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DENDROECOLOGICAL RECONSTRUCTION OF FOREST DISTURBANCE HISTORY, COMPARISON AND PARAMETRIZATION OF METHODS FOR CARPATHIAN MOUNTAINS

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Abstract

The reconstruction of forest disturbance history has become a major research issue for natural and mountainous forests because of their influence on the stand characteristics and structure. Different methods were developped to identify past disturbance events from the variations in tree ring width. The most used one, referred to as growth release detection method, is based on the comparison of the growth rates observed on two consecutive periods. This method, used in many ecological studies, has the disadvantage of requiring three parameters to be implemented, that were hypothesized to be species- and region-specifics. The present study aimed at quantifying the influence of the parameters choice on the number of detections realized in the case of forest stands of the RODENDRONET dendrochronological network. The objective was to assess the best parameters combinations for large-scale application in Romanian forests, with respect to the species studied. The method`s results were compared against a time-series analysis method that relies on a statistical test to decide whethear the changes in the growth rate are significant or not. The results showed that, surprisingly, there is a universal parameter combination regardless of the species or of the site. The growth release method is shown to be very sensitive and potentially lead to detecting false perturbances, especially when the used threshold value is low, but this problem can be easily corrected by comparing the individual tree-series between them.

Key words: disturbance, tree-ring data

Rezumat

RECONSTITUIREA DENDROECOLOGICĂ A PERTURBĂRILOR DIN ARBORETE, COMPARARE ŞI PARAMETRIZARE A METODELOR PENTRU MUNȚII CARPAȚI

Reconstituirea regimului perturbărilor din arborete suscită un interes tot mai mare pentru comunitatea ştiinţifică mai ales datorită impactului major al acestor fenomene asupra structurii ecosistemelor forestiere montane. În prezenta lucrare s-au testat diferite metode de identificare a perturbărilor bazate pe analiza variațiilor inelului anual. Una dintre cele mai uzuale, cunoscută ca metoda ratelor de creştere, constă în compararea creşterilor radiale ante- şi postperturbare. Această metodă, în vederea aplicării, are dezavantajul de a necesita stabilirea prealabilă a unor parametri de calcul. După literatura de specialitate acești parametri, în număr de trei, variază în raport cu specia și condiții de creştere locale. Acest studiu are drept scop determinarea influenţei parametrilor metodei asupra numărului de perturbări detectate. Analiza s-a bazat pe seriile dendrocronologice din rețeaua RODENDRONET. Obiectivul este determinarea combinației optime pentru aplicarea la scara spațiului Carpatic, diferențiat în raport cu specia studiată. Rezultatele obținute folosind diferite combinații de parametri au fost comparate cu cele care provin din aplicarea unei metode statistice fundamentate pe analiza matematică a seriilor de timp (detectarea intervenției). Rezultatele arată, în mod deosebit, existența unei combinații unice de parametri care nu variază în raport cu specia sau regiunea ecologică. Metoda ratelor de creştere s-a dovedit a fi mai sensibilă, putând conduce la detectări de perturbări false, dar această problemă poate fi corectată prin compararea valorilor individuale obținute pentru fiecare arbore din situl studiat.

Cuvinte cheie: perturbări, inele anuale

1. INTRODUCTION

Tree rings were shown to contain a variety of useful signals that were exploited for studying the effect of e.g., sylvicultural treatments, climate, as shown by the considerable body of literature (Fritts, 1976). Tree rings were also used as a mean of dating events and found applications to reconstructing natural disturbances and forest dynamics. Natural disturbances such as windthrow (Morin, 1990), fire (Swetnam and Betancourt, 1990) or massive insect outburst were dated based on tree-ring studies (Hogg, 1999). Dendrochronological dating of events such as tree recruitment or growth release as resulting from a specific disturbance have for long been considered and successfully applied in contrasted forest types, including in natural forests. The difficulty in these studies is to separate the signals existing in the ring width series in order to extract those related to variations in growth rate that would have resulted from a natural disturbance.

The study of natural disturbances based on tree rings is using methods specifically developed to detect changes in growth rate related to disturbance. There are two types of abrupt changes in growth that reveal the existence of a disturbance: a decrease of growth rate as a result of an insect (defoliation), climatic disturbance (drought, frost) or pollution damage; an increase in growth rate following the disturbance as a result of a decrease in competition. This last type of change in growth rate is referred to as “growth release” (Lorimer and Frelich, 1989) and is by far the most studied. The family of the methods used to identify such disturbances can be classified into two main groups. A first group is based on empirical filter functions, generally referred to as running mean methods, which requires a large sample size to be correctly implemented and involves some subjective decisions (Drukenbrod, 2005). These methods, which have been developed and improved all over the last decades, are also the most applied in dendroecology and are largely reported in literature (e.g. Abrams et al., 1999; Lorimer and Frelich, 1989; Nowacki and Abrams, 1997; Payette et al. 1990). A thorough review can be found in Rubino and McCarthy (2004). A second group of methods is based on statistical techniques. A statistic comparison (t-test) of the mean growth rate observed in two consecutive periods of given length was proposed and used. It is a somewhat similar to the running mean methods except that the decision criterion to detect an event is not an arbitrarily defined threshold but rather a statistical test. But to our point of view, this method is not valid as it violates the hypothesis of independence that is at the basis of the t-test itself. The statistical method we preferred and used as a reference one is based on time-series analysis. Far less used, this last method however permits deeper analyses and less subjective results (Drukenbrod, 2005).

