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Yield variations of some common wild berries in Finland in 1956–1996

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Estimates of some of the most common wild berry abundances and changes in their yields compared with the previous year were made in 1956–1996 as a part of the annual autumn game inquiries. The berries included in the inquiry were bilberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.), cloudberry (*Rubus chamaemorus* L.), both cranberry species (*Vaccinium oxycoccos* L. and *V. microcarpum* (Rupr.) Schmalh.), crowberry (*Empetrum nigrum* L.), rowan (*Sorbus aucuparius* L.), and wild strawberry (*Fragaria vesca* L.). On average, 500 observers throughout the country participated annually in the inquiry. Despite the subjective nature of the berry yield estimates, the results are valid for assessing annual changes in the yields of the most common wild berries as well as in long-term trends. The results are coincident with berry researchers' observations that the yields of cloudberry and wild strawberry have declined during the last decades. The significant ($p < 0.01$) positive correlations between the yields of the different berry species indicate that meteorological factors influence yields of most berry species in a similar way. Nevertheless, I was not successful in explaining the differences in abundances of bilberry and cloudberry with climate variables. Contrary to expectations, the previous year's yield did not correlate negatively with the next yield, except for rowan.

Key words: berry yield, bilberry, cloudberry, cranberry, crowberry, cowberry, rowan, wild strawberry, yield variation

INTRODUCTION

Thirty-seven edible wild berry species grow in Finland (Raatikainen *et al.* 1987). In a good year, they can together produce a yield of 1 000 million kilograms (Moisio 1996). Only a small proportion of the yearly yield of these berries is picked by men. Nevertheless, the monetary value of the harvest in Finland can be up to 445 million marks (Moisio 1996). In addition to their commercial value, berries are important food resources for many animals ranging from large mammals to small birds.

According to numerous reports, wild berry yields display a marked short-term variability (Veijalainen 1979, Kortesharju 1988, Tokarev 1990, Yudina 1993). There are many causes for that. The most important ones seem to be frost (Jaakkola & Oikarinen 1972, Solantie 1983, Kortesharju 1988, Yudina 1993), and factors affecting pollination success (Mäkinen 1972, Hippa & Koponen 1975, 1976, Nousiainen *et al*. 1978, Kortesharju 1988). Additionally, amount of precipitation (Solantie 1983, Raatikainen 1984) and harshness of winter (Solantie 1980a, Kortesharju 1981, Raatikainen & Vänninen 1988) can have a marked effect on berry yields. It has also been suggested that one year's good berry yield results in a poor berry yield the following year (Nousiainen 1983, Raatikainen 1985, Raatikainen *et al.* 1990). Nevertheless, this hyphothesis has never been tested with a longer time series of berry yield measurements.

Long-term changes have also been proposed for the yields due to changes in land use. Negative trends have been observed particularly in cloudberry (*Rubus chamaemorus* L.) (Raatikainen 1977, Salo 1982, Solantie 1983) and wild strawberry (*Fragaria vesca* L.) (Raatikainen 1984). However, the nature of these long-term changes is not well known.

In relation to the overall significance of berries, the spatial and temporal range of the berry yield studies is narrow. Better understanding of the factors affecting the yields could help in their prediction. Furthermore, knowledge about changes in the yields could help to explain variation in the populations of some wild game species (Kauhala 1995).

Finnish studies of natural berry yields have been mostly comprised of one-year research projects concentrating on few berry species (Mäkinen 1972, Huttunen 1978, Raatikainen 1978, Jääskeläinen 1981, Jaakkola 1983, Raatikainen & Raatikainen 1983). The three longest time series of berry yield measurements in Finland were at the maximum 3–6 successive years (Jäppinen *et al.* 1986, Kortesharju 1988 and Raatikainen *et al.* 1990). In Karelia, in the former Soviet Union, berry yields in certain areas were studied continuously over longer periods (10–19 years, depending on species) (Kuchko 1988, Tokarev 1993, Yudina 1993). However, all the above-mentioned berry yield studies were fairly small, local investigations typically consisting of only a few study plots. This is mainly due to the labouriousness of the work involved in picking and measuring berry yields over large areas.

In this study, annual yield variations of seven common wild berry species were examined throughout Finland over a period of four decades. The species included in the study were cowberry (*Vaccinium vitis-idaea* L.), bilberry (*Vaccinium myrtillus* L.), cloudberry (*Rubus chamaemorus*), cranberry (*Vaccinium oxycoccos* L.), crowberry (*Empetrum nigrum* L.), wild strawberry (*Fragaria vesca*) and rowan (*Sorbus aucuparius* L.). The data were collected in the form of an annual inquiry. On the basis of the data, it was not possible to assess yield in kilograms. Nevertheless, the data offered the possibility of studying short-term variations as well as long-term trends.

In this paper, my aims are: (1) to examine yield variations in different berry species and highlight the years of good and poor yields in the last four decades; (2) to study the influence of previous years' berry yields on the following years' yields; (3) to examine the importance of different meteorological factors on berry yields (only in bilberry and cloudberry); (4) to reveal possible long-term trends in berry yields.

MATERIALS AND METHODS

The berry yield data and the indices derived from it

With the exception of wild strawberry, all the berry species included in the study are encountered throughout the country. Unfortunately, the available data did not allow me to distinguish small cranberry (*Vaccinium microcarpum* L. (Rupr.) Schmalh.) and cranberry. The two subspecies of crowberry (*Empetrum nigrum* ssp. *nigrum* and *E. nigrum* ssp. *hermaphroditum* (Hagerup) Böcher) are also treated together.

Berry yield data were collected as a part of the autumn game inquiries of the Finnish Game and Fisheries Research Institute (FGFRI). Approximately 500 field observers, most of them game wardens and hunters, replied to the inquiries each autumn. In practice, the same persons observed the same areas year after year. In most cases, the observation area was the observer's home municipality or a part thereof (Fig. 1).

The layout of the inquiry form and the coding of the abundance classes have changed over the years, but the form of the questions has remained more or less consistent. The observer was asked to estimate the abundance of each game/ berry species according to the following scale: (0) the species does not occur in the area; the relative abundance of the game species/berry yield is (1) below average; (2) average; (3) above average. The change in the abundance compared with the previous year was always evaluated and reported in the same manner: population/berry yield was (+) bigger, (=) equal, (–) smaller than in the previous year.

The berry yield observations form a continuous series covering the years 1956–1996, except for rowan, which was included in the study in 1959. Altogether, about 20 000 filled forms were received. I entered the data into a computer applying the coding (0–3) used since 1964 in the forms. For the symbols marking the change in abundance (*see* above), I assigned the following numerical values: – is –1, = is 0 and + is 1.

As a measure of abundance, FGFRI has used an abundance index (AI), which is simply the average of abundance approximations (0–3) in a given area. I applied the same method in this study. The zero values were included in the index because most observers had understood that zero means crop failure. This could be seen from the high yearly variations in the number of zero values.

In most cases, the analysis of AIs by province proved to be the most appropriate method. In the same manner as for AIs, I calculated the means for the numerical variables (–1, 0, 1) derived from the evaluations of change in berry yields compared to the previous year. In order to demonstrate the trends, I simply counted the cumulative sums of the means of abundance change. This resulted in a new index called the cumulative change in abundance (CAI). To study the long-term changes in berry yields by region, I calculated CAI for different species in four parts of Finland (Fig. 1).

