Ornis Fennica 91:39–47. 2014

Autumn migratory movements of raptors along the southern Baltic coast

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Received 25 January 2013, accepted 14 December 2013

Some of the known major bottlenecks on European flyways are yet insufficiently explored and require more intensive study. On the basis of raptor counts on the Vistula Spit (southern Baltic coast, Poland), from 15th August to 15th November 2008–2011, we consider this bottleneck to be important at a European scale. Every year we observed there almost 11,000 individuals of 22 raptor species. The flyway is especially important for Peregrine Falcons, Hen Harriers, Merlins and Eurasian Sparrowhawks. To analyse the species composition observed we related the mean annual number of raptors recorded on the Vistula Spit to the corresponding numbers at Falsterbo. The linear mixed model showed that the median migration date showed a significant effect on the species composition and the flight strategies a nearly significant effect. The southern Baltic coast seems to be the most important bottleneck in the autumn passage for late migrating raptors with flapping flight and differ in composition and numbers of species from the flyway at Falsterbo.

1. Introduction

Bird migration has been extensively studied, and many aspects of this phenomenon are well documented (Berthold 1993, Newton 2008). However, the migration routes and strategies of soaring birds (including raptors) are still inadequately studied and are not entirely clear. During their autumn migration from breeding areas in European and Asian northern latitudes to their southern wintering quarters, raptors encounter barriers created by seas, which restrict migration wave and shape distinct flyways (Porter & Beaman 1985, Zalles & Bildstein 2000, Sammut & Bonavia 2004, Verhelst *et al*. 2011). As a consequence, birds of prey often concentrate along narrow routes, which leads to the occurrence of bottlenecks (Zalles & Bildstein 2000).

There are two main raptor migration routes known in the Western Palearctics: the Western European-West African (Atlantic) and the Eurasian-East African (western Black Sea) Flyways (Bildstein & Zalles 2005, Bildstein 2006). The first one, which is followed by up to 400,000 raptors per year, leads from Scandinavia, through western Europe to Spain and west Africa. A total of 22 species are regularly recorded on this flyway; some of these species spend the winter in western Europe while others migrate further to west Africa. The second raptor migration route, i.e. the Eurasian-East African Flyway, begins in north-eastern Europe and western Siberia, passes through the Middle East and ends in Sub-Saharan Africa. It is followed by over 1.5 million birds of 40 raptor species per year (Bildstein 2006). The main migratory bird count sites of the Western European flyways are situated in Sweden, Spain, Italy (Porter & Beaman 1985, Kjellén & Roos 2000, Bildstein 2006), while those on the Eurasian flyway are in Bulgaria, Turkey, Georgia and Israel (Porter & Beaman 1985, Yosef & Tryjanowski 2002, Yosef *et al*. 2003, Bildstein 2006, Michev *et al*. 2011, Verhelst *et al*. 2011).

Birds from western Scandinavia follow the Western European-West African Flyway through Falsterbo (Kjellén 1997), while those from eastern Scandinavia and Siberia follow the Eurasian-East African Flyway (Bildstein 2006). However, less is known about the migration routes of raptors from breeding sites situated in the borderline areas between these main flyways, such as northern Scandinavia, western Siberia and the Baltic states. Earlier studies have shown that passage along the southern Baltic coast is very important to passerine birds, but data on raptor migration were scarce (Busse & Halastra 1981). We presume that some northern European raptor populations migrate along the southern Baltic coast and make a strong contribution to the Western European-West African Flyway. However, we expect that large water bodies like the Baltic Sea would influence the flyways of particular raptor species, and favour accumulation along the Baltic coast of later migrating species, with flapping rather than soaring flight.

The main aim of this paper is to investigate the numbers and species composition of raptors on the southern Baltic coast during the autumn passage, and to determine the importance of this flyway in comparison to the other Western Palearctics Flyways. In order to determine migration patterns and species composition in relation to relevant predictors, we related the numbers observed to data from Falsterbo, which is a migratory bottleneck for raptors from Scandinavia (Kjellén 1997). This important site of the Western European Flyway is situated 450 km NW of our study site and concentrates *ca*. 50,000 birds every autumn (Bildstein 2006). We expected that geographical location might influence the numbers and species composition at both count sites (Falsterbo and the Vistula Spit). The counts were used to test the hypothesis that the median date of raptor migration is different in both sites *inter alia* due to the species composition where later migrants are more numerous on the southern Baltic.

