DET FORSTLIGE FORSØGSVÆSEN I DANMARK

THE DANISH FOREST EXPERIMENT STATION
STATION DE RECHERCHES FORESTIÈRES DE DANEMARK
DAS FORSTLICHE VERSUCHSWESEN IN DÄNEMARK

BERETNINGER UDGIVNE VED DEN FORSTLIGE FORSØGSKOMMISSION

REPORTS — RAPPORTS — BERICHTE

BIND XXXIII

HÆFTE 1

INDHOLD

KØBENHAVN
TRYKT I KANDRUP & WUNSCH'S BOGTRYKKERI
1972

RELATION OF CLIMATE TO THE START OF DANISH OUTBREAKS OF THE PINE SHOOT MOTH

(Rhyacionia buoliana Schiff.)

KLIMAETS BETYDNING FOR IGANGSÆTTELSE AF DANSKE MASSEFORMERINGER AF FYRREVIKLEREN

(Rhyacionia buoliana Schiff.)

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1. INTRODUCTION

In a previous paper (*Zethner* and *Bejer-Petersen* 1971) it has been shown that in Denmark there is a trend towards large-scale outbreaks of the pine shoot moth in certain years. These outbreaks cover the whole country. In other years local outbreaks may occur.

Only climate can initiate simultaneous outbreaks of the moth populations over large geographical areas. The climatic factors found in common for these general outbreaks in Denmark were, therefore, investigated.

The biology of the pine shoot moth in Denmark is roughly as follows: Flight period and egg-laying in July; larval hatching and first boring in needles in July-August; borings in the first bud in August-September; hibernation; renewed activity in March-April; boring in buds and shoots in April-June; pupation in June.

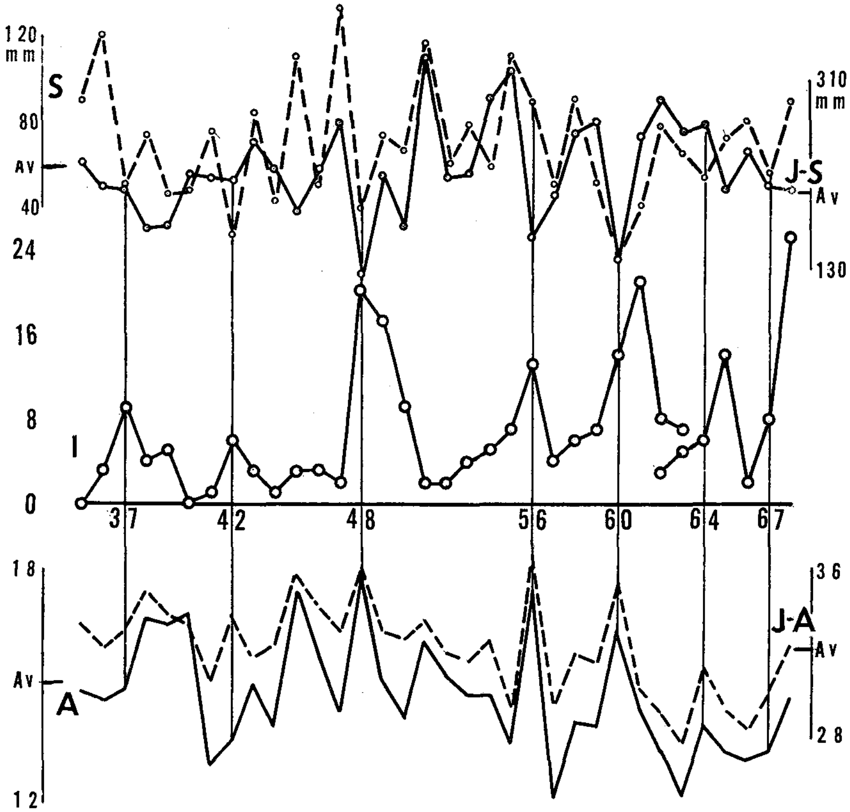
Climate may have a coordinating influence, especially in the following situations:

a) flight and egg-laying, which might be favoured by warm dry weather;
b) initial borings of the larvae in needles and buds, which might be favoured by the same kind of weather (see discussion);
c) hibernation, when low winter temperatures may kill the larvae;
d) spring, when larval activity and tree reaction might be influenced by the weather.