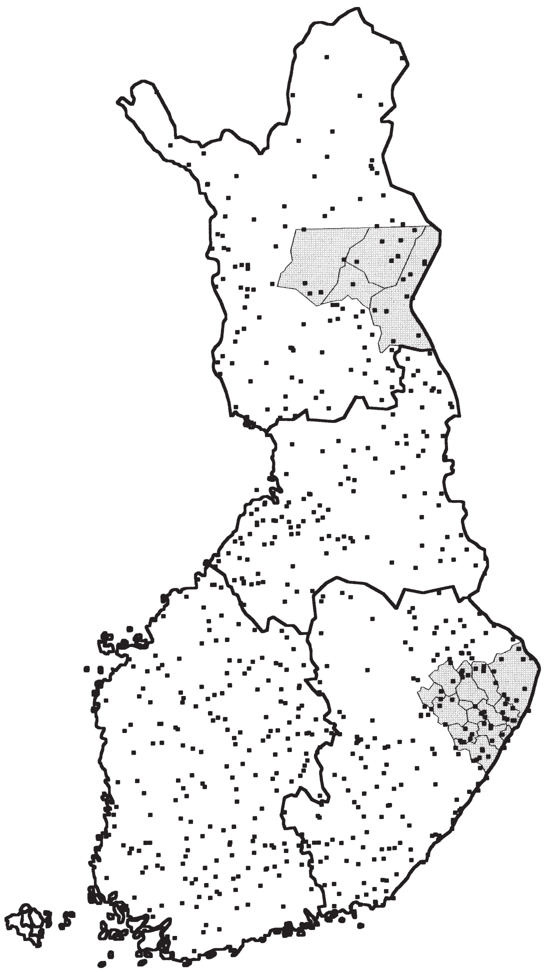

Fig. 1. The approximate locations of observers in 1983. Map also displays the four areas of Finland used for studying the long-term changes in berry yields: the province of Lapland (the northernmost); the province of Oulu; the area of western Finland (the provinces of Turku-Pori, Vaasa, Middle Finland, Uusimaa and Häme); and the area of eastern Finland (the provinces of Mikkeli, Kuopio, North Karelia and Kymi). Grey areas are the areas used for studying the effects of meteorological variables on berry yields. The northern one is Sodankylä-Salla area and the southern one is Joensuu-Ilomantsi area.

Evaluation of the validity of the berry yield data and the abundance indices

The expression "average yield/population" in the inquiry forms was not precisely defined. Due to the subjective nature of the inquiry, it was advisable to be cautious with the conclusions drawn from the data. Strictly speaking, the abundance estimates of the berry yields only reflect each observer's opinions and remembrances of the present and past years' berry yields.

Kauhala (1995) used game inquiries (following the same format as this study) for investigating the population ecology of the raccoon dog (*Nyctereutes procyonoides*). She noticed a very high correlation ($r = 0.93$) between the annual AI for raccoon dog and the trap indices of the species. Furthermore, Siivonen (1951) examined the validity of the game inquiry data for several game species. He concluded that the abundance indices provide a good picture of the relative abundance of the species.

In order to study the validity of the berry yield estimates, I compared the quantities of commercially picked cloudberries in the province of Lapland in 1977–1996 (Malin 1996, 1997) to the corresponding years' AI values (Fig. 2). The value of Spearman's correlation coefficient (r_s) was 0.88, and the significance (p) with three decimals was 0.000. The correlation coefficient can be considered excellent since neither of the correlated factors is an absolute measure of the berry yield. The AI and the statistics of the amount of berries purchased from pickers contain their own specific error sources as measures of a berry yield. For instance,

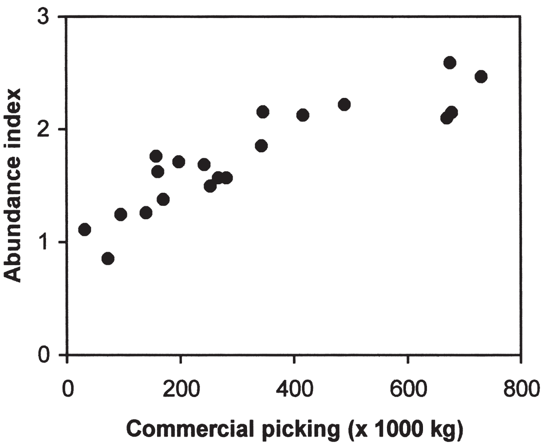

Fig. 2. The commercial picking of cloudberry (*Rubus chamaemorus* L.) and its abundance index in the province of Lapland in 1977–1996. $r_s = 0.88$.

commercial berry picking is strongly affected by the offered price.

The corresponding correlations between commercial picking and AI for bilberry and cowberry in various parts of Finland were not as high (r_s = 0.41–0.86) as those for cloudberry in Lapland. The reason for this might be that for the first two berries, commercial picking volumes did not correlate well with the actual yields. This is due to e.g., price factors or the termination of berry purchases during the picking season (Malin 1996). As I have no evident reason to believe that the yields of cowberry and bilberry as well as other berry yields were estimated less carefully than those of cloudberry, I conclude that the abundance estimates and the AIs derived from them are sufficiently accurate for the purposes of this study.

Meteorological factors influencing berry yields

In order to study the effect of meteorological factors on bilberry and cloudberry yields, I acquired meteorological observation data for the years 1961–1990 from four meteorological stations (Observatorium of Sodankylä, Salla, Ilomantsi and the airfield of Joensuu). The data were supplied by the Finnish Weather Service. The high price of this data restricted the time period and amount of ordered data. The data included: (1) the temperature sum in day degrees (dd) i.e., the sum of the parts of the mean temperatures of 24-hour periods exceeding 5°C; (2) the frost sum (in day degrees) i.e., the sum of absolute values of nightly minimum temperatures (< 0°C) measured at ground level; (3) the precipitation sum in millimetres; (4) the number of days of heavy rain (≥ 10 mm); (5) the mean of temperature measurements at time 15:00; (6) the number of days with a maximum temperature of 21°C or over; (7) monthly minimum temperatures and the depth of snow at the time of minimum temperature observation during early winter (September–December). The data were ordered for Julian days 115–284 in five-day sequences (e.g., precipitation for days 115–119, 120–124, … , 280–284).

To compare the impact of meteorological factors on the berry yields during the different phenological phases of the plant, one has to examine those factors together with the simultaneous phenological phenomena which occur in that particular year and locality. With the help of meteorological observations and phenological data, collected by The Finnish Society of Science and Letters and supplied by the Finnish Environmental Centre, I determined the average starting days of flowering for cloudberry and bilberry in the study areas as well as the cumulative temperature sums (daily mean temperature > 5°C) at that time (Table 1). Due to the different periods of phenological observations and berry yield evaluations, I had to assume that in 1961–1990 flowering started (on that day of the year) when the same cumulative temperature sum was reached as during the first part of the century, from which period the phenological data originated. From the meteorological data augmented by literature and the phenological data, I formulated 26 climate variables explaining variations in berry yields (Table 2).