Growth change methods are amongst the most widely applied, which are based on running means comparison of growth over two consecutive periods. To be correctly applied, this method family used more specifically to detect growth release in natural forests or old-growth forests (e.g., Nowacki and Abrams, 1997; Piovesan et al., 2005), require the preliminary knowledge of some key parameters. Literature shows that the parameters vary depending on the species and the global growing conditions. In the view of an application over a large scale in Romanian forests, these parameters have to be carefully and specifically estimated and tested. A protocol was therefore set up to (i) test the impact of the variations of these parameters, and (ii) estimate what the best parameters could be for application in Romania. After this preliminary study, the different methods of growth change detection were applied to all the species and sites of RODENDRONET. The results were also compared to those from the analytic statistical method.

2. MATERIAL AND METHODS

Description of the data used

An unprecedented tree-ring data-basis of 1530 cores was constituted that focuses on the major coniferous species of Carpathian Mountains in Romania: Norway spruce with 40% of the trees (314 trees), Silver fir (17%), Larch (12%), Scots Pine (23%), and Pinus Cembra, Pinus Nigra and Pinus Strobus. The network, RODENDRONET, is a collection of tree-ring series collected from 780 trees sampled over 40 sites, with an average of circa 20 trees per site, which ensures a proper representativeness of the stand growth (fig. 1). According to the international standard, two cores per trees were sampled whenever possible (Fritts, 1976; Schweingruber, 1989). The average age of a tree, which refers to the number of rings present in a -transversal section of the stem at 1.3 m, is 136 ± 48 years (mean ± standard deviation), with a maximum age of 454 years for a Norway spruce in Călimani.

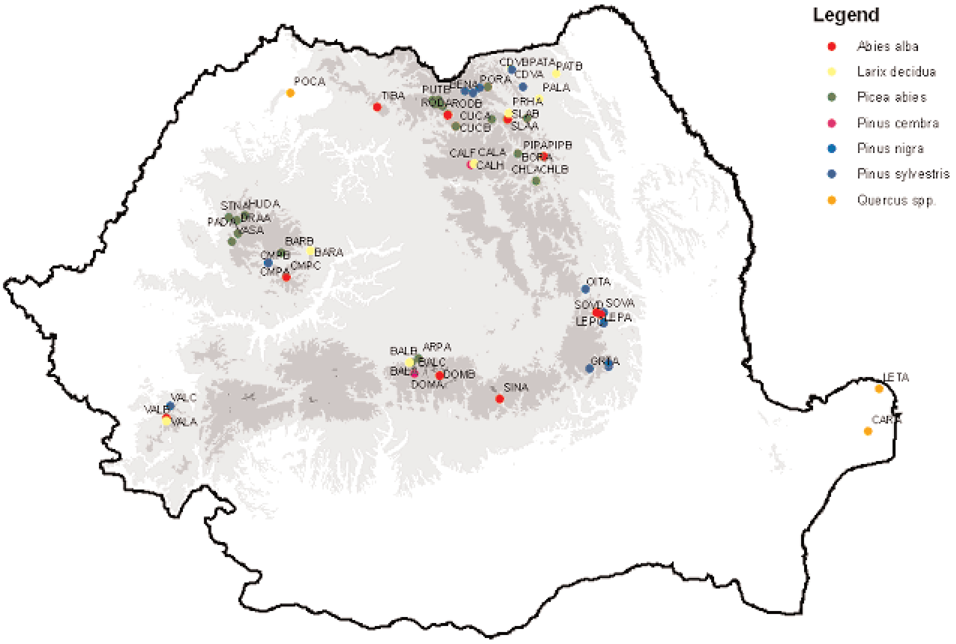

Fig. 1. Location of the sampling sites of the RODENDRONET dendrochronological network
Localizarea suprafețelor experimentale din rețeaua RODENDRONET

The sampling focused on the likely oldest trees of the stand. Dominant old trees offer longer series and the signal in their rings is considered to be more representative of the stand-level history (Schweingruber, 1989ş Cook and Kairiukstis, 1990). The variability between sites reflects the variability in forest structure and in growing conditions encompassed by the sampling.

We used three statistics for quantifying the variability in growth amongst sites and species. The statistical indices quantify the synchronism between trees, the strength of the signal common to all trees sampled: the average correlation coefficient between individual series and mean chronology, the signal-to-noise ratio (SNR) and the expressed population signal (EPS) were computed as a description of the fundamental chronology quality and potential in climate-growth analysis (Fritts, 1976; Wrigley et al. 1984).

The signal-to-noise ratio is defined as:

$$SNR = N r / (1-r)$$

where: N is the number of trees, r is the average Pearson correlation between trees.

The expressed population signal is defined as:

$$EPS = N r / (N r + 1-r)$$

Methods for detecting perturbations from tree-ring series

Growth change methods

Following Lorimer (1984) and Lorimer and Frelich (1989), a growth release occurred if the change in growth observed in two successive periods overcomes a given threshold: a fixed value (Fraver et White, 2005) or a relative value (Nowacki and Abrams, 1997ş Winter et al., 2002ş Steward and Rose ,1990). If using relative change, the growth change index (GCt) is computed as for a given year t:

$$GC_t = \frac{(Agr_2 - Agr_1)}{Agr_1} \times 100 \qquad (1)$$

where: Agr_1 is the average growth rate for n1 years before year t (before the event);

Agr_2 is the average growth rate for n2 years past the event, including the year at which the index is being computed (fig.2).