2. METHOD

As the climatic factors must have operated before the first major increase in numbers of the R. buoliana, *the increase year which is not necessarily the peak year, is analysed.* As basis is used the record of inquiries on R. buoliana (*Zethner* and *Bejer-Petersen* 1971) seen in fig. 1. Only years with an increase by more than 3 have been considered. As the total number of inquiries has been steadily growing during the period 1935—1968, really a higher limit might actually be demanded at the end of the period to correspond to the same rise in R. buoliana damage. This is, however, fulfilled automatically except in the year 1964.

With the above basis, some climatic factors have been surveyed for two and one years before the rise in R. buoliana damage (= inquiry numbers). Special attention has been paid to the change in the climatic factors from one year to the next, and less to the absolute level of these factors, as it must be some positive change in climate which causes a major population rise. Of course, very large relative changes will often result in "extreme" absolute levels.



Figur 1. I: No. of inquiries on Rhyacionia buoliana (actual years), left larger scale. S and J-S: September and July-September rainfall for Denmark, mm. Scale left and right respectively.
A and J-A: Average temperature for August and July-August for Denmark, Centigrades. Scale left and right respectively.
The climatic data are those of the year BEFORE the inquiry year.
AV corresponding 40-year averages (1886—1925).

Figur 1. I: Antal forespørgsler (faktiske år) skala tv., store tal.
S og J-S: September og juli-september nedbør for Danmark, mm. skala henholdsvis tv. og th.
A og J-A: Middeltemperaturer for august og juli-august for Danmark C°.
Klimadata er for året FØR forespørgsels-året.
AV: Angiver langtidsgennemsnit. 1886—1925.

An increase in inquiry numbers by more than 3 has in the period concerned, taken place in the years 1937 - 1942 - 1948 - 1956 - 1960 - 1964—65 - 1967. It is somewhat doubtful whether 1964 or 1965 should be considered as the initial year because of a change in those years in the basis of registrations of inquiries. 1964 is very likely the right one as a continuation of the former registration should in theory add about 3.5 (average of two years before) to the figure given by the new registration only.

3. TEMPERATURE AND PRECIPITATION DURING THE EARLY AND PROPER SUMMER BEFORE AN R. BUOLIANA OUTBREAK STARTS

3 a. Temperature.

For a number of months, and combinations of months respectively, the monthly averages and their sums have been compiled two and one year before the rise in inquiries.

Increasing averages are given in table 1.

Table 1. Increasing temperature during the summer before outbreaks start.

Year	Months							
	J	J	A	S	J+J	J+A	A+S	J+J+A
1935—1936	×	×	×	—	×	×	—	×
1940—1941	—	×	×	×	×	×	×	×
1946—1947	×	—	×	×	×	×	×	×
1954—1955	—	×	×	×	×	×	×	×
1958—1959	×	×	×	—	×	×	×	×
1962—1963	×	×	×	×	×	×	×	×
1965—1966	×	×	×	—	×	×	—	×
Sum	5	6	7	4	7	7	5	7

It will be seen that increasing August temperatures give the best (complete) agreement and July comes next. Of the sums for two or more months those which include July give similarly complete agreement. In fig. 1 it is thus chosen to delineate the average temperature for August and for the sum of the two "best" single months July + August.

Table 2. Declining precipitation before outbreaks start.

Year	Months										
	M	J	J	A	S	O	A+S	S+O	J+A+S	J+J+A+S	J+A+S+O
1935—1936	—	×	—	×	×	×	×	×	×	×	×
1940—1941	×	—	×	—	×	—	—	×	×	—	—
1946—1947	×	×	—	×	×	×	×	×	×	×	×
1954—1955	—	×	×	×	×	×	×	×	×	×	×
1958—1959	×	×	×	×	×	×	×	×	×	×	×
1962—1963	×	—	×	—	×	—	—	—	—	—	—
1965—1966	—	—	×	—	×	—	—	—	×	×	—
Sum	4	4	5	4	7	4	4	5	6	5	4

3 b. Precipitation.

Table 2 gives a survey of the change in rainfall for Denmark in a similar manner as for the temperatures in table 1.

For the single months full agreement is found for September only with July second. Sums including September give the best agreement for the period July-September with only one exception (1963). Rainfall in this period and in September is seen on fig. 1.

3 c. Occurrence of the same climatic factors before years with no or only local outbreaks.

It has been found above that a rise in temperature averages for August and July plus August (3 a) and a simoultaneous decline in rainfall in September and July plus August and September (3 b) in all or nearly all years has preceded the beginning of a Rhyacionia outbreak.

Table 3. Summer and autumn climate before non-initial yers.