I formulated definitions of phenological phases for different parts of Finland that were based on the phenological data, literature and my own observations. Accordingly, I defined the flowering time of bilberry as a 15-day period commencing during the five-day period in which the temperature sum required for flowering is attained. The required temperature sums were 98 and 108 day degrees in Joensuu and Sodankylä, respectively (Table 1). A ripening period for bilberry was the 50-day period commencing immediately after flowering. I defined a ripe berry period as the 15-day period which immediately follows the ripening period. I also examined the impact of most meteorological factors

Table 1. The mean Julian flowering days for bilberry (*Vaccinium myrtillus* L.) and cloudberry (*Rubus chamaemorus* L.) and the temperature sums (dd) attained on the mean flowering day in different areas.

	Bilberry	Cloudberry
Mean Julian flowering day in Sodankylä-Salla area	162	162
Mean Julian flowering day in Ilomantsi-Joensuu area	147	156
Temperature sum acquired at beginning of flowering in Sodankylä-Salla area	108	108
Temperature sum acquired at beginning of flowering in Ilomantsi-Joensuu area	98	161

during the 10-day period prior to flowering.

I defined the flowering time of cloudberry as the 20-day period which begins in the Ilomantsi-Joensuu area, when 161 day degrees were completed. In the Sodankylä-Salla area, flowering requires 108 day degrees. According to phenological data, the maturing of cloudberry takes longer in the south than in the north. I determined the ripening time of cloudberry as 45 days in Sodankylä and as 50 days in Ilomantsi. According to my observations, cloudberries overripen sooner than bilberries. Therefore, I defined the ripe berry period for cloudberry as 10 days.

My northern study area, situated in the northern boreal vegetation zone (Ahti *et al*. 1968) and containing only a few lakes, comprised the municipalities of Salla, Savukoski, Sodankylä and Pelkosenniemi (Fig. 1). I excluded observations made in the northern parts of Sodankylä and Savukoski since the environmental conditions were under the influence of the large artificial lakes in these areas. The eastern study area included the province of North Karelia, except for the southernmost and the four northernmost municipalities. It is situated between the middle boreal and southern boreal vegetation zones (Ahti *et al*. 1968). Although it contains some large lakes, Solantie (1980b) considered it as belonging to the southern Finnish region with few lakes.

I needed to adjust the sizes of the study areas so that they were, on one hand, sufficiently large to be covered by several observers and, on the other hand, small enough that the meteorological factors were roughly similar everywhere within these areas. The correlations were calculated between AIs and the means of various meteorological variables within the area.

RESULTS AND DISCUSSION

Abundance indices and their variations

Eyeball examination does not reveal clear trends in the AI graphs (Figs. 3–10). However, short-term variations are clear and sharp in cowberry,

Table 2. Meteorological variables and the relevant literature as footnotes. Time periods are defined in the text.

Meteorological variable
The temperature sum for period before flowering [1) 2)]
The temperature sum for flowering period [1) 2)]
The temperature sum for period of unripe berries [1) 2)]
The temperature sum for period of ripe berries [1) 2)]
The mean of afternoon temperatures for period before flowering [3) 4)]
The mean of afternoon temperatures for flowering period [3) 4)]
The mean of afternoon temperatures for period of unripe berries [3) 4)]
The mean of afternoon temperatures for period of ripe berries [3) 4)]
The frost sum for period before flowering [1) 2) 3) 5) 6) 7)]
The frost sum for flowering period [1) 2) 3) 5) 6) 7)]
The frost sum for period of unripe berries [1) 2) 3) 5) 6) 7)]
The frost sum for period of ripe berries [1) 2) 3) 5) 6) 7)]
The number of days with heavy rain (≥ 10 mm) for period before flowering [8) 9) 10) 11)]
The number of days with heavy rain (≥ 10 mm) for flowering period [8) 9) 10) 11)]
The number of days with heavy rain (≥ 10 mm) for period of unripe berries [8) 9) 10) 11)]
The number of days with heavy rain (≥ 10 mm) for period of ripe berries [8) 9) 10) 11)]
The precipitation sum for period before flowering [6) 12)]
The precipitation sum for flowering period [6) 12)]
The precipitation sum for period of unripe berries [6) 12)]
The precipitation sum for period of ripe berries [6) 12)]
The number of days with maximum temperature of 21°C or over in June of the previous year [13) 14) 15) 16)]
The number of days with maximum temperature of 21°C or over in July of the previous year [13) 14) 15) 16)]
The number of days with maximum temperature of 21°C or over in June-July of the previous year [13) 14) 15) 16)]
The number of days with maximum temperature of 21°C or over in August of the previous year [13) 14) 15) 16)]
The number of days with maximum temperature of 21°C or over in June-July-August of the previous year [13) 14) 15) 16)]
The minimum temperature in September–December of the previous year in such conditions that the snow cover was less than 25 cm in eastern Finland and less than 15 cm in northern Finland [11) 15) 17) 18)]

[1)] Kortesharju 1993, [2)] Yudina 1993, [3)] Veijalainen 1979, [4)] Hippa *et al*. 1981, [5)] Jaakkola and Oikarinen 1972, [6)] Solantie 1983, [7)] Kortesharju 1988, [8)] Mäkinen and Oikarinen 1974, [9)] Nousiainen *et al*. 1978, [10)] Kuchko 1988, [11)] Raatikainen 1993, [12)] Raatikainen 1984, [13)] Hippa and Koponen 1975, [14)] Hippa and Koponen 1976, [15)] Kortesharju 1981, [16)] Junttila *et al*. 1983, [17)] Solantie 1980a, [18)] Raatikainen and Vänninen 1988.

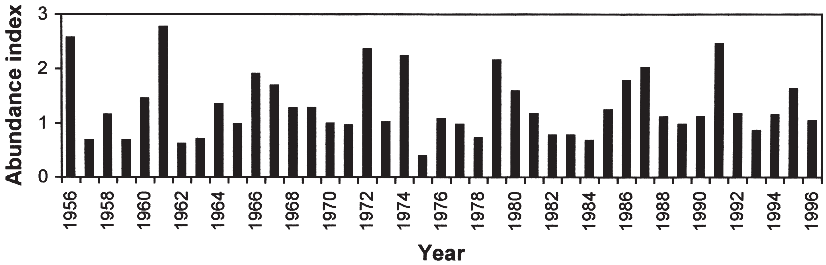

Fig. 3. The abundance index of cloudberry (*Rubus chamaemorus* L.) in the province of North Karelia in 1956–1996.

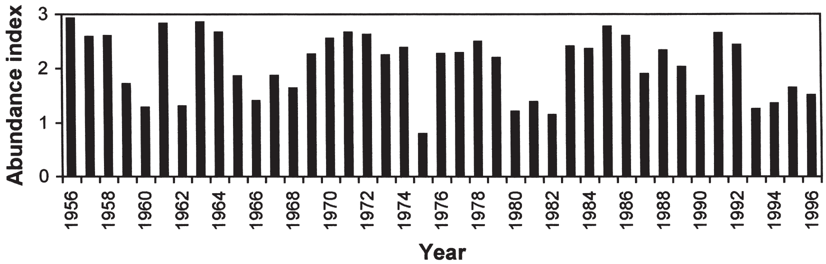

Fig. 4. The abundance index of bilberry (*Vaccinium myrtillus* L.) in the province of North Karelia in 1956–1996.

