Autumn irruptions of red-footed falcons *Falco vespertinus* in east-central Poland

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ABSTRACT

The red-footed falcon *Falco vespertinus* inhabiting SE Europe is known for its irruptive migrations. Here we attempt to outline the causes (weather conditions, dietary composition etc.) of the irruptions in 2014–2016 in east-central Poland. From 2004 to 2016 a total of 2873 falcons were counted during 542 observation bouts. The speeds of E and SE winds in August and September differed significantly between irruption and non-irruption years and were 1.3 km/h faster in the irruption years. Other weather factors, such as the number of days with E and SE winds, air temperature and the global North Atlantic Oscillation (NAO) and Scandinavia (SCAND) indexes, did not differ statistically between irruption and non-irruption years. The remains of 813 prey items were found in pellets collected in August and September, with a 93% dominance of insects; 84% of these were Coleoptera and Orthoptera. The irruptions of red-footed falcons in 2014–2016 may be also associated with increase in the number of breeding pairs in SE Europe.

INTRODUCTION

Most migrations of birds are regular events, taking place at the same seasons each year, with individuals moving between fixed breeding and wintering areas. Characteristic of some species, however, are the considerable year-on-year differences in the numbers of birds sighted in some areas, i.e. irruptive migrations. It is well known that irruptions are triggered by a lack of food, resulting from, e.g. poor crops of seeds or berries, or from the crash of prey populations (Newton 2010). In Europe, the best-known examples of irruptive species are great spotted woodpecker *Dendrocopos major*, Eurasian siskin *Carduelis spinus*, common redpoll *Acanthis flammea* and Eurasian jay *Garrulus glandarius* (Newton 2008). However, irruptions can also be elicited by certain set of weather conditions, which actually compel the birds to undertake large-scale displacements, or facilitate their migration (Elkins 2005, Bateman *et al.* 2015).

The red-footed falcon *Falco vespertinus* is a long distance, trans-equatorial migrant. Its breeding range covers open, typical steppe-like habitats extending from eastern Europe (Hungary, Romania, Ukraine) to Lake Baikal in central Asia (Cramp and Simmons 1980, del Hoyo *et al.* 1994). The species is listed as near-threatened both in Europe and globally, and as vulnerable within the EU; the European breeding population is estimated at 30 000–64 000 pairs (BirdLife International 2015). It is known to migrate in a loop, flying along a broad front over the eastern Mediterranean in autumn and returning by a more westerly route in spring (Cramp and Simmons 1980). The autumn pre-migration of the red-footed falcon takes place in August–September, while long-distance overnight migratory flights are undertaken in late September and early October (Fehervari *et al.* 2014, Palatitz *et al.* 2015). Satellite-tagged birds from eastern European populations have shown that the usual direction of migration is westwards, but the birds then turn south, flying along a broad front over the Balkan Peninsula and the eastern Mediterranean (http://satellitetracking.eu/inds/showmap). Along the Baltic Sea coast in northern Poland, an important European migration route for raptors in autumn, no more than 10 red-footed falcons were recorded in each year between 2008 and 2011 (Polakowski *et al.* 2014). Unusually, however, 113 birds were recorded along the Baltic coast in 1996 (Sikora and Cenian 1996). Sometimes in Europe, these migration flights become invasive, and the birds turn up in very large numbers in areas where they are not normally seen (Sikora and Cenian 1996).

In the last 13 years (2004–2016), there have been three consecutive years (2014–2016) with irruptions of red-footed falcons in east-central Poland (data from the Mazowsze-Swietokrzyskie Society for the Protection of Birds). The aim of this study is to identify the causes of these irruptions. On the basis of a literature survey (Hagemeijer 1994, Nightingale and Allsopp 1994, Kołodziejczyk *et al.* 2014), we anticipated that the numbers of red-footed falcons in a given year (autumn) ought to depend on: i) the number of days with E and SE winds, ii) the speed of the winds from these directions, iii) the air temperature. Irruption flights should take place in the years with a large number of days with strong winds blowing from these directions, in combination with higher than average air temperatures. Moreover, as the appearance of these falcons has been linked with the availability of dragonflies Odonata, a suitable prey item for these birds (Nightingale and Allsopp 1994, Sikora and Cenian 1996), it was expected that these insects should make up a substantial percentage of their diet.

