CHAPTER 2

Distribution

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Wild oats have achieved a very deep penetration of world agriculture. From their centres of origin, possibly in the Pamir, they moved both westwards and eastwards, initially through the agency of Neolithic man. In recent centuries, the migrations of Caucasian peoples, transplanting their systems of agriculture and the associated appurtenances, have been responsible for a great deal of the spread. The enormous development of world trade in seed, food grain and feedstuffs contributed to this spread, and the intensification of cereal farming (especially barley and wheat) greatly aggravated the problem in many parts of the world. This chapter seeks to review the sources of information on the spread of wild oats, the current records of incidence in various parts of the world, recent changes in levels of infestation, and methods of dissemination of wild oats.

WORLD DISTRIBUTION

SOURCES OF INFORMATION

Information comes from two sources: the literature, and herbarium or seed collections. In the literature there is some direct information, the result of surveys (see under separate countries, below), but there is also the indirect evidence of papers on control of wild oats, implying that they must be present in agronomically important amounts but frequently not defining the species, let alone the varieties or strains being controlled.

Most world-famous herbaria probably contain some specimens of wild oats, but the specimens may be incomplete, unripe, and sometimes even incorrectly labelled. Those at the Royal Botanic Gardens, Kew, and Edinburgh, for example, contain far fewer specimens and span fewer countries than the seed-collection built up at Rothamsted as the result of two major sampling efforts (England and Wales in 1951, European countries in 1960) augmented by specimens contributed by correspondents over many years and from many parts of the world.

Absence of wild oats cannot be proved from the literature or from herbaria or seed-collections, and information on exact distribution by geographical regions, and on identity, frequency and density within those

regions, is generally scarce. However, it is highly probable that any region growing wheat or barley either has, or is liable to develop, a wild oat problem.

DISTRIBUTION OF SPECIES AND TYPES

If *A. fatua* originated in South West Asia, especially the Pamir, and *A. sterilis* including *A. ludoviciana* in Asia Minor (Malzew, 1930) then they must have been introduced to distant countries, eg North America and Australia, most probably in seed-corn taken by early settlers (see p. 57-8). This probability is emphasised by the occurrence of a greater number of sorts of wild oats on the research farm at Toowoomba than on non-experimental farms in Australia as indicated by the Rothamsted seed collection. Presumably samples of cereals have been imported from many different countries to be tested under local growing conditions at the research station, whereas farmers can buy only those varieties available in commercial quantities from a limited number of sources.

When wild oats reach a new country, local conditions will select out from the mixture any types which are specially suited to the new environment. The external appearance may remain unaltered, but less readily-observed, nevertheless far more important, physiological differences appear. Thus, there is a relationship between latitude, day-length, and time from germination to flowering such that one can roughly determine the latitude of origin of a sample from the length of the developmental period. Such considerations apply to *A. fatua, A. sterilis* and *A. ludoviciana* alike. The interval from sowing to 50% ear emergence when specimens were pot-grown together in England averaged from 93 days for plants from Israel to 135 days for plants from Britain, ie it was longer in specimens from higher latitudes (Thurston 1963b). Whalley and Burfitt (1972) confirmed this in Australia.

Avena fatua is the characteristic wild oat of Great Britain and North West Europe, North America, and other regions with similar climate. *A. sterilis* occurs in regions with Mediterranean climate, whether actually surrounding the Mediterranean or as far away as Queensland, Australia. Of all the variations of *A. sterilis,* whether classified as subspecies or varieties or elevated to the rank of independent species, *A. ludoviciana* seems to be the most widely distributed and abundant. Its more northerly distribution in Europe, including the midlands of England, suggests that it is the most winter-hardy, and it is doubtful whether the sale of *A. sterilis* ssp. *macrocarpa* for flower arrangements in England and Norway poses any threat to agriculture there. The specimens in florists' shops have usually been gathered unripe to ensure that the decorative spikelets are not shed, but it is possible that some seeds would be viable. *A. barbata* is also a Mediterranean species and sometimes invades fields of cereals, but it is predominantly a weed of roadsides and waste places (Baum *et al* 1972).

There is considerable variation within species (Malzew 1930, Thurston 1957). Curiously, by far the most common sorts of *A. fatua* and *A. ludo-*

viciana in England and probably also throughout the world are similar in appearance, with dark brown very hairy lemmas and long brownish hairs surrounding the abscission-scar. Possibly this combination of characters has some survival-value, eg the seeds do not show up on damp soil from which birds might collect them. Many combinations of characters occur frequently, and some have been given varietal names (Malzew 1930) but colour, one of the most obvious characteristics, is seldom used in this context. For convenience the most commonly-occurring types of *A. fatua* and *A. ludoviciana* found in England were given letters (Thurston 1957, p. 261, reproduced here as Table 2.1). Unfortunately the results of the 1951 survey were recorded on sheets of paper before the lettering-system was introduced and cannot easily be sorted to give numerical estimates of frequency. When the European wild oat samples were received in 1960 punched-card recording was introduced. For these and subsequent samples the relative abundance of the common sorts, as indicated by the Rothamsted seed-collection, can be assessed (Table 2.2). This shows that, while type fA (the commonest in England) is almost universal in countries where *A. fatua* has been collected, it forms very different proportions of the population within those countries. In contrast, a yellow glabrous form with short silvery hairs at the callus, too uncommon in England to have been given a code, but since referred to as 'Dutch yellow', accounts for 12% of the samples from Holland and 8% from West Germany, but has not been received from other countries. Between these two fall type fF and its almost indistinguishable variant with brown hairs (called 'Belgian brown' because of its prevalence in Belgium and neighbouring countries), and a grey almost or completely glabrous form with short silver hairs at the callus, also seldom seen in England, which was named 'Scandinavian grey' from its distribution. These variants do not show agriculturally-important differences, apart from a tendency for fA to flower two or three days earlier than the others, but the visual differences might be helpful in tracing the origin of a new infestation and thus helping to prevent further trouble from the same source.

The only sort of *A. fatua* to differ from the rest of the species in agriculturally-important ways was fD (Table 2.1), which probably belongs to a different subspecies from the other English types. Although some seeds partly resembling it have been found in European samples, none of them showed the non-dormant first seeds nor the hairy nodes to the culms when grown-on. Another English type not yet collected in Europe is fM. Some large and rather discoloured specimens of Dutch yellow could be mistaken for it at first sight, but they lack the waxy bloom on the lemmas and are shiny instead. They are also fully dormant at harvest.

In *A. ludoviciana,* type 1A predominates in England, and other countries, with 55 samples out of 151. Type 1C, not very common in England, comes second with 20 samples, 11 of them from France. Other variants are less easily grouped. Grown-on specimens very rarely showed hairy nodes recorded in three English plants of 1C. Again, agriculturally-important characteristics are seldom associated with visual differences, type 1D (Table 2.1) being an exception.

Table 2.1 *Selections of wild oats grouped according to lemma characters (from Thurston 1957)*

Type	Selection nos.	Lemma colour	Hairiness of lemma	Hairs at callus	Hairiness of awn	Other distinguishing features	Botanical name
A. fatua L.							
*f*A	29, 30, 31, 32, 72, 73	Brown	Very hairy	Long, brown	Scabrid	–	*Avena fatua* L. var. *fatua* = *A. fatua* subsp. *fatua* var. *pilosissima* S. F. Gray
*f*B	41, 42, 44, 69, 69 *a*, 70, 75, 76, 77	Grey	Moderately hairy	Long, silvery	Scabrid	–	–
*f*C	33, 34, 35, 36, 81, 82	Yellow	Glabrous	Long, silvery	Scabrid	–	*A. fatua* subsp. *fatua* var. *glabrata* Peterm.
*f*D	33 *a*, 43, 47, 48, 49, 50, 79, 80	Pale grey	Very hairy	Long, golden	Scabrid	Numerous tillers, hairy nodes, large grains, percentage dormancy lower than in other types of *A. fatua*	*A. fatua* subsp. *septentrionalis* var. *valdepilosa* Malzew
*f*E	61, 62, 63, 64	Yellow	Moderately hairy	Short, silvery	Scabrid	First leaf pinkish or purplish	–
*f*F	37, 39, 40, 74	Brown	Very hairy except just above the callus	Short, silvery	Scabrid	–	–
*f*G	52, 53, 54, 78	Grey	Moderately hairy	Short, silvery	Scabrid	–	*A. fatua* subsp. *fatua* var. *pilosa* Syme
*f*H	55	Grey	One or two hairs at base of awn	Long, silvery to pale yellow	Scabrid	–	–
*f*I	45, 46	Dark brown	Almost or completely glabrous	Long, brown	Scabrid	–	–
*f*J	57, 58, 60	Yellow	Very hairy	Long, golden	Scabrid	–	–
*f*K	59, 65, 68	Yellow	Hairy at base of awn only	Long, golden	Scabrid	–	–

*f*L	47 *a*	Brown	Very hairy	Long, brown	Scabrid	Numerous tillers, hairy nodes, large grains	Probably a hybrid between *f*D and another type, possibly *f*A
*f*M	51	Cream	Glabrous with waxy 'bloom'	Short, silvery	Scabrid	Wide grains, low dormancy	*A. fatua* subsp. *fatua* var. *hybrida* Aschers
A. ludoviciana Dur.							
*l*A	1, 2, 3, 4, 5, 7, 71	Brown	Very hairy	Long, brown	Scabrid or moderately hairy	–	Possibly included in *Avena ludoviciana* var. *typica* Malzew
*l*B	23, 24	Brown	Moderately hairy	Long, brown	Moderately hairy	–	–
*l*C	6, 12, 27, 28	Grey	Very hairy	Long, silvery to golden	Scabrid	Three plants in sel. 27, type *l*C, had hairy nodes but in all other plants of this type the nodes were hairless	Possibly included in *A. ludoviciana* var. *typica* Malzew
*l*D	10 *a*, 11, 11 *a*, 13, 14	Grey	Moderately hairy	Long, silvery, gold or brown	Moderately hairy	Numerous shoots, long period from germination to ear emergence	Habit of *A. ludoviciana* var. *typica* subvar. *hibernans* Malzew
*l*E	15, 17	Grey	Almost glabrous	Long, greyish brown	Very hairy, long hairs	Mildew resistant, hairy nodes, wide grains	Possibly *Avena sterilis* subsp. *trichophylla*
*l*F	9, 21, 22	Grey	Tuft of hairs at base of awn	Very long, silvery, golden or brown	Scabrid	Sels. 21 and 22, hairy nodes	–
*l*G	19, 20	Grey	Glabrous	Short, silvery	Scabrid	Non-dormant	*A. ludoviciana* var. *glabriflora* Malzew
*l*H	18	Brown	Very hairy	Short, brown	Scabrid	High percentage dormant grains	*A. ludoviciana* var. *media* Malzew
*l*J	25, 26	Yellow	Glabrous	Long, orange	Scabrid	–	*A. ludoviciana* var. *glabrescens* Malzew
*l*K	25 *a*, 26 *a*	Pale grey, or cream	Glabrous	Long, brownish orange	Scabrid	–	*A. ludoviciana* var. *glabrescens* Malzew

Table 2.2 *Frequency of occurrence of types of* A. fatua *as percentage of total specimens from each country represented by more than 10 specimens in Rothamsted seed-collection*

Country	fA	fF Belgian brown	Scandinavian grey	Dutch yellow
Australia				
New South Wales	18			
South	53			
Western	67			
Belgium	19	28		
Czechoslovakia	23	20		
Denmark		26	32	
Finland	13	6	19	
France	57	11	2	
Germany, East	4			
Germany, West	27	11	16	8
Netherlands	10	23	18	12
Norway	14	10	21	
South Africa	45			
Sweden		15	23	
Turkey	70			
UK				
England	Very common	Common	Uncommon	Uncommon
Scotland	2	22	20	
USA	33			

WORLD DISTRIBUTION DETAILED BY COUNTRIES

Wild oats have been recorded in 45 countries, the records—as already indicated—being derived from a variety of sources. Altogether, over a hundred references have been read and carefully checked against the available evidence. Where appropriate, comments on the validity of the records have been included. There can be little doubt that wild oat infestations await recognition in many other countries. A summary of the world distribution as indicated by specimens in the Rothamsted collection is given in Table 2.3.

Algeria

A. sterilis ssp. *macrocarpa* was found by the Official Seed Testing Station at Cambridge in seed imported into Britain. It was identified at Kew Herbarium.

Arabia

A. sterilis ssp. *trichophylla* (C. Koch) var. *calvescens* Malzew from Beihan was identified at Kew.

Argentina

A. fatua was among the most frequent contaminants of seed-lots in the wheat growing region (Ibarra and Pardo 1962) and a brown-husked, threshed specimen of *A. fatua* was found in Germany in imported Argentinian cereal in 1965.

Australia

Wild oats are common, and frequently constitute a serious problem, in the cereal-growing areas of Queensland and New South Wales. Their date of introduction is unknown, but by 1895 they were recognized as a pest. In 1918, 350 seeds of *A. fatua* per kg were found in barley imported from the USA., but plant quarantine regulations should now have greatly reduced introductions (Whalley and Burfitt 1972).

Three species, *Avena fatua* L., *A. sterilis* L. *(A. ludoviciana)* and *A. barbata* Pott. occur in the wheat belt of New South Wales and South Queensland, although *A. barbata* is confined to pastures and roadsides in the south. The region extends from latitude 28° to 38° S and from 250 m to 1000 m altitude on the Great Divide range. *A. fatua* covers the whole area but is mqre concentrated in the south, whereas *A. ludoviciana* is confined to the north. The National Herbarium of New South Wales has no other subspecies of *A. sterilis* besides *A. ludoviciana* (Whalley and Burfitt 1972).

Quail and Carter (1968) associate the dominance of *A. ludoviciana* in Queeensland and northern New South Wales with its winter germination and the great longevity of its second seeds, in an area where winter wheat is often sown in June (equivalent to January in the Northern Hemisphere), destroying all autumn germinated plants. In contrast, in southern New South Wales crops are sown in April and May (equivalent to September–October in the Northern Hemisphere) when the wild oats germinating are mainly *A. fatua.* This suggests that the ratio of autumn to spring-germinating *A. fatua* in Australia must be different from that in England (Thurston 1963b) although seeds of Australian stock, grown in England, germinate to the same pattern as English ones grown alongside them. Strains of *A. fatua* and *A. ludoviciana* from New South Wales differ in their speed of after-ripening (Quail and Carter 1969). McNamara (1966) stated that in Australia there is no difference between the germination periods of *A. fatua* and *A. ludoviciana* but offered no supporting evidence.