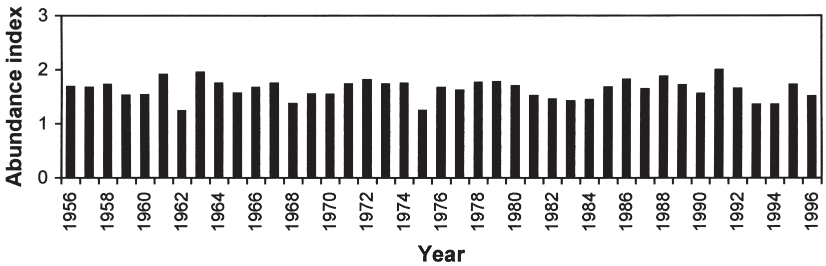

Fig. 5. The abundance index of crowberry (*Empetrum nigrum* L.) in the province of North Karelia in 1956–1996.

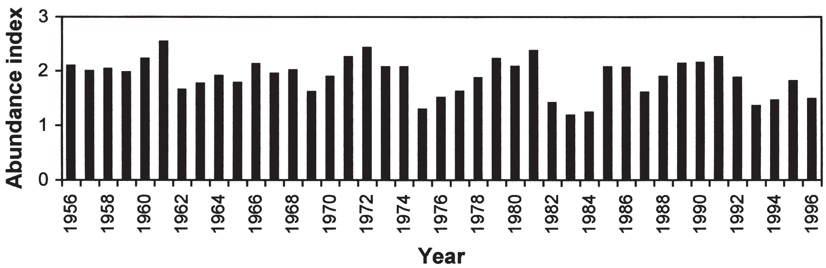

Fig. 6. The abundance index of cranberry (*Vaccinium oxycoccos* L.) in the province of North Karelia in 1956–1996.

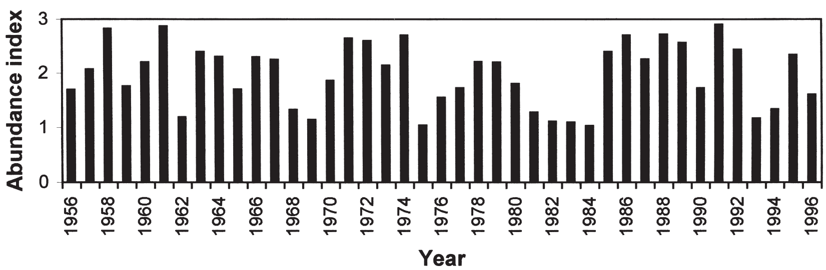

Fig. 7. The abundance index of cowberry (*Vaccinium vitis-idaea* L.) in the province of North Karelia in 1956–1996.

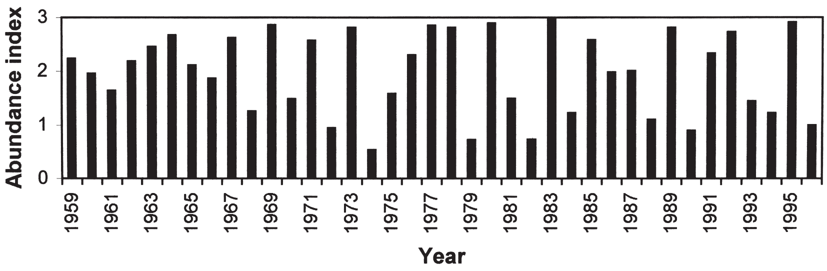

Fig. 8. The abundance index of rowan (*Sorbus aucuparia* L.) in the province of North Karelia in 1959–1996.

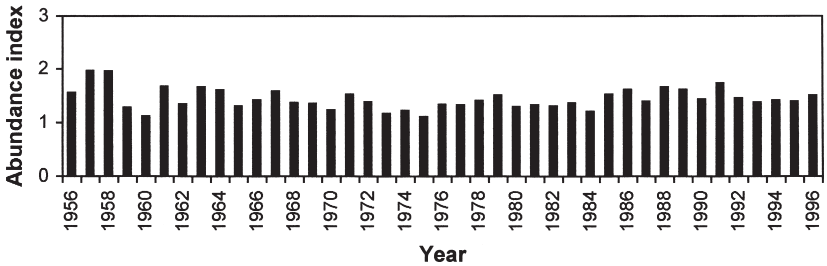

Fig. 9. The abundance index of wild strawberry (*Fragaria vesca* L.) in the province of North Karelia in 1956–1996.

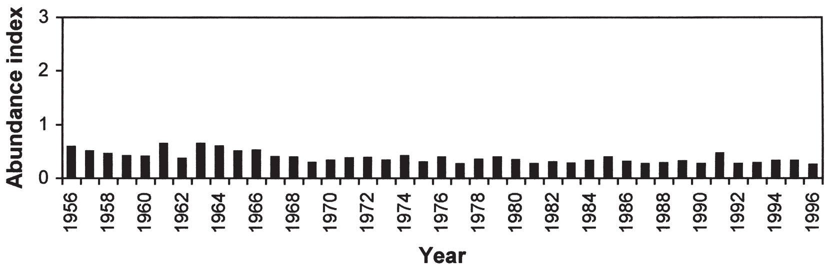

Fig. 10. The abundance index of wild strawberry (*Fragaria vesca* L.) in the province of Oulu in 1956–1996.

bilberry and cloudberry, and especially rowan. In case of the latter species, top yields and, correspondingly, crop failures follow in sequences of 2–4 years. The variations in crowberry's AIs around the country were relatively small.

As expected, yields of rowan, bilberry, cloudberry and cowberry fluctuate greatly (Raatikainen 1984, Kortesharju 1988, Raatikainen *et al.* 1990). The magnitude and variation of crowberry yields are not well known, but it has generally been considered a species with more or less stable yields from year to year. There is also some evidence to the contrary (Sepponen & Viitala 1983, Raatikainen 1984). However, according to this study, the crowberry yields are steady as compared with those of most other berry species.

In principle, the mean of AIs for the study period should have a value near 2 in each study area. This is the case concerning bilberry, cowberry and rowan. Nevertheless, it seems that the observers have not proportioned their observations with the local mean yield but with their expectations for the mean of the whole country. This can be seen, e.g., in the AIs of cloudberry. The average AI of cloudberry was 1.6 for Lapland, but only 1.0–1.1 in southernmost Finland. According to Raatikainen (1984) and Malin (1995), the greatest cloudberry yields ripen in Lapland. Furthermore, the AIs of crowberry diminish clearly from north (2.0) to south (1.2–1.6). Similarly, the most abundant yields of crowberry are produced by its northern subspecies *Empetrum nigrum* subsp. *hermaphroditum* (Jaakkola 1983, Raatikainen 1984). In addition, the AIs of wild strawberry were very small in the northern provinces (Lapland and Oulu), but relatively high in their southern counterparts (Figs. 9 and 10). However, this is partly due to the southern distribution of wild strawberry.

For demonstrating the occurrence of abundant and scanty berry yields, I used the same definition for different berries. Very abundant berry yields were defined as those with AIs in the highest quintile of the variation range of the study period (Table 3). Placement in the lowest quintile indicated a crop failure (Table 4). For most of the berries, the years with best yields were 1957, 1958, 1961 and 1991. In those years, four of the seven assessed species produced an excellent yield. In terms of berry picking, the gloomiest summer was 1975. That year, the yields of all the examined berry species failed, with the exception of that of rowan. Cloudberry has reached the top quintile of its range every tenth year. On average, bilberry has yielded well once in four years.

Due to methodological differences , not all the years with good or poor berry yields reported by other researchers are included in Tables 3 and 4.