MATERIALS AND METHODS

The data was collected in east-central Poland, mainly in the province of Mazovia (35 579 km^2). This region has a preponderance of arable land (46.9%), with meadows and pastureland having a 14.7% coverage, and orchards, mainly apple trees, occupying 2.6% of the land. Woodlands make up 24.8% and built-up zones 5.7% of the province's area. The remaining 5.3% consist of water bodies and wasteland (Statistical Yearbooks 2015).

The data was gathered in autumn from 2004 to 2016. Here, the autumn period was taken to be from August to October, the months during which these falcons were sighted most often. The records, obtained by 111 bird-watchers, were deposited in the ornithological database of the Mazowsze-Swietokrzyskie Society for the Protection of Birds, and then placed at our disposal with the consent of all the observers. During these 13 years, observers explored open areas in east-central Poland very thoroughly with the aim of gathering data on the occurrence of raptors. Although these observations were intensive, they were not part of any particular research project. Consequently, it is hard to specify the exact numbers of falcons in each year, but their numbers in August and September can be estimated at 150–300 each year. The extensive, open patches of meadows and arable land found all over this part of Poland were monitored several times every autumn. Although the intensity of monitoring was not identical each year, it was sufficient to distinguish falcon irruption years from non-irruption years.

We divided the years 2004–2016 into two periods: one (2014–2016) during which red-footed falcon irruptions were commonplace, and the other (2004–2013) during which falcon sightings were far fewer. Some birds may have figured in our calculations more than once, though it is impossible to say exactly how many. A study in Hungary has shown that during the pre-migration period these falcons frequently change their overnight roosting sites, which can be up to several hundred kilometres apart (Palatitz *et al.* 2015). We took E and SE winds to be those blowing from the 67.5–157.5^{o} sector.

We obtained the meteorological data from the internet for the weather station in Warsaw, which lies in the centre of our study area (52°10´N; 20°52˝E, 110 m am.s.l., http://en.tutiempo.net/climate/ and www.meteo.waw.pl). Since Warsaw is more or less half way between NE Europe, given as the centre of the red-footed falcons irruption peak (Sikora and Cenian 1996), and the probable area of origin of the falcons (SE Europae), the weather data from this station should be a good reflection of the conditions prevailing during the pre-migration period of the birds, which subsequently induce their irruptions. Since the falcons made their appearance in autumn from 11 August to 4 October, we used the weather data for the two key months of August and September in the statistical analysis. Apart from these meteorological factors obtained for east-central Poland, we also used in our analysis the global North Atlantic Oscillation (NAO) index (the mean value for August and September of each of the 13 years under consideration), which has been proven to affect the ecology of birds (Sanz 2003). The NAO is a major source of atmospheric mass balance between pressure centres over Ponta Delgada, Azores and Stykkisholmur, Reykjavik, Iceland (Hurrell 1995). The NAO index is estimated as the difference between normalized sea level pressures by dividing each monthly pressure by the long-term standard deviation (1865–1984). As a second global index we used the Scandinavia pattern (SCAND) in our analysis (the mean value for August and September of each of the 13 considered years). The Scandinavia pattern consists of a primary circulation center over Scandinavia, with weaker centers of opposite sign over western Europe and eastern Russia/western Mongolia. The Scandinavia pattern has been previously referred to as the Eurasia-1 pattern by Barnston and Livezey (1987). The positive phase of this pattern is associated with positive height anomalies, sometimes reflecting major blocking anticyclones, over Scandinavia and western Russia, while the negative phase of the pattern is associated with negative height anomalies in these regions. The positive phase of the Scandinavia pattern is associated with below-average temperatures across central Russia and also over western Europe. It is also associated with above-average precipitation across central and southern Europe, and below-average precipitation across Scandinavia. NAO and SCAND data were obtained from http://www.cpc.ncep.noaa.gov. The effect of the number of days with E and SE winds, the average wind speed on those days, the mean daily air temperature over this two-month period and the NAO and SCAND indexes (mean in two months) on the occurrence or non-occurrence of red-footed falcon irruptions was analysed statistically using the Mann-Whitney test in the module provided by Statistica 10.0 (StatSoft 2012). The values are reported as median and quartiles. Only results with a probability of $\alpha \leq 0.05$ were assumed to be statistically significant. Irruptive flights of red-footed falcon took place in 2014–2016, whereas in 2004–2013 sightings of these birds were far less frequent. In turn, we applied the G test (Sokal and Rohlf 2001) to compare the percentages of age classes of red-footed falcons between irruption and non-irruption years. The age classes according Cramp and Simmons (1980) were as follows: adult falcons (including 18 second-year birds), and first-year birds (juveniles).