In New South Wales both *A. fatua* and *A. ludoviciana* show considerable morphological and physiological interspecific variation, as might be expected in collections from the wide range of environmental conditions provided by the region, but there is no obvious relationship between habit, which varies from prostrate through ascending to erect, and locality of origin (Whalley and Burfitt 1972). In the Rothamsted collection types fA and lA and others similar to them predominate.

Cartledge (1973) recognised about 20 separate strains of *A. fatua* and *A. ludoviciana* in Queeensland, differing in tolerance to herbicides, maturity-rate, plant size, habit and vigour, number of seeds produced, dormancy and reaction to germination-conditions. Generally one paddock (field) has few

Table 2.3 *World distribution of wild oat species, as indicated by specimens in the Rothamsted seed-collection*

Country	Total specimens	*A. fatua*	*A. ludoviciana*	Other *A. sterilis*	*A. barbata*
Algeria*	1	–	–	1	–
Arabia*	1	–	–	1	–
Argentina*	1	1	–	–	–
Australia	(185)	(87)	(55)	(2)	(41)
Western	33	18	1	–	14
South	105	55	24	–	26
New South Wales	33	11	21	–	1
Queensland	14	3	9	2	–
Belgium	129	128	1	–	–
Canada*	1	1	–	–	–
Chile	1	–	–	–	1
Corfu	2	–	–	1	1
Crete	2	–	–	1	1
Cyprus	1	–	1	–	–
Czechoslovakia	39	39	–	–	–
Denmark	19	19	–	–	–
England†	228	191	37	–	–
Ethiopia	1	–	–	1	–
Finland	31	31	–	–	–
France	218	165	47	4	2
Germany East	23	23	–	–	–
Germany West	98	98	–	–	–
Greece	5	–	1	4	–

Iraq	8	1	7	–	–
Israel	13	–	–	11	2
Italy	10	–	1	6	3
Kenya	2	–	–	2	–
Majorca	1	–	–	–	1
Malta	3	–	–	1	2
Morocco	3	–	1	2	–
Netherlands	125	125	–	–	–
New Zealand	9	9	–	–	–
Norway	44	42	2	–	–
Pakistan*	1	1	–	–	–
Philippine Is.	1	1	–	–	–
Poland	4	4	–	–	–
Portugal	9	5	4	–	–
Rhodesia	3	3	–	–	–
Russia	5	2	3	–	–
Scotland	45	45	–	–	–
South Africa	25	11	2	11	1
Spain	2	–	–	–	2
Sweden	13	13	–	–	–
Tunisia*	1	–	–	1	–
Turkey	35	10	24	1	–
U.S.A.	16	12	1	–	3
Wales	2	1	1	–	–
Yugoslavia	6	2	1	–	3
TOTAL	1144	879	152	50	63

* Greatly under-represented

† Only a representative selection of types kept for seed-collection

strains, a state that reflects the initial infestation. The Rothamsted seed-collection supports this, but shows greater variation within samples from research stations. It also reflects the higher proportion of *A. ludoviciana* in Queensland than in New South Wales, and the variability of both. The three samples of *A. fatua,* nine of *A. ludoviciana* and two others (possibly a yellow *A. sterilis*) from the same place show no dominant type.

The Rothamsted seed-collection contains numerous and very varied samples of *A. fatua, A. ludoviciana* and *A. barbata* from South Australia with types fA and lA predominating, *A. fatua* from West Australia also mainly fA, but only one *A. ludoviciana* from Western Australia (brown husked, glabrous, with long hairs at the callus, ie not the common type lA) and fewer *A. barbata.*

According to Carne and Gardner (1924), *A. fatua* ('black oat') was the common wild oat of Western Australia, occurring as a weed in crops. *A. barbata,* called Yatheroo oat from the homestead where it first appeared in the 1860s, was seldom found in crops but occurred in pastures where it could be a useful fodder-species. It also inhabited railway tracks along which it spread. Neither *A. ludoviciana* nor *A. sterilis* were mentioned.

Losses due to wild oats (species not mentioned) in Western Australia can now reach nearly 500 kg/ha, and in 1966/7 about 71,500 tonnes of wheat were subject to dockage for wild-oat content. The increase in recent years is ascribed to changing from pasture to multiple-cropping techniques, to widespread use of 2,4-D with consequent diminished competition from broad-leaved weeds and to earlier cutting by combine resulting in more wild-oat seeds being harvested with the crop (Paterson 1969).

Patton (1968) noted that *A. fatua* and *A. ludoviciana* occurred on most farms in the cereal growing areas of Victoria, but infestations were generally light (6 to 8 plants per 50 ha) with occasional patches of several square metres, occasionally up to 1 plant/m^2. Infestation was greatest on poor-structure clays where winter wheat was sown early, and had been worse in the 1920s and 1930s than in 1968. Most of Victoria grew a legume-ley rotation which provided good cultural control for wild oats.

Belgium

The distribution and variability of wild oats in Belgium was studied intensively from 1959 to 1962 by sampling just before harvest (Stryckers and Pattou 1963). Only *A. fatua* was found (and some *A. strigosa* which is not a wild oat). It was most frequent in the lower-lying northern regions, especially Flanders and Limburg. Eighty one per cent of all samples contained *A. fatua.* Up to 16 types were recognised, generally only 2 or 3 occurring in each field, but up to 7 or 8 per field in West Flanders where the infestation is longest established. The commonest type is fF or 'Belgian brown' in 55% of all samples, with fA in 48%, fB in 26, fG in 19%, fE in 16% and nine other types represented in 1 to 11% of samples. Types fA, fB and fC are commonest in West Flanders, and this is attributed to straw imported from England in the First World War. In East Flanders the common type is fF. (Stryckers and Braeckman 1961). Pattou (1961) did detailed research on

Belgian *A. fatua* but it is difficult of access as his thesis is in Flemish. The same difficulty is encountered in various other accounts of wild oat research published annually (eg Stryckers and Braeckman 1959, 1961) but some is included in Stryckers and Pattou (1963) with very brief French, English and German summaries.

The Rothamsted seed-collection includes material from the survey described above. It agrees with the preponderance of types fF (36/126) and fA (24/126). Partly because fF is the most abundant, types with short hairs at the callus outnumber those with long hairs by 67 : 59. Eight other types with short hairs at the callus are included and also 13 long-haired types other than fA.

Although Stryckers and Pattou (1963) did not find *A. ludoviciana* growing in Belgium, unripe lA found in hay imported from Italy into Belgium in 1960 is in the Rothamsted collection.

Bulgaria

A. ludoviciana occurs, but only in the South (Georgijev 1963, quoted in Kropac and Lhotska 1971). Two specimens of lA, collected by a roadside in 1971, are in the Rothamsted collection.

Canada

A. fatua is the only wild oat species recorded in Canada. The climate is unsuitable for the Mediterranean species and spring sowing also militates against winter germinating *A. ludoviciana.* Clark (1914) stated that the husks of Canadian *A. fatua* varied from almost black to brown, and grey to white but did not mention hairiness. The only seed he illustrated has long hairs at the callus and a tuft of hairs at the base of the awn, as in type fH.

Lindsay (1952, 1956) described four types of *A. fatua,* all occurring in Manitoba, Saskatchewan and Alberta and belonging to subsp. *fatua* (L.) Thell. He identified them from Malzew (1930) as var. *intermedia* (Lestib.) Lej. et Court., var. *vilis* (Wallr.) Hausskn., var. *pilosissima* S. F. Gray and var. *glabrata* Peterm. He also found a few panicles of *A. fatua* ssp. *cultiformis* which he considered unimportant as the seeds were non-dormant. In the specimens which Lindsay called *intermedia* and *pilosossima* the lemmas were dark brown to black, while those of the other two varieties ranged from yellow to dark grey. He also found specimens with pubescent lemmas of various colours and classified them under one of his four varieties according to lemma colour and length of hairs at the callus, although they differed from the type-descriptions in hairiness of the lemmas. Malzew does not mention lemma colour. Partly as a result of this misuse of the nomenclature and partly because the application of comparative criteria such as hairiness depends on the opinion of the observer and on the range of specimens available for comparison, Lindsay's specimens do not correspond to the British specimens to which the same names have been applied.

Specimens of Lindsay's four varieties of ssp. *fatua* were grown in pots at Rothamsted in 1953 (Thurston 1957). All the Canadian specimens bred true and tended to flower earlier than those from Rothamsted farm grown for

comparison. His so-called var. *pilosissima* were only slightly hairy and were type fI (not fA) and his so-called var. *glabrata* was not glabrous and the lemmas were grey, corresponding to the least hairy English specimens of fB, not to fC. The Rothamsted-grown spikelets of his var. *intermedia* were considerably more hairy than the parent grains (possibly because the lemmas of the originals had lost some hairs in transit), and corresponded to type fF. His var. *vilis* had much narrower grains than type fM and agreed with English specimens of type fG, to which C. E. Hubbard of Kew Herbarium proposed to apply the varietal name *pilosa* Syme. Malzew regards this as a synonym of var. *intermedia* (Lestib.) Lej. et Court.

Canadian samples collected in 1953 (Lindsay 1956) indicated the relative abundance of the four types in western Canada as fF 44%, fG 33%, fI 19% and fB 3%, in marked contrast to their abundance in England, and also with many other countries where fA is the commonest type. Each Canadian type consisted of a number of races or strains, some differing considerably in time of panicle-emergence and seed-ripening, but Lindsay did not relate this to the place of origin. Some strains had prostrate and others erect tillers. Artificial crosses suggested to him that fF may have been the fundamental type in Canada and that the other three were produced by crossing it with *Avena sativa* and back-crossing. He suggested that the wild-oat population in western Canada contained many hybrids and that new strains were being produced continually. He did not discuss the possibility of fresh introductions from other countries with a different range of types.

Corns (1953) collected black-grained selections of *A. fatua* in various parts of Alberta and grew them in field plots at Edmonton. The numbers of tillers per plant, 17 to 22, did not differ significantly, but the differences in number of panicles, from one to four per plant, were highly significant.

Canadian samples of *A. fatua* seed can differ considerably in dormancy at collection. Bibbey (1948) had difficulty in obtaining dormant seeds in one year from a site which yielded 95% dormant in another season under apparently similar conditions. Some variability is found in varieties and strains (Sexsmith 1967). It may also be caused by differences in temperature and soil moisture during ripening. Sexsmith (1969) reported that *A. fatua* was less troublesome in the warmer and drier parts of south-eastern Alberta than in irrigated areas or the cooler and more moist parts of the Province. To test this, he grew in pots two less-dormant strains of *A. fatua,* which he related to Lindsay's var. *intermedia* (probably type fF) and two with above-normal dormancy of Lindsay's var. *vilis* (probably type fG), with controlled temperature and soil-moisture. At 15.6°C with approximately 75% available soil moisture, dormancy was from 31 to 100% greater than in seeds grown at 26.7°C and approximately 25% available soil moisture. Both strains and varieties differed; at 10 and 14 days after maturity his var. *intermedia* germinated 100 and 94% and his var. *vilis* 70 and 31%. The number of days after maturity affected the results. He concluded that in the field, under hot dry conditions a small amount of wild oat seed would be produced, with limited and rapidly-overcome dormancy, leading to a gradual decrease in the wild-oat population, but a proportionate increase in the more dormant

strains. In contrast, a succession of seasons of low temperature and high soil-moisture would give rise to much very dormant wild-oat seed, whatever the strains originally present. This contrast could explain the differences in wild-oat infestations observed between climatic regions of Alberta.

The only Canadian wild oats in the Rothamsted collection are Lindsay's own examples of his types, and some threshed *A. fatua* with brown, brownish-grey, grey or yellow lemmas, taken from imported Canadian feeding-barley on a farm in Northamptonshire.

Chile

The Rothamsted collection contains one specimen of *A. barbata,* collected in October 1965 from waste land, 30° 30′ South in an area with only 150 mm rainfall per year.

Corfu and Crete

Both *A. sterilis* and *A. barbata* have been collected, but no records of distribution in agricultural land have come to light.

Cyprus

Herbicides for control of wild oats in wheat were being tested in 1966. on three farms at Kondemenos, one at Morphou and one at Pyroi, and untreated plots had from about 20 to 150 wild oat plants/m^2. A field free of wild oats was used for toxicity studies at Mesacria (Cyprus Agric. Res. Inst. 1966). The wild-oat species is not stated, nor the sowing date of the wheat, but there is a specimen of *A. ludoviciana* from Cyprus in the Rothamsted seed-collection. Good control was obtained with barban and tri-allate and the wild-oat experiments do not appear in subsequent reports, so presumably the wild-oat problem in Cyprus is considered capable of solution. There is no evidence to show how successful control has been in commercial practice, but field trials in 1965-7 showed consistent, though not always statistically significant, increases in yield where wild oats were controlled with herbicides (Papasolomontos 1967).

Czechoslovakia

Collections of wild oats from nine fields, in six localities in Bohemia, were received for the Rothamsted seed-collection in 1961. All are *A. fatua.* Every field has fA and in all except one it is by far the most abundant type. The exception is a spring barley field from the south where fF outnumbered fA by four to one. Spring barley near Prague and further north-west contained mainly fA, and fF was present as a minority in all the fields except a potato field in Eastern Bohemia. Seeds resembling fD were found in seven fields, but have not been grown-on yet to see if the habit and hairy nodes and low percentage dormant seeds place them in ssp. *septentrionalis.*

Denmark

A. fatua ssp. *fatua* reached Denmark with *A. sativa* in the Bronze Age and was a serious problem from the Middle Ages. It now occurs in all parts of

Denmark and is comparatively dense on the southern islands and parts of Zealand. It is increasing over most of Jutland, where it was formerly almost unknown. *A. sterilis* ssp. *ludoviciana* is also reported from a few places, eg Ringkøbingegnen (Odgaard 1970).