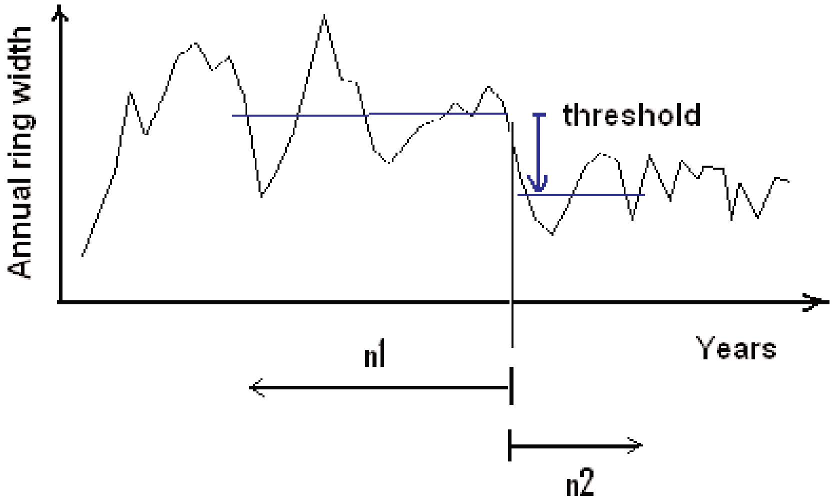

Fig. 2. Parametrization of the running mean method
Parametrizarea metodei mediei mobile

Black and Adams (2003) further refined this method in what they named the “boundary line method” in order to limit the risk of detecting a false disturbance by considering the magnitude of the prior mean growth rate as an additional criterion.

The number of years classically used for this computation (i.e., n1 and n2) varies between 5 and 15, depending on the geography and the species studied. In order to avoid the risk of carry-over or lags in events detection, Popa (2004) suggested for Romania to set n2=1. Also, according to the classification published, the major perturbations are those for which GC>100, moderate where GC lies between 50 to 75%, and minor for GC ranging between 25 to 50% (Schuler and Fajvan, 1999).

The growth change methods are based on the comparison of growth rates observed before and after a given year, during periods which duration should be defined: in formula 1, the first number to be defined is n1, the number of years prior to the event over which the growth rate should be averaged; the second and equivalent, n2. The last value to be estimated is the threshold value, the most used value being 25%, but this has not been tested nor validated in Romanian growing conditions and should be tested for each of the RODENDRONET species.

The empirical approach decided to assess the best parameter choice consisted in the so-called sensitivity testing, in which all combinations are tested and compared to each other as often done (Fraver and White, 2005). The first step is to compute GC using successively all the possible combinations of the parameters over the same time series. The results for each combination are compared, which enables a direct quantification of the influence of each parameter on the final result. Finally, a decision can be taken by selecting the combination that offers the results the most reliable and the closest to the objectives.

The table 1 presents the range of the values tested for each method and each parameter. The range decided was purposely wider than generally done as this study has an exploratory character. They were 75 combinations per tree to be tested, and for each combination, there were 18 percent thresholds per combination to be tested, that is, for each tree, 1350 runs. At the scale of RODENDRONET, this represents a total of 1 053 000 computations. The growth change index would be noted further GC(x,y) with x referring to n1 and y to n2: GC(6,2) is the index with n1=6 and n2=2.

Table 1. List of parameters tested for each method in the benchmark
Lista parametrilor testaţi pentru fiecare metodă

Method	Number of years before (n1)	Number of years after (n2)	Threshold
Lorimer	2,3,4,5,6,7,8,9, then from 10 to 30 by 5	2,3,4,5,10	20 to 100 by 5%
Popa	2,3,4,5,6,7,8,9, then from 10 to 30 by 5	1 (constant)	20 to 100 by 5%

Statistical method for detecting forest disturbance history:Intervention detection

Tree ring time series are known to be auto-correlated, and autoregressive or autoregressive integrated moving average (ARIMA) models have for long been proved to adequately model the ring width series (Cook, 1985; Guiot, 1991). Tree-ring series are generally assumed to be a pure ARIMA process. However, a disturbance that would impact trees growth would by definition modify the process. In one special kind of ARIMA model called intervention model, an additional input series is an intervention variable containing discrete values that flag the occurrence of an event affecting the response series. This event is an intervention in or an interruption of the normal evolution of the response time series, which, in our case, represents a disturbance. Intervention variable may either be known a priori or detected from data via intervention detection procedure (Tsay, 1988). The procedures will not be detailed here for they are very complex and highly specialized, but in a few words, they consist in fitting iteratively an intervention model and testing the significance of the parameters and the improvement of the model fit, therefore deducing the opportunity of considering an intervention at the corresponding year. Thus, this approach offers a mean of assessing the statistical significance of a disturbance, unlike the running mean approaches. The software AUTOBOX (Version 6.0, Automatic Forecasting Systems Inc., Hatboro) was used to fit the intervention model and list the candidate years for intervention. Three types of intervention were considered: pulse, step or trend according to the definition in Downing and McLaughlin (1990).

3. RESULTS

3.1 Description of the mean characteristics of the tree-ring series

The statistics indicate a high correlation of growth variations between the trees in the sites. In particular, the EPS is lower than 0.85 in two cases only: DOMA and STNA. This value of 0.85 is considered as a threshold for any dendroclimatological study, a value below which the individual variations are thought to impact the stand-level curve and its correlation to climate. In the case of the current study, the high values obtained resulting from a good sampling and preparation of the cores, prove that the number of cores per site is enough to capture stand-level signals. Thus, increasing the number of cores per site would not result in any improvement of the chronology.