We described the dietary composition based on the analysis of pellets collected at three sites. Two were situated in a mosaic of crop fields and meadows, where from 13 to 22 September 2014 we collected 34 and 7 pellets, respectively. The third place was the building site around a shale gas drilling rig – there we gathered 49 pellets: 35 on 11 August and 14 on 15 September 2012. All the pellets were picked up beneath the falcons' night-time roosts, so it is highly unlikely that some did not belong to this species. The numbers of prey items (total items) were determined by different specialists from the remains characteristic of a given taxon, i.e. heads, legs, antennae, cerci, parts of or whole wings in the case of invertebrates, and jawbones or mandibles in the case of mammals.

RESULTS

Numbers and age structure of falcons

From 2004 to 2016 a total of 2873 red-footed falcons were counted during 542 observation bouts (Fig. 1), an average of 5.3 birds per bout. The first birds turned up on 11 August (2012 and 2013), while the last ones were seen on 4 October (2015) and 28 September (2014). The migration peak was between 26 August and 9 September in non-irruption years and between 5 and 19 September in irruption years (Fig. 2). From 2004 to 2011 less than 10 birds per annum were seen in the study area, while the respective figures for 2012 and 2013 were 12 and 30. As a rule only single birds were seen (1.1 birds per observation bout on average), at most 3 birds in a flock. In 2014–2016, by contrast, migrations occurred on an unprecedented scale (Fig. 3). During 482 observation bouts in these three years a total of 2805 falcons was seen, an average of 5.8 per observation bout, with a maximum concentration of 149 birds.

Of the 56 birds that were aged in 2004–2013, 26.8% were adults (of which males 17.9%, females 8.9%) and 73.2% juveniles. On the other hand, during the irruption years of 2014–2016, 20.8% of the 1888 precisely identified falcons were adult birds (males 10.2%, females 10.6%) and 79.2% were first-year birds. The age proportions did not differ between these two periods (G-test, G = 0.99, df = 1, $P = 0.320$).

The effect of wind air, temperature NAO and SCAND indexes on the intensity of red-footed falcon migration flights

In the red-footed falcon's irruption years (2014–2016) E and SE winds in August and September blew for 11.5 days longer than in non-irruption years (Table 1). The median wind speed from these directions was 1.3 km h^{-1} faster than in the non-irruption years. In addition, the median daily air temperature in August and September of 2014–2016 was 1.1°C higher than in 2004–2013. The NAO index was -0.52 in August and September of the irruption years, but -0.06 in the non-irruption years. The SCAND index was 0.27 in August and September of the irruption years, and -0.11 in the non-irruption years. The