A. fatua tolerates all variations of soil and climate found in Denmark. It is a weed of cultivated land only, especially spring cereals (Odgaard 1972).

A. fatua seeds of Danish origin at Rothamsted (some of them from a Finnish collection) show a majority with short hairs at the callus, the commonest being 'Scandinavian grey' and fF (Table 2.2). Type fG, and a type with glabrous yellow husks and short hairs at the callus each occur once. Six types with long hairs at the callus also occur once each; these are fA, fB, fC and three with unusual combinations of characters, ie like fB but glabrous (or like fC but grey), like fA but with the glabrous region just above the callus characteristic of fF, and like fI with silver hairs.

Ethiopia

A small-seeded sample of *A. sterilis* with pale grey very hairy husks, long hairs at the callus and smooth awns, from the Asmara plateau, is in the Rothamsted collection.

Finland

Wild oats were recorded sporadically in Finland from 1860. A comparison of infestation in imported and home-produced cereal seed annually from 1919 to 1958 showed sporadic heavy infestations in imported oats and barley and fewer in wheat and rye from 1924 to 1946, with less-frequent infestations in home-produced oats, very few in wheat and barley and none in rye over the same period. From 1947 imported oats usually, and home-grown oats and barley always, contained wild oats. Home-grown wheat was usually infested from 1950 onwards, but wild oats did not appear in home-grown rye examined at the seed-testing station until 1958. Between 1923 and 1958, wild oats were most dense in the south-west of Finland but occurred in almost the whole southern half of the country. In 1958 home-grown seed from 82 places contained wild oats (Hilli 1959) but by 1967 this had increased to 180 (Hilli, personal communication).

Most of the Rothamsted samples from Finland were supplied in 1959 by Professor Hilli from his collection of wild oats at Helsinki. All originated from the southern half of the country, the furthest north from Ylikiiminki inland from Oulu, one from Ramtasalmi in the east, half way between Savonlinna and Varkaus, two in the west, inland from Vaasa (Voyri and Vahakyro) and eight from the south-west, in an area roughly bounded by a triangle from Turku to Helsinki to Tonala. All are *A. fatua,* about half with long hairs at the callus and half with short. As these specimens are from a seed-collection and not directly from a field, it is unwise to stress the relation between types and locality of origin, since only the less-common ones may have been kept. However, it is worth noting that the most northerly place had the uncommon type fH as well as fB. Indeed, fH was represented at four sites, as were Scandinavian grey and fA. Other types were mainly unusual combinations of

characters, some cream instead of more definite colours, or less hairy than similar seeds from elsewhere.

France

Wild oats had become very troublesome in south-western France by the mid-1850s with losses estimated at 15% of the potential yield of cereals in 1853 and 1855. Both *A. fatua* and *A. ludoviciana* were present, the latter described and named by M. Durieu of Maisonneuve. The fields around Moissac at this period contained almost exclusively *A. ludoviciana* which up to that date had been described in the flora of Tarn-et-Garonne as *A. fatua* (Lagrèze et Fossat 1856). By 1925, *A. fatua* was present in most of France except the north west (Chevalier 1925). He considered *A. barbata* to be a subspecies of *A. fatua. A. sterilis* and *A. ludoviciana* were not found north of the Loire.

Maps of more recent wild oat distribution (Barralis 1961) show that *A. fatua* covers most of France, is common or very common except in the East, the Mediterranean region and the upper Rhône valley and reaches the highest altitudes at which cereals are grown, eg 1100 m in Haute Savoie. It is especially abundant in those regions where spring barley is most frequentl' cultivated (de Gournay 1964).

A. ludoviciana (=*A. sterilis* ssp. *ludoviciana* in Barralis 1961) is less widespread than *A. fatua,* occupying only about 30-50% of the total area of France. It is mainly concentrated in the Atlantic region (Basses-Pyrénées, Landes, Charente Maritime, Deux-Sèvres, Vendée) but can occur as far north as Nièvre and Loiret, and occasionally in Oise and Aisne. It is a lowland species, not exceeding 200-300 m altitude, and is a weed of cereals, grassland and vineyards.

A. sterilis ssp. *macrocarpa* is abundant throughout the Mediterranean region in fields, vineyards and on heaths as far as Drôme and Ardeche and the Southern Alps, and here and there in the south-west at low altitudes. It is very rare in the rest of France, being found very occasionally in the lower Loire valley, Eure, Meurthe and Moselle, and Nord near Hazebrouck. It is a weed of vineyards, clean cultivated crops of the Midi and also of roadside and waste places throughout the midi of Provence.

A. barbata, which Barralis (1961) calls *A. strigosa* ssp. *barbata,* is found in the same regions as *A. ludoviciana* and *A. sterilis* ssp. *macrocarpa* and also further north into Finistère and Côtes du Nord, especially around Dinard. It is a ruderal, characteristic of mediterranean steppe vegetation, heaths, short turf, dry barren hillsides, uncultivated places and road-sides up to 350 m altitude at most.

The probable reasons for the spread of *A. fatua* in French cereal crops since 1945 are listed by de Gournay (1963) as (1) fewer broad-leaved weeds, eg *Sinapis arvensis,* since the introduction of herbicides for control of broad leaved weeds, (2) use of heavy dressings of nitrogenous fertilisers, (3) combine harvesting after most seeds of *A. fatua* have shed in contrast to the earlier harvesting customary with a binder, (4) the lack of suitable crop-rotation which would allow control by cultivations and prevent build-up of wild oat seeds in the soil. By 1964, it was estimated that 10% of the arable

land of France was contaminated with *A. fatua* and about 30% of the barley-growing areas (de Gournay 1964).

More recently Guillemenet (1971a) has reviewed the status of *A. fatua* and *A. ludoviciana* in the Department of Vienne. Both species show considerable autumn germination there. In 1970, *A. fatua* had 63% germination and *A. ludoviciana* 80.5% of first seeds and 26% of second seeds by 23 November. Wild oats were present on soils of Jurassic and Cretaceous origin except where they were podsolised, and almost or completely absent on soils derived from younger rocks.

Over 200 specimens of French wild oats in the Rothamsted collection include only two *A. barbata,* reflecting the conclusion of Barralis (1961) that it belongs in waste places, not in fields. *A. fatua* is the best-represented species and out of 153 specimens, 94 are type fA. The remainder cover most of the types in the English list (Table 2.1) plus 'Scandinavian grey', with a few samples of each. Type fF is represented by 18 samples, 8 from Nord, 5 from Pas de Calais, 3 from Aisne and 1 from Somme, agreeing with its distribution on North Sea and Channel Coasts of Holland and Belgium, and only one sample, from Corrèze, extending its range. There are 14 samples which might be type fD, but without culm-nodes to examine for hairiness, and in the absence of germination tests to show whether only 50% of the seeds are dormant at harvest, the existence of *A. fatua* ssp. *septentrionalis* in France remains unproven. Less-common combinations of characters also occur, with one to five examples of each.

A. ludoviciana is represented by 47 samples, 25 of the very widespread type lA, 11 of lC, one each of lD, lJ and lK, and other combinations of characters by one or two specimens of each. Two samples came from Arras in the north-east, but others from further south, as might be expected from the distribution described by Barralis (1961).

Germany, West (Federal Republic)

The increase in area infested and in density of stand of wild oats during this century is well documented since Zade (1912) published a detailed map showing the distribution of *A. fatua* in Germany in 1909. Bachthaler (1966) produced a corresponding map for 1965. Both show *A. fatua* throughout the whole country, with the greatest concentration in the south, but the more recent study shows increased density in parts of the east and west. Another map (Bachthaler 1966) demonstrates that the regions most heavily infested with wild oats are those growing the biggest area of spring cereals, ie Bayern, Baden-Württemberg, Rheinland-Pfalz, Hessen and Nordrhein-Westfalen, and also those parts of Niedersachsen and Schleswig-Holstein where spring cereals are most often grown. The increase since the second world war is often ascribed to the introduction of combine-harvesting and the decreasing agricultural labour-force, resulting in emphasis on cereal cultivation, which has given the wild oats an opportunity to multiply. That they have done so is demonstrated by the increasing percentage of cereal seed-multiplication samples from Bayern rejected because of wild oats. Comparing the means for 1952-62 with 1963-73, rejections of winter wheat increased from 19 to 36%

spring wheat 46 to 74, spring barley 43 to 60 and oats 54-66%. Wild oats are now the chief cause of rejection of field crops of cereals for seed, accounting for 46.6% of rejections, ie almost as much as diseases, other weeds and the presence of rogue varieties combined. Mittelfranken is the only one of seven subdivisions of Bayern showing even a slight decrease (from 55 to 47%), this being entirely due to the rejection of less of the oat crop. In Schwaben the total acreage rejected is almost identical in the two decades but losses of spring barley were less and oats more in 1963-73 (Bachthaler and Kanzler 1974). There is no mention of *A. ludoviciana* in these papers but it is said to occur in north-west Germany in the Ems valley (Locock 1972 personal communication).

Regions in southern Bayern with intensive row crop cultivation are kept free of wild oats, or only slightly infested, by the mechanical cultivations and herbicides applied to beet and potatoes. Late-sown winter wheat offers little competition to spring-germinating *A. fatua* (Bachthaler 1966).

Wild oats in the Nordrhein region were investigated by Kiewnick (1966). Although he was familiar with *A. ludoviciana* he did not find it in samples; the wild oats in winter wheat were autumn-germinated *A. fatua.* The only districts where wild oats were not found were Siegkreis Oberbergischen Kreis and Rheinisch-Bergischen Kreis. From the remainder he obtained nine forms of *A. fatua*; 43% of the samples contained type fA, the next commonest being fF, fB and fI. The remaining five sorts occurred in less than 16% of the samples–they were fC, fD, 'Dutch yellow', 'Scandinavian grey' and one not previously listed, with dark brown, rough, slightly hairy lemmas and long brown hairs surrounding the callus. All forms occurred in both spring and winter cereals.

The 98 samples of wild oats from all over West Germany in the Rothamsted collection are all *A. fatua*–26 fA, 16 'Scandinavian grey', 11 fF (=Belgian brown), 8 'Dutch yellow', 3 each fC and fI, 2fB, 1 fE and 28 others of nine different types, each represented by one to six samples. These cover a wider area than those of Kiewnick (1966) although they include some sent by him and by Bachthaler. They agree on the dominance of fA and put fF high on the list, but include more 'Scandinavian grey' and less fB than Kiewnick's samples.

Germany, East (Democratic Republic)

Zade's (1912) map of *A. fatua* in Germany in 1909 includes present day East Germany, showing that wild oats were concentrated in the southern half. Comparison with Feyerabend's map of *A. fatua* distribution in 1960 (Masurat and Stephan 1961) shows that it is probably still so, but the large numbers of areas from which information was lacking in 1960 prevents a more exact comparison. The smaller dense area to the east seems to have persisted since 1909.

Wild oats entered East Germany long ago, starting with heavy soil areas such as Oderbruch, in Thüringen and in Altmärker Wische. Since then they have spread, and the absence of samples in parts of the map does not imply absence of wild oats, eg they are known from other collections to be present

in Frankfurt/O and Magdeburg in addition to Oderbruch, the Erfurt region and around Jena and Eisenberg, all parts of Halle, and around Delitzsch, Leipzig, Borna, Döbeln and Oschatz and they are particularly dense in Torgau district. In Cottbus, the Jessen, Herzberg and Finsterwalde areas are more heavily infested than Liebenwerda, Luckau, Lubben, Cottbus and Calau, and the eastern parts of this region have no wild-oat problem. Around Frankfurt/O wild oats have not yet appeared on the lighter soils, and in Magdeburg the heavier soils are most severely affected. Meinigen is the worst infested part of its region (Masurat and Stephan 1961).

The 18 samples contributed by Feyerabend to the Rothamsted collection are all *A. fatua* but surprisingly contain no type fA, unless one of the unripe specimens belongs to it. Types fC, fG and fI are recognisable, and five less usual combinations of characters, and three specimens are unripe. Five samples from another source include 1 fA, 1 fG and 3 others not belonging to any of the described types. Evidently fA is not dominant in East Germany and types less frequently seen further West occur frequently.

Greece

Much of the area under cereals is invariably infested with wild oats. The main species is said to be *A. ludoviciana. A. fatua* ssp. *fatua* is of minor importance and confined to the north of the country. Biological differences within and between species make chemical control difficult. Spread is ascribed to the usual factors—less competition from broad-leaved weeds since the introduction of hormone herbicides, the trend towards monoculture of cereals, contract ploughing and harvesting introducing seeds with machinery, sowing of inadequately-cleaned seed—and two less often mentioned, ie the recent introduction of less competitive semi-dwarf wheats and the absence of frost in three or four recent winters (Skorda 1972).

The five samples in the Rothamsted seed-collection were all contributed by returning holiday-makers and may not have come from fields. One from Delphi is type lA. The others are all very hairy types of *A. sterilis,* two of them unripe and the others with brown lemmas. They came from Lindos Mykonos and Delos.

India

Five papers presented at the 3rd All India Weed Control Seminar in 1973 listed wild oats among the species requiring control in the areas New Delhi (Gautam *et al* 1973), Allahabad (Chowdhary *et al* 1973), Hissar (Hooda *et al* 1973), Rajasthan (Rathore and Singh 1973) and Punjab (Bir and Sidhu 1973); in the latter, *A. fatua* was among the four weed species most often found to be dominant. In the final plenary session of the seminar it was noted that during the last ten years grasses had replaced most of the dicotyledons in the weed flora of dwarf wheat. Chief among them were *A. fatua* and *Phalaris minor;* they could be controlled by tri-allate or barban. Most of the papers omitted to identify the species of wild oat.

Iraq

No literature on distribution of wild oats in Iraq has been found. Eight samples of wild oat seeds collected in fields in 1958 by a member of Rothamsted staff consist of 7 *A. ludoviciana* and 1 threshed *A. fatua,* the latter with brownish-grey husks. None of the combinations of lemma characters in the *A. ludoviciana* samples fit any of the published groupings. Unusually, 5 have glabrous lemmas, 1 has a tuft of hairs at the base of the awn and 1 is moderately hairy, whereas very hairy lemmas are more frequent elsewhere. All have long gold hairs at the callus. Three are brown-husked, 1 brown-grey, 2 yellow and 1 pale grey.