Year	Increase in Temperature		Decline in Precipitation	
	August	July-Aug.	Sept.	July-Sept.
1934—1935	—	—	—	×
1936—1937	×	×	—	×
1937—1938	—	—	×	—
1938—1939	×	—	—	—
1939—1940	—	—	—	×
1941—1942	×	—	—	—
1942—1943	—	×	×	×
1943—1944	×	×	—	×
1944—1945	—	—	×	—
1945—1946	—	—	—	—
1947—1948	—	—	—	—
1948—1949	—	—	×	×
1949—1950	×	×	—	—
1950—1951	—	—	×	×
1951—1952	—	—	—	—
1952—1953	—	×	×	—
1953—1954	—	—	—	—
1955—1956	—	—	×	—
1956—1957	×	×	—	—
1957—1958	—	—	×	—
1959—1960	—	—	—	—
1960—1961	—	—	—	—
1961—1962	—	—	×	×
1963—1964	—	—	—	×
1964—1965	—	—	—	—
1966—1967	×	×	—	×

It remains to be investigated to which extent other years show the same climatic combinations. This is shown in table 3.

While 6 of the 7 initial outbreak years had all of the four important factors present, and 1 had three, none of the other 26 years have all four factors, 4 have three and 22 less. There is therefore a very high degree of difference between the two groups of years, the proportions with three or more factors in common differ significantly (99.9 % level, χ^2, Yates corr.).

The temperature factors taken alone differ (proportion of 2 agreements to lower numbers) significantly on the 98 % level and precipitation alone similarly on the 99 % level.

4. CLIMATE IN WINTER PRECEDING AN INCREASE YEAR

It is known that very low winter temperatures may cause mortality in hibernating Rhyacionia larvae. The lethal temperatures involved are at a level of about — 15° - — 30°C, but acclimatization takes place very quickly (*Green* 1962).

In the Atlantic climate of Denmark such low temperatures are extremely rare. The 40-year average for the coldest month (February) is — 0.1°C. The actual coldest month in the period considered here was — 7.1°C (February 1947). In view of the Danish climate therefore, the periods of cold winter weather and their duration can be left out as determinators of Rhyacionia outbreaks.

5. CLIMATE IN EARLY SPRING PRECEDING AN INCREASE YEAR

Table 4 gives some temperature and precipitation data for the early part of the increase year itself.

Table 4. Weather in the early part of the seven initial outbreak years.

	Temperature		Precipitation	
	Above average	Increasing	Below average	Declining
January	4	4	3	3
February	3	4	3	3
March	3	3	5	5
April	6	5	5	5
May	6	4	5	3
June	3	1	4	1
March + April	4	5	5	5
April + May	5	6	5	4
March + April + May	5	5	5	4

High temperatures in April and May and increasing temperature for their sum are found in 6 of 7 initial outbreak years. All three factors are present in four years, while three years (1942, 1956, 1960) have only two. Of the other 26 (non-initial) years, 5 (1943, 1945, 1946, 1952, 1959) similarly have all 3 factors, 8 have 2, 10 have 1 and 3 have zero. The proportions of years with and without all 3 factors are significantly different on the 95 % level (χ^2, Yates corr.).

Precipitation was below average for March, April and May in 5 of the 7 initial years. 5 years have an declining March plus April precipitation.

All four precipitation factors are found in 4 years, the three others have 3 (1942), 1 (1937) and 0 (1967).

Of the 26 non-initial years 4 (1941, 1943, 1946, 1952) have four factors, 7 have 3, 9 have 2, 4 have 1 and 2 have zero. The proportions of years with all 4 factors present are not different in initial and non-initial years on the 95 % significance level. When all the spring weather factors are looked upon the 7 initial years have two with all 7 factors, two with 6 and one with 5, 4 and 3. The other years have 3 with 7, zero with 6 and 23 with less. The proportion of years with 6 and more factors is significantly higher in the initial years on the 95 % level (χ^2) but somewhat lower than temperature alone.

6. COMPARISON WITH SOME OTHER DANISH OUTBREAKS

Table 5 summarizes the weather factors which have been found most important and most significant for initial outbreak years during the period 1935—1968.

A comparison with previous R. buoliana outbreaks known (*Zethner* and *Bejer-Petersen* 1971) from more than one locality in Denmark is tempting. This can be undertaken only for the period for which meteorological data have been regularly recorded. One complication is, however,

Table 5. Occurrence of the most frequent weather factors before some Danish outbreak years.