3.2.Testing the sensitivity of the running mean methods to the parameters value

The influence of the parameters n1, n2 was tested by comparing the number of detections (i.e., when GC is greater than a given threshold) for each combination of n1, n2. The sensitivity threshold was empirically set to 25%, which is a relatively low value but is the most used in literature, and is also more discriminating. The value of the parameters n1 and n2 are changed as shown in table 2, the average GC for each species and site is computed to absorb the individual (tree-level) variations. The tests show that there are no or little improvements to having n1 above 10 years regardless of the species or location. There was a salient difference between sites on the number of detections for a given combination of the parameters which has offset much of the potential differences between species as illustrated in figure 3 for silver fir.

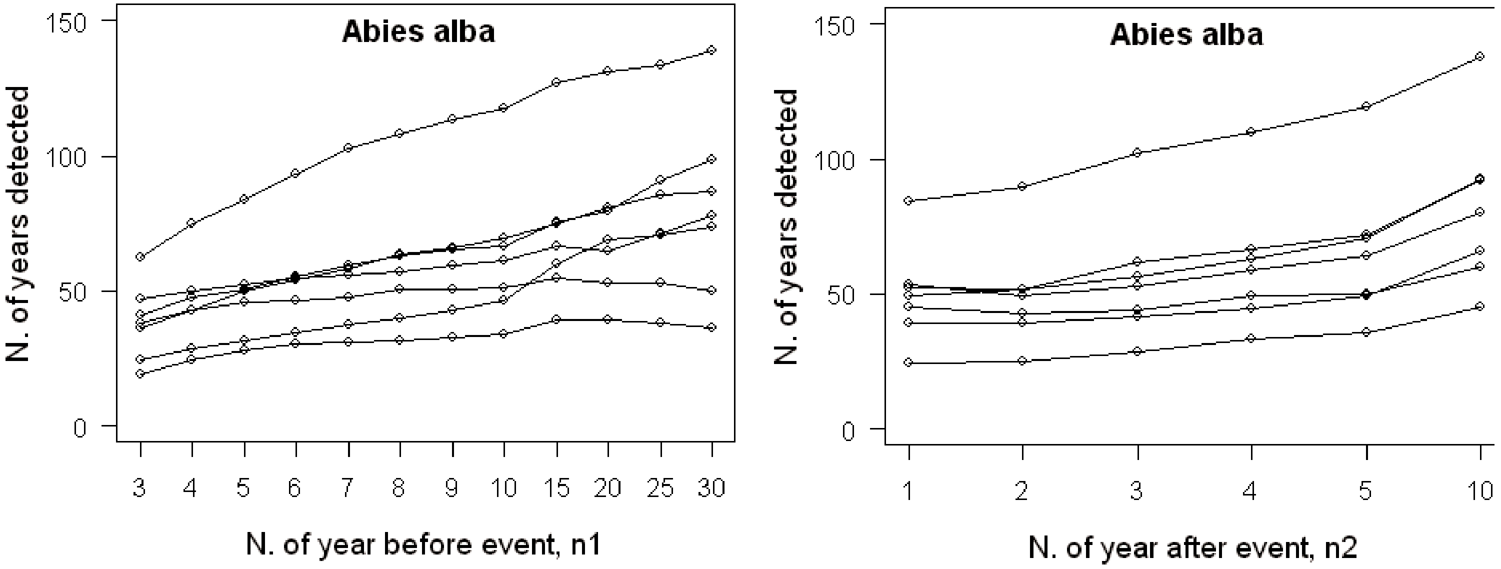

Fig. 3. Number of detections as a function of the parameter n1 (number of years of the period before the event used in the computation of the growth change index). Each line correspond to one different site of the RODENDRONET
Numărul de perturbări detectate în funcție de parametrul n1 (numărul de ani ai perioadei post eveniment utilizați în calculul indicilor ratelor de creştere). Fiecare linie corespunde unei suprafețe experimentale din RODENDRONET

When averaged over the species, the tests prove that low values of n1 and n2 lead to much less detections then with higher values of the parameters, but the evolution in the number of detections is not linear (fig. 4). Still, the plateauing was more strongly marked in fir, spruce and pines. The number of detections seemed less sensitive to n2 than to n1 and increasing n2 above 6 or 8 hardly had incidences over the detection level.

Increasing the number of years is indeed an obstacle to the practical use because the corresponding periods at the beginning and the end of each series are lost in the computation of the running mean. Also, increasing the number of years mechanically results in a lag between the year of change and the resulting peak in GC. On the basis of these tests and given these limitations, it can be decided to use n1=10. A value larger than n1=10 will not modify the number of detections but will prune too much of the series. As a partial conclusion, the best parameters combination to use is 10 years before (n1=10), and also 10 years after. To avoid any problem of lag, setting n2=1 is an efficient alternative solution.

3.3. Testing the threshold value

The problem in the choice of the threshold values is that a value too low would lead to detecting false disturbances. On the contrary, a value too high might lead to missing events. Also, there are no reasons why the threshold value should be the same for all species. To test the impact of the threshold value the computation of the indices is done for a wide range of threshold values in order to observe its impact on the number of disturbance detected. This time, the other two parameters are fixed: both n1 and n2 are set to 10 years as suggested by the previous analyses. The results are synthesized in figure 5. One first result is that the species seem to have very little influence on the test, as the pattern of the decrease in the number of detections with increasing threshold values is very similar amongst the species used for the test.

The decrease of the number of detections is very large when increasing the threshold from 20 to 25%. Above 40-50%, the reduction in the number of occurrence is quite modest. Another aspect that we investigated is whether the reduction in the number of detections is a result of fewer events detected, or of a reduction of the number of years for each event, as illustrated in figure 6.

