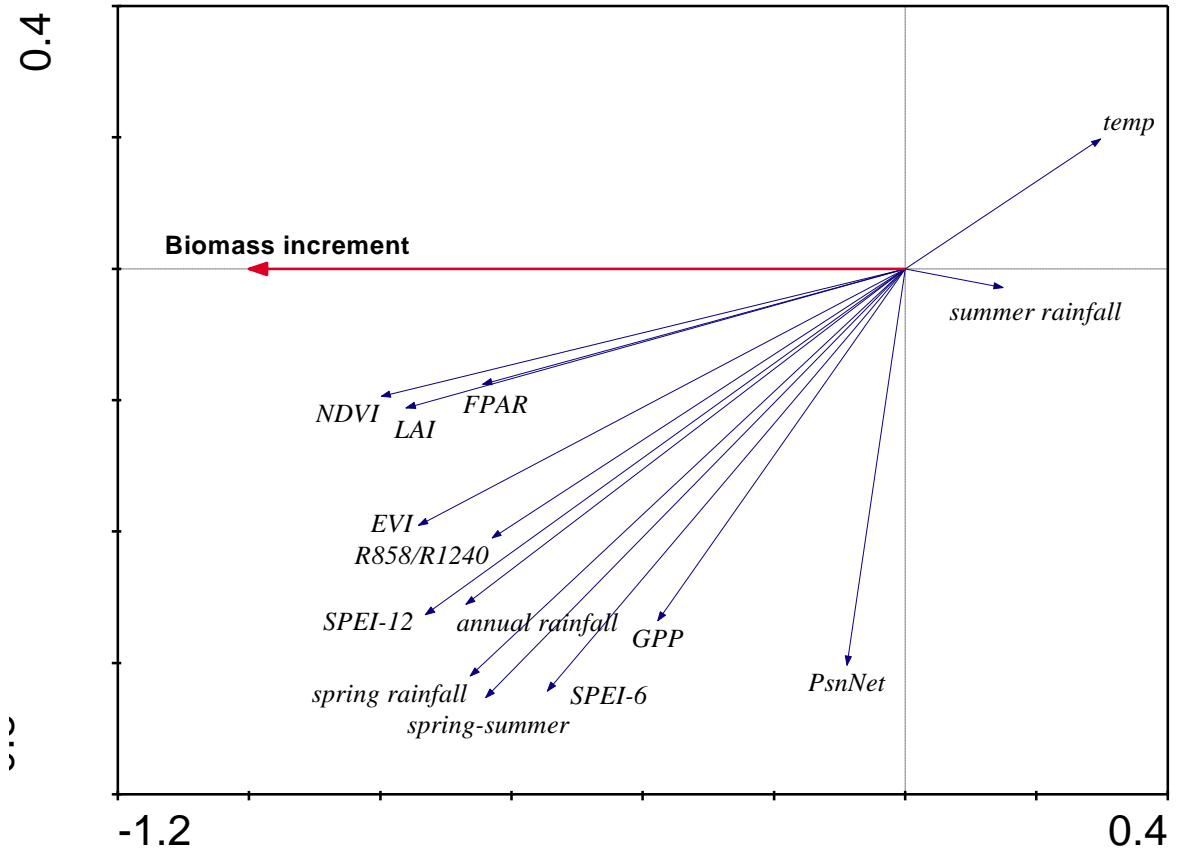
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564 Fig. 7

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570 Fig. 8

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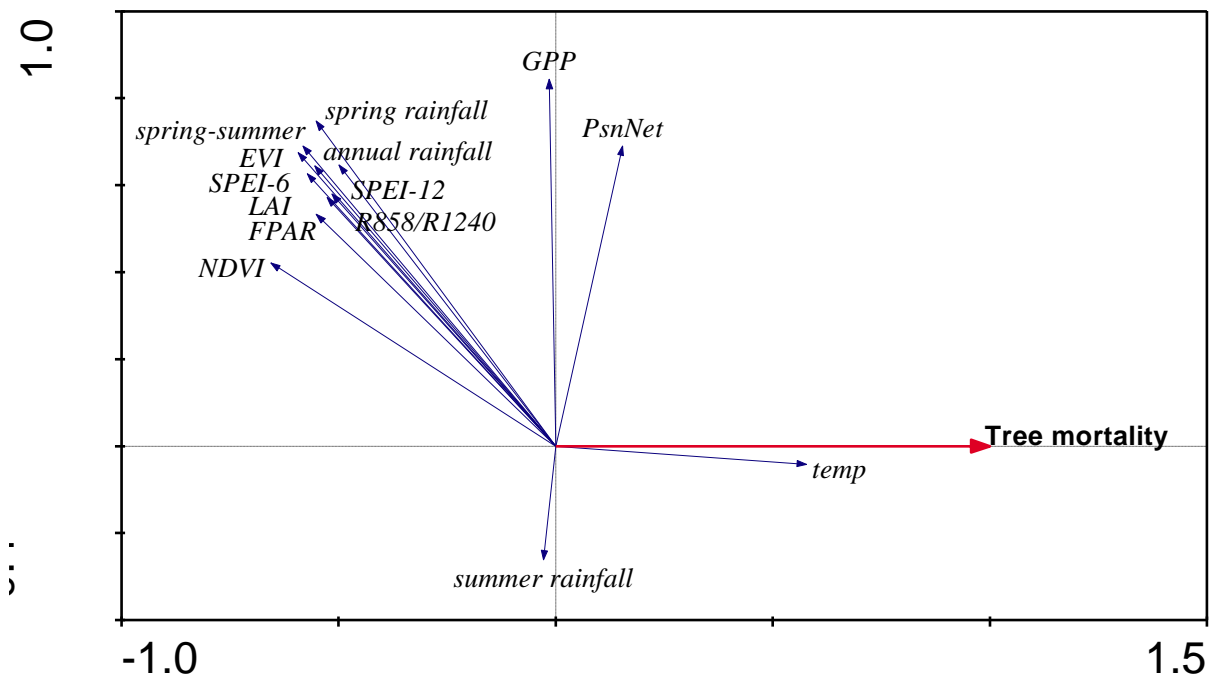
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587 Fig. 9