Weather factor	Period	Years of 7 initial years, period 1935-68	Before other outbreaks 1869-73	1913-14	1921	1970
Rising temperature,	August, year before	7	1868	1911	1920	1969
„ „ ,	July + „ „ „	7	1868	1911	1920	1969
Declining precipitation,	Sept. „ „	7	1868	1911	(1919)	1969
„ „ ,	July-Sept. „ „	6	1868	1911	(1919)	1969
Temp. above average,	May same year	6	—	(1913)	1921	—
„ increasing,	April-May „ „	6	—	(1913)	1921	1970
Precipitation below average,	March-May same year	5	1869	(1913)	1921	—

that the years known as outbreak years may very well not be the initial year but perhaps a later maximum. It will be seen from fig. 1 that such a situation often occurs. For table 5 the data for both one and two years before outbreaks have, therefore, been looked up.

Besides the old outbreaks also the year 1970 is noted, as the number of inquiries — though not yet completed — rose from 1969 by at least 8.

The four main characteristics (above) give full agreement for three of the four years. The more secondary spring climate characteristics show less agreement. The outbreak 1920—21 fits 5 of the seven characteristics but not all four main ones. Two characteristics, therefore, fit all 11 years considered, one (Sept. precipitation) fits 10 and July-Sept. precipitation 9. The three spring characteristics all fit for a lower number of years.

7. DISCUSSION

The search for a weather factor to explain major outbreaks of Rhyacionia buoliana is far from new. *Voûte* and *Walenkamp* (1946) found a good relationship between R. buoliana outbreaks and low July rainfall before. Also *Neugebauer* (1952) finds for Germany some relationship between low rainfall and high temperatures for the period May-July of the previous year, but he does not seem to have considered later months. The geographical distribution of R. buoliana (*Schröder* 1966, *Bakke* 1969) clearly reflects for the Atlantic NW-Europe, that not winter cold but rather lack of high summer temperatures is the probable limitation as pointed out by *Harris* (1960). High summer temperatures may therefore improve conditions for R. buoliana and Harris explains this as a quicker development of buoliana in relation to the differentiation of resin canals in the buds. These are less dependent on temperature and more on day-length.

Harris rejects the low precipitation found by Voûte and Walenkamp, and now also in these Danish data, as a factor limiting resin flow and thereby increasing survival of the small larvae. However, he seemingly overlooks the fact that the first borings are in needles and not in buds, and also the sparse experimental evidence given by Voûte and Walenkamp with more or less watered shoots. In Danish experiments (*Esbjerg* 1971) this experimental basis has, however, become strengthened. As the boring in needles takes place in July-August the coincidence with low rainfall is good.

Also September rainfall might be an important biological factor. The borings into the first buds take place in August-September and the investigations by Harris show a major loss of larvae taking place in September. In this month, according to his investigations, the resin canals develop strongly. Small buds have small resin canals, and as high rainfall in the vegetative period results in larger buds, this is one possible relation between resin flow and rainfall. But, more important, low rainfall in September might directly reduce resin flow from the buds, because resin pressure has been found to decrease in several Pine species during periods of drought (*Vité* and *Rudinsky* 1960).

All in all, there appears to be a very good biological background for an effect of summer and early autumn weather as that described in this paper.

Of course, the same level of climatic factors cannot be expected to operate as an outbreak initiation througout the whole geographical distribution of R. buoliana. In regions with continental climate, low winter temperaures may further cause severe mortality (*Green* 1962, *Koehler* 1967) and eliminate some outbreaks. A favourable early spring, high temperatures in March and April, and low rainfall in spring were in East Germany (*Ebert* and *Häussler* 1969) found to be more important than the summer weather. In the central part of the distribution, other factors than extreme climate e.g. parasites, and soil conditions may play a greater part (*Nef* 1969). Nevertheless many major European R. buoliana outbreaks occur simultaneously (*Schröder* 1966).

The somewhat lower and more uncertain influence of early spring weather found in this investigation might principally operate in a similar way as described above, namely by displacing the activity of the larvae relative to growth of the host tree and through influence on the resin pressure.

The drought influence indicated may also be a partial explanation of the high susceptibility of lodgepole pine (Pinus contorta) found in Denmark as compared to Scotch pine (P. silvestris) and Austrian pine (P. nigra). In Denmark the former species is undoubtedly undersupplied with rainfall much more often than in its home region, NW-America. This is especially true of the coastal type (contorta) which sometimes, also in Danish provenance plots, tends towards a greater degree of R. buoliana infestation than the inland (murrayana) type (*Esbjerg* and *Feilberg* 1971).