Ireland (see also N. Ireland, under United Kingdom)

A. fatua has been recorded as rare and occasional, eg in floras of Ireland in 1836, 1866, 1888 and more recently in cereal fields in various parts of the country (Curran 1967). By 1965 it was well established in North County Dublin, where one small field had approximately $1/m^2$ and adjacent fields much less. It is locally believed to have been introduced about 1940 in Canadian imported oats fed to horses (Curran 1965). *A. fatua* is also reported from Counties Kildare and Wexford (Curran 1967) but *A. ludoviciana*, *A. sterilis* and *A. barbata* are not mentioned and there are no specimens from Ireland in the Rothamsted seed-collection.

Israel

There are 16 *Avena* species in the flora of Israel, in groups with 14, 28 or 42 chromosomes (Ladizinsky 1971b). Many of them are native components of natural vegetation and do not invade fields, but they are among the most conspicuous annual grasses of Israel. They vary in their preferences for soil-type and ecosystem and hence are associated with different localities. *A. hirtula* occasionally invades roadsides and the edges of cultivated fields. Tetraploid forms of *A. barbata* are widespread over the Mediterranean part of Israel, on a great variety of soils and at altitudes up to 1500 m on the slopes of Mt. Hermon. They often form dense stands at the edges of cultivated fields and on roadsides. On the coastal plain they are especially associated with sandy soils and with stony habitats in the hills, but are less frequent on deep heavy soils. They are very variable in panicle shape, spikelet colour (white, red or black) hairiness of lemmas, and hairy or glabrous leaf-sheaths. Hexaploid *A. sterilis* forms are widespread over the entire Mediterranean territory of Israel, forming genuinely wild components of the oak park-forest belt and similar steppe-like formations in Eastern Galilee, the Samarian hills and foothill regions, characterised by a lush herbaceous cover in winter. Here, *A. sterilis* is often the most important annual constituent of the flora, and so far from being a weed, is a valuable pasture plant in winter and spring. *A. sterilis* is also a conspicuous coloniser of opened-up lands in the Mediterranean heaths and shrubby regions and is an aggressive weed in cereal fields, the edges of cultivated areas, and on roadsides. It often colonises abandoned cultivated areas and is closely associated with heavier, richer soils but more rare and less luxuriant on poor soil, due more to low fertility than

to insufficient water. This species is best suited to areas with relatively mild winters and 350-800 mm rainfall. It is a very variable species and stands are often highly polymorphic. The most obvious variations are in spikelet size (15-25 mm), coloration (whitish-yellow, brown or black) and hairiness of lemmas and awns. *A. fatua* is rare in Israel but occurs sporadically mainly as a weed in cereal fields. On the south slopes of Mt. Hermon it, together with *A. sterilis,* colonised an area cleared of natural vegetation.

A. sativa is often grown for hay in Israel and hybridisation with wild or weedy *A. sterilis* is apparently quite frequent, giving rise to 'hybrid swarms' and variation within species due to hybridisation (Ladizinsky 1971b).

A. sterilis is a strong competitor for water and can dominate first year seedlings of local dwarf shrubs on deep soil, but on shallow poor soils the shrubs predominate (Litav *et al* 1963; Litav 1965).

The Rothamsted seed collection has 11 samples of *A. sterilis* from Israel mainly from the Haifa, Jaffa and Ashkelon regions. Five have brown lemmas and are mainly very hairy with glabrous awns. The abscission-scar is too oblong for *A. ludoviciana.* Three are similar with grey lemmas. Two are yellow husked with hairy awns and one is unripe. There are also two specimens of *A. barbata* from the Jaffa region, one out of wheat and the other from an orange-grove.

Italy and Sicily

Cesari and Sgarzi (1973) found *A. ludoviciana* in wheat crops all over Italy, with *A. fatua* in the north and *A. sterilis* in the centre and south. *A. barbata* was also recorded but is confined to field margins and waste places.

The Rothamsted seed-collection contains 10 samples, contributed by five people, none of them Italian. The two specimens from Foggia in Southern Italy have very hairy lemmas, long hairs at the callus and moderately hairy awns; one has brown lemmas and the other grey. Two unripe specimens collected in 1960, one from Bologna on the south edge of the Po valley and the other from Laigueglia on the Italian Riviera, are very hairy with long hairs at the callus and smooth awns. It is possible that when ripe the lemmas would be brown. A specimen from Syracuse, Sicily, in 1963 has yellow very hairy lemmas, long hairs at the callus, and scabrid awns. One from Taormina, Sicily, also in 1963, is unripe with very hairy lemmas. A specimen collected near Brescia in 1963 has yellow very hairy lemmas, long gold hairs at the callus and smooth awns, the scar is oval and the spikelets are smaller than the yellow *A. sterilis* from Syracuse; it is probably a form of *A. ludoviciana* not listed from England. The remaining three specimens are *A. barbata,* one from Torcello near Venice in 1960 and two from Sicily (Syracuse and Taormina) in 1963. There are no Italian samples of *A. fatua.*

Japan

Nishiyama and Inamori (1966) studied the length of the dormant period in seeds of *Avena* species including *A. fatua, A. barbata* and two samples of *A. sterilis* ssp. *macrocarpa* but, as no translation was available, the origin of their material is not clear. There are no Japanese specimens in the Rothamsted collection.

Kenya

Nothing seems to have been published about the distribution of wild oats in Kenya, but there is considerable interest in the subject (Owino 1974, personal communication). Wild oats occur in the wheat-growing areas especially at altitudes over 2100 m. At present, *A. fatua* is said to be the commonest species, reaching densities over 150 panicles/m^2 and threatening wheat production in some areas. Type fA predominates in the sample sent to Rothamsted, with a few seeds of fF. Intermediate types (fatuoids or hybrids between wild oats and *A. sativa*) also occur in patches among *A. fatua.* Previously, *A. sterilis* var. *maxima* was more serious, but it seems to have been reduced substantially and is now more common below 2000 m. Other specimens of this variety, also at Rothamsted, were collected in the mid-1960s, one from the Kenya Highlands (exact locality not specified) and the rest from Mau Narok at 2600 m. Another form of *A. sterilis,* probably ssp. *macrocarpa,* is now also found below 2000 m.

The remaining recent sample is an awnless oat with lines of hairs up each side of the lemmas. Its locality of origin is not known and it does not match anything in the Rothamsted collection. Mr. Hubbard, formerly of Kew Herbarium, suggests that it may be a hybrid between *A. sativa* and one of the wild oats, but it has not yet been grown on to see if the plants or the next generation of seeds provide clues to its origin.

Majorca

There is one specimen of *A. barbata* in the Rothamsted collection, probably from a roadside.

Malta

In 1957 an English agriculturist found cereal fields infested with unfamiliar wild oats and sent specimens to Rothamsted (Haesler 1957, personal communication). One type was identified at Kew as *A. sterilis* L. var. *scabriuscula* Perez-Lara and the other as *A. barbata* Brot. They came from winter barley and waste ground, and from what we know of these species elsewhere we can guess that *A. sterilis* was out of winter barley and *A. barbata* from waste ground. At that time wild oats growing in stubble provided useful grazing and there was no pressure from farmers to eradicate them. Another Maltese specimen of *A. barbata* was received in 1967.

Morocco

In 1969, herbicide trials for destruction of *A. sterilis* were in progress in Morocco (Geigy 1969) so it must have been a serious problem then. Although trial-results were promising, the species has not been eradicated, as four samples of *A. sterilis* ssp. *macrocarpa* and two of *A. ludoviciana* type 1A were received in 1974. No other specimens have been sent in from Morocco.

Netherlands

The occurrence of wild oats, and reasons for their spread, were investigated in 1956 (Zonderwijk and van Dord 1958). Only *A. fatua* was found. Four

'subspecies' (varieties) were recognised: *hybrida* (probably 'Dutch yellow' and/or 'Scandinavian grey') .accounting for 42% of the material collected, *pilosissima* (fA) and *intermedia* (possibly fF) for 25% each, and *glabrata* (fC) 8%. No connection was found between growing conditions and distribution of types. Only 6% of fields sampled contained all four types, 18% had three, 32% had two and 44% had only one (this probably reflects recent introduction in the one-type fields, in contrast to the complex mixtures found in most English fields, with their long-established infestations). Wild oats were said to have spread widely in the Netherlands since 1954 with the increased cultivation of spring cereals (this would also militate against the establishment of *A. ludoviciana*). Wild oats were not as serious in well established winter cereals, and it was said that in the Netherlands *A. fatua* did *not* germinate in autumn, so stubble ploughing in autumn was ineffective in control. The use of herbicides against broad-leaved weeds had allowed the wild oats to multiply, and because many people were unfamiliar with *A. fatua,* controls were usually applied too late. Mechanical control was effective in beet and potatoes, and wild oats did not develop fully in flax and peas (in contrast to experience with those species in Britain and Canada, for example). Wild oat control by herbicides was being sought.

Most of the samples (93 out of 123) from the Netherlands in the Rothamsted collection, have short hairs at the callus–28 fF, 23 'Scandinavian grey', 15 'Dutch yellow', 6 fE, 4 fG, 22 fH. The rest consist of one to three examples of unusual combinations of characters or of unripe specimens. Only 30 have long hairs at the callus–12 fA, 4 fB and 1 or 2 each of other less usual combinations of characters. In addition, types fA and fF were found in cereals for food, imported into Germany from the Netherlands.

New Zealand

Until 1974, New Zealand had only one regulation for control of wild oats–seed of herbage cultivars was rejected if wild oats were found in the paddock (field) where it was grown or in harvested seed. Nevertheless, it is recognised as a serious weed in New Zealand, and contaminated cereal seed as one cause of spread. Variety Tama has a particularly high percentage of contaminated samples passing through the Seed Testing Station. The New Zealand authorities, even when faced with residual weed-seed contamination, have always been reluctant to condemn machine-cleaned stocks of cereal seed at that late stage, after so much effort and money has been expended on producing them. Furthermore, rejection did not guarantee that they would not be sown somewhere. Starting with the 1974 inspection, cereal seed crops with wild oats growing in the same field will be rejected. Farmers are urged, but not compelled, to use rejected stocks for feeding and not to attempt to sell them for seed (Lithgow 1974). The article is illustrated by a picture of dense patches of wild oats in barley at Methven, but the species is not mentioned and cannot be recognised from the picture.

The Rothamsted seed collection has 9 samples of *A. fatua* from New Zealand and no other species. They are 3 fF, 2 fA, 2 fB, 1 like fA but with silver hairs, and 1 like 'Scandinavian grey' except for its brown-grey

lemmas. Seven of the samples are from the Canterbury Plain in the South Island, the origin of the other two is not known.

Norway

A. fatua was already a serious weed in parts of Norway in the 18th century, and although it was probably never deliberately cultivated, it was harvested for food in years of famine. By 1958, anxiety about wild oats had increased (Bylterud 1958), although it is only a problem in certain parts of the country. It is commonest in the valleys of East-Central Norway and also in parts of the Oslo district. The valleys of Hallingdal, Valdres, Gudbrandsdal and Österdal and the vicinity of lakes Tyrifjorden, Randsfjorden and Mjøsa are particularly affected. The northernmost infestation is on a small island at 65° N. The districts where *A. fatua* is common have less than 600 mm precipitation per year (Storhaugen 1961a,b).

Considerable variation in seed characters is shown by *A. fatua* in Norway, brown or grey lemmas with varying density of hairs occurring. A hairless type seems to have become more common in Scandinavia during the last century (Storhaugen 1961a), presumably 'Scandinavian grey'. Fykse (1970b) illustrates in a black and white photograph four types which probably represent fA, fF or fG. fC and 'Scandinavian grey', and lists some of the places where they occur, and from which he obtained samples for his experiments. He sowed 20 selections, from four to seven of each of four types obtained from different parts of Sweden, in two places with contrasting climate. At Vågå the mean precipitation was 326 mm and the mean temperature 2.6° C and at Ås precipitation was 793 mm and temperature 4.9° C. At each place he used three types of soil and different depths of sowing. In Vågå germination was greatest in the first year and decreased steadily thereafter, whereas in Ås it was greatest in the second year and least in the third. Wild oats died out more quickly in Vågå than in Ås, regardless of soil type, depth of burying, and management. The maximum viability of buried seeds was five years for dry samples inland and six to nine years for regions with a milder, wetter climate. The greatest longevity was in heavy soil. Individual selections differed somewhat in dormancy under various experimental treatments, but this was not related to husk-characters (Fykse 1970b).

The 41 Norwegian samples of *A. fatua* seed in the Rothamsted collection include nine 'Scandinavian grey', 6 fA, 3 fB, 3 fC, 1 fE, 4 fF, 2 fG, 2 fI and a number of less common combinations of characters, each represented from one or two places. Some *A. fatua* samples from Norway took only 109-112 days from germination to flowering when grown in a pot experiment at Rothamsted, indicating their origin in grain imported from USA (Thurston 1964a).

A. ludoviciana is very occasionally found in Norway (Storhaugen 1961a). One of the samples of 1A in the Rothamsted collection was collected on a rubbish dump near Bergen in 1947 and the other was found in imported fodder grain in 1960. Imported grain was also the source of a sample of *A. sterilis* with small grey glabrous spikelets, collected in 1969 and resembling

a sample from Toowoomba, Australia. *A. sterilis* ssp. *macrocarpa* is sometimes sold in Norway for floral arrangements.

'Giant oats' are sometimes reported from fields in Norway, standing well above the surrounding crop and having very broad leaves and thick culms. These appear to be aberrant forms of *A. sativa.* Some specimens grown-on at Rothamsted in 1963 formed panicles but few of the seeds were viable. When propagated from tillers rooted in water-culture in the glasshouse, the resulting plants retained their 'giant' form. Tubular leaves were sometimes formed on giant oat plants in the glasshouse, although there was no possibility of hormone spray having reached them. The cause of the giant habit was not discovered.