The decrease of the number of detections is very abrupt from 20 to 50% and comes more from a reduction in the average number of years per event than from a reduction in the number of events detected. Increasing the threshold to 100% resulted from detecting much fewer events (fig. 7), but little changes are seen between 100 and 125%, which means that only the most stringent events are still detected using high threshold (table 2).

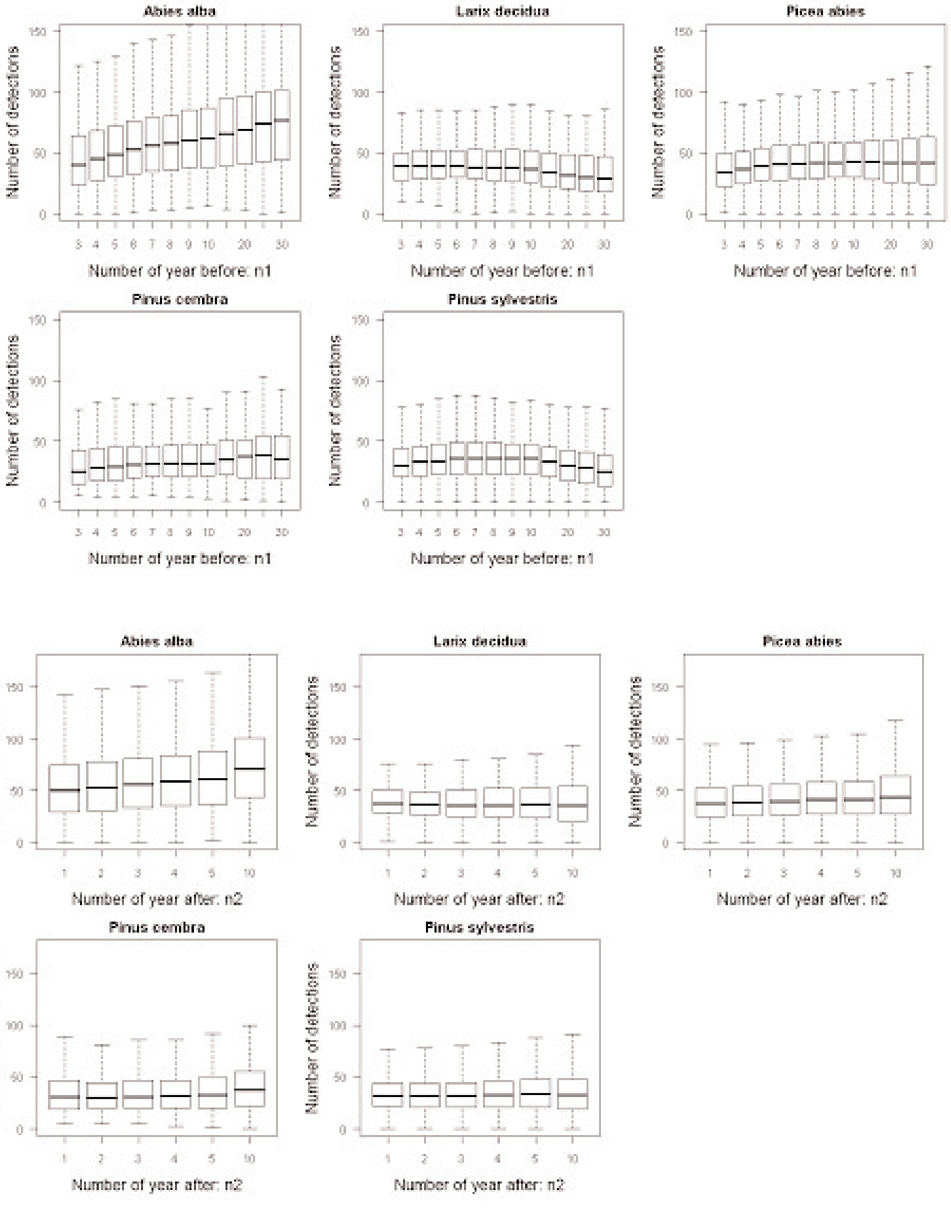

Fig. 4. Number of detections as a function of the parameter n1 (top) and n2 (bottom) for each species. Boxes represent the 25th to 75th percentile of the distribution with the solid line showing the average while the whiskers show the standard deviations.
Numărul de perturbări detectate în funcție de parametrul n1 (sus) şi n2 (jos) pentru fiecare specie. Căsuțele reprezintă quantilele de 25 şi 75 ale distribuției cu linie continuă fiind redată media, iar barele extreme indică abaterea standard