Moreover, large barrier of the Baltic Sea might influence on type of migration strategy of raptor species observed in both areas. We predict that raptors with flapping flight are more common in the Baltic region, because crossing the Baltic sea requires active flapping flight.

2. Material and methods

The study site was located in the eastern part of the southern Baltic coast, on the Vistula Spit, which separates the Vistula Lagoon from the Gulf of Gdańsk in the Baltic Sea (Fig. 1). The counting site was a watch tower standing high on the sand dune (54°24'11.71"N, 19°31'17.04"E). This allowed all the raptors passing along the spit to be observed. Every day from one to three experienced observers counted the migrating birds from sunrise (6:00–7:00 h) to afternoon (15:00–17:00 h) in all weather conditions. The counts were performed during the period from 15th August to 15th November in 2008–2011.

To define the importance of the pathway, the observed counts were compared to the estimated population sizes of two possible breeding areas: Fennoscandia (Sweden and Finland) and the Baltic states (Lithuania, Latvia and Estonia). The numbers of breeding pairs were obtained from Birdlife International (2004). To estimate the actual autumn population sizes of the possible breeding areas, we summed the estimated number of individuals and an estimate of the number of

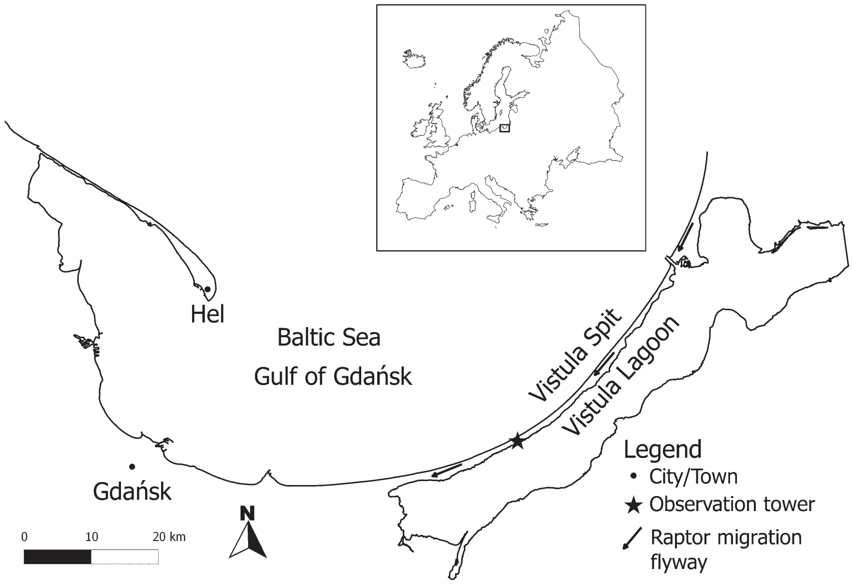

Fig. 1. Map showing the counting site on the Vistula Spit.

young, which in turn was obtained by multiplying the number of pairs with average reproductive success (according to Cramp 1977, Newton 1979).

To test our hypothesis, we compared our results with analogous data from Falsterbo (Falsterbo Fågelstation 2012). For twelve regularly seen species we related the mean annual number observed for each species with the corresponding numbers at Falsterbo. The Difference Index ($D_{i,j}$) was calculated as the natural logarithm of the ratio between the numbers observed at the two sites, for each species (i) and year (j):

$$D_{i,j} = \ln(\text{Vistula Spit}_{i,j} / \text{Falsterbo}_{i,j}) \qquad (1)$$

The value was negative if more individuals were seen at Falsterbo; otherwise it was positive. The Difference Index was used as the dependent variable in a linear mixed model (GLMM; with identity link and normal error distribution). Subject variables in the model were species identity and the year of the survey ("Year": 2008, 2009, 2010 and 2011). Species and Year were considered as random effects (intercepts) with scaled identity covariance.

Based on suggestions in earlier studies (Spaar 1997, Mellone *et al*. 2012) we determined three predictors that were included as fixed effects in the model. We used two categorical predictors. One was "Migration distance" including long-distance migratory species: Honey Buzzard (*Pernis apivorus*), Marsh Harrier (*Circus