Correlations between the yields of different berry species

Examination of the correlation matrices by provinces reveal that the abundance indices of most berry species correlated significantly ($p < 0,01$) with each other. Cowberry and crowberry had the best correlations ($r_s = 0.44–0.86$). Throughout the country, significant correlation cofficients were also attained by bilberry and wild strawberry ($r_s = 0.39–0.84$), bilberry and cowberry ($r_s = 0.39–0.75$) as well as bilberry and crowberry ($r_s = 0.37–0.74$). The yields of rowan did not correlate with other species.

An apparent conclusion regarding the good correlations between yields of the different berry species is that some common factor is influencing the yields. Besides meteorological factors, there are no others with a similar impact on all the species that can be conceived of. The distinct yield rhythm of rowan indicates that it is not dependent on the annual variation of the same meteorological factors as those affecting the other berries. The lack of snow cover on rowan buds in winter is a clear difference between this and the other species included in this study. Thus, winter weather could cause the distinct yield rhythm of rowan which might be intrinsic to the species and may help plants avoid herbivory.

Autocorrelations of the berry yields

I assessed the effect of previous years' yields on the following year's yield by calculating the autocorrelations with lags of 1–10 years. Rowan was the only species whose autocorrelations (with one year lag), were greater than the upper confidence limit (95.4%) in all provinces. Rowan's AIs correlated negatively ($r \approx -0.5$) with the previous year's indices. In all provinces, the AIs of cranberry and wild strawberry correlated positively between subsequent years. Nevertheless, in most cases the autocorrelations were not greater than the confidence limits. The four-year lag in bilberry showed a clear negative correlation in eight out of eleven provinces.

Contrary to the observations made by many researchers (Nousiainen 1983, Raatikainen 1985, Laakso *et al.* 1990), this study provided no evidence that one year's abundant bilberry and cowberry yields would negatively affect the next year's yields. Moreover, the AIs of cloudberry and crowberry did not correlate with the previous year's index values. The negative autocorrelation in bilberry (four year lag), could be explained by the recovery time needed by a plant which has endured severe conditions. According to this supposition, some factor could impair the plant's productivity for a time longer than one year. Probable candidates for the destruction agent are se-

Table 3. The years of very abundant berry yields in Finland (1956–1996).

Cloudberry	1956			1961						1972									1991		
Bilberry	1956	1957	1958		1963	1964			1970	1972		1977			1983				1991		
Crowberry		1957	1958	1961	1963								1978				1988		1991	1992	
Cranberry				1961						1972											
Wild strawberry		1957	1958																		
Cowberry		1957	1958	1961													1988		1991		
Rowan						1964	1967	1969			1973		1978	1980	1983	1985		1989		1992	1995

vere frost during the growth period or a harsh winter, either of which can kill flowers, flower buds and even leaves and shoots (Solantie 1980a, Nousiainen 1983, Raatikainen 1993).

Wild strawberry in the province of Oulu and cranberry mostly in the southern provinces had a positive autocorrelation series which values gradually decreased with a growing time lag. This type of pattern indicates the presence of a trend in the phenomena under observation (Ranta *et al.* 1994). In this case, the trend was negative. Although I removed the effect of the trend by partial autocorrelation, there was still a positive correlation between subsequent yields. An explanation for the positive autocorrelation of the subsequent yields of cranberry, wild strawberry and, in some cases, of bilberry, could be that meteorological factors affecting the yield at ripening time have a similar effect on the next year's yield in all the species. This could also be the reason for the seemingly independent (from previous yields) behaviour of cloudberry, crowberry and cowberry. Although a good yield may deplete a plant's resources, they could be replenished during the same summer. Kortesharju (1981), for instance, proposed that one summer's temperature sum could positively affect the next flowering. For its part, this study has revealed that the temperature sum has a significant positive correlation with the AI of cloudberry.

The strong negative autocorrelation in rowan supports the hypothesis of Raatikainen *et al.* (1990) that one year's yield affects the next year's one through the nourishment resources of the tree. Recovery from the production of an abundant yield can take more than one year in small trees. The cyclic changes in rowan's yields could also be connected to the occurrence of a certain moth species, *Argyrestia conjugella*. In 1984, when rowan had a poor yield, 69% of the berries were damaged by the moth in the trees studied by Raatikainen *et al.* (1990). It is unclear how much the damage done by the moth affected the yield estimates.

Correlations between the meteorological variables and the abundance indices of cloudberry and bilberry

In the Sodankylä-Salla area, the AIs of cloudberry correlated significantly with only the temperature sum of the ripening period ($r_s = 0.49$, $p = 0.006$), and the mean of daily temperature measurements at 15:00 during the ripening period ($r_s = 0.51$, $p = 0.004$). However, these variables correlate very strongly with each other. Thus, only one of them can be considered at a time. The yield variation of cloudberry was best explained ($r^2 = 0.26$) by the afternoon temperatures.

In the study area of eastern Finland, the AIs of cloudberry are highly correlated with the temperature sum ($r_s = 0.50$, $p = 0.005$) and the frost sum ($r_s = –0.50$, $p = 0.005$) during flowering time. In addition, the frost sum during the ripening period correlated negatively with the AI ($r_s = –0.37$, $p = 0.047$), but during the ripe berry period it had a positive effect ($r_s = 0.43$, $p = 0.019$), as did the sum of precipitation ($r_s = 0.37$, $p = 0.045$). The temperature sum and the frost sum at flowering time correlated strongly with each other. In terms of berry yield, the most important of these is probably the frost sum, which affects berry yield later in the season. The frost sum at flowering and ripening periods together explained 38% of the variation of cloudberry's AI.

In the northern study area, bilberry's AI correlated best with the temperature sum ($r_s = 0.50$, $p = 0.005$), the frost sum during the ripening period ($r_s = –0.47$, $p = 0.009$) as well as the mean of daily temperature measurements obtained at 15:00 ($r_s = 0.46$, $p = 0.010$) during the ripening period of berries. From these three variables which also

Table 4. The years of crop failure in Finland (1956–1996).

Cloudberry	1959		1962	1963						1975				1982		1984						
Bilberry										1975		1980		1982								
Crowberry			1962							1975												
Cranberry										1975				1982	1983	1984						
Wild strawberry	1959	1960			1965					1975				1982		1984	1987	1990	1993	1994	1995	1996
Cowberry	1959		1962			1968	1969			1975		1980	1981	1982		1984			1993			
Rowan						1968		1972	1974		1979			1982		1984		1990		1994		1996

correlated with each other, the temperature sum had the best explaining power for the berry yields ($r^2 = 0.25$).

In eastern Finland, bilberry's AI reached its highest correlation ($r_s = -0.45$, $p = 0.012$) with the frost sum during the ripe berry period. The number of days when temperature exceeded 21°C in June–July of the previous year correlated with bilberry's AI almost as well ($r_s = -0.44$, $p = 0.026$). Also, afternoon temperatures (15:00) during the bilberry ripening period correlated ($r_s = 0.37$, $p = 0.042$) with the AI of the berry. If we add together the above-mentioned three meteorological variables (despite the weak correlation between afternoon temperatures during the ripening period of berries and the frost sum during the ripe berry period ($r_s = -0.25$, p = 0.178)), they will explain about a half of bilberry's yield variation in eastern Finland.