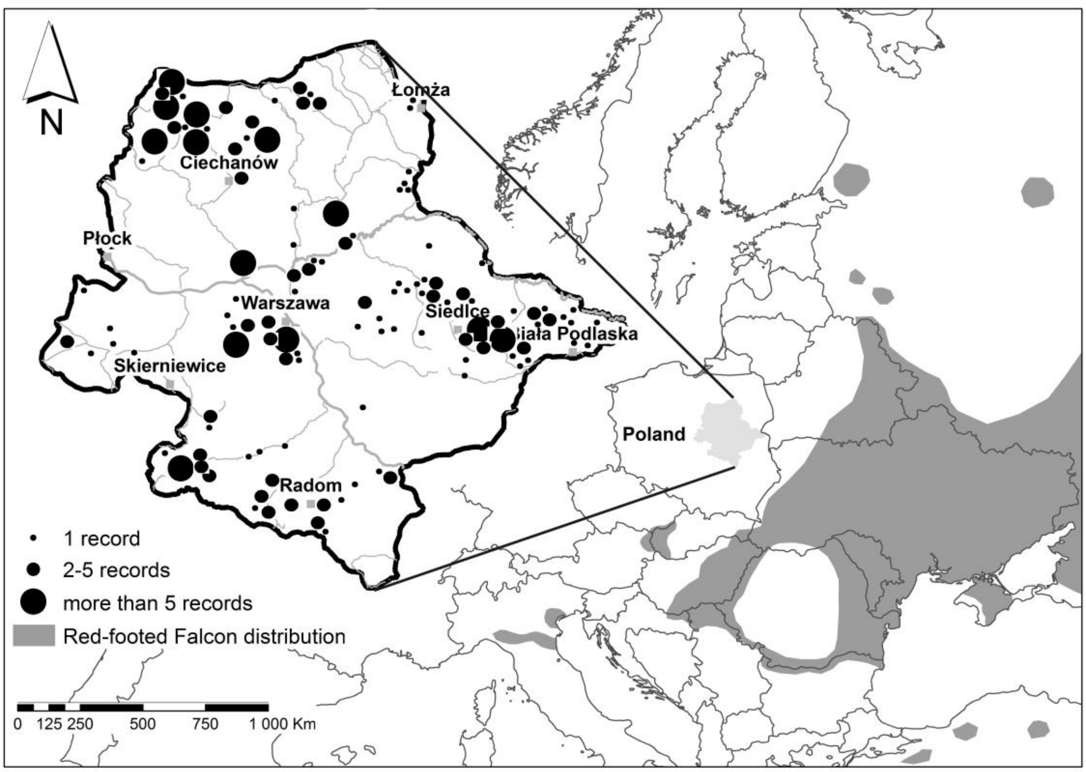

Fig. 1. The breeding range of red-footed falcons in Europe. Data according to Orta and Kirwan (2017) and distribution of the records of this species in east-central Poland in 2004–2016.

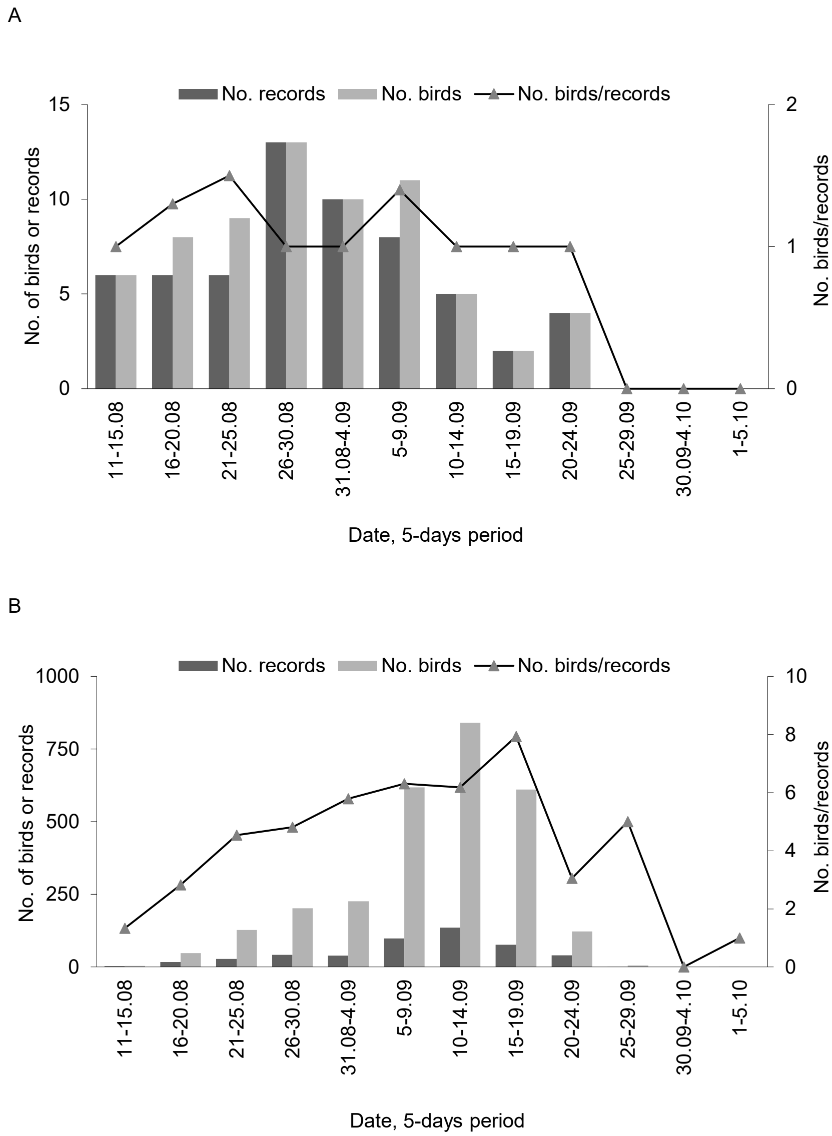

Fig. 2. Number of individuals, records and number of individuals/records of red-footed falcon in east-central Poland in successive pentads of autumn in 2004–2013 (A) and 2014–2016 (B).

only weather factor that differed significantly between irruption and non-irruption years was the wind speed. The other four parameters were not statistically significant (Table 1).

