Agriculture, Ecosystems and Environment 259 (2018) 61–71

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Decreasing diversity in the soil seed bank after 50 years in Danish arable fields

Christian Andreasen*, Hans Arne Jensen, Signe Marie Jensen

Department of Plant and Environmental Sciences, Faculty of Science, University of Copenhagen, Højbakkegard Allé 13, DK-2630 Taastrup, Denmark

ARTICLE INFO

Keywords:
Agroecology
Biodiversity
Floristic change
Viable seeds
Weed management

ABSTRACT

Side-effects of intensification have raised public concerns. Declining diversity and abundance of wild species and pollution have been reported worldwide. National surveys are necessary to assess the overall effect on the wild flora of the changing management of arable land. We studied how the plant diversity in 40 fields in Denmark has changed over a period of 50 years. Three surveys of the vegetation and the viable soil seed banks were conducted at the same locations in Danish fields in 1964, 1989, and 2014. The same methods were used to estimate the soil seed bank in the ploug layer and to describe the corresponding vegetation in the three surveys. Soil samples were placed in trays in a greenhouse for nine months, and the plants from germinating seeds were identified. Significant changes were found in the viable soil seed bank and the vegetation. A drastic decline of plant species and seeds was observed after the first 25 years. The frequency of species and the number of seeds were reduced considerably from 1964 to 1989. In 2014, the number of seeds in the soil seed bank had increased to the same level as in 1964, whereas the frequency of the species in the vegetation was at about the same level as in 1989. The species in the vegetation deviated partly from those found in the viable soil seed bank as the number of species recorded in both assessments made up only about 50% in all surveys. Relatively few species dominated and have been able to adapt to modern cultivation practice.

1. Introduction

Information on seed banks in arable soil and documentation of flora changes is of practical, economic and ecological interest. Among the pests, weeds are considered an important biotic obstacle to food production. Their competition with crops reduces agricultural output (quantity and quality), increases external costs, and is further a major constraint for improving productivity (FAO, 2017).

From an ecological point of view, common weed species make up an important food reservoir for the wildlife and, as such, help to maintain the biological diversity and the quality and quantity of wildlife in the landscape (Grime, 1989; Cunningham et al., 2004). Knowledge of changes in the flora and the soil seed bank is valuable as grounding for political decisions concerning the biological diversity of farming areas and other decisions related to the management of the open landscape.

Since 1964, agriculture has gone through a great structural and technological development characterized by a significant change in cropping methods and land use in Denmark as well as in Europe. Between 1964 and 1989 intensive chemical control of weeds took place and gradually the autumn sown crops became dominant at the expense of spring sown crops. In 1964, 5.8% of the total cropped area in Denmark was winter wheat and winter rye (Anon., 2017a). In 1989, two more autumn sown crops were grown, winter barley and winter oilseed rape, and the four crops covered 25% of the total cropped area. In 2014, the area with autumn sown crops was increased to 40.2%. Between 1989 and 2014 maize replaced fodder beets and legume crops became rare in Denmark (Anon., 2017b). In 1988, a set-aside scheme was introduced by the European Economic Community (EEC) (Regulation (EEC) 1272/88) (Anon., 1988). The aim was to help reduce the massive and costly surpluses produced in Europe under the guaranteed price system of the Common Agricultural Policy, and to deliver some environmental benefits after considerable damage to agricultural ecosystems and wildlife as a result of the intensification of agriculture.

From 1989 to 2014 the area of organic farming in Denmark increased from 5.565 ha to 159.973 ha (Anon., 2017c). The average farm size increased from *ca.* 17 ha in 1964 to *ca.* 69 ha in 2014. Merging farms often results in the removal of hedges and use of more consistent management of larger fields, which often leads to reduced biodiversity (Roschewitz et al., 2005). Such fields are easily managed with large, heavy agricultural machinery and little human resources. The use of heavy machines may result in soil compression and lower oxygen partial pressure in the soil and may increase the competitive ability of

* Corresponding author.
E-mail address: can@plen.ku.dk (C. Andreasen).

https://doi.org/10.1016/j.agee.2018.02.034
Received 20 April 2017; Received in revised form 22 February 2018; Accepted 27 February 2018

some noxious grass weeds like *Alopecurus myosuroides* and *Poa annua* (Mullverstedt, 1963; Yasin, 2017), which also have developed herbicide-resistant biotypes (Andreasen et al., 1995; Mathiassen and Kudsk, 2016). The amount of sold herbicides in Denmark declined dramatically from 3969 t in 1989 to 1205 t in 2014 (70% reduction), mainly because old chemicals were replaced with new much more potent herbicides (e.g., sulfonylureas). The estimated spraying intensity declined from 1.61 to 1.57 applications ha^{-1} (Anon., 2017d).

In 1964, the average amount of applied artificial [N, P, K] fertilizer was [56, 18, 60] kg ha^{-1}, respectively, but increased to [142, 14, 45] kg ha^{-1} in 1989 (Anon., 2017a). In 2014, it was reduced to [78, 5, 20] kg ha^{-1} as a result of national regulations in an attempt to reduce leaching of plant nutrients to the groundwater and the surroundings (Anon., 2017b). The same trend was observed for manure. All these changes happening after 1989 may favour some weed species and select against others.