Pakistan

A single sample at Rothamsted, collected in 1962 near Sukkur in the Sind of West Pakistan, is of type fA. Plants raised from it were only about half the height of British specimens grown under the same conditions and it flowered in 94 days, compared to 129 days for similar material from Western Europe (Thurston 1964a).

Philippine Islands

A sample of *A. fatua* found near Manilla in recently-introduced cultivated oats was a pale-grey version of 'Scandinavian grey'. When grown in a pot experiment at Rothamsted, the number of days from germination to ear-emergence (111) suggested an origin in the wheat-growing belt of USA (Thurston 1964a).

Poland

The distribution of *A. fatua* in Lower Silesia in relation to ecological conditions and possibilities for chemical and cultural control was studied from 1963-69 (Pejka 1971). A map shows that at least half of the region was infested, the western part severely. Germination is mainly in the second and third years after shedding, making control difficult, and is unaffected by soil-type, but drought and waterlogging restrict growth of wild oats. Control-methods incorporating both chemical and cultural means are suggested.

Four wild oat samples from the Wroclaw region in 1966, now in the Rothamsted seed collection, are types fA, fC, fE and a moderately-hairy version of fA.

Portugal

The Flora of Portugal (Coutino 1935) listed *A. sterilis,* mainly from uncultivated fields, with vars. *maxima* and *scabriuscula* said to occur frequently and var. *calvescens* rarely; *A. fatua* vars. *glabrata* and *intermedia* from cultivated fields mainly in the north and centre; *A. barbata* from both cultivated and uncultivated areas; and various interspecific hybrids between *A. sterilis, A. fatua* and *A. sativa.* This was amended (Morais 1936) for *A. sterilis,* to read *macrocarpa* frequent in all parts of the country and adding *ludoviciana* from

Tras-os-Montes and Beira. *A. fatua* var. *intermedia* was said to be moderately frequent in cultivated and uncultivated situations. Morais (1938) subsequently reviewed the Portugese species of *Avena,* subdividing them and adding some new subvarieties of his own naming, usually based on single specimens in herbaria. The paper is concerned with classification rather than distribution or abundance. On this basis, 15 types of *A. sterilis* (including 5 of *A. ludoviciana*), 7 of *A. fatua* and 13 of *A. barbata* are recognised for Portugal. Most of the types of *A. barbata* are represented by far more herbarium specimens than those of *A. sterilis* or *A. fatua.*

Amaro and Guerreiro (1971) include *A. sterilis* ssp. *sterilis* (not a subdivision of the species recognised by Morais) in the 11 major weeds of Portugal and show that it reaches its greatest density in the south, where it is often classed as abundant or frequent but less often as the dominant weed species.

Specimens in the Rothamsted collection comprise 4 types of *A. ludoviciana,* (one lA, one lC and two others), 5 of *A. fatua,* (2 fA, 1 fC, 1 fH, 1 fJ), and 2 of *A. barbata* but the localities of collection are not known.

Rhodesia

Interest in the occurrence and distribution of wild oats, and factors affecting control, started in about 1970. At present only a limited area is thought to be infested (Thomas 1974, personal communication). The threshed sample sent to Rothamsted consisted entirely of *A. fatua,* mostly with brown lemmas. Two seeds were very hairy, the rest glabrous or with the broken remains of a few hairs, and almost all the callus-hairs had been rubbed off making recognition of types impossible. Only 3% of this large sample had grey lemmas.

Romania

A. ludoviciana was reported as a new species in Romania in 1969, on the basis of herbarium specimens from the Dobrogea district, wrongly labelled as *A. fatua* (Kropac and Lhotska 1971).

Russia

Malzew (1930) shows the distribution of four subspecies of *A. fatua* in a map (his Fig. 63) indicating that ssp. *septentrionalis* occurs in the north-east of Russia, ssp. *fatua* in the south, ssp. *meridionalis* around the southern half of the Caspian Sea and south coast of the Black Sea, and isolated pockets of ssp. *cultiformis* in central Russia. In his Fig. 64, *A. sterilis* ssp. *ludoviciana* extends slightly further north than *A. fatua* ssp. *meridionalis,* occurring all round the Black Sea, and *A. sterilis* ssp. *trichophylla* occurs only to the south and east of the Black Sea, not reaching as far as the southern end of the Caspian Sea. He does not map *A. barbata.*

No modern surveys of wild oats in Russia have come to light. The regional literature contains many experiments on cultural and more recently chemical control of wild oats, but the species is seldom named, and it does not seem feasible to attempt to review the Russian literature here.

Five specimens of wild oats from Georgia, in the Rothamsted seed-collection, are 3 *A. ludoviciana* (1A, 1f and a very hairy type with yellow lemmas) and 2 *A. fatua,* one fA and the other resembling fD, but without nodes to examine for hairs its relationship to ssp. *septentrionalis* remains unproven. Malzew's (1930) map indicates that ssp. *septentrionalis* is unlikely to occur in Georgia, but he did not expect to find it in Britain either, although it was there in 1951 (Table 2.1).

South Africa

A. fatua is frequently found in the South Cape area, less common in other parts of the country. It is an introduced species, often growing on roadsides and in cultivated lands, especially wheat fields (Henderson and Anderson 1966). Their description does not include lemma colour but describes the spikelets as bearded, presumably meaning very hairy, as the awns are described separately.

Most of the Rothamsted specimens were sent from Stellenbosch in 1965 or 1973. There are 11 of *A. fatua* all with long hairs at the callus (5 fA, 2 possibly fD, but without nodes to check for pubescence, 1 possibly fI and 3 other less common sorts). There are also 11 *A. sterilis,* eight of them very hairy (2 yellow, 1 cream, 1 grey, 2 brown-grey), one glabrous slate-grey and two moderately hairy (1 cream, 1 brown-grey). In addition, *A. ludoviciana* occurs twice, one 1C and one with brownish-grey, slightly hairy lemmas and long gold hairs at the callus. *A. barbata* occurs once.

A comparison of these samples with others in the Rothamsted collection reveals many affinities with Australian types and some with Kenya, Algeria, Portugal, France, Malta, Greece, Sicily, Israel and of course many countries for fA.

Threshed grains of *A. fatua* from Bethlehem Research Station included 30 fB and 86 brown with all hairs rubbed off. A similar sample from Senekal had 158 brown and 33 grey grains.

Samples of intermediate types between wild and cultivated oats have been received from representatives of two herbicide-manufacturing firms. One suggested that this might explain why some 'wild oats' from South Africa were more resistant than 'normal' *A. fatua* to tri-allate. Three of these intermediate types were collected in the eastern Free State.

Spain

Paunero (1957) in describing the Spanish *Avenae* lists *A. ludoviciana* and six types of *A. fatua* but does not mention their distribution or abundance. *A. barbata* is included under the unfamiliar name *A. alba* Vahl

A. fatua, A. ludoviciana and other forms of *A. sterilis* are all found in fields in Spain, but *A. barbata* occurs only on roadsides (Portal 1970, personal communication). The only Spanish samples in the Rothamsted collection are two *A. barbata* from roadsides near holiday-resorts.

Sweden

The types of *A. fatua* present in seven regions of Sweden were explored, starting in 1961 and involving examination of nearly 17,000 plants (Nilsson, Åberg and Avholm 1973). Seventeen types were distinguished, five of them without counterparts in descriptions of types common in Britain and Europe. Two of these had short silky hairs at the callus, a feature not previously noted. Others had glabrous grey lemmas and long callus-hairs, and brown lemmas with short callus-hairs and few or no hairs on the lemmas. One type had shorter kernels than the more usual specimens. Similar short grains were found in England (Thurston 1957) but the condition did not affect viability or dormancy and did not persist into the next generation. Although the authors quote this British paper, they do not use its lettering system for the types common to both surveys, but use Roman numerals for the Swedish types. However, their descriptions and photographs permit a comparison of their types and the British ones.

Type fA, so common in most countries (Table 2.2), was the most abundant, accounting for 31% of all samples, followed by 'Scandinavian grey' (25%) and their grey glabrous type IV with long hairs at the callus (21%). These high frequencies were due to dominance in a few areas, fA accounting for 89% of the plants from Kopparberg, the most northerly area sampled and 91% from the Baltic island of Götland, 'Scandinavian grey' for 71-72% in the area immediately north of Lakes Vennern and Vattern and also west of Lake Vennern, and the unusual type IV 43% to the east of Lake Vattern, 34% in the Uppsala region and 27% in the extreme south (Skåne).

Conversely, the relative abundance of types differed greatly between regions. The northernmost, Kopparberg around Lake Siljan, had 89% fA, 4% 'Scandinavian grey', 4% probably fF and no others of the seven major types. North of Lakes Vennern and Vattern 71% of the plants were 'Scandinavian grey' and all the seven important types were present, as they were east of Lake Vattern, although amounts varied, type IV contributing 43% and fA 25%. The island of Götland had 91% fA and no 'Scandinavian grey', in contrast to Skaraborg west of Lake Vennern which had 72% 'Scandinavian grey' and no fA or fB. Skåne in the extreme south had no single dominant but 28% 'Scandinavian grey', 27% type IV, 21% fF and none of type V, probably corresponding to fH. The locations of the main areas are shown in a map (Esbo and Nilsson 1957b).

Most of the samples at Rothamsted were collected in 1959, half of them around Uppsala. These were 2 'Scandinavian grey', 2 fH, 1 fF and 1 fG, all recorded for that area in the Swedish survey. One fA came from Jämtland further north than any area sampled by Nilsson *et al* (1973), and interesting as their northernmost area was dominated by fA. An unripe specimen, probably 'Scandinavian grey', was collected in Halland on the west coast, south of Göteborg. From the east of Lake Vattern came 1 fF, and 1 of type IV shown to be dominant there by Nilsson *et al.* Two samples originating in Sweden but supplied from a collection in Finland, are 'Scandinavian grey' and type VII of Nilsson *et al* (1973) which has no equivalent in Table 2. Thus the few samples at Rothamsted fit in well with the bigger Swedish survey.

Although that study was undertaken to see if any types of wild oats in Sweden differed so much from the generally described material that they needed special methods of control, Nilsson *et al* (1973) concluded that most of the considerable differences they found were not of agricultural importance. An exception was their type V, probably fH, with plants only 100 cm tall, which seemed more likely to be overlooked in a standing crop than the others which all exceeded 130 cm. Their type VII (brown glabrous lemmas and long callus-hairs) had only 19% dormant seeds compared with 60-90% for other types and might be less persistent, and type fC was less cold-hardy than the others, whereas type fG was above average in cold-resistance of growing plants.

Tunisia

A sample of *A. sterilis*, probably ssp. *macrocarpa*, has recently been sent to Rothamsted.

Turkey

Material from a survey of wild oats in five areas of Central Turkey was received at Rothamsted in 1967. From near Ankara there were 3 specimens of *A. ludoviciana*, 2 lA and 1 possibly lC, 7 intermediate types (collected from at least 3 different places) and 1 *A. sativa* with weak awns. From north-east of Ankara (Çankiri) came 10 *A. ludoviciana* (7 lA, 1 lC, and 2 unripe specimens) and 6 *A. fatua*, 4 fA, 1 with grey very hairy lemmas but too small for type fD and one unripe of either this type or fA. At Eskişehir, west of Ankara, *A. ludoviciana* predominated with 3 samples of lA, and there was one sample of another type of *A. sterilis*, one *A. fatua* (fA) and an unripe specimen of the same species and possibly the same type. Kütahya, south-west of Ankara also had both *A. ludoviciana* (1 lA and 1 lC) and *A. fatua* (2 fA). To the south-east too, Kirşehir had *A. ludoviciana* (3 lA and 1 with yellow lemmas and glabrous except for a tuft of hairs at the base of the awn, and long hairs at the callus) and a single specimen of *A. fatua* (fA) but Kayseri had only *A. ludoviciana* (1 lA) in the collection sent. The single sample from Atkaracalar, south of Constantinople, was *A. ludoviciana* type lC. Thus, *A. ludoviciana* appears to be the main species of wild oat in Turkey, occurring in all seven areas sampled, whereas *A. fatua* was found in four and *A. sterilis* in only one. The occurrence of hybrids or fatuoids in the Ankara area might give rise to problems in the use of tri-allate for control of supposed wild oats, if they behaved like those reported from South Africa.

United Kingdom

A. fatua has been present from about 700 BC (Jessen and Helbaek 1945) but *A ludoviciana* was first recorded in England at about the time of the First World War (Thurston 1954). Both introductions appear to have been in imported contaminated cereal seed. The increased frequency of cereal growing during the Second World War increased the density of wild oats in infested fields and introduced them to previously clean areas eg the compulsorily-ploughed pastures of Leicestershire.

A survey in 1951 (Thurston 1954) in which 621 samples were examined showed that *A. fatua* was present in all wheat- and barley-growing areas of England, in both winter and spring cereals and on all soil-types. It occurred in 97% of the samples. *A. ludoviciana* was found only in an area of approximately 80 miles radius of Oxford, mainly on heavy soils and chiefly in winter cereals, these two factors being closely correlated, and on the site of an old aerodrome further north, where it may have been introduced in packing-straw. It was present in only 13% of samples. No other wild oat species were found.

The amount of wild oats present in a field depended on the frequency in the rotation of crops (mainly cereals) in which wild oats could develop and shed seeds before harvest, and many fields within the area of overlap (Fig. 2.1) contained both species.

There was great variation in appearance of spikelets within both species (Table 2.1). In *A. fatua,* fA was by far the most frequent and abundant, followed by fB and fC. All those represented by four or more selections in Table 2.1 occurred widely in England and none was characteristic of particular regions. Selections numbered 71-82 were short-seeded variants of their types as collected but their progeny were of normal length. Similar short-seeded plants have been found in Sweden.

By far the most widespread and abundant type of *A. ludoviciana* in England was lA. It resembled fA in having dark brown very hairy lemmas and long hairs at the callus, but the spikelets were always larger and the lack of abscission-scar on the second seed and awnless third seed served to distinguish lA from fA. Of the other types, only lC and lD occurred at all widely and their only as a small proportion of the population (Thurston 1957).