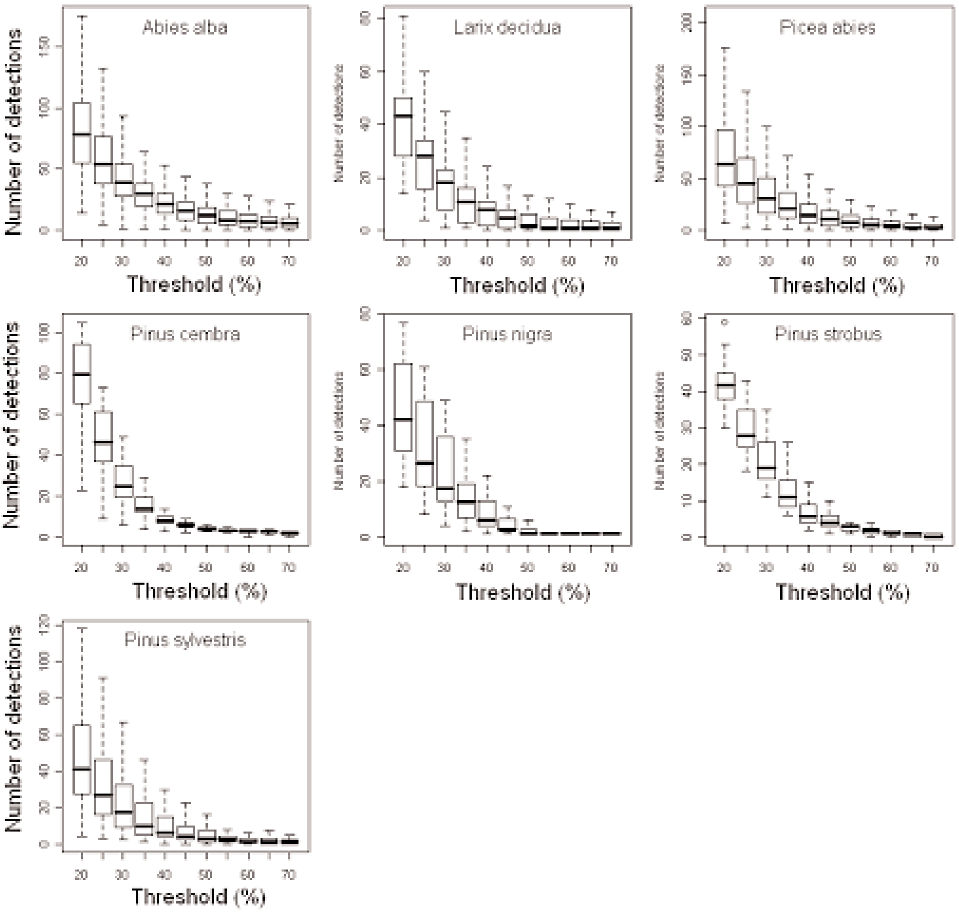

Fig. 5. Boxplot of the number of detections for each value of threshold from 20 to 70%. Boxes represent the 25th to 75th percentile of the distribution with the solid line showing the average while the whiskers show the standard deviations.
Numărul de perturbări detectate pentru fiecare valoare a limitei de semnificație de la 20% la 70%. Căsuțele reprezintă quantilele de 25 şi 75 ale distribuției cu linie continuă fiind redată media, iar barele extreme indică abaterea standard

3.4. Comparison against the intervention detection method

Because the intervention detection method has a statistical basis, its results can be regarded as a reference. The intervention detection procedure was thus applied to each series in RODENDRONET. Three different types of potential growth changes were screened: a pulse, a regime shift or a trend, but only regime shifts and pulses of large magnitude can theoretically be also detected by the running mean methods and were therefore retained for the comparison. The intervention models fit proved that they are a lot of interventions in the series, over 90% of the trees having at least one.

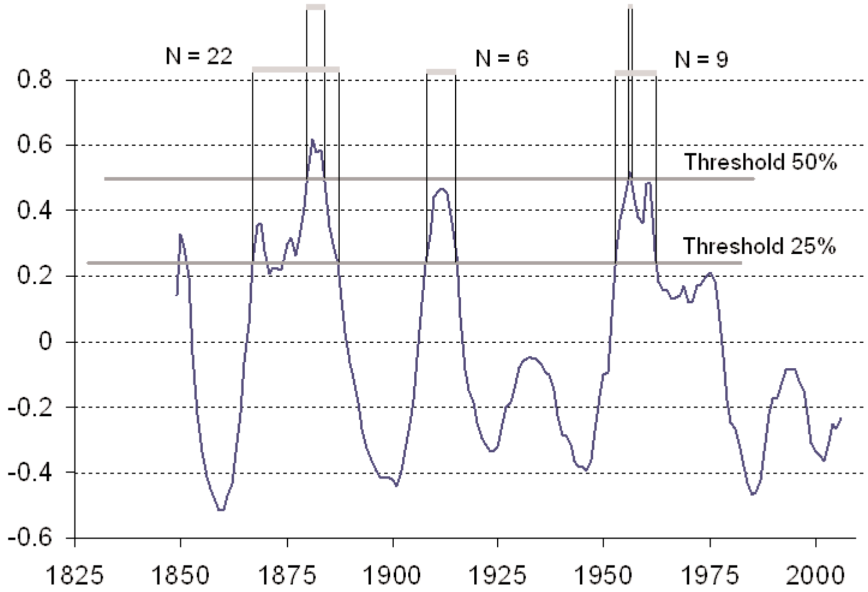

Fig. 6. Two distinct sources of decrease of the number of detections: a reduction in the number of events, or in the number of years per event, as shown in the example for a tree in the site ARPA (Arpaşul, Norway spruce stand).
Două surse distincte ale scăderii numărului de perturbări detectate: o reducere a numărului de evenimente sau a numărului de ani pe eveniment, aşa cum este arătat pentru arborii din suprafaţa experimentală ARPA (Arpaşul, arboret de molid)

Table 2. Number of years with intervention detected in the growth series, for each type of intervention
Numărul de ani cu intervenţii detectate în seriile de creştere, pentru fiecare tip de intervenţie

Species		Intervention type		
	Level shift	Pulse	Trend	Total
Abies alba	1.7	4.5	2.0	8.3
Larix decidua	2.1	5.3	1.4	8.8
Picea abies	2.2	4.2	1.9	8.3
Pinus cembra	1.9	4.4	1.8	8.0
Pinus nigra	1.5	5.4	2.5	9.4
Pinus strobus	2.4	4.5	2.0	8.9
Pinus sylvestris	2.4	5.5	1.7	9.5
Average	2.0	4.8	1.9	2.5

However, many of these interventions were linked to the initial part of trees development, when competition reaches high levels (i.e. canopy closure). We found up to 18 years of intervention for a given series, the average being around 6 interventions per tree on average with little differences between species. The date of occurrence of these interventions was compared to the results of the running mean method.