Dietary composition

The remains of 813 prey items were found in the falcon pellets (Table 2). Insects made up as many as 92.9% of these items, and Coleoptera and Orthoptera were predominant among the 7 orders (83.7% of all prey items). Eighteen families were represented among the insects, the highest percentage being that of Gryllidae – 32.7% of all the prey items. Noteworthy were the small insects from the family Formicidae, making up 3.2% of all the prey items. Only one dragonfly Odonata was found (Table 2). Apart from insects, other invertebrates included a few from the orders Araneae and Opiliones in the class Arachnida. Among vertebrates there were remains of rodents (6.6% of all the prey items), members of the family Cricetidae being prevalent (6.2% of all the prey items) (Table 2).

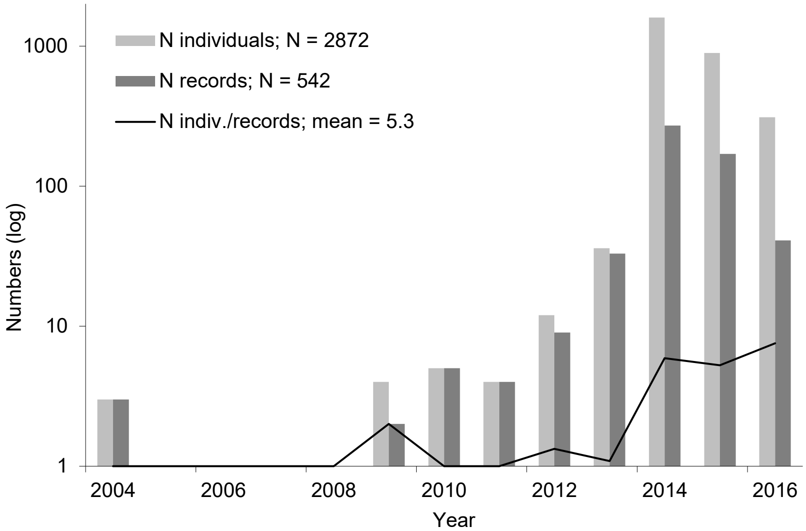

Fig. 3. Number of individuals, records and number of individuals/records of red-footed falcon in east-central Poland in 2004–2016.

DISCUSSION

The irruptions of red-footed falcons in 2014–2016 contrasted with their appearances in earlier years, with respect not only to the numbers of birds recorded and numbers of observation bouts, but also to the average flock size, which was 5.3 times bigger than in the previous 10 years. The age proportions did not differ between irruption and non-irruption years. Always dominant were birds in juvenile plumage: in the extreme case, in 2016, only first-year birds were recorded. The dates of their appearance were much the same as those recorded in south-western Poland in 2012, i.e. between 10 August and the end of September, with numbers peaking around 20th of September (Kołodziejczyk *et al.* 2014). The birds were sighted in open farmland, very frequently on crop fields and meadows, where they were usually seen to forage (Mroz and Golawski 2015).

Characteristic of the irruption years were the stronger E and SE winds compared with those in non-irruption years. This tallies with the explanations given in the literature. Irruptions are closely associated with a certain type of pressure system over Europe: an area of high pressure building up over NE Europe leads to strong E and SE winds, which

Table 1. Median (quartiles) of selected weather factors, North Atlantic Oscillation (NAO) and Scandinavia (SCAND) indexes in irruption years (2014–2016) and non-irruption years (2004–2013) of the red-footed falcon; these two periods were compared using the Mann-Whitney test.

Parameter	Irruption years	Non-irruption years	Mann-Whitney test, Z	*P*
	Median (quartiles)	Median (quartiles)		
Number of days with E and SE winds	27 (15–27)	16.5 (10–21)	1.52	0.128
Speed of E and SE winds (km h^{-1})	11.6 (10.6–14.5)	10.3 (9.6–10.7)	2.03	0.043
Air temperature (^{o}C)	17.7 (16.6–19.4)	16.6 (16.1–16.8)	1.69	0.091
NAO index	-0.52 (-0.71–-0.03)	-0.06 (-0.79–0.50)	0.42	0.672
SCAND index	0.27 (-0.72–0.98)	-0.11 (-0.25–0.17)	0.25	0.799

Table 2. Numbers and percentages of different prey taxa in the red-footed falcon's diet (n = 90 pellets and 813 prey items; 2012 and 2014 years).