The number of days with heavy rain, which I included in the study because of its reported negative effect on flowering (Raatikainen 1984), did not correlate with the yields. In addition, precipitation variables, which according to Raatikainen (1984) could affect cloudberry and bilberry yields, did not correlate clearly with AIs. Only precipitation during the ripe berry period seems to improve the yield of cloudberry in eastern Finland. Frost during the growth period, and especially during the flowering period, which is mentioned almost without exception when factors affecting berry yields are discussed (Jaakkola & Oikarinen 1972, Solantie 1983, Kortesharju 1988, Raatikainen 1993, Yudina 1993), did not fulfill all expectations. Particularly conspicuous was the absence of frost as one of the factors affecting the yields of cloudberry in the Sodankylä-Salla region. Support for this and the previous result is given by Junttila *et al.* (1983). They summarised the results of the Norwegian cloudberry studies by concluding that night frosts and the precipitation sum do not correlate clearly with the yields of cloudberry.

In general, the temperatures during the growth period had the most potent effect on bilberry and cloudberry yields. If only the values of correlation coefficients and the level of significance were examined, warm weather — i.e. the temperature sum, or in the case of cloudberry in the north, the mean of afternoon temperatures — could explain the yield variation better than the frost sum. Kortesharju (1993) reported that the temperature sum speeds up the ripening of cloudberry. Nevertheless, I did not find in literature any mention of the fact that the temperature sum during the ripening period of berries alone increases yields.

According to this study, the harshness of winter does not have an adverse effect on bilberry yields (nor cloudberry yields) in northern and eastern Finland. Similar observations were made by Solantie (1980a) and Raatikainen and Vänninen (1988). In northern and eastern Finland, snow cover is almost without exception sufficiently thick to protect plants from freezing. In the northern study area, only the yield of bilberry in 1968 might have been affected by the severe winter. In December 1967, the temperature at the Salla meteorological station fell as low as –39.4°C, and at same time there was only 12 cm of snow cover. The next summer, the AI of bilberry was only 1.6, which is clearly less than the mean (2.1) for this area.

Of the effect of meteorological variables of one summer on the next year's berry yields, I studied only the daily maximum temperatures (≥ 21°C) of different months and month combinations. The hypothesis was that too high a temperature could reduce the formation of flowerbuds in cloudberry (Junttila *et al.* 1983). High temperatures may also promote the mass occurrence of *Galerucella nympaea*, a beetle which feeds on cloudberry leaves (Hippa & Koponen 1975). However, it seems that the high temperatures of one year did not influence the next year's yields of cloudberry in Finland. The contrary was true for bilberry in eastern Finland. On the basis of the available data, it is impossible to state what the mechanism is for the negative correlation in question. The phenomenon could just be a coincidence. Regardless, the positive correlation between the AI of cloudberry and the frost sum during the ripe berry period in the eastern study area is a coincidence. Frost does not improve cloudberry yields.

From the results, it can be concluded that the active periods that I had defined were quite fitting. The meteorological variables calculated for the periods before flowering had no effect on yields. In addition, the variables during the ripe berry periods had no significant correlation with the yields of cloudberry and bilberry. Nevertheless, it should be acknowledged that there were only a few significant ($p < 0.01$) correlations even in the variables of berries' flowering and ripening periods. Better results might be attained if the

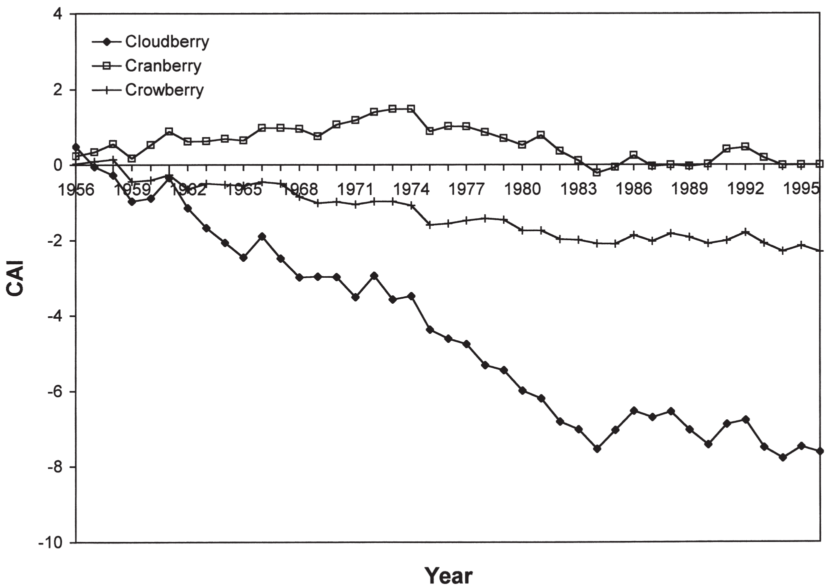

Fig. 11. Cumulative change in abundance indices (CAI) of cloudberry (*Rubus chamaemorus* L.), cranberry (*Vaccinium oxycoccos* L.) and crowberry (*Empetrum nigrum* L.) yields in western Finland in 1956–1996.

meteorological variables could be determined in another way. It would be interesting, for instance, to assess the effect of frost sum below –1, –2, –3 and –4°C.

At best, the individual meteorological variables that I defined explained about 25% of the yield variations of bilberry and cloudberry. However, the results can not be considered poor. Rather, they demonstrate the complexity of the phenomena influencing the yield of berries; yield is evidently influenced by several factors and their mutual effects.

Berry yield trends according to cumulative change in abundance index

The cumulative change in abundance index (CAI) was used for examining berry yield trends in four areas of Finland over the 1956–1996 period (Figs. 11–18). In the first study year of 1956, the yields were compared to the yields of 1955. The graph of rowan begins in 1959. The steep decrease of the CAI of cloudberry in all four areas (Figs. 11, 13, 15 and 17) indicates apparently reduced berry yields. This can probably be explained by the 5.2 million hectares of peatlands drained in Finland, mostly after World War II (*see* Kuusipalo 1982). In different areas, the CAI of cloudberry has fallen to different values. It is interesting to note that the curve of CAI for southern Finland has declined more steeply than for northern Finland. This coincides with the observations of Raatikainen (1984) that the decrease in cloudberry yields was more severe in southern and middle than in northern Finland.

If the cloudberry yields in bogs have diminished, it can be asked why those of cranberry, as expressed by CAI, did not share the same fate since cranberry is especially sensitive to a decrease of water level caused by ditching (Ruuhijärvi 1976, Sepponen 1979). The cause for that is probably that abundant cranberry yields originate in marshes (small-sedge bog and sedge fen) which are mainly excluded from ditching (Huttunen 1983). Further, Raatikainen (1984) reports that cranberry has suffered less than cloudberry from the drainage of peatlands. The observed decrease in cranberry's CAI in the province of Lapland (Fig. 17) is without evident explanation.