In several countries in Europe scientists have conducted regular surveys of the weed flora and the soil seed bank in arable fields (e.g., in Finland (Hyvönen et al., 2003), Hungary (Novák et al., 2009), France (Fried et al., 2009), and Switzerland (Richner et al., 2017)). Many of the European surveys have demonstrated extensive changes in the weed flora during the last 50 to 100 years, and there is increasing evidence of biodiversity loss in agricultural landscapes (Robinson and Sutherland, 2002; Fried et al., 2009).

In Denmark, Ferdinandsen (1918) reported the first minor survey of the weed flora in 1911. Later, comprehensive surveys were conducted in 1960-70 (Mikkelsen and Laursen, 1966; Laursen, 1967; Mikkelsen, 1970; Laursen and Haas, 1971; Streibig, 1979), in 1987–1989 (Andreasen, 1990; Andreasen et al., 1996) and 2001–2004 (Andreasen and Stryhn, 2008, 2012; Andreasen et al., 2010). These surveys have also identified new noxious weed species such as *Setaria viridis* and *Echinochloa crus-galli* (Andreasen et al., 1992). The surveys have furthermore contributed to the public debate about the differences in vegetation on roadsides and arable fields, on the changing biodiversity in Denmark and the effect and side-effects of using herbicides and modern cultivation technologies (Andreasen and Streibig, 2011; Andreasen and Andresen, 2011).

In 1896–1910 Dorph-Petersen (1910) performed the first minor survey of the soil seed bank in Denmark. Jensen (1967, 1968, 1969, 1974) examined the vegetation in 1964 and analysed soil samples from 40 m^2 experimental areas, located in 57 Danish fields. In 1989, 37 of those fields were analysed using the same methods as in 1964. This survey disclosed that the content of viable seeds in these areas, determined by washing and laboratory germination, were reduced. Also, the average number of plant species, found by germination in a greenhouse, was reduced (Jensen and Kjellsson, 1992, 1995).

In 2014, fifty years after the first survey by Jensen (1967), we analysed the vegetation, collected soil samples and analysed the viable seed banks in 40 of the fields examined in 1964. The fieldwork in 2014 followed the exact procedures applied in 1964 and 1989.

The aim was to investigate whether the general decline in the soil seed banks observed between 1964 and 1989 has continued in spite of the many political initiatives to reduce unwanted side-effects of the intensive agricultural production, or whether the soil seed banks had stabilized or even increased. Another interesting question was to investigate whether some of the species which became rare in the period between 1964 and 1989 have been able to maintain or even increase their seed banks in spite of their relatively low seed production.

We describe how the soil seed banks and the corresponding vegetation have changed during the last 50 years and relate the changes to shifts in agricultural management and other factors of importance for the flora diversity on arable land.

2. Materials and methods

2.1. Activities before the survey in 2014

In 1964, 57 randomly selected fields were investigated of which 20 fields were grown with root crops and 37 fields with cereals. In the following 50 years, many different crops have been grown in the fields. The distribution of crops in the fields examined in 1964, 1989 and 2014 are shown in Table 1. A map showing the location of the areas can be found in Jensen (1969) and Jensen and Kjellsson (1992, 1995). During the 1964 and 1989 surveys, we recorded names and addresses of the owners or persons responsible for the experimental areas. All surveyed areas were situated at least 20 m from the edge of the field. To make it possible to recover the exact locations of the area, a sketch was made showing the precise location of the area within the field. The distances to fixed points in or around the fields were measured, i.e., distance to the edge of the pavement of the closest road, dikes, electricity masts or similar. Finally, the compass direction from a fixed point to the centre of the experimental area was noted.

Before the survey in 2014, we identified the persons responsible for the experimental areas using the addresses from 1989 and public registration of the present users of the areas. We compared the 1989 sketches of the locations with copies of air-photos. This comparison facilitated the findings of the experimental plots. Geo-referencing the plots with Global Positioning System (GPS) will make it much easier to find the plots in the future. Before the survey, we got permission to visit the fields.

One of the 37 areas examined in 1989 was not available in 2014 due to a new farm building on the site. Four farmers in 1989 did not want our visit, while the users in 2014 had no reservations. Therefore, in total 40 fields were included in the 2014 survey. Some of the fields were newly ploughed and without vegetation when the fields were visited. Therefore fewer vegetation analyses than soil analyses were included in the survey (Tables 1 and 3).

Table 1
Crops types grown in the field in 1964, 1989, and 2014. The number of fields of each crop is marked in bold. The fields are, furthermore, grouped after the time of planting: Summer annuals (e.g. spring barley, sugar beet), winter annuals (winter rye, winter wheat), and perennials (crops planted/sowed the year before or earlier).

Year of survey	1964	1989	2014
Summer annual crops (percentage)	98%	54%	28%
Maize			4
Potatoes			2
Spring barley	18	10	4
Spring barley with under sown ryegrass		2	
Spring barley with under sown grass and clover	6	1	
Spring barley, peas, grass and clover			1
Spring barley and spring oat	2		
spring oat with grass and clover	1		
Spring oilseed rape		2	
Sugar beets	10	5	
Swedes	2		
Winter annual crops (percentage)	2%	16%	28%
Winter barley			1
Winter oilseed rape		4	
Winter rye	1		2
Winter wheat		2	8
Perennial crops	0%	30%	44%
Christmas trees			1
Grass leys (1st or 2ed year)		8	6
Mixed forest (20 years old)			1
Permanent grass leys			7
Perennial ryegrass for seed production		1	
Red fescue for seed production		1	
Set-aside (15 years old)			1
Strawberries		1	
Willows (10 year old)			1
Information not available			1
Total number of fields	40	37	40