Class	Order	Family	Species	Specimens	%
Insecta				755	92.9
	Orthoptera			310	38.1
		Acrididae	unidentified	42	5.2
		Gryllidae	*Gryllus campestris*	266	32.7
		Tettigonidae	*Tettigonia* sp.	2	0.2
	Coleoptera			371	45.6
		Silphidae		11	1.4
			Nicrophorus vespillo	2	0.2
			Phosphuga atrata	1	0.1
			Silpha obscura	1	0.1
			Silpha sp.	7	0.9
		Geotrupidae		5	0.6
			Geotrupes stercorarius	1	0.1
			Geotrupes sp.	4	0.5
		Carabidae		110	13.5
			Amara sp.	1	0.1
			Pterostichus sp.	1	0.1
			Unidentified	108	13.3
		Curculionidae		7	0.9
		Scarabaeidae		155	19.1
			Acilius sulcatus	1	0.1
			Aphodius distinctus	28	3.4
			Aphodius sp.	125	15.4
			Euheptalaucus sp.	1	0.1
		Brentidae		10	1.2
			Apion sp.	1	0.1
			Unidentified	9	1.1
		Staphylinidae		2	0.2
		Chrysomelidae		4	0.5
		Histeridae	*Margarinotus bipustulatus*	1	0.1
		Dytiscidae	*Hydaticus continentalis*	1	0.1
		Unidentified		66	8.1
	Hymenoptera			27	3.3
		Formicidae		26	3.2
			Formica sp.	22	2.7
			Myrmica sp.	4	0.5
		Unidentified		1	0.1
	Heteroptera			35	4.3
		Miridae	*Deraeocoris* sp.	2	0.2
			Unidentified	29	3.6
		Pentatomidae		4	0.5
	Dermaptera			3	0.4
		Forficulidae		3	0.4
			Forficula auricularia	1	0.1
			Unidentified	2	0.2
	Lepidoptera			6	0.7
	Odonata	Platycnemididae	*Platycnemis pennipes*	1	0.1
	Unidentified			2	0.2
Arachnida	Araneae			4	0.5
		Tetragnathidae	*Pachygnatha degeeri*	1	0.1
		Lycosidae	*Trochosa* sp.	2	0.2
	Opiliones	Phalangiidae	*Phalangium opilio*	1	0.1
Mammalia				54	6.6
	Rodentia			54	6.6
		Cricetidae		50	6.2
			Microtus arvalis	34	4.2
			Microtus sp.	16	2.0
		Muridae	*Apodemus agrarius*	1	0.1
		Unidentified		3	0.4

force the birds westwards. Such weather systems affect both the autumn (Sikora and Cenian 1996, Kołodziejczyk *et al.* 2014) and spring migration (Nightingale and Allsopp 1994, Hanzel 2015) of falcons, and determine whether or not an irruption will occur. The effect of strong winds as a factor causing rare species or large numbers of birds to turn up in areas where they normally do not occur is well known (summary in Elkins 2005, Newton 2008). Such irruptions are often associated not only with favourable winds but also with a high level of breeding success in a given year (Camphuysen and van IJzendoorn 1988).

Air temperature can also have an impact on irruption formation: in the present analysis this factor was close to being of statistical significance. Global warming has caused a distinct rise in temperatures during the year (Parmesan 2006). The greatest temperature increase takes place in spring, and the consequences of this for the earlier arrival of many migrant species have been described in depth (Zalakevicius *et al.* 2006, Tottrup *et al.* 2012). But temperature rises have also been recorded in late summer – early autumn, which may lead to a prolonged period of post-breeding dispersal, before the onset of migration to the wintering grounds, as has been recorded, for example, in the case of the crane *Grus grus* in Russia (Volkov *et al.* 2016). Higher temperatures, enhancing the activity of insects (Arbeiter *et al*. 2016), the basic food of these falcons, may therefore favour a longer period of their dispersal. In combination with winds, this may facilitate flights to areas which are far beyond their normal range in years with more typical weather patterns. The global factor, i.e. the NAO index, did not turn out to be a significant factor impacting red-footed falcons irruptions. This index is probably of greater importance in spring, when birds migrate to their breeding grounds and begin reproduction (Møller 2002, Ordo 2007), and not during the post-breeding dispersal phase in summer and autumn. In any case, the effect of the NAO is felt more strongly in western than in eastern Europe (Hurrell 1995). Similarly, the SCAND index did not differ between the years with irruption and in non-irruption years. However, it should be emphasized that the available data was limited to 3 years with irruption, so they were rather scarce.