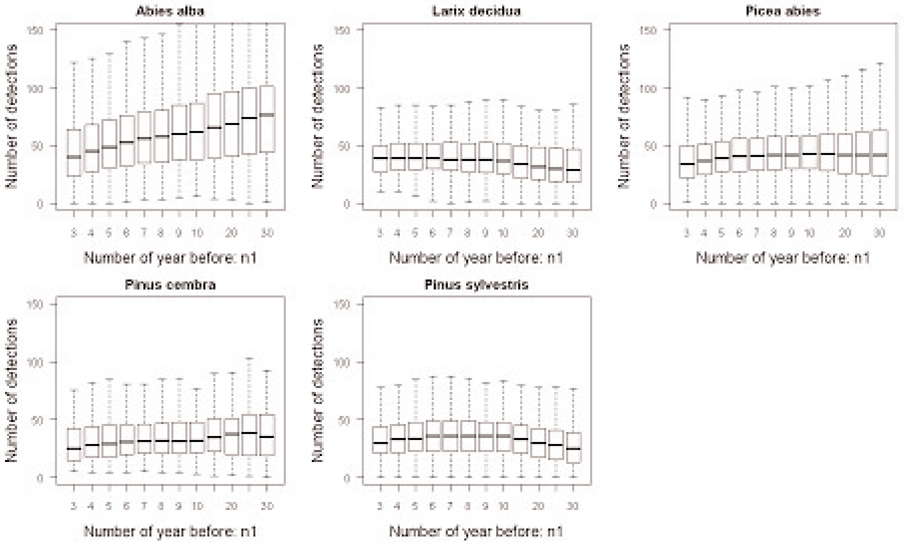

Fig. 7. Percentage of the number of detections (threshold set to 20% taken as reference) for each threshold value: percentage of the number of events and of the total number of years
Procentul numărului de perturbaţii detectate (limită de semnificaţie de 20% luată drept referinţă) pentru fiecare valoare de semnificaţie: procentul numărului de evenimente şi numărul total de ani

The computations were done at the scale of the individual tree series, and a filter was applied to make the results closer to the application conditions and more useful: the number of events detected was counted and the events were considered as relevant only if at least half of the trees in a given site show a common feature. This filtering avoids false detections necessary because tree-level series can contain some ‘noise’ not related to the stand history. The comparison of the number of detections obtained by both methods show that the running mean method is from far the most sensitive, even for relatively high threshold values (up to 100%), but the difference is much reduced by increasing the threshold. The difference between the two methods is the weakest when n2=1 regardless of the species or the site. The relative influence of n1 was greater than that of n2.