The relationship between appearance and agriculturally-important characters of English selections of wild oats was explored (Thurston 1957). Only one type of *A. fatua,* fD, differed consistently from the others. It resembled *A. ludoviciana* in the numerous tillers and rosette habit of the young plant and in having only about 50% dormant seeds at harvest. It belongs to ssp. *septentrionalis* whereas all the others which fit any of Malzew's (1930) subdivisions of *A. fatua* are in ssp. *fatua.* Occasional selections of other types had less than the 95% dormant seeds more usually found. Similarly, although occasional selections of *A. ludoviciana* differed from the species-average in dormancy, these differences were not consistently associated with visual characters. At that period there were no wild-oat herbicides which could have been tested against the selections.

In 1951 the NAAS reported that there was no wild oat problem in Wales, and sent no samples. However, *A. fatua* was found on five farms near Newport, Mon. and *A. ludoviciana* in Flintshire (Thurston 1954). *A. fatua* now occurs in all Welsh counties, introduced in seed-corn from England or in uncertified local seed (in Wales, if one wild oat plant is seen during field inspection, no certificate is issued). *A. fatua* was first recorded for Pembrokeshire in 1968, on two farms near Boncath, but by 1971 it was widespread in the north and central districts, including the St. David's peninsula. The origin

Fig. 2.1. Distribution of *Avena fatua* and *A. ludoviciana* in England and Wales in 1951 as determined by examination of samples of wild oat seed submitted by agricultural advisory officers (see text for further details). (From Thurston 1954.)

of this infestation is said to be seed-corn from Stratford-on-Avon in about 1965 (Davis 1972). A survey showed that by 1974, over 40% of the fields visited had some degree of infestation but most of these were at the stage of hand-roguing (Arable Farming 1974). Bought-in straw, as well as grain, was a possible source of infestation.

Some parts of England and Wales were re-surveyed in 1972 and parts of Scotland and Northern Ireland included (Phillipson 1974). Because this survey, unlike that of 1951, was on a statistical basis, the map (Fig. 2.2) indicates the per cent of infested fields within the counties affected, and demonstrates that wild oats have spread to the southwest of England, Lancashire and Wales and that in all except Lancashire they are sufficiently

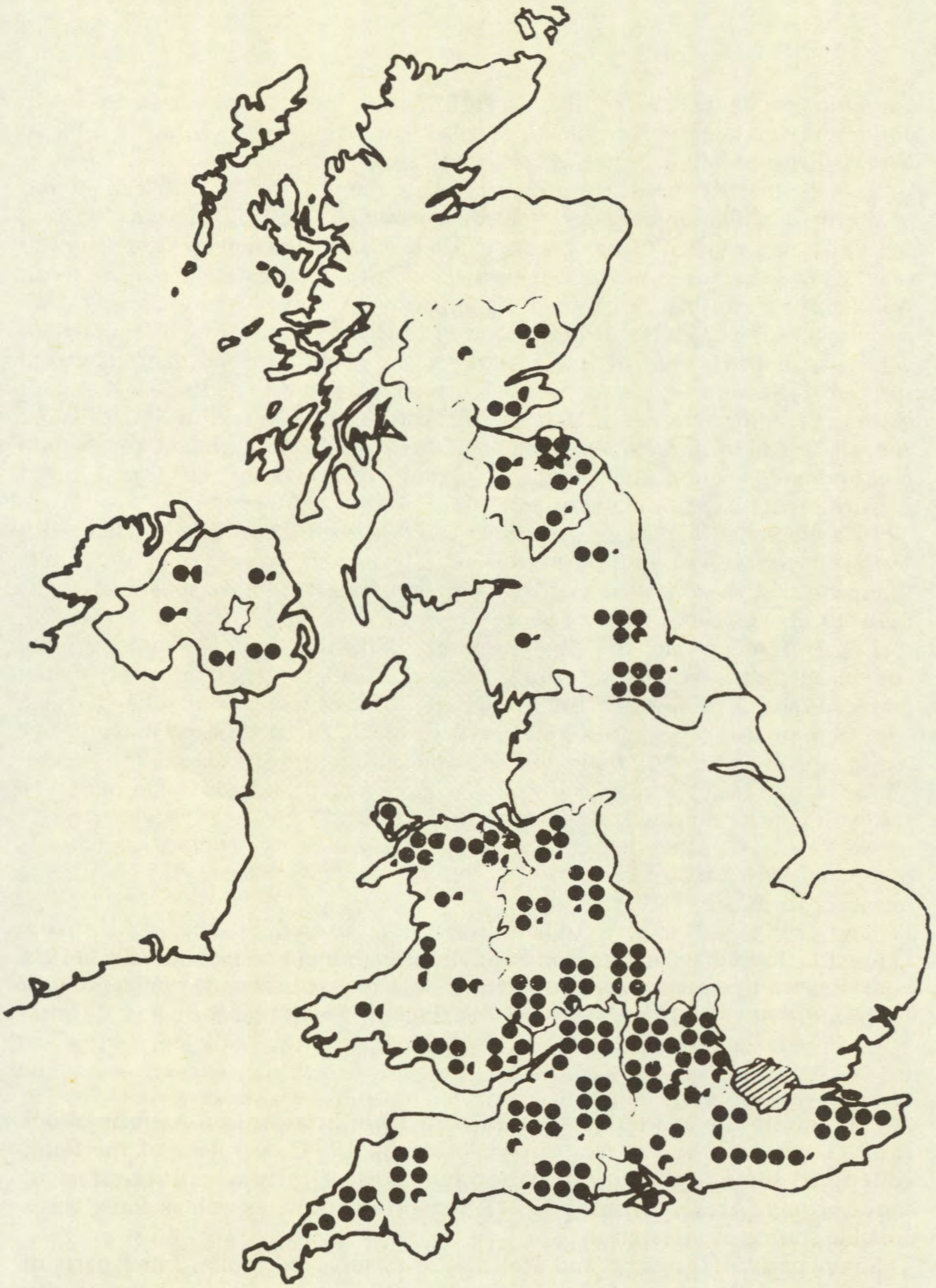

Fig. 2.2. Distribution of wild oats (species not determined) in England, Wales and Scotland in 1972. Certain regions (including three important wheat and barley regions known to be generally infested) were not included in the survey: they may be identified by the absence of county boundaries. The black dots are proportional to the percentage of infested surveyed fields in each county. (From Phillipson 1974.)

common to cause difficulties. Unfortunately, no attempt was made to determine the species, or indeed, to verify that the reports referred only to wild oats, excluding *A. sativa, A. strigosa*, fatuoids and hybrids.

To see whether the distribution of *A. fatua* and *A. ludoviciana* had altered in the West Midlands since 1951, sample panicles taken on the same basis as for Phillipson's (1974) survey were examined at Rothamsted. These showed that *A. ludoviciana* was still present in south Worcestershire and south Warwickshire and had not spread. In contrast, *A. fatua* was now present in all parts of Cheshire, Staffordshire and even in Herefordshire which reported no wild oats in 1951. Half of the *A. fatua* in the newly infested districts was in spring cereals, and only two of the fields had carried cereals for less than half of the preceding five years. Half of the newly-infested areas in Staffordshire and all in Cheshire were on light soils, suggesting that spring cereals would predominate there. This could explain why *A. fatua* had spread but *A. ludoviciana* had not (Thurston 1974).

In a botanical survey of roadsides in Oxfordshire and Essex (Chancellor 1969) *A. fatua* was found on 6% of sites near Oxford but none near Chelmsford. It was never a major species and seemed to have spread from the fields to the verge and not vice versa.

Local farmers in Buckinghamshire, Berkshire and Oxfordshire are convinced that wild oats have spread to more fields, and become more dense, in recent years in spite of the availability of herbicides; but 48% of them admitted to using no control-methods, chemical or cultural (Watson 1974). Again, species were not distinguished. And in Cambridgeshire in 1956, winter wheat on the heavy land in the west was more heavily infested than barley on the light land in the south. Less than 30% of the winter wheat fields were free of wild oats (species unspecified) and 28% had one or more plants/m^2, compared with 60% of barley fields free of wild oats and only 15% with one or more per m^2.

Scotland and Northern Ireland were not covered by the 1951 survey (Thurston 1954). Prior to 1968, Scotland was thought to be relatively free of wild oats, but samples taken then from a random selection of barley-growing farms showed that 5% of the barley acreage in Argyll and Bute had *A. fatua,* 1.4% in Ayr and Wigtown, 0.69% in Lanark, Renfrew and Dunbarton and 0.58% in Dumfries and Kirkcudbright, while in Stirling, Clackmannan and West Perthshire only 0.1% was infested (Waterson and Davies 1973). *A. ludoviciana* is not mentioned, and the Atlas of the British Flora (BSBI 1962) shows it on only one site, near Banff, and then not necessarily on agricultural land. The 1972 survey (Phillipson 1974) adds Berwick, Fife and Forfar to the parts of Scotland with some *A. fatua.*

Northern Ireland was believed to be free of wild oats up to 1965, but in 1966 31 acres were found to be infested and the area increased sharply to 700 in 1968, 2600 in 1969 and 5400 in 1971 when legislation was introduced prohibiting the sale of contaminated grain (Courtney 1974). Wild oats were found in the four easternmost counties in 1972 (Phillipson 1973). The infestations are less dense than in England and most are only at a level where hand-roguing is possible (Courtney 1974). Imported feeding-barley seems to

be a major source of wild oats, but once there the wild oats can be spread by spillage from grain-tankers and in contaminated straw and farmyard manure.

Contaminated imported cereals for feed can also be important in England. Records received at Rothamsted from Somerset and Devon show that this may have helped in the westward spread of wild oats, but contaminated seed-corn is probably more important (Elliott and Attwood 1970), 11-27% of samples taken from seed-drills in regions of England, 13% in Wales, 6-33% in Scotland and 6% in the east of Northern Ireland containing viable wild oat seeds. Seed obtained from a merchant was cleaner than from farm sales, except in Northern Ireland where many farms are still free of wild oats but imported seed-corn is likely to contain some.

Very few samples of wild oats from the United Kingdom have been added to the Rothamsted collection since 1951, only those of special interest being kept. 'Scandinavian grey' was found near Salisbury, Wilts in 1958. A sample from Dunbar consisted of fF and another Scottish one, from Udny, was unripe but probably included fC and fI. A plant from East Craigs Research Station, Edinburgh, in 1964 was a cream-husked *A. fatua* with short hairs at the callus and a tuft of hairs at the base of the awn. Short callus-hairs seem to be frequent in Scottish *A. fatua*.

USA

A. fatua is the chief weed problem in northern USA from the Great Lakes to the Pacific, ie from Minnesota to California. In 1961, 24.7 million ha were estimated to be infested, half of this area seriously (Hannah, Hamm and Selleck 1960; Hannah, Selleck and Althaus 1960). Up to that date, control by frequent cultivation and delayed seeding was proving partially successful, but costly. Crop losses from *A. fatua* in North Dakota, where it is considered the chief weed, were estimated at $35 million in 1966 (Bell and Nalewaja 1966) and at least $195 million in 1973 (Nalewaja 1973) due partly to the increased value of cereal crops, although the highest values for late 1973 were not used in this calculation. Wild oat populations of 191/m^2 could decrease flax yields by almost 90% and applying fertilisers benefitted the wild oats more than the crop. Six wild oat plants/m^2 decreased barley yields by 6% and 191 plants by 31% (Bell and Nalewaja 1966). By 1973, despite the introduction of herbicides, wild oats were still considered the chief weed of North Dakota. All parts of the State were equally affected, with 90% of all wheat fields and 82% of barley having at least some wild oats, with 57% of wheat and 41% of barley estimated to have sufficient to cause at least 25% loss in yield. About 1% of wheat fields were so heavily infested that they looked like oat crops (Nalewaja 1973).

A. fatua in USA is very variable genetically. Lute (1938) and Imam and Allard (1965) have compared material obtained in different localities. Lute found more difference in percentage germination between three samples from Colorado than between one from Iowa and one from Ottawa. Imam and Allard used material from seven localities representing three regions of California, an arable area at 50-100ft (15-30 m) in the Sacramento valley, a region of infested grazing-lands in the inner Coast Range and another in the

foothills of the Sierra Nevada mountains where wild oats were distributed through a wide range of habitats. They found genetic differences in wild oats from different geographic regions and these were related to habitat-differences. Families from the same site, and also single-plant progenies, contained many different genotypes and this genetic flexibility was considered to contribute to the success of *A. fatua* in establishing in a wide range of habitats. From 1 to 12% of outcrossing was observed, with the hybrids being slightly more vigorous than plants from self-pollination.

Although *A. fatua* is the main species in USA, *A. ludoviciana* and *A. barbata* also occur in California. The Rothamsted collection contains lA from Goleta, *A. barbata* from St. Barbara, Goleta and an unspecified locality, and six samples of *A. fatua* type fA from Davis, St. Barbara, Goleta and the unnamed location. Type fC also occurred at St. Barbara; and also a cream *A. fatua* with long hairs at the callus and a few hairs at the base of the awn.

Marshall and Jain (1967) compared the growth of *A. fatua* and *A. barbata* in artificial mixed populations in California and found that *A. fatua* gave better seedling-establishment but *A. barbata* produced more seeds.

A. fatua taken from cereals imported into Europe for feeding to animals is represented by six samples in the Rothamsted collection. All are threshed, and consist of grains with brown or grey lemmas.

Yugoslavia

Both *A. fatua* and *A. ludoviciana* occur in cereals in Yugoslavia (Kovacevic 1973). *A. barbata* is also present in roadsides and waste places but not as a weed of cultivation. The Rothamsted collection contains threshed brown and cream-husked *A. fatua* and some *A. barbata. A. ludoviciana* and possibly other types of *A. sterilis* were seen in fields and on roadsides in southern Yugoslavia in 1971 but specimens were unripe and not easy to identify in detail nor suitable for inclusion in the seed-collection.

RECENT CHANGES IN DISTRIBUTION

Examination of relevant, mainly European, literature on wild oat distribution reveals that rarely does any single author record direct evidence of changes in distribution. Many statements imply an increase in the spread of wild oats, and some are even categorical. Experience in farming circles over a period of years leaves little doubt that the facts are broadly as stated; but supporting quantitative data from successive comparable assessments are lacking. This is a serious deficiency.