There is also no apparent cause for the fall in the CAIs of cowberry and bilberry between the end of the 1970s and the beginning of the 1990s. However, I assume that poor weather conditions affecting cowberry and bilberry yields could cause six successively diminishing annual yields. Raatikainen (1984) reported poor yields for cowberry and bilberry at the turn of the 1970s and 1980s. In addition, Jäppinen *et al.* (1986) measured poor cowberry yields in the municipality of Ilomantsi in 1982–1984. In these studies, unfavourable weather conditions were the reason for poor yields

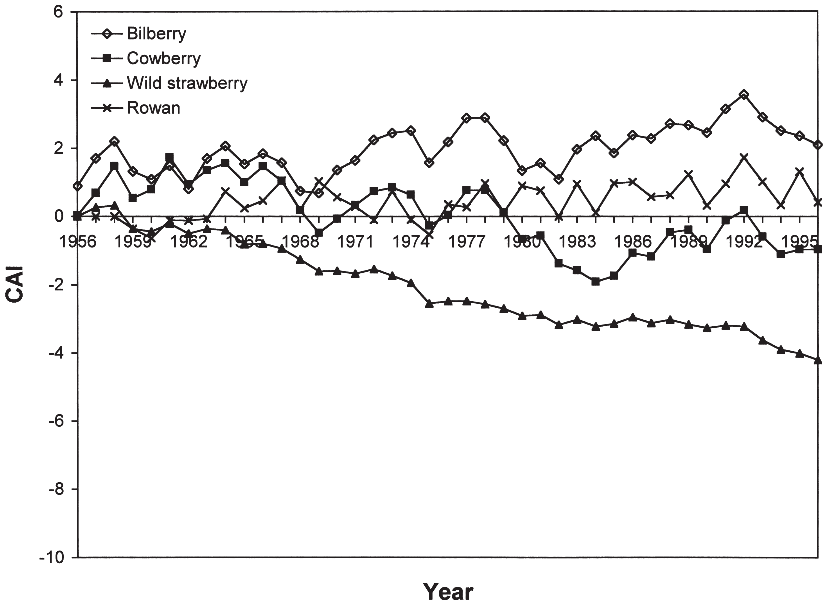

Fig. 12. Cumulative change in abundance indices (CAI) of bilberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.), rowan (*Sorbus aucuparia* L.) and wild strawberry (*Fragaria vesca* L.) yields in western Finland in 1956–1996.

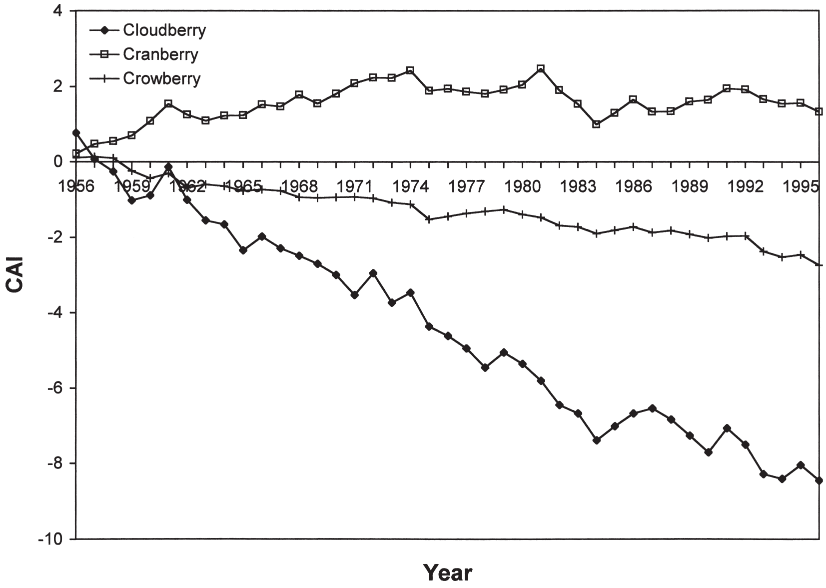

Fig. 13. Cumulative change in abundance indices (CAI) of cloudberry (*Rubus chamaemorus* L.), cranberry (*Vaccinium oxycoccos* L.) and crowberry (*Empetrum nigrum* L.) yields in eastern Finland in 1956–1996.

of the berries. Scanty yields could also be caused by changes in forestry methods. The decrease of cowberry yields in northern Finland began 15 years earlier than in southern Finland (Figs. 12, 14 and 18).

The shrinking of wild strawberry yields reported by Raatikainen (1984) is also attested to by the decrease of CAIs in all four areas (Figs. 12, 14, 16 and 18). According to Raatikainen, some of the most important reasons for the disappearance of wild strawberry are that subsurface draining has become a more common practice, slash-

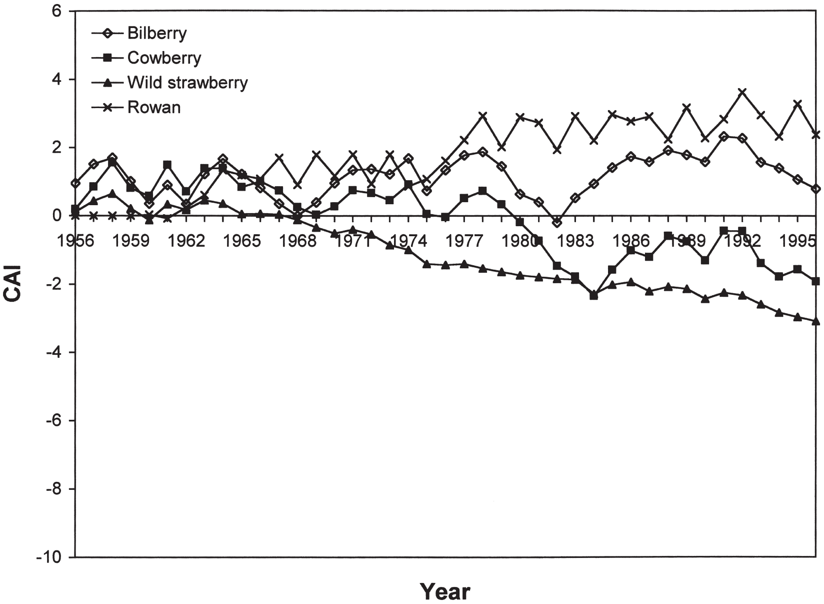

Fig. 14. Cumulative change in abundance indices (CAI) of bilberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.), rowan (*Sorbus aucuparia* L.) and wild strawberry (*Fragaria vesca* L.) yields in eastern Finland in 1956–1996.

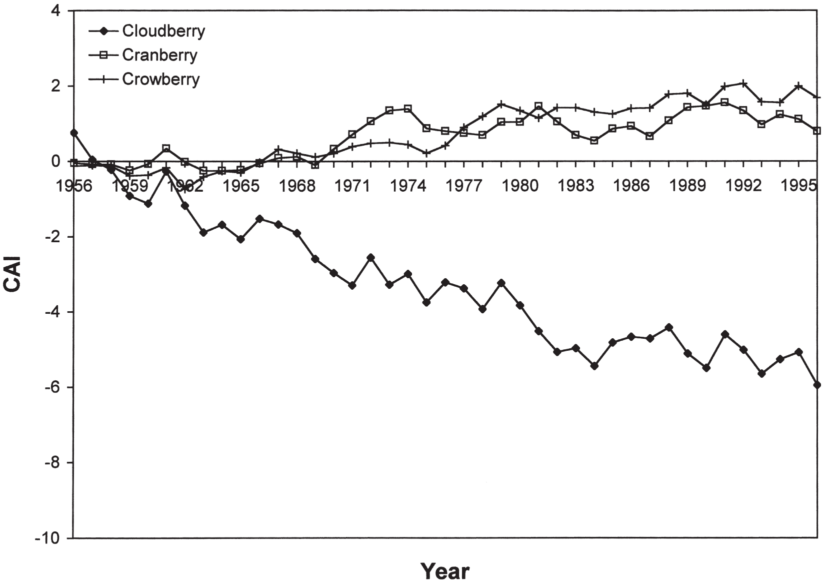

Fig. 15. Cumulative change in abundance indices (CAI) of cloudberry (*Rubus chamaemorus* L.), cranberry (*Vaccinium oxycoccos* L.) and crowberry (*Empetrum nigrum* L.) yields in the province of Oulu in 1956–1996.

and-burn cultivation has ended, and forest pasturing has been rejected. The CAI of wild strawberry has fallen at the slowest pace in eastern Finland. The fastest descent has taken place in the province of Lapland. Agricultural activity there consists mainly of cattle-breeding. Thus, it is understandable that the rejection of traditional natural pastures in Lapland has resulted in a decline of wild strawberry yields. It is possible that wild strawberry reacted to the changes in land use most strongly in the areas of its northernmost distribution in Lapland.