This does not necessarily indicate that the number of eggs laid on the pine species and provenances are identical. Different authors have arrived at different results in this respects (*Harris* 1960, *Haynes* and *Butcher* 1962). The absolute amount of resin exuded by larval borings in the buds of the pine species may have some influence, but, according to Harris, the larvae more easily remove lodgepole pine resin than that of the other two pines.

The good correlation between R. buoliana initial outbreaks and climate is probably found in this work, because the initial years, and not the outbreak peaks, have been used. As will be seen from fig. 1, outbreaks may maintain a high level or even rise in following years with less favourable (other) conditions (e.g. 1961). A possible explanation might be that the R. buoliana population could increase considerably compared with that of parasites in the initial year and thus result in a low (delayed) percentage of parasitism in the following year. This, however, still needs investigation.

8. SUMMARY

Years with a marked increase of Rhyacionia buoliana damage in Denmark are found to have been preceded by special weather conditions. There is a high degree of correlation to rising temperature averages for August and the period June-August the year before. Simultaneously, September precipitation and to a lesser degree July-September precipitation was declining. During the period 1935—68 there were no years with this climate constellation without a rise in R. buoliana damage.

A weaker relationship has been found to high May temperature and increasing April-May temperature in the year, while low or declining early spring precipitation is rather common but does not reach significance level.

In the Atlantic Danish climate fatal winter temperatures are almost without importance.

Especially for the late summer period quoted literature gives a good biological background for the importance of the climatic factors found.

The findings are of value for outbreak prognoses.

9. DANSK SAMMENFATNING

Mange år er kraftige angreb af fyrrevikleren (Rhyacionia buoliana Schiff.) samtidige for hele Danmark og må derfor som eneste mulige koordineringsfaktor være fremkaldt af klimaforhold. I dette arbejde er der foretaget undersøgelse af, hvilke klimafaktorer der var fælles i året forud for stigninger med mindst 3 i antallet af forespørgsler vedrørende fyrrevikleren. Det viser sig herved (tabel 1), at stigning (i forhold til endnu et år forud) i gennemsnitstemperaturen for august og for perioden juni-august og især juli-august er fælles for alle 7 år, og samtidig er september nedbør dalende, i mindre grad også juli-september nedbøren (fig. 1). Ingen andre år opviser samme klimakonstellation i perioden 1935—68 (tabel 3).

Lave vintertemperaturer (niveau ÷ 15° til ÷ 30°) kan virke dræbende på overvintrende larver, men er i Danmark så sjældne, at de ikke kan spille synderlig rolle.

En lidt svagere sammenhæng end nævnt for sommer-eftersommerperioden findes med høje/stigende temperaturer i maj og april-maj, og måske med lav/dalende nedbør marts-maj (tabel 4 og 5) i selve udbrudsåret. Nogle af de ældre danske angrebsår (på flere lokaliteter) og det ikke afsluttede 1970 viser ligeledes (tabel 5) god overensstemmelse med især sommer-eftersommerperioden.

Diskussion.

Alt tyder derfor på, at de pågældende klimadata kan benyttes i prognoseøjemed, men det må her fremhæves, at det jævnligt drejer sig om masseformeringens indledning og ikke dens top. Denne kan falde senere og under andre vejrforhold, muligvis fordi parasiteringen bliver lav i gennembrudsåret og først senere indhenter R. buoliana.

Sammenhænge som de fundne behøver naturligvis ikke at være egentlig kausale. Der foreligger dog litteratur, delvis som led i disse undersøgelser, der støtter, at de faktisk er det. Det synes således, at tørke kan påvirke de små larvers indboringssucces såvel i nålene (juli-august) som i knopperne (august-september) ved nedsætning af harpikstrykket. Høj temperatur kan bl. a. fremskynde larvernes udvikling i forhold til tidspunktet for harpikskanalernes færdigdannelse i knopperne, som mere er daglængdebestemt.

Vejrfaktorernes betydning er muligvis en delvis forklaring på, at contortafyr er mere angrebet i Danmark end f. eks. skovfyr og Østrigsk fyr, og på den ofte høje modtagelighed af kysttype (contorta) fremfor indlandstype (murrayana), gennem tørkefølsomheden. Derimod synes den absolutte harpiksmængde ikke nødvendigvis at være afgørende, idet fyrreviklerlarverne er fundet lettere at kunne fjerne contortaharpiks, som trængte ind i deres gange, end de kan fjerne f. eks. silvestris harpiks.

De fundne sammenhænge mellem R. buoliana opformering og klimafaktorer vil kunne udnyttes i prognoseøjemed, idet en direkte prøvetagning kan påbegyndes efter klimaets „varsling“.

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