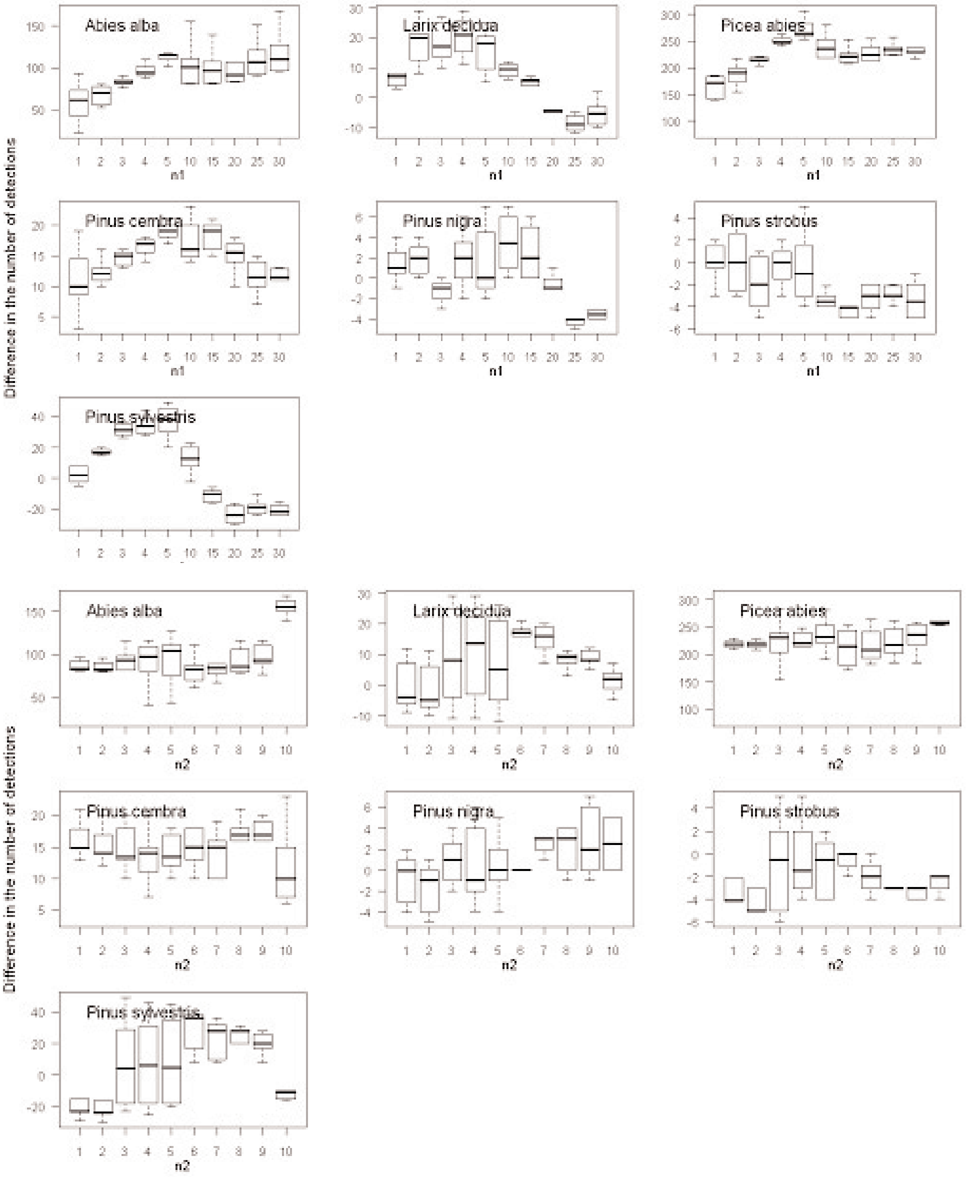

Fig. 8. Difference in the number of detection between the -running mean method and the -intervention detection, as a function of the parameters n1 (up) and n2 (below)
Diferența în numărul de perturbări detectate între metoda mediei mobile şi a detectării intervenției, în funcție de parametru n1 (sus) şi n2 (jos)

4. DISCUSSION

The tests of the influence of parameters on the running mean method were already realized and quoted in some dendroecological publications (e.g. Fraver and White, 2005) but published in only one article (Rubino and McCarthy, 2004). However, the authors did not test systematically the differences of the parameter choice or of the threshold, nor did they compare the performance obtained on different species. It is noticeable that Rubino and McCarthy (op. cit.) did underline the great difference between methods in the number of events detected.

Our tests showed that there were little influences of the site or of the species on the performance of a given parameter combination. This simplifies considerably further analyses as the choice of the parameters seems mainly determined by intrinsic -computational limitations. Still, it can be advised to test a few combinations before finalizing a computation. Taking n2 larger than 10 is clearly not helpful because it will smooth out the signals. The increase of the length n1 or n2 also goes with an undesired lag in the detection of the disturbance and a reduction of the sensitivity as the perturbation is being averaged together with post-perturbation. Taking 10 years for both n1 and n2 seems a valuable compromise between sensitivity and abusive inclusion of years ante- or post-event. Yet the modification suggested by Popa (2004) (i.e. n2=1) was proved to be leading to the closest estimates as compared to the intervention detection, mainly because it is not as sensitive as with higher n2 values. One valuable advantage of using this combination is to avoid the lag between the peak of the growth change index and the true disturbance event that is mechanically introduced by the computation method. Another advantage comes from the fact that the computations do not cut off the end of the series. Further, we did not observe any missing of events while using a moderate or low threshold value (25 to 50%). These results are therefore encouraging the use of the set parameters as n1=10, n2=1 and threshold =25% for a high sensitivity.

Results are a little different concerning the threshold value used. We observed a very high sensitivity of the method to the threshold when its value was low, typically around 20%: a little increase of the threshold then induced quite large diminution of the total amount of detections. By setting a higher threshold value (typically above 100%), there is a risk of missing some events. On the other hand, the risk of false detection is minimized by the protocol used to reconstruct forest history, according to which the individual GC series are compared to each other. Cross-checking amongst trees enables to filter out such false detection simply and efficiently. Therefore, it seems safer to use a low threshold value and to filter out potential false detections by inter-tree comparisons, than to use a high threshold value. Several studies are making use of a low threshold value (25%) (Nowacki and Abrams, 1997; Abrams et al., 1999) although some authors recognize that false detections are very likely. As shown in Black and Adams (2003) and Fraver and White (2005), the growth rate has a key influence on the threshold value to be used and it can explain a difference between species. Using a large threshold value (100% or more) can be preferred specifically for detecting the occurrence of the canopy accession (Black and Abrams, 2003). Nevertheless, a substantial amount of empirical decision remains in the use of this method as no clear criterion can be applied to decide what threshold truly filters disturbances that correspond to noticeable changes in stand structure.

The comparison with the intervention detection method suggests that the growth change methods are the most sensitive ones and may be prone to suggesting false events, even while using a filter that would rely on the percent number of trees per site affected. Given the large difference in the number of detections that result from changing the threshold value, we strongly advise to do some tests and try to compare with some known reference of an event (windthrow, thinning) to see how this event translates in changes of growth.

The reason why the parameters happened to be the same for all species is rather a surprise and is unfortunately not documented. A similarity in growing conditions cannot be invoked though, for the RODENDRONET network was set from assembling remote sites. Regardless of the species, a tree benefits from a canopy opening, and the degree to which it would increase its growth may vary between species. In our study, we limited our investigations to detecting the occurrence of disturbances: if the percent growth change index overcomes a prescribed threshold, the year is counted as year of event. But we did not compare the magnitude of the response itself and differences between species could be more salient regarding the average intensity and the duration of the response as already reported, mostly for North-American stands (e.g. Black and Abrams, 2003). Another study could be focused on such species-specific features related to forest structure and tree physiology.

The running mean methods were used largely because their implementation is rather simple and the results easy to interpret. They also offer quite good results but are not skilled for detecting trends or pulses limited in time (two to three years). For many aspects, the intervention detection is a much more satisfying method; the only true limitation of this method consists in the understanding of the user and its proper implementation. It can reveal with high confidence the date of an event, unlike the running mean methods that have not such a precision for simple computation reasons. But it appeared less sensitive and may not be as efficient for detecting small-scale disturbances.

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