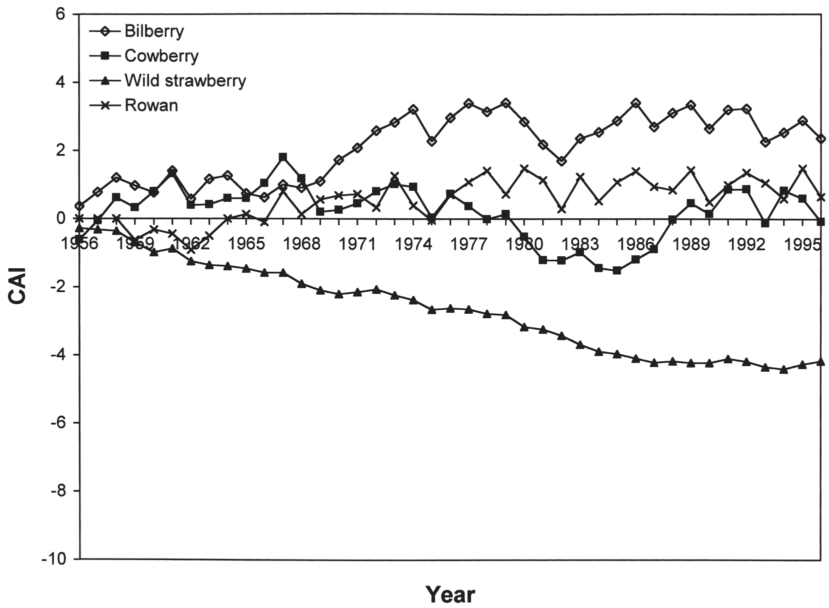

Fig. 16. Cumulative change in abundance indices (CAI) of bilberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.), rowan (*Sorbus aucuparia* L.) and wild strawberry (*Fragaria vesca* L.) yields in the province of Oulu in 1956–1996.

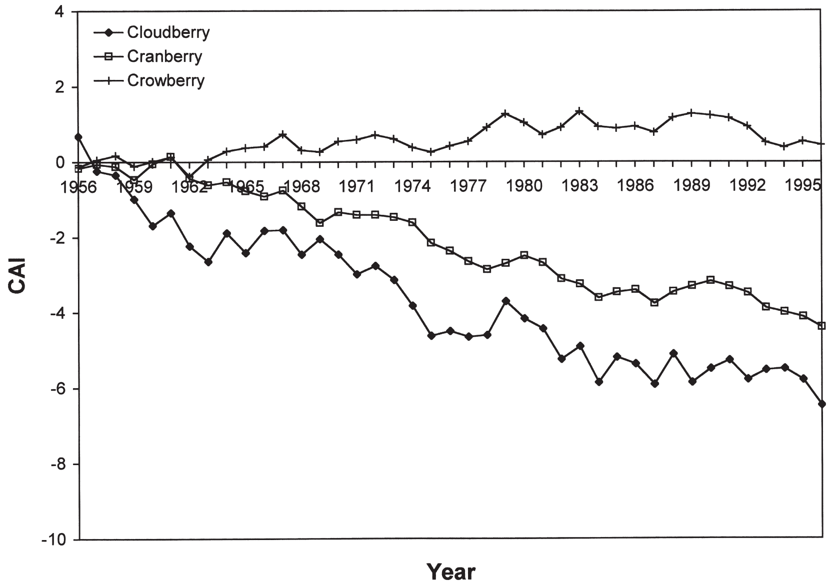

Fig. 17. Cumulative change in abundance indices (CAI) of cloudberry (*Rubus chamaemorus* L.), cranberry (*Vaccinium oxycoccos* L.) and crowberry (*Empetrum nigrum* L.) yields in the province of Lapland in 1956–1996.

CONCLUSIONS

Despite the subjective nature of the study, the data are valid for assessing the direction of annual changes as well as long-term trends in the yields of the most common wild berries in Finland. The results of this study coincide with the negative trend of the yields of cloudberry and wild strawberry already long foreseen by berry researchers. The significant ($p < 0.01$) positive correlations between the yields of the different berry species indicate that meteorological factors affect the yields of most berry species in a similar way. Nevertheless, I was not very successful in explaining the differences in the abundances of bilberry and cloudberry with climate variables. Contrary to expectations, the previous year's yield did not correlate negatively with the next year's yield, except for rowan. The reasons and the mechanism for the specific yield rhythm of rowan are unclear.

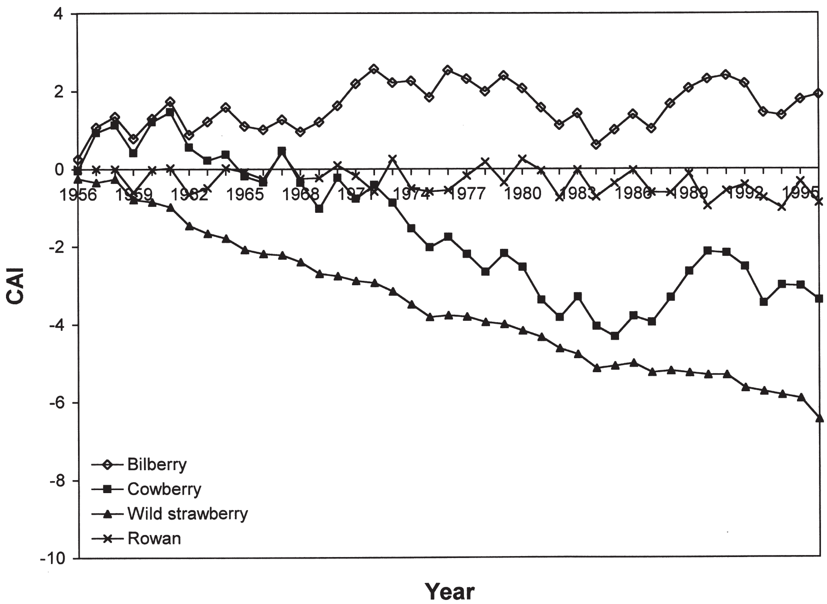

Fig. 18. Cumulative change in abundance indices (CAI) of bilberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.), rowan (*Sorbus aucuparia* L.) and wild strawberry (*Fragaria vesca* L.) yields in the province of Lapland in 1956–1996.

This is an especially interesting subject to additional study.

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