BRITISH ISLES

The word 'distribution' often confuses the frequency of occurrence in a number of fields surveyed with the density of population found in them. Brown, D (1953) in a review of world literature on methods of surveying and measuring vegetation and in reference to criteria of botanical analysis, states:

'of the scores, possibly hundreds, of techniques which have been devised, developed and described . . ., several similar ones have been given different names while widely different methods have been given a similar name. The result is no little confusion.'

In the present context it is necessary to refer to and define two relevant criteria. The first 'frequency of occurrence', is the proportion (usually measured as a percentage) of sampling units in which at least one wild oat plant is present. Brown suggests that the term may have originated from the Danish word 'frekvens' translated as 'frequency' (perhaps unfortunately as the word suggests number). The second, 'population density', is the number of individual plants per unit area. The areas used as a basis of both may differ greatly in size from one investigation to another.

Frequency of occurrence.

Where frequency of occurrence is used as the criterion in mapping the distribution throughout the country, as for example, by the use of a sample unit of a 10 km square (Perring and Walters 1962), it is possible that 'presence' could consist of only a single plant in a large area (100 km^2). A farmer might not be very concerned about such evidence. However the commercial interest of the farmer and the more academic view of the botanist should coincide in the case of the wild oat because of its known capacity to take advantage of man's intervention to extend and intensify its presence. Thurston (1954), in writing of a survey in 1951, suggests the possibility of the gradual spread of *Avena ludoviciana* from a centre in Abingdon in 1926 to an area of about 20,000 ml^2 (52,000 km^2). Although there may well have been other points of introduction at about the same period, few would doubt that *A. ludoviciana* did spread widely from small beginnings in a relatively short period; yet there is little evidence from any earlier survey strictly comparable with that in 1951 to show the presence or absence of the species, and little since.

The 1951 survey data on *A. fatua* in England and Wales (Thurston 1954) are included in the map by Perring and Walters (1962) (confirmed by the authors in a private communication); thus the general areas of the country where the weed is shown to be present are roughly the same on both occasions, with some records of presence in additional areas in the later survey. The two surveys were conducted in different ways. The 1951 survey was arranged with the help of MAFF officials who collected wild oat samples during their normal farm advisory visits, the data being gathered from scattered points. Although a presence of wild oats at one of these points in 1951 could be related to a presence in a particular 10 km square as seen by the botanists contributing at a later date for the 1962 survey, there is no means of confirming that the weed was in fact absent from the area in 1951 simply because it was not seen at the scattered points. Thus the records of presence in the additional areas in 1962 cannot be accepted as evidence of new presence or of changes in distribution. A survey in 1967 of England and Wales by a commercial firm (Fisons Ltd) quoted by Pfeiffer (1968) was based on information supplied by the firm's field representatives all over the

country. It was estimated that 1-1½ million acres (400,000-600,000 ha) were infested with wild oats. These infested areas of England and Wales, which when mapped showed a smaller total area than that of the 1951 survey (Thurston 1974) and a less scattered infested area than that of the 1962 survey by Perring and Walters. Details of the methods used to arrive at the estimates are not quoted, but again they were obviously different from those of the other surveys, and the author states, 'In talking about the changing weed populations we must realise that few scientific facts are available to prove that such changes are taking place, however obvious it may seem that the problems are increasing and changing.'

From a survey of parts of the United Kingdom in 1972, in which seven official organisations took part (Phillipson 1974), estimates were obtained of the proportion of the cereal acreage infested with wild oats (*A. fatua* and *A. ludoviciana*) in certain agricultural advisory regions (Table 2.4). Samples of cereal-growing farms were selected at random (100 per region). On each farm two fields were selected, without bias, for inspection by agricultural officers. Although it is not possible to make any comparison on a 10 km square basis, the area of cereals with wild oat present grown in five of the ADAS regions can be estimated as nearly 2½ million acres (1 million ha). Part of the difference between the 1967 and 1972 estimates is due to different standards of assessment, the earlier survey refers to 'infestation' and is not so rigorous as to include every field in which as few as one wild oat plant is present, the criterion adopted in the later survey (see Fig. 2.2, and cf Fig. 2.1).

In the 1972 survey, there is evidence of change in infestation of fields on the farm. Farmers were asked if wild oat had been present in previous years in the fields surveyed. Their replies are collated in Table 2.4. According to the official report, 'Twenty-four per cent of the infested acreage was stated to have become so in the two previous years, and 55% within the previous six years. These figures may seem rather high, and some farmers may have been reporting obvious infestations rather than the few wild oat plants which may have been present for more years. Nevertheless the evidence points overwhelmingly to a major increase in the last decade'.

Table 2.4 *Acreage infested for periods of years as percentage of wild oat infested acreage (averaged for all seven UK agricultural advisory regions involved in the 1972 survey*)*

Years	1	2	4	6	10	15	20	20+	Many	Not known
Acreage infested (%)	13	11	11	20	18	12	4	5	4	2

* Agricultural Development and Advisory Service regions–South East, South West, West Midland, Northern, Wales. The other two regions surveyed were the East of Scotland and Northern Ireland.

Density of population

There are some references in the literature on distribution to density of population or degree of infestation, but an assessment of this kind on a wide survey basis is fraught with difficulty. Measurement in terms of weed plants per unit area is rarely practicable in extensive surveys, and descriptive subjective classifications, for example, 'light', 'medium' and 'intense', have had to be accepted. Comparisons are likely to be reasonably valid only when individuals repeat their own assessments, although guide lines, including some simple numerical standards, have been given in attempts to standardise classification where many observers were involved (Phillipson 1974).

Dadd (1953) describes a survey of nearly 500 cereal fields made from the roadside in the Eastern Provinces of England in 1952 and repeated in 1953 on a slightly larger scale. A classification of 'slight infestation' was used when hand-pulling was possible and 'high' when it was not. The proportion of spring-sown cereals with a 'high' infestation rose from 12 to 26% from 1952 to 1953.

Pfeiffer (1968) estimated the infestations to be 'heavy' on about one-third of the acreage but did not give the basis of the assessment. Phillipson (1974) gave three infestation classes: 'light', 'intermediate' and 'heavy', and estimated these to be 57, 35 and 8% respectively of the infested acreage. The technique adopted to arrive at these figures was necessarily arbitrary. It was to locate in the randomly selected field a notional square with sides of 120 yards (109 m) at a set distance and attitude from wherever the surveyor entered the field. On the edge of the 'square', the surveyor counted, in a path 2 paces wide, the number of plants of wild oat up to ten plants per side. A weed population up to this level on one or more sides (a maximum of about 500 plants/ha) was classified as a 'light' infestation. When plants could be seen continuously in the path on any three sides with every step taken the infestation was termed 'heavy'. Any degree of infestation between these extremes was termed 'medium'.

Undoubtedly the standards of assessment differ from survey to survey, making it difficult to draw confident inferences about change in population density. Probably the most useful qualitative criterion is a 'light' category defined as 'roguing (or hand-pulling) feasible' which in numerical terms could be up to a maximum of 500 panicles per acre (1200/ha).

From the earlier surveys (Thurston 1954, Perring and Walters 1962) it is clear that wild oats were closely associated with cereal crops. It could be inferred from the 1972 survey that the weed was fast becoming ubiquitous in cereals; clean farms and even fields were becoming exceptional. Future assessments of the agricultural situation may be expected to concentrate on changes in density of population to determine whether control of the weed is being achieved on a unit area of field or farm. The growing awareness of the importance of the wild oat infestation and the increasing drive for control may restrict further development of the infestation.

SWEDEN

Seven Swedish papers referring to wild oat distribution were examined. As in Britain there is an implication of increased frequency of occurrence and increased density of population, again without strictly comparable numerical data. Esbo and Nilsson (1957b) quote a report by Linnaeus of the occurrence of wild oats in the South of Sweden in 1740. The Swedish Institute of Science recognised the problems and discussed solutions in 1743 and 1749, one suggestion being the sowing of rye instead of spring cereals; also the use of spring cultivations and the late sowing of barley. A farmer at this time is recorded as saying that in spite of four cultivations during a summer fallow, with thorough spring cultivations and late sowing of barley, he succeeded in harvesting only a few measures of barley and 18 measures of wild oats! Under a Swedish law enacted in 1694, any person found throwing wild oats and other weeds on another farmer's strip would be castigated as dishonourable, would be responsible for subsequent cleaning and would be fined.

In more recent times, it is stated that there has been a marked increase in wild oats. In 1955-56, the official seed control department carried out a survey (96,000 samples) and looked at 3000 fields. The infested areas were mapped. There appeared to be centres of infestation which radiated outwards to areas of reduced infestation. But practically every parish had a fairly dense population of wild oats. The precise figures were not quoted.

DENMARK

In the last few decades, according to Odgaard (1970), wild oats have appeared on farms where they have not been seen previously. This is one of the few instances where there have been regular annual reports since 1958, with apparently comparable investigations in different years. Reports from the agricultural unions in Jutland give evidence of a considerable increase in wild oats. From 1963 onwards, from 330 to 430 farms were examined in Skernegen. In 1963 2% were infested, and in 1968 17%. Wild oats were particularly abundant north of Limford.

In 1970, a survey of 23 parishes on the island of Fyn showed a 40% infestation of farms (fields?) compared with 17% in 1956 and 6% in 1949-50. The 1970 survey showed the density of population as: very heavy–1%; heavy–5%; medium–12%; light–22%; none–60%.

OTHER COUNTRIES

Increases in the incidence of wild oats are reported in relevant publications for Belgium, France, the Netherlands, Norway and West Germany, but again the essential requirements for strict quantitative comparisons are lacking. Information, when available, has been briefly recorded above under 'World Distribution detailed by Countries', p. 24 *et seq* (see particularly West Germany and East Germany).

METHODS OF DISSEMINATION

The ways in which wild oats are spread from one place to another fall into two distinct groups. Those resulting from man's activities are the most important because they transfer more seeds over greater distances. On the other hand, it should be possible to control them. The other group, the natural methods (wind, animals, birds), although smaller-scale, can nevertheless be important, partly for the very reason that they are small-scale and may pass unnoticed until the few plants originally introduced by them have multiplied into a major problem. Control of dissemination by natural methods may not be possible, so the opposite approach—removal of the few plants introduced each year—must be adopted.

References to work on dispersal by natural methods and by machinery are scarce, although general papers on wild oat control usually mention the possibility. About 45 papers were read for this section and 22 are quoted, including two showing that wild oats were not present in the material examined. As was to be expected, the survey of the literature has revealed many gaps. Attention is drawn particularly to the need for quantitative information on the spread of wild oats by birds and mammals and in straw; in the latter case, actual examples of introduction are required to lend weight to the promotion of control measures. There is also a need for a method of disinfesting sacks, which is both quicker and more thorough than hand-picking seeds.

DISSEMINATION BY MAN

In crop seeds for sowing

Transference of wild oat seeds over long distances by this method began in prehistoric times (Jessen and Helbaek 1945, Odgaard 1970) although it must have taken place by easy stages, as migrating peoples entered new territory bringing with them their contaminated cereal seed to plant in their new home. *A. fatua* reached Denmark in the Bronze Age and Britain by the Iron Age. Similarly, wild oats must have travelled to Canada, Australia and New Zealand with the early settlers. Although this is regrettable it was almost inevitable before the development of sophisticated seed-cleaning machinery, but there is less excuse for it now. However, the process continues.

In East Germany, winter wheat and winter barley contained from 28 to 2940 wild oat seeds/kg of harvested grain, or up to 60 kg/tonne. Even after cleaning, spring barley contained seven wild oat seeds/kg (Metz 1970).

Data on wild oats found in cereal seed samples passing through the Official Seed Testing Station for England and Wales between 1961 and 1968 (Tonkin 1968) showed that barley was more often and more severely contaminated than wheat or oats, the mean contamination in the peak period 1963-66 being 9-10%, compared with 5% for wheat samples and 6% for oats, with less before and after those years. Rye remained constant at 3% contaminated samples throughout the seven-year period. In the season 1967-68 the greatest

number of wild oat seeds found in a 227 g sample was 194 for barley, 15 for wheat and 22 for cultivated oats. Although the majority of these samples were probably intended for sowing, some may have been feeding-stuffs. The varieties concerned are not stated in Tonkin's summary but the New Zealand seed testing station found that seed of one particular variety, Tama, was particularly heavily contaminated with wild oats (Lithgow 1974). This situation could arise because the seeds were of such a size that mechanical removal of wild oats was more difficult than usual, or because seed-stocks had become contaminated during the early stages of multiplication and not been adequately cleaned thereafter. Of 4599 samples of seed-corn examined at the Central Seed Testing Station for Sweden in 1955-6, only 3.7% contained wild oats; 99% of these had only 1 or 2 seeds/kg and only 0.1% contained more than 15 seeds/kg (Nilsson-Leissner 1956), but wild oats were less widespread in Sweden 20 years ago than they are now.

There is no escaping the fact that wild oats were being drilled with spring cereals, mainly barley, in the United Kingdom in 1970. In a seed-drill survey (Elliott and Attwood 1970) on randomly-selected farms where barley had been grown in 1969, 19% of the 3.2 kg samples in England and Wales, 16% in Scotland and 3% in Northern Ireland contained wild oats. In England and Scotland, seed stocks supplied by merchants were cleaner than seed harvested on the same farm or obtained direct from another farm, only 11 and 10% of the merchants stocks but 41 and 24% of the others being contaminated. In Northern Ireland where wild oats are less prevalent (Phillipson 1974) the situation was reversed, 5% of stocks from merchants and only 2% of stocks direct from farms containing them. Some farm samples contained over 50 wild oat seeds but the merchants' samples mostly only one and the worst had 11. Bearing in mind that one seed per sample represents a sowing-rate of about 40 wild oats/ha, these findings indicate a serious state of affairs for any region which does not already have a heavy infestation of wild oats, and where unawareness of the problem may cause neglect of hand roguing. Contaminated seed-corn is undoubtedly one factor in the spread of wild oats to English counties such as Devon, Cornwall and Lancashire which were believed to be free of it in 1951 (Thurston 1954). Transference between countries also occurs, as indicated by the wider range of varieties found on the research farm at Toowomba compared with other Australian farms.