The literature fails to provide any data regarding the food ingested by red-footed falcons away from their breeding areas, and even from these areas such data is sparse. Analysis of pellets from roosts in Hungary showed that as many as 97.4% of prey items were Coleoptera, including 52.3% Amara beetles, whereas the proportion of Orthoptera was only 2.6% (Szeles *et al.* 2010). On the other hand, data on the red-footed falcon's diet based on the remains of prey collected in nests with young in the former Yugoslavia showed the dietary composition to be much the same as that obtained in the present study (Purger 1998). Red-footed falcon nestlings consumed mainly Orthoptera (60% of prey items), Coleoptera (36%) and Odonata (4%), while Vertebrata made up 6% of prey items (Purger 1998); these figures are almost identical to those obtained in east-central Poland. The preference for Orthoptera is also emphasized in other papers (Szovenyi 2015). It is thought that access to dragonflies might be a factor determining whether an invasion will or will not take place (Nightingale and Allsopp 1994, Sikora and Cenian 1996), but in east-central Poland dragonflies were not found to be an important component of these birds' diet – the remains of just one such insect were found. Moreover, the sites from which pellets were collected are not environments with large densities of dragonflies. On the other hand, it may well be possible that dragonfly remains are poorly preserved in pellets, as whole insects are digested by falcons. There may have been some overinterpretation of the proportions of some taxa, such as Coleoptera; this was stressed following analysis of pellets of e.g. the red-backed shrike *Lanius collurio* (Golawski 2006), whose diet is similar to that of the red-footed falcon. It was certainly surprising to find in the Polish falcons' diet small prey items like scarabaeid beetles (19% of all items), as well as less numerous beetles from the family Brentidae, not to mention spiders and ants. The red-footed falcons appear to be very flexible in terms of prey selection, which may favour the irruptions.

The irruptions of red-footed falcons in east-central Poland in 2014–2016 coincided with stronger E and SE winds in comparison with the non-irruption years. However, one must not lose sight of the fact that relatively few relevant data was available for analysis, especially for those seasons when irruptions did take place. It is quite curious that irruptions should have taken place only in the last three of the 13 years under scrutiny. The appearances of large numbers of falcons could have been due to some other factors. For example, following a long-term decline in the population of this species, an increase in the number of breeding pairs was recorded in the more productive breeding grounds closest to east-central Poland, i.e. in Hungary (Palatitz *et al.* 2015). This increase has remained constant since 2010, and in 2014 the number of pairs was double that in 2006, when the lowest number of 558 pairs was recorded. This rise in numbers is most likely due to the large-scale deployment of nest boxes for red-footed falcons (Palatitz *et al.* 2015). It could be that the predominance in east-central Poland of first-year birds, especially in 2016, was a consequence of the high level of breeding success of falcons in Hungary, since this is one of the more important factors giving rise to such extraordinarily large numbers of species in areas where they are normally absent or present in small numbers only (Elkins 2005). On the other hand, our analysis of dietary components did not show that Odonata were of any great importance, even though some authors consider dragonflies to be a significant factor governing falcon irruptions (Nightingale and Allsopp 1994). Our data indicate that these falcons have a highly variable diet, and it seems, therefore, that red-footed falcons are very flexible in their selection of prey, and are not averse to consuming spiders, harvestmen, and even ants.

In the context of these autumnal irruptions of red-footed falcons in the last three years in east-central Poland, the question arises whether such irruptions are likely to recur in the future. Climate changes have caused wind speeds to increase (McInnes *et al.* 2011), a factor that favours the movements of birds. Indeed, it would be interesting to find out whether such frequent irruptions of these falcons would ultimately lead them to nest in this region. Such a scenario, i.e. an increase in the non-breeding fraction of a population, leading to breeding, has occurred in, for example, the great white egret *Ardea alba*, which now nests every year in Poland (Lawicki 2014). Although Fehervari *et al.* (2009) claim, based on models of the red-footed falcon's breeding habitats, that its distribution range will not expand even if its numbers do increase, it is always worth tracking the fate of this severely endangered falcon.

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