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Weed occurrence in Finnish coastal regions: a survey of organically cropped spring cereals

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Weed communities of organically cropped spring cereal stands in the southern and the northwestern coastal regions of Finland (= south and northwest, respectively) were compared with respect to number of species, frequency of occurrence, density and dry weight. Regional specialization of agricultural production along with differences in climate and soil properties were expected to generate differences in weed communities between south and northwest. Total and average numbers of species were higher in the south than in the northwest (33 vs. 26 and 15.6 vs. 10.0, respectively). Some rare species (e.g. *Papaver dubium*) were found in the south. *Fumaria officinalis* and *Lamium* spp. were found only in the south. The densities and dry weights of *Lapsana communis, Myosotis arvensis*, *Polygonum aviculare*, *Tripleurospermum inodorum* and *Vicia* spp. were higher in the south, while the densities and dry weights of *Elymus repens, Persicaria* spp. and *Spergula arvensis* were higher in the northwest. Total density of weeds did not differ between south and northwest (average = 565 vs. 570 shoots m^{-2}, respectively). Total dry weight of weeds was higher in the northwest compared with the south (average = 1594 vs. 697 kg ha^{-1}, respectively), mainly due to the high dry weight of *E. repens*. The only variable that was dependent on the duration of organic farming was weed density in the south. The abundance of nitrophilous in relation to non-nitrophilous weed species was higher while the abundance of perennial ruderal and grassland weed species was lower compared with previous weed surveys. This can be regarded as the result of increasing cropping intensity on organic farms in Finland. Different weed communities call for the application of specific target-oriented weed management in the respective coastal regions.

Key words: cereals, coastal regions, farm case studies, Finland, organic farming, weed flora, weed management, weed occurrence

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Introduction

Weed community composition and weed abundance are influenced by climate and soil properties, thus leading to regional differences. The development of regional differences in arable weed communities is further affected by specialization of agricultural production, changes in production intensity and conversion to alternative farming concepts (El Titi 1995, Mäder et al. 2002). In Finland, this development has been studied by recurrent weed surveys.

In the first national weed survey carried out in Finland, Mukula et al. (1969) attributed geographical differences of frequency of occurrence and abundance of weed species to differences in climate and soil properties. Since the 1960s, mechanization and specialization have brought with them a decline in the number of farm enterprises in Finland. As a result of regional specialization, stockless crop husbandry has become predominant in southern Finland, while animal husbandry prevails in central, eastern and northwestern Finland. At the same time, the crop rotations have become more monotonous and production has been intensified (National Board of Agriculture 1991, Information Centre of the Ministry of Agriculture and Forestry 2003). Commenting on the second national weed survey, Erviö and Salonen (1987) pointed out that the weed flora composition in conventionally cropped fields was changing due to interacting factors related to the intensification of crop production.

Since 1991 when a financial support program for organic agriculture was launched in Finland, the area devoted to organic agriculture has increased from 0.3% (1991) to 7.0% (2002) of the total area of arable land. In 2002, 6.8% of all active farms in Finland were acknowledged as organic farms (Plant Production Inspection Centre 2003). Both conventional and organic farms in Finland strive for advantages of scale, i.e. increase in size of arable land, specialization on a few branches of production and high proportions of cash crops (Plant Production Inspection Centre 2003).

Monotonous crop rotations along with fertilization and application of herbicides have been found to be detrimental to the species diversity of weed communities. Monotonous crop rotations contribute to a decrease in weed species richness (Hald 1999, Leeson et al. 2000). However, out of all agricultural management practices, the application of herbicides exerts the largest influence on weed species diversity and abundance (Doucet et al. 1999, Hyvönen and Salonen 2001). In Finland, the application of herbicides on agricultural land started to increase after the first nation-wide weed survey was carried out 1961–1964 (Mukula et al. 1969). Another measure that has a selective impact on weed species is seed cleaning (Svensson and Wigren 1986). Intensive soil cultivation, on the other hand, leads to a more general decline of weed species diversity and abundance (Cardina et al. 1991, Frick and Thomas 1992). High soil nutrient levels favour shade-tolerant and competitive weed species (Ellenberg et al. 1991, Blackshaw et al. 2003) but suppress others and lead generally to a decrease of weed species diversity and abundance (Erviö 1972, Pyšek and Lepš 1991).

Organic farming has been found to support populations of rare and threatened weed species (Rydberg and Milberg 2000) and to contribute to larger species diversity (Hald 1999, Hyvönen and Salonen 2001, Hyvönen et al. 2003). However, organic farming *per se* does not necessarily contribute to higher species diversity. In fact, intensification of weed management on organic farms has been observed to have a negative impact on weed species diversity (van Elsen 2000). A combination of intensive tillage, high soil nutrient status, high-yielding crop varieties and efficient mechanical weed control may result in organically managed crops that are highly competitive in relation to the weed flora (Albrecht and Mattheis 1998). Legume-rich leys, grain legumes and legume-cereal intercrops provide symbiotically fixed nitrogen (Jensen 1986, Nykänen et al. 2000). In some cases large amounts of manure are transferred from conventional to organic farms.

Weed abundance in organically cultivated crop stands has been found to be higher than in conventionally cropped stands (Leeson et al. 2000, Salonen et al. 2001a). Salonen et al. (2001b) emphasized that the spreading of especially *Chenopodi-*

um album, *Cirsium arvense, Elymus repens* and *Sonchus arvensis* might seriously threaten the further adoption of organic farming in Finland. Lack of understanding of the specific features of an organic cropping system may cause a rapid increase of weed infestation (Rantzau et al. 1990, Freyer 1991). On the other hand, Mela (1988), surveying pioneer farms of organic agriculture in Finland, found that weed biomass decreased as a function of the period of organic production (while weed density increased). According to Davies et al. (1997), a rapid increase of weed density and weed seedbank numbers during the first years of conversion might be followed by a stabilization, provided that ley and intensively managed horticultural crops make up a part of the crop rotation. After all, the management skills of the farmer are decisive for the level of weed infestation (Rasmussen et al. 1998).

Owing to the geographical differences in weed flora composition and abundance found in the first national weed survey carried out in Finland, Mukula et al. (1969) proposed a floristic division of Finland into different zones, among others the southwestern archipelago and the northwestern region along the Gulf of Bothnia. The following two national weed surveys concentrated on the inland regions of Finland (Erviö and Salonen 1987, Salonen et al. 2001a). Salonen et al. (2001a) confirmed the contribution of the regional specialization of plant cropping to the differences between weed floras in the southern and southwestern regions as well as between the central and eastern regions. However, the impact of specialization and intensification on the weed floras in the southern and the northwestern coastal regions remains to be investigated. Nothing is known about the impact of organic cropping practices on the weed communities of the Finnish coastal regions since the 1980s (Mela 1988).

This study aims to supplement the latest national survey of weed occurrence (Salonen et al. 2001a, b) by investigating organically cropped spring cereal stands in the southern and the northwestern coastal regions. Weed communities were expected to differ from each other due to different geographical location and regional specialization of agricultural production. Furthermore, it was expected that the weed community composition in the coastal regions would differ from that of the inland regions. As a result of specialization and intensified production methods, weed communities in organically cropped spring cereal stands along the Finnish coast were expected to be less diverse and less abundant than the weed communities that had been recorded in these regions in conventionally cropped spring cereals 1961–1964 (Mukula et al. 1969) and in organically cropped cereal stands 1984–1986 (Mela 1988). Organic farms in the coastal regions were expected to differ from each other with regard to weed abundance, depending not only on climatic and edaphic conditions but also on agricultural management.

Material and methods

Study area, farms and fields

Weed communities in organically cropped spring cereal stands were studied by a survey that was carried out 2002. The fields were located along the Gulf of Finland in the south, in the southwestern archipelago and along the Gulf of Bothnia in the northwest. The southern coastal region includes the districts of Itä-Uusimaa, Uusimaa, Varsinais-Suomi and Ahvenanmaa (hereafter = south). The northwestern coastal region covers the district of Pohjanmaa (hereafter = northwest). The investigated coastal regions stretch from about 60° to 65° North and differ from each other with regard to climate, soil properties and branches of production. Precipitation is lower and soil types differ in the coastal regions compared with the adjacent inland regions (Kurki 1982, Mukula and Rantanen 1987, Finnish Meteorological Institute 2003).

Thirty farms managed according to the regulations of organic farming (European Council 1991, 1999) were selected with the help of the regional extension services. Farm and field data are specified in Table 1. The large geographical area covered by this study and limitations with respect to labour advocated a restricted sample size.

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Table 1. Farm and field data.

	Southern coastal region	Northwestern coastal region
Number of fields [a]	18	12
Branch of production		
animal husbandry	9	7
crop husbandry	9	5
Proportion of ley or fallow in rotation, %		
10–29	5	5
30–39	2	6
40–70	11	1
Proportion of winter cereals in rotation, %		
0–10	3	1
11–20	4	2
21–30	4	–
>30	1	–
Soil type [b]		
clay	13	3
silt	3	4
sand	2	3
organic	–	2
Year of conversion [c]		
1981–1990	1	2
1991–1995	10	5
1996–2000	7	5
Cereal crop		
wheat	13	4
barley	1	3
oats	3	3
mixture	1	2

[a] Number of fields corresponds to number of farms.
[b] Humus contents varied between 3–5.9% in most of the clay and silt soils, between 6–11.9% in some clay, silt and sand soils and between 12–19.9% in a few clay and silt soils. The organic soils investigated in northern Pohjanmaa contain 20–39.9% humus and are classified as mull soils.
[c] Year of conversion refers to the surveyed field.

The farms participating in this survey cultivated on average 67.7 ha of arable land (median = 53.3 ha) whereas the average Finnish organic farm comprised 30.9 ha of arable land (Plant Production Inspection Centre 2003). Sixteen out of the 30 farms were engaged in animal husbandry. However, 10 out of the 14 stockless farms imported animal manure from other farms situated in their neighbourhood. Animal husbandry farms and stockless farms were not evenly distributed along the coastal regions but reflected structural differences similar to the regional distribution of conventional farms. In the south as well as in the southernmost part of the northwest, the farms were mainly stockless or kept beef cattle, while all farms in the northern part of the northwestern region specialized in milk production.

On every farm, one field cropped with spring cereals was randomly selected. Fields were not chosen to be representative of the respective farms. Instead, the objective was to establish samples of weed communities characteristic of the southern and the northwestern coastal regions, respectively. Pure stands of spring wheat, oats or barley were preferred. In five cases no pure stand of spring cereals was grown and a crop with undersown ley was therefore chosen. The average size of the fields was 3.2 ha (median = 2.3 ha), with a range between 0.5–11.0 ha. Soil data were derived from samples taken by the farmers and analyzed according to the routines described by Vuorinen and Mäkitie (1955).

With the exception of one field, primary tillage had been carried out by ploughing. Stubble cultivation with spring-tine cultivators had been carried out in 6 out of 30 fields prior to ploughing. Twenty-four fields had been ploughed during autumn while 5 fields had been ploughed in spring. Spring cereals had been sown during April on Ahvenanmaa, during the first half of May in the other southern districts, and during the second half of May in the northwest. Weed harrowing was applied in 5 out of 30 cereal stands.

Weather conditions

The growing period in the study year (calculated in days when the base temperature of 5°C was exceeded) lasted 163 days in the south and 148 days in the northwest. The effective temperature sum (calculated in degree days accumulated above the base temperature of 5°C, DD5) reached 1536–1693ºC in the south and 1405–1499ºC in the northwest. Precipitation during April, May, June and July varied from 117.7 mm to 275.9 mm in the different districts included in the survey. Precipitation was generally lower at the south coast than in the inner parts of the southern districts or in the northwest. Compared with the average data of the latest 30 years period, the growing period in 2002 was characterized by a high effective temperature sum. Precipitation was low in April and May but high in June and July (Finnish Meteorological Institute 2003). The investigation comprised of only one year but included different climatic zones, different soil types and different management systems.

Sampling

Number of weed species (species m^{-2}), weed density (shoots m^{-2}) as well as dry weights (g m^{-2}) of crop and weed species were assessed at the stage when both weeds and crop had reached their maximum biomass, i.e. at DC (decimal code) 70–79 on the scale of Zadoks et al. (1974). Because the fields were situated along the coastline from the southeast to the northwest, sampling could be conducted within a narrow range of crop development stages.

Due to the plentiful occurrence of weeds and limitations with respect to labour, sampling was restricted to four plots per field. The sampling plots were chosen by dividing the longest diagonal across the field into five even distances. Headland, shallow sites suffering from drought, compacted sites or sites close to artesian springs were avoided. Sampling was carried out with a rectangular metal frame measuring 0.25 m^2. The frame was placed so that the distance from crop row to frame was the same both in the upper and lower margin of the frame. Crop and weed species were cut at soil surface, sorted by species, counted and dried in paper bags. The samples were dried by airflow dryer at 30–40ºC. The samples were weighed to the nearest 0.1 g. Density and dry weight were used as measures of weed abundance.

Assessment of weed species

The plant species nomenclature follows that of Hämet-Ahti et al. (1998). The full scientific names with attributions together with the BAYER codes of weeds (Bayer 1992) are given in Table 2. Species that could not be identified were pooled by genera and taxa. Individuals belonging to the taxa *Brassica* spp., *Chenopodium* spp., *Galeopsis* spp., *Galium* spp., *Lamium* spp., *Persicaria* spp., *Rumex* spp., *Taraxacum* spp., *Trifolium* spp., *Veronica* spp. and *Vicia* spp. were not identified to species level. Only few individuals of the species *Matricaria matricaroides* (LESS.) PORT. and *Matricaria recutita* L. were found, and these were therefore included in the species *Tripleurospermum inodorum* (L.) SCH. BIP.; likewise, *Viola arvensis* includes *V. tricolor*. Grasses other than *Elymus repens* were treated as one taxon. Although ley grasses and *Trifolium* species in pure stands of cereals cannot be considered to be part of the crop, they were not regarded as weeds with respect to weed density. The competitive potential of ley species was expressed by including the biomass of ley species either into the weed biomass or, in the case of undersown ley seed, into the biomass of the nurse crop.

Analyses of the data

The Wilcoxon two-sample test (see Sokal and Rohlf 1995) was applied to compare average numbers of species, densities and dry weights of crop and weeds as well as single weed species between the southern and the northwestern regions. The relationship between the duration of organic farming and the number of species, the density, and the dry weight of weeds was studied by linear regression in both regions separately. For this purpose, density and dry weight data were log (x + 1) transformed.

Since the number of sampled fields varied between south and northwest, the total species numbers of these regions could not be compared. The expected number of species $E(S_n)$ for each region was therefore calculated by rarefaction. In rarefaction, the number of species of larger samples is scaled down to a given number of individuals that permits the comparison of the numbers of species between samples differing in size:

$$E(S_n) = \sum_{i=1}^{S} \left(1 - \frac{\binom{N - N_i}{n}}{\binom{N}{n}} \right),$$

where $E(S_n)$ = the expected number of species in a random sample of n individuals, S = the total number of species in the entire collection, N_i = the number of individuals per species i, N = the total number of individuals in the collection, and n = the sample size (number of individuals) chosen for standardization (see Heck et al. 1975, Krebs 1999). Sample size was scaled down to 6500 individuals (the number of individuals was 6839 in the northwest), and standard deviations were calculated for each sample size. For the analysis, data were pooled across fields.

Results

Frequency of occurrence

Certain species such as *Capsella bursa-pastoris*, *Fumaria officinalis*, *Lamium* spp., *Plantago major*, *Stachys palustris* and *Thlaspi arvense* were found only in the southern coastal region while others, i.e. *Achillea millefolium*, *Achillea ptarmica*, *Leontodon autumnalis* and *Rumex* spp. occurred only in the northwestern coastal region (Table 2). The weed species *Brassica* spp., *Galium* spp., *Lapsana communis*, *Myosotis arvensis*, *Polygonum aviculare*, *Tripleurospermum inodorum*, *Vicia* spp. and *Viola arvensis* were more common in the south, while *Galeopsis* spp., *Persicaria* spp. and *Spergula arvensis* were more common in the northwest (Table 2). Among the perennial weed species, *Elymus repens* was somewhat more frequent in the northwest, while *Cirsium arvense* and *Sonchus arvensis* were more frequent in the south (Table 2). *Chenopodium* spp., *E. repens* and *Stellaria media* were very common in both regions (Table 2).

Number of weed species

A total of 38 weed species and weed taxa were found in the coastal regions. Both the observed (S_{OBS}) and expected ($E(S_{6500})$) total number of species were higher in the south than in the northwest: 33 and 31.8 (SD = 0.91) vs. 26 and 25.9 (SD = 0.23), respectively. The same pattern was found with regard to the average number of species per field. The average number of species in the south and northwest was 15.6 vs. 10.0 (median = 16.0 vs. 9.5; SD = 3.2 vs. 3.2), respectively ($Z = –3.63$; $P < 0.001$). Some of the species that were found are considered rare, i.e. *Anchusa arvensis*, *Centaurea cyanus* and *Erodium cicutarium* or extinct, i.e. *Papaver dubium* (Hämet-Ahti et al. 1998, Rassi et al. 2001). The number of weed species was not dependent on the duration of organic farming in either region (south: $R^2 = 0.11$, $P = 0.186$; northwest: $R^2 = 0.005$, $P = 0.835$).

Abundance of single weed species

The most frequent species were generally most abundant with respect to density and dry weight. The only exception was *Sonchus arvensis*, which was more prominent in the northwest with respect to dry weight than could be deduced from frequencies and densities. Weed abundance in the south differed from the northwest with respect to density and dry weight. The densities of *Lapsana communis*, *Myosotis arvensis*, *Polygonum aviculare*, *Sonchus arvensis*, *Tripleurospermum inodorum* and *Vicia* spp. were significantly higher in the south, whereas *E. repens*, *Persicaria* spp. and *Spergula arvensis* (at the limit of significance) occurred at significantly higher densities in the northwest (Table 3). Dry weights of *L. communis*, *Myosotis arvensis* (at the limit of significance), *Polygonum aviculare*, *Tripleurospermum inodorum* and *Vicia* spp. (at the limit of significance) were significantly higher in the south, while *E. repens*, *Galeopsis*

Table 2. Frequencies of all weed species and weed taxa found in the southern and the northwestern coastal regions.

Weed species and taxa	BAYER code [a]	Both regions	Southern coastal region	Northwestern coastal region
Achillea millefolium L.	ACHMI	3.3	–	8.3
Achillea ptarmica L.	ACHPT	3.3	–	8.3
Anchusa arvensis (L.) MB	ANCHA	3.3	5.6	–
Brassica L. spp.	BRASS	20.0	27.8	8.3
Capsella bursa-pastoris (L.) MEDIK.	CAPBP	23.3	38.9	–
Centaurea cyanus L.	CENCY	3.3	5.6	–
Chenopodium L. spp.	CHESS	96.7	100.0	91.7
Cirsium arvense (L.) SCOP.	CIRAR	16.7	22.2	8.3
Elymus repens (L.) GOULD	AGRRE	83.3	77.8	91.7
Equisetum arvense L.	EQUAR	26.7	33.3	16.7
Erodium cicutarium (L.) L HÈR.	EROCI	3.3	5.6	–
Erysimum cheiranthoides L.	ERYCH	73.3	72.2	75.0
Fallopia convolvulus (L.) Á. LÖVE	POLCO	60.0	66.7	50.0
Fumaria officinalis L.	FUMOF	43.3	72.2	–
Galeopsis L. spp.	GAESS	76.7	66.7	91.7
Galium L. spp.	GALSS	56.7	66.7	41.7
Gnaphalium uliginosum L.	GNAUL	3.3	–	8.3
Grasses other than *Elymus repens* (L.) GOULD [b]	–	46.7	27.8	75.0
Lamium L. spp.	LAMSS	43.3	72.2	–
Lapsana communis L.	LAPCO	56.7	88.9	8.3
Leontodon autumnalis L.	LEBAU	3.3	–	8.3
Myosotis arvensis (L.) HILL	MYOAR	50.0	72.2	16.7
Papaver dubium L.	PAPDU	3.3	5.6	–
Persicaria L. spp.	POLLA	63.3	44.4	91.7
Plantago major L.	PLAMA	6.7	11.1	–
Polygonum aviculare L.	POLAV	56.7	72.2	33.3
Ranunculus repens L.	RANRE	20.0	11.1	33.3
Rumex L. spp.	RUMSS	6.7	–	16.7
Sonchus arvensis L.	SONAR	56.7	77.8	25.0
Spergula arvensis L.	SPRAR	66.7	61.1	75.0
Stachys palustris L.	STAPA	3.3	5.6	–
Stellaria media (L.) VILL.	STEME	96.7	100.0	91.7
Taraxacum L. spp.	TAROF	23.3	33.3	8.3
Thlaspi arvense L.	THLAR	16.7	27.8	–
Trifolium L. spp. [b]	TRFSS	66.7	66.7	66.7
Tripleurospermum inodorum SCH. BIP.	MATSS	53.3	72.2	25.0
Tussilago farfara L.	TUSFA	3.3	5.6	–
Veronica L. spp.	VERSS	3.3	5.6	–
Vicia L. spp.	VICSS	30.0	44.4	8.3
Viola arvensis MURRAY	VIOAR	76.7	88.9	58.3

[a] Bayer codes (BAYER 1992).
[b] Not included in the number of weed species.

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Table 3. Mean densities and dry weights of the weed species dominating in the southern and the northwestern coastal regions including statistical differences between regions.

	Density (shoots m^{-2})		Z[a]	P-value	Dry weight (kg ha^{-1})		Z[a]	P-value
	South	Northwest			South	Northwest		
Brassica spp.	5.6	0.1	–1.36	0.173	61.6	0.2	–1.39	0.164
Chenopodium spp.	156.3	99.8	–1.06	0.290	171.9	299.7	1.25	0.212
Cirsium arvense	0.6	0.2	–0.95	0.344	3.2	0.1	–1.01	0.312
Elymus repens	56.1	212.1	2.25	0.025	101.6	882.3	2.61	0.009
Erysimum cheiranthoides	23.5	17.4	1.43	0.152	13.1	20.6	1.62	0.104
Fallopia convolvulus	27.7	2.5	–1.51	0.131	45.1	7.0	–1.36	0.175
Fumaria officinalis	5.3	–	–3.64	0.001	11.6	–	–3.42	0.002
Galeopsis spp.	20.4	32.7	1.60	0.110	29.1	93.3	2.62	0.009
Galium spp.	10.0	4.4	–1.39	0.174	23.7	6.4	–1.67	0.108
Lamium spp.	24.1	–	–3.63	<0.001	31.6	–	–3.42	0.001
Lapsana communis	33.0	0.3	–4.02	<0.001	15.9	0	–4.13	<0.001
Myosotis arvensis	13.6	0.25	–3.12	0.004	3.9	0.4	–2.01	0.054
Persicaria spp.	6.2	19.8	2.07	0.038	5.4	32.9	2.76	0.006
Polygonum aviculare	4.5	0.9	–2.19	0.036	4.1	1.3	–2.05	0.049
Sonchus arvensis	19.7	3.7	–2.78	0.005	35.6	38.2	2.39	0.020
Spergula arvensis	19.7	120.0	1.96	0.050	5.7	122.1	2.02	0.044
Stellaria media	50.2	28.3	–1.74	0.082	43.3	24.1	–0.91	0.363
Tripleurospermum inodorum	16.6	0.3	–2.93	0.007	10.5	0.03	–2.74	0.011
Vicia spp.	6.8	0.3	–2.01	0.044	22.9	0.3	–2.04	0.051
Viola arvensis	43.5	16.9	–0.68	0.495	10.6	6.9	–0.30	0.765

[a] Wilcoxon test statistic.

spp., *Persicaria* spp., *Sonchus arvensis* and *Spergula arvensis* had higher dry weights in the northwest (Table 3).

More weed species dominated in the south than in the northwest. In the south, eight weed species and taxa (*Chenopodium* spp., *E. repens*, *S. media*, *V. arvensis*, *L. communis*, *F. convolvulus*, *Lamium* spp., *E. cheiranthoides*; ranked in descending order) made up 73.3% of total weed density, while in the northwest only three species and taxa (*E. repens, Spergula arvensis*, *Chenopodium* spp.; ranked in descending order) were required to reach 75.7% of total weed density (Fig. 1).

70.4% of the total weed dry weight in the south consisted of seven species and taxa (*Chenopodium* spp., *E. repens*, *Brassica* spp., *F. convolvulus*, *S. media, Sonchus arvensis, Lamium* spp.; ranked in descending order), while only two species (*E. repens, Chenopodium* spp.; ranked in descending order) made up 74.1% of the total weed dry weight in the northwest (Fig. 2).

Abundance of crop and weeds

Crop density was significantly higher in the south than in the northwest whereas crop dry weight did not differ between the regions (Table 4). Density of annual weed species did not differ between south and northwest whereas perennial weeds occurred at significantly higher density in the northwest (Table 4). Due to the high abundance of perennial species, weed dry weight was significantly higher in the northwest than in the south (Table 4).

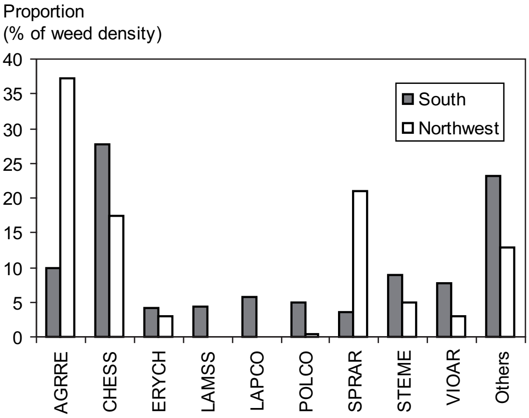

Fig. 1. Proportional density of the weed species and taxa dominating in the southern and the northwestern coastal regions. AGRRE = *Elymus repens*, CHESS = *Chenopodium* spp., ERYCH = *Erysimum cheiranthoides*, LAMSS = *Lamium* spp., LAPCO = *Lapsana communis*, POLCO = *Fallopia convolvulus*, SPRAR = *Spergula arvensis*, STEME = *Stellaria media*, VIOAR = *Viola arvensis*

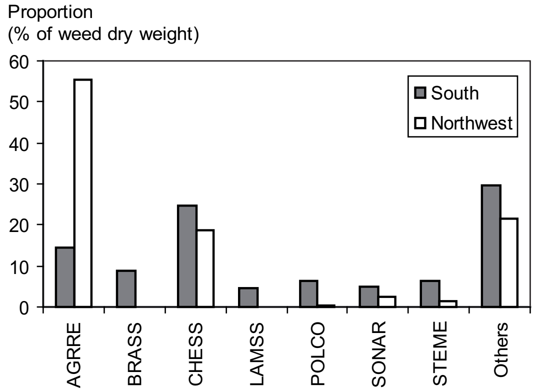

Fig. 2. Proportional dry weight of the weed species and taxa dominating in the southern and the northwestern coastal regions. AGRRE = *Elymus repens*, BRASS = *Brassica* spp., CHESS = *Chenopodium* spp., LAMSS = *Lamium* spp., POLCO = *Fallopia convolvulus*, SONAR = *Sonchus arvensis*, STEME = *Stellaria media*

Table 4. Mean densities and dry weights of crop and weeds in the southern and the northwestern coastal regions including statistical differences between regions.

	South			Northwest				
	Mean	Median	SD	Mean	Median	SD	Z [a]	P-value
Density (shoots m^{-2})								
Crop	685.1	657.5	205.5	527.7	505.5	153.2	–2.27	0.026
Weeds								
all species	565.4	467.5	437.4	569.9	507.5	334.4	0.32	0.751
annuals	483.1	363.5	399.5	344.2	255.5	264.8	–1.12	0.236
perennials	82.3	44.0	115.6	225.8	190.0	196.5	2.18	0.029
Dry weight (kg ha^{-1})								
Crop	6183.0	6564.7	2112.0	6685.4	6533.1	2390.2	0.15	0.882
Weeds								
all species	696.7	480.4	573.0	1594.1	1476.5	974.0	2.65	0.008
annuals	521.7	328.1	504.4	615.4	494.3	379.2	1.55	0.122
perennials	175.0	98.1	189.3	978.8	758.9	868.9	2.60	0.009

[a] Wilcoxon test statistic
SD = standard deviation

Average weed density in relation to weed and crop density was 41.6 vs. 48.7% in the south compared with the northwest while the average proportion of weed dry weight in relation to total weed and crop dry weight was 11.4 vs. 20.6%, respectively. The high abundance of perennial weed species in the northwest was due to *E. repens*. On average, *E. repens* constituted 4.3 vs. 18% of the total crop and weed density and 1.8 vs. 10.8% of the average total crop and weed dry weight in the south

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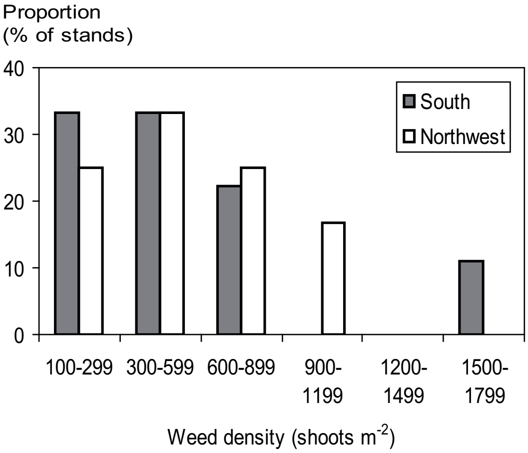

Fig. 3. Distribution of cereal stands in the southern and the northwestern coastal regions with regard to weed density.

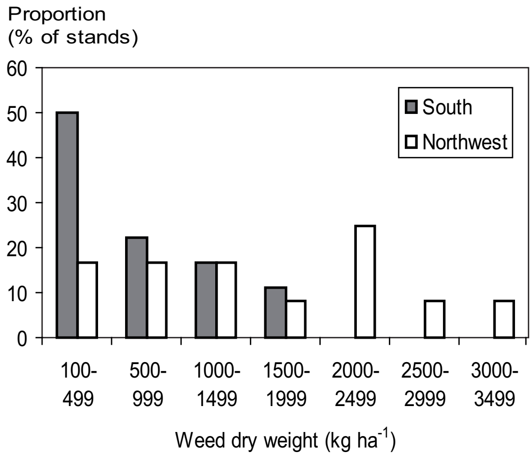

Fig. 4. Distribution of cereal stands in the southern and the northwestern coastal regions with regard to weed dry weight.

and northwest, respectively. In some crop stands *E. repens* was not found at all while in certain crop stands it made up close to 30% of the total dry weight.

Distribution of weed abundance

The spring cereal stands included in this survey differed remarkably from each other with regard to weed density and dry weight. In 30% of the investigated spring cereal stands, weed densities ranged between 100–299 shoots m^{-2}. In one third of the cereal fields, the density of weeds amounted to 300–599 shoots m^{-2} whereas it exceeded 600 shoots m^{-2} in 36.7% of the crop stands. With regard to lower classes of weed density, the distribution of spring cereal fields was about the same in both regions. However, the highest levels of weed density were found in the south (Fig. 3).

The dry weight of weeds exceeded 500 kg ha^{-1} in 63.3% of the investigated crop stands. In the south, weed dry weight in half of the fields was lower than 500 kg ha^{-1} while it exceeded 1000 kg ha^{-1} in 27.8% of the fields. In the northwest, weed dry weights lower than 500 kg ha^{-1} were found in only 16.7% of the spring cereal stands. Weed dry weight exceeded 1000 kg ha^{-1} in 66.7% of the fields surveyed in the northwest (Fig. 4).

In the south, weed dry weight tended to be dependent ($R^2 = 0.21$, $P = 0.055$), and weed density was dependent ($R^2 = 0.23$, $P = 0.042$) on the duration of organic farming. In the northwest, no dependence was detected (weed dry weight: $R^2 = 0.02$, $P = 0.650$; weed density: $R^2 = 0.029$, $P = 0.598$).

Discussion

Number of weed species in the coastal regions

The number of weed species found in the coastal regions was lower compared with the weed surveys conducted in the late 1990s (126 species found in 165 organically cropped fields; Salonen et al. 2001b), and in the early 1960s (304 species found in 2710 conventionally cropped fields; Mukula et al. 1969). The investigation by Mukula et al. (1969) covered all agricultural regions of

Finland whereas the survey by Salonen et al. (2001b) included southern and central Finland. Since the number of species is dependent on the sample size (Heck et al. 1975), the likely reasons for the lower species number in the present study were the lower number of studied fields and the restriction to coastal regions. Furthermore, in our investigation, all weed species were not distinguished by species level, but instead pooled by genera and taxa, which underestimates the real number of weed species.

Despite of the small sample size, some rare weed species were encountered. This is in accordance with previous findings by Albrecht and Mattheis (1998). Thus, organic cropping benefits biodiversity by the conservation of rare and endangered species. The number of weed species was higher in the south than in the northwest, which is in agreement with previous investigations (Mukula et al. 1969, Salonen et al. 2001b). Weed species number in the south is enhanced by a longer growing season and a larger species pool (Hämet-Ahti et al. 1998). In agreement with Becker and Hurle (1998), the number of weed species was not related to the duration of organic farming. Rather than the duration of organic farming, the factors that determine the number of weed species include single crop management measures, such as choice of crop rotation, soil tillage, weed management, and fertilization.

In comparison with the surveys carried out by Mukula et al. (1969) and Salonen et al. (2001b), the number of dominating weed species was on the same level in the south, while it was lower in the northwest. About 70% of the total weed density had been made up by eight species in conventionally cropped spring cereals in the beginning of the 1960s (Mukula et al. 1969) and by ten species in organically cropped stands 1984–1986 (Mela 1988). This proportion was reached by the accumulated density of eight weed species in the south whereas in the northwest only three species together exceeded 70% of total weed density. Eight species had constituted 70% of the total weed dry weight recorded 1961–1964 (Mukula et al. 1969). In our investigation, the seven most dominant weed species in the south reached 70% of the total weed dry weight. In the northwest, however, this proportion of weed dry weight was made up of only two species. In the south, milder winters offer better conditions for cropping of winter cereals and thus for more diverse crop rotations whereas in the northwest fields are subjected to more simple summer cereal or ley-and-cereal rotations. Therefore, a lower number of weed species gain dominant positions in the northwest than in the south (Mukula et al. 1969, Hald 1999).

Weed communities in the coastal regions

In agreement with previous investigations (Mukula et al. 1969, Salonen et al. 2001b), regional differences in the occurrence of weed species were detected. Species preferring a warm climate such as *Lamium* spp. and *S. palustris* were only found in the south (Mukula et al. 1969, Salonen 1993). *Lamium* spp. and *F. officinalis* are known to thrive in dry clay soils (Mukula et al. 1969, Salonen 1993, Hallgren 1996). Clay soils prevail in the south, which might contribute to the fact that *Lamium* spp. and *F. officinalis* were found only in this region. Likewise, the significantly higher densities and dry weights of *M. arvensis*, *P. aviculare* and *T. inodorum* in the south can be explained by the preference of these weed species for dry mineral soils (Mukula et al. 1969, Erviö and Salonen 1987, Ellenberg et al. 1991, Erviö et al. 1994). On the other hand, the significantly higher abundances of *Galeopsis* spp. (by dry weight), *Persicaria* spp. and *Spergula arvensis* (by both density and dry weight) in the northwest are likely due to the moist coarse mineral and organic soils common in this region (Mukula et al. 1969, Salonen 1993). The tolerance of *Persicaria* spp. and *Spergula arvensis* to soils with low pH results in significantly higher densities and dry weights of these species in the northwest where such soils are more common than in the south. In the contrary, significantly higher abundances of weed species preferring soils with high pH, such as *Lamium* spp., *L. communis* and *M. arvensis* were found on the clay soils of the south (Albrecht and Bachthaler 1989, Erviö et al. 1994).

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Galeopsis spp., *Persicaria* spp. and *Spergula arvensis* are classified as summer annuals, while *A. arvensis*, *C. cyanus*, *E. cicutarium*, *M. arvensis* and *P. dubium* also readily germinate in autumn (Fogelfors 1977). The latter are favoured by the cultivation of winter annual crops, which is common in the south, but rather an exception in the northwest (Table 1). *Brassica* spp. was more frequent in the south than in the northwest, which was not expected since Salonen et al. (2001b) have not found any consistent differences between localities with regard to the occurrence of this weed taxon. *Brassica* spp. disseminates independently of geographical region as a volunteer crop, or through seeds contained in feed cereals that transfer to manure fertilizer. A probable reason for the relatively low occurrence of *Brassica* spp. in the northwest is the lower proportion of turnip rape both in conventional and organic crop rotations applied in this region (Information Centre of the Ministry of Agriculture and Forestry 2003).

In contrast to the results obtained by this survey, *C. bursa-pastoris*, *F. officinalis* and *T. arvense* have previously been recorded as frequent in the northwest (Mukula et al. 1969, Mela 1988, Salonen et al. 2001b). *G. uliginosum*, which was found in the northwest only, has been reported to occur in the south, too, although at lower frequencies than in the northwest (Mukula et al. 1969, Mela 1988, Salonen et al. 2001b). The cause for these contradictions is probably the low number of fields included in this survey.

Most of the annual weed species and seedlings of perennial species that were found in the spring cereal stands in this survey can be controlled by weed harrowing. Exceptions are *Galeopsis* spp. (high dry weight in the northwest) and *Galium* spp. (frequent both in the northwest and the south). Weed harrowing is effective against the seedling and early rosette stages of weeds and can be carried out before the emergence of the crop, as well as after DC 13 (Habel 1954, Koch 1959, Kees 1962). In contrast to weed harrowing, stubble cultivation is only effective against those weed species germinating in autumn (Boström and Fogelfors 1999). Stubble cultivation is effective against volunteer crops as well, although in the case of *B. rapa* spp. *oleifera*, cultivation must be shallow (Pekrun and Lutman 1998).

The perennial weed species *E. repens*, *C. arvense* and *Sonchus arvensis* have been regarded as the most noxious for organic cropping in Finland (Salonen et al. 2001b). *C. arvense* and *Sonchus arvensis* occurred at higher frequencies in the south compared with the northwest. The density of *Sonchus arvensis* was significantly higher in the south, while its dry weight was significantly higher in the northwest. Higher occurrences of these weeds in the south have previously been recorded by Mukula et al. (1969), Mela (1988) and Salonen et al. (2001b). *C. arvense* prefers clay soils while *Sonchus arvensis* also thrives in coarse mineral soils (Mukula et al. 1969, Salonen 1993). *C. arvense* has a deep reaching root system and therefore competes successfully with agricultural crops, especially in the dry clay soils that prevail in the south. The establishment of both *C. arvense* and *Sonchus arvensis* is favoured by a high proportion of annual crops (Mukula et al. 1969, Donald 1990) while cultivation of ley in combination with three cuts is an appropriate measure against *C. arvense* (Dock-Gustavsson 1997). On farms where the proportion of ley is low, *C. arvense* and *Sonchus arvensis* can be controlled by stubble cultivation, provided that tillage operations can be launched in early autumn (Boström and Fogelfors 1999).

The higher abundance of *E. repens* in the northwest is in line with the results obtained by the latest survey of inland sites (Salonen et al. 2001b) and is explained by the preference of this weed for moist silt and organic soils (Mukula et al. 1969, Erviö et al. 1994). Compared with the 1960s, the frequency of *E. repens* in fields not treated with herbicides has generally increased (cf. Mukula et al. 1969, Mela 1988, Salonen 2001b). *E. repens* has an extensive rhizome system and its spreading is incited by lower tillage intensity (Håkansson 2003). Stubble cultivation accomplished twice per autumn is recommended as an efficient measure against *E. repens* (Boström and Fogelfors 1999). However, the further to the north the fields are situated, the more limited are the opportunities for stubble cultivation after the harvest of grain crops. Cropping of late-ripening varieties further shortens the period suitable for stubble cultivation. *E. repens* had previously been less frequent and less abundant in the northwest than in the south (Mukula et al. 1969, Mela 1988). More rare and less favourable opportunities for stubble cultivation than in the south have likely favoured the spreading of *E. repens* in the northwest. Due to the absence of tillage, the maintenance of leys for more than three years favours the spreading of *E. repens* (Håkansson 2003).

Differences in the occurrence of weed species between the southern and the northwestern coastal regions can thus be related to climate and edaphic as well as to management factors. Owing to the occurrence of different weed species, appropriate weed management in the south and north must rely on different strategies. In regions with short growing seasons or on organic soils, perennial weed species emerging from root shoots and rhizomes are generally restrained by integrating a spring and early summer fallow into the regular crop rotation (Bylterud 1965, Kakriainen-Rouhiainen et al. 2003).

Weed abundance and cropping intensity

Compared with previous national surveys, *Chenopodium* spp. in organically cropped stands reached higher abundances both in the southern and the northwestern coastal regions. The abundances of *Brassica* spp., *F. convolvulus, Galium* spp. and *Lamium* spp. in the south were much higher compared with previously found national average numbers. In the northwest, *E. repens* exceeded previously recorded average levels of density and dry weight (Mukula 1974, Mela 1988, Salonen et al. 2001b). The density of *E. cheiranthoides* was the same as reported at national level in the 1960s (Mukula 1974) and 1980s (Mela 1988). However, its dry weight in the northwest was twice as high.

The above mentioned weed species are either nitrophilous or, owing to their climbing growth form, competitive in conditions of increasing nitrogen levels (Mahn 1988, Albrecht and Bachthaler 1989, Ellenberg et al. 1991, Jørnsgård et al. 1996, Blackshaw et al. 2003). Of the weed species found to be more abundant in the coastal regions compared with previously recorded national average levels only *C. bursa-pastoris*, *Spergula arvensis* and *Vicia* spp. are non-nitrophilous (Ellenberg et al. 1991). These findings suggest higher nitrogen levels compared with the organically cropped fields investigated by previous surveys (Mela 1988, Salonen et al. 2001b) as well as compared with the conventionally cropped fields included in the first national weed survey 1961-1964 (Mukula et al. 1969). The dominance of nitrophilous weed species in organically cropped spring cereal stands in the coastal regions of Finland contradicts the prediction by Rydberg and Milberg (2000) that conversion to organic farming practices would lead to an increase of non-nitrophilous weed species. High nitrogen levels in organically cropped fields might be due to high humus levels, to frequent cropping of legumes, to recent application of manure to a single field or to regular import of nitrogen by manure acquired from other farms. High soil nitrogen levels offer a potential for high crop yields, provided that weeds are kept under control.

Frequencies of ruderal and perennial grassland weeds such as *A. millefolium*, *A. ptarmica*, *E. arvense*, *E. cicutarium*, *L. autumnalis*, *P. major*, *R. repens*, *Rumex* spp. and *T. farfara* were somewhat lower compared with the average national frequencies reported by Salonen et al. (2001b) and Mela (1988), and much lower than the frequencies found in the beginning of the 1960s (Mukula 1974). The decrease of these species has been attributed to land amelioration, the decline of agricultural land devoted to pasture, higher shares of annual crops, shorter duration of leys and intensified soil tillage, as well as to the application of herbicides (Erviö and Salonen 1987, Rydberg and Milberg 2000). Owing to the fundamental importance of symbiotic nitrogen fixation by red clover-grass leys for the nitrogen supply of non-leguminous crops, grassland is part of the regular crop rotation, especially on organic farms. The leys are usually terminated after two or three harvest years, tilled and grown with annual crops. A spreading of ruderal and perennial grassland weeds under organic farm-

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ing management is therefore not to be expected. Important exceptions are *C. arvense* and *E. repens* which are adapted to soil cultivation. Consequently, the frequencies and abundances of these species have increased.

Weed density in the coastal regions was on about the same level as reported in previous national surveys of low-input conventional and organic farming (Mukula et al. 1969: 550 shoots m^{-2}; Mela 1988: 505 shoots m^{-2}; Salonen et al. 2001b: 469 shoots m^{-2}). Average weed dry weight found in the south (697 kg ha^{-1}) exceeded the national average found in the 1980s (Mela 1988: 575 kg ha^{-1}), but was on the same level as found by the recent national survey of organically cropped spring cereal fields (Salonen et al. 2001b: 678 kg ha^{-1}). In the northwest, however, weed dry weight was tremendously high, reaching an average of 1594 kg ha^{-1}, and thus widely exceeding the national average of 1000 kg ha^{-1} found in the 1960s (Mukula et al. 1969). The difference in weed dry weight between south and northwest is supported by Salonen et al. (2001b) who had found higher weed dry weight in the western part of central Finland compared with the southern mainland. The significantly higher crop density in the southern coastal region probably contributed to higher competitiveness of the crop and thus to lower weed abundance (Erviö 1972, Erviö 1983). While the level of weed infestation was clearly influenced by climate, edaphic factors and management, there was only a weak positive correlation between the duration of organic farming and weed abundance in the south, and no correlation at all in the northwest. Regardless of region, the investigated spring cereal crops differed widely from each other with respect to weed abundance.

Conclusions

Weed communities of organically cropped spring cereal stands in the southern and the northwestern coastal regions differed from each other with regard to species composition, frequency of occurrence and abundance. Weed species frequencies and abundances in the coastal regions differed from the inland regions. By favouring populations of rare and threatened weed species, organic farming proved to be beneficial for species diversity.

The present level of weed occurrence in organically cropped stands of spring cereals in the coastal regions calls for target-oriented weed management over an extended time span as well as the integration of preventive, cultural and physical control measures. Due to different weed communities, different weed control measures have to be applied in the southern, and in the northwestern coastal region, respectively.

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SELOSTUS

Rikkakasvien esiintyminen rannikkoalueiden luomukevätviljapelloilla

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Tutkimuksessa vertailtiin eteläisen (Itä-Uusimaa, Uusimaa, Varsinais-Suomi ja Ahvenanmaa) ja Pohjanmaan rannikkoalueiden luonnonmukaisesti viljeltyjen kevätviljapeltojen rikkakasviyhteisöjä. Alueet eroavat toisistaan maataloustuotannon erikoistumisen, ilmaston ja maaperän suhteen. Näiden tekijöiden odotettiin aiheuttavan eroja rikkakasviyhteisöjen lajimääriin sekä lajien esiintymisfrekvensseihin, tiheyksiin ja kuivapainoihin.

Sekä lajien kokonaismäärä että keskimääräinen lajimäärä olivat suurempia eteläisellä rannikkoalueella kuin Pohjanmaalla (33 vs. 26 ja 17,3 vs. 10,8). Eteläiseltä rannikkoalueelta löydettiin joitakin harvinaisia lajeja (esim. ruisunikko), ja joitakin yleisiä lajeja tai sukuja, kuten peltoemäkki ja peipit, tavattiin ainoastaan etelästä. Linnunkaalin, peltolemmikin, pihatattaren, peltosaunion ja virnojen tiheydet ja kuivapainot olivat suuremmat eteläisellä rannikkoalueella, kun taas juolavehnän, ukontatarien ja peltohatikan tiheydet ja kuivapainot olivat suuremmat Pohjanmaan rannikolla. Rikkakasvien kokonaistiheys ei eronnut tutkimusalueiden välillä (565 vs. 570 versoa m^{-2}). Sen sijaan kokonaiskuivapaino oli suurempi Pohjanmaalla kuin eteläisellä rannikkoalueella (1594 vs. 697 kg ha^{-1}), mikä paljolti johtui suuresta juolavehnän määrästä Pohjanmaalla.

Ainoastaan eteläisellä rannikkoalueella rikkakasvitiheys vaihteli luomuviljelyn keston mukaan. Aiempiin kartoituksiin verrattuna typpeä suosivat rikkakasvilajit olivat runsaampia, kun taas nurmipitoisessa viljelykierrossa yleisten monivuotisten rikkakasvilajien runsaus oli alhaisempi. Tämä johtunee luomuviljelyn tehokkuuden noususta Suomessa. Rikkakasviyhteisöjen alueelliset ominaispiirteet pitäisi ottaa huomioon suunniteltaessa rikkakasvien torjuntaa.