Although cereals are the main vehicles for transference of wild oats in seed-stocks for sowing, they can also occur in other crops, eg rape, and also occasionally in peas and beans with weevil-holes in which wild oat seeds become stuck. Herbage-seeds, especially tetraploid ryegrasses, may also carry small wild oat seeds, but the EEC legislation on purity of seed should decrease this hazard (see p. 231).

In grain for animal food

The international trade in feeding-stuffs, especially barley, can be responsible for the transference of very large numbers of wild oat seeds between

Table 2.5 *Examples of introduction of wild oats in imported feeding-stuffs*

Imported by	Exported by	Crop	Species	Date	*Notes*
Finland	–	Oats	*A. fatua*	Before 1959	–
West Germany	Netherlands	Cereals	*A. fatua*	–	–
Ireland	Canada	Oats	*A. fatua*	1940	Fed to horses
Northern Ireland	Canada/ USA	Barley	*A. fatua*	–	On farms and on road verge
Norway	USA?	Cereals	*A. fatua*	Before 1961	Origin deduced from growth period
Norway	Australia?	Cereals	*A. ludovici-ana*	1960 and 1969	Origin deduced from spikelet appearance
Philippines	USA	Oats	*A. fatua*	1962-3	Origin confirmed by growth period

continents, as well as between and within countries (eg Nilsson-Leissner 1956, Esbo and Nilsson 1957a). Examples of such transferences are shown in Table 2.5.

Although these seeds are not deliberately sown, they may still find their way into fields where they can become established. Some are spilled while the grain is being handled. Wild oats are seen growing on motorway verges in Scotland and Northern Ireland where imported grain is regularly carried between docks and mills, and if this occurs in country areas they could invade adjacent fields. Others may be dropped from sacks on the farm or distributed in dung (Thurston 1952, 1953b, Kirk and Courtney 1972). Since the import of Canadian barley via Belfast ceased in October 1973, the incidence of wild oats in feed-grain has decreased dramatically, from a mean of 1088 seeds/kg to 27/kg. Supplies now come mainly from France and are subject to the more stringent EEC regulations, but even so, the number of seeds being imported to this relatively lightly-infested area is alarming (Courtney 1974, personal communication).

The proportion of wild oats present in feeding-stuffs is often very much greater than in seed-corn, but the risk of their becoming established is minimised if the material is milled before being taken on to farms. The mill should be set to the finest adjustment (below 3 mm for hammer mills) to ensure that all seeds are crushed (Metz 1970). Wild oats in grain for human consumption would seldom find their way on to the land.

In straw and hay

Straw-bales can contain large numbers of viable wild oat seeds. Wilson (1970a) found approximately 8 to 600 seeds/kg of straw and the most heavily

contaminated sample in his investigation yielded 19,360 seeds of *A. fatua* from a bale weighing 23 kg. The straw trade is likely to be from the main cereal growing areas, where wild oats are abundant, to areas of mixed or predominantly dairy farming, where they are scarce or unknown, so this is a potent source of introduction of wild oats and may have contributed to the spread of *A. fatua* to western and south-west England. Unripe *A. ludoviciana* was found in Belgium in 1960, in hay imported from Italy, but Stryckers and Pattou (1963) did not find it growing in Belgium.

Straw used as packing-material can also be responsible for new outbreaks of wild oats. *A. ludoviciana* is believed to have entered a farm in Lincolnshire, 40 miles north of its main area of distribution in England, in this way (Thurston 1954). Straw is forbidden as a packing-material for goods entering Australia, unless it can be certified free of wild oats. Seeds may be shaken out of straw or hay during handling and can contribute to infestations on roadsides and railway banks. Infested straw is blamed for some of the increase in wild oats in Wales between 1951 and 1974 (Arable Farming 1974).

On or in farm machinery

Any farm machine, cart or trailer which has been used in an infested field or for transporting infested produce can be responsible for transferring wild oat seeds, though mainly between adjacent fields or farms. Mobile threshers, seed-cleaners and combine harvesters are particularly liable to have quantities of wild oats trapped within them, to be swept out into the next stock of grain passed through. Moreover they may travel considerable distances between farms. Leaflets offering advice on cleaning combine harvesters are being produced by the MAFF as part of the National Wild Oat Advisory Programme in Britain. It is suggested that two men, using a vacuum cleaner, can remove sufficient of the wild oat seed in 45 minutes to prevent field to field transference, and that this should be done before passing from a contaminated to a clean field. Where possible, clean fields or parts of fields should be harvested first, using a clean machine, and before starting work the machine should be inspected to ensure that it is free of wild oats.

Trailers or lorries used for transporting grain or straw should be swept out where the sweepings cannot contaminate fields, and the platform of a baler used in an infested field needs similar treatment.

Wheels, especially tractor wheels with deep treads, may carry seeds embedded in mud. If, when these eventually drop off, they do so in another field, they could start an infestation. There do not seem to be any counts of wild oat seeds in mud on wheels, but Salisbury (1961) showed that the mud on shoes could carry 6 to 200 seeds over considerable distances. Anyone who has seen mud spread over a lane where farm implements have come out of a field, will realise the potentialities for weed-seed transference in this way, especially when the seeds are on or near the surface before an infested stubble has been ploughed.

In sacks

When grain contaminated with wild oats is put into a woven sack, the seeds become entangled in the material and even more in the seams. They are then very difficult to remove by brushing, because the hairs act like the barbs on a fish-hook. Eventually, however, the seeds become detached and may contaminate whatever is put into the sack. Hired sacks could introduce wild oats to a farm which previously had none, and the firms supplying sacks are well aware of this. Normal brushing does not clean out all the seeds, and hand-picking is laborious and therefore expensive. Sacks are dried after cleaning and before re-use, so an attempt was made to use heat to kill adhering wild oat seeds (Williams and Thurston 1964). It failed because the seeds proved more heat-resistant than the sacks. Fumigation was rejected as unsuitable because any vapour then known to be sufficiently toxic to kill the seeds (eg methyl bromide) would be a health-hazard to the workers handling the treated sacks.

In dung

Wild oats may be fed to animals in considerable quantities in contaminated grain, and not all are destroyed by the digestive processes, a small but significant proportion being voided in the droppings. Ten seeds of *A. ludoviciana* out of 2000 fed to a calf germinated in the collected dung (Thurston 1952). In a more detailed study of survival of *A. fatua* seeds in dung, Kirk and Courtney (1972) fed intact, scarified or de-husked seeds to bullocks. They recovered a mean of 15% of the seeds from the dung but only a quarter of these, 3.9% of those originally fed to the animals, were viable. There was no significant difference between animals but a consistent, significant difference between seed-lots, the greatest mean recovery of seeds being 7.5% for de-husked, followed by 3.5 for scarified and 0.7 for intact seeds. Possibly the larger size of intact seeds made them more vulnerable to damage. Differences in viability of recovered seeds were not significant. The viability of seeds scattered on the bedding of bullocks in a cattle yard, where they were subjected to trampling and urination, decreased from 95% at the start to 27% after four weeks and by 13 weeks no viable seeds remained.

When *A. fatua* seeds were placed in different positions in a manure-heap built on concrete, seeds survived longest at ground level, and longer near the sides of the heap than in the middle, the greater survival being associated with lower temperature, eg 15-20°C near the ground and 35-40°C near the top of the 2 m high mound. Only 18% of the seeds near the outside, and 5% near the middle, remained viable after 12 weeks, and all were dead by 21 weeks (Kirk and Courtney 1972). Metz (1970) found that 78% of wild oat seeds remained viable after exposure to 110°C for 90 minutes, but that 120°C for 90 minutes or 140°C for 30 minutes were lethal. Immersion in liquid manure (slurry) for three weeks killed all wild oat seeds and after four weeks the seeds had liquefied and disintegrated.

Both temperature and moisture are involved in the death of wild oat seeds in manure. Kiewnick (1964) showed that viability of *A. fatua* seeds stored at

20-22°C in the presence of soil microflora lost viability more quickly at 100% relative humidity than at 60-80%, the difference between treatments increasing from 23% at three months to 36% after six months in storage (Kiewnick's work is discussed in greater detail under Plant Health, p. 217 *et seq*).

Chemical toxicity must also be involved in death of seeds in digestion and in manure. Reider (1966) showed that seeds were killed by soaking in liquid manure for three to four months (as did Metz 1970), but that *A. fatua* was one of the more resistant seeds to a toxic factor which he concluded was ammonia.

It follows from these studies that animals fed grain containing viable wild oats can distribute at least some in their droppings when they are turned out to graze, but that fine grinding of contaminated feeding-stuffs can render them safe. If dung from cattle-yards is likely to contain viable wild oat seeds from feed or straw, it should be stacked for at least one to two months before being spread on clean fields, and even then the cooler parts of the heap (sides and bottom) should be avoided. This material can be used to form the nucleus of the next heap.

In silage

Leys sown as part of a programme of wild oat control may contain wild oat plants, especially during their first year. Frequent cutting will ensure that no viable seeds are in the material put into the silo. If, however, there are ears with more mature seeds, it seems improbable that they will survive the silage-making process. High temperature and very moist conditions should prevail, and these will be detrimental to seed-viability, as has already been discussed above (p. 0000). A few small-scale unpublished investigations confirm this. Moist storage of grain in silos, using propionic acid as a preservative, also seems highly toxic to wild oat seeds. Various samples collected by ADAS staff, mainly in the West Midlands and South-West England, and tested at Rothamsted, have suggested that few or no seeds of *A. fatua* survive this treatment, but these results are not from controlled experiments and so have not been published. A test recently completed, with seeds taken before and after treatment with a proprietary preparation at its recommended rate, showed that 97% of the seeds of both *A. fatua* and *A. ludoviciana* were viable before treatment and none survived (Bastiman and Thurston, unpublished).

NATURAL METHODS OF DISSEMINATION

By wind

Both *A. fatua* and *A. ludoviciana* are taller than the cereal crops in which they generally occur, and this difference has increased with the change to short-strawed varieties. The wild oat culms are relatively thin and pliable and the panicles lax, so movement in wind is considerable. As the seeds ripen, they become detached at the abscission-scar and are flicked away from the

parent plant. In a previously clean field the distance to which they travelled is seen in the dimensions of the infested patch in the subsequent crop, and may be 1½-2 m in diameter, according to whether the wind blew steadily in one direction, carrying the seeds to one side only of the parent plant or, by changing direction, scattered them all round it. Wind transference over greater distances is unlikely, unless the seeds are being scattered from a greater height, eg from the top of a grain-lorry, or trailer loaded with infested straw-bales.

By birds

Seed-eating birds collect ripe wild oat seeds, and if disturbed while doing so they carry away seeds of *A. fatua* or spikelets of *A. ludoviciana* in their beaks. Such seeds may be dropped in flight, the concentration decreasing with distance from the source, or they may be deposited under a perch to which birds are attracted, eg a wire fence, or telegraph wire or electric cable crossing an adjacent field. A line of wild oat plants beneath an overhead cable crossing an otherwise clean field shows that this must happen frequently, and a farmer trying to prevent wild oats from invading his farm from neighbouring infestations would be well advised to rogue carefully in such places every year. There does not seem to be any research published on external transference of wild oat seeds by birds.

Birds may eat large quantities of wild oat seeds (985 and 1355 seeds have been recorded from the crops of shot pigeons (Dadd 1956)) but the warmth, moisture and grinding action of the gizzard probably combine to kill most of them before they are deposited in the droppings. Seeds from the crop of one of the pigeons examined by Dadd were non-viable when tested at Rothamsted. Wild oats do not usually figure in the lists of viable weed-seeds recovered from bird-droppings (eg Salisbury 1961), but should any survive they might be carried further than those held in the beak. In a study of crop-contents of 211 pheasants shot in East Anglia in 1915, Evershed (1918) did not record wild oats, although samples were obtained throughout the year and cultivated cereals including oats and 'black oats' were found in 28 birds and these oats were rarely attributable to hand-feeding. It seems unlikely that wild oats were rare in East Anglia before the First World War, although the main build-up occurred during the Second World War. If they were present, then this negative result suggests that pheasants do not take wild oats when cultivated cereals are readily available, and that they would be unlikely to disseminate wild oats. However, local and seasonal circumstances could alter this, and a study of selective feeding and fate of wild oat seeds in relation to the larger seed-eating birds would be interesting.

In a field experiment at Rothamsted where different plots were sown with *A. fatua* or *A. ludoviciana* worked into the surface layers of the soil or ploughed in to 15 cm, rooks were seen on the shallow-sown plots soon after sowing and were believed to have taken more *A. ludoviciana* than *A. fatua*, possibly because the whole spikelets of *A. ludoviciana* were easier to find, or more attractive, than the single seeds of *A. fatua* (Thurston 1961). This experiment was in a part of Rothamsted farm free of wild oats and there were

no signs that the rooks transferred live wild oat seeds to adjacent areas, although the wild oat experiment suffered from cultivated oats dropped on it by sparrows carying them from the standing crop in the next field.

By mice

Wood-mice (*Apodemus*) can do great damage to pot experiments where wild oat seeds are ripened and allowed to shed in cellophane bags, the mice climbing the stems and tearing the bags to get at the seeds. They will also invade containers of stored seeds and live in them, apparently for months if not detected, and they will even take seeds out of germinators with ventilation holes in their lids. Moreover, a spikelet of *A. ludoviciana* is good bait for a mouse-trap. Although mice are known to collect field bean seeds and store them in holes in hedge-banks, there are no records of their collecting wild oat seeds in this way. Indeed, on a farm in Northamptonshire, mice dug up sown beans and rejected spikelets of *A. ludoviciana* encountered in the process. There do not appear to be any published investigations into mice and transference of wild oat seeds, but the distances covered would probably be too short to make much difference to the spread of an infestation beyond the boundaries of the original field.

In fur of larger, non seed-eating animals

In view of the ease with which wild oat seeds attach themselves to human clothing, and the readily-observed fact that cats, especially the long-haired varieties, frequently get weed-seeds caught in their fur and clean them out at a considerable distance from their origin, we might expect to find a few wild oats being carried between fields by hares, rabbits and farm cats. This does not seem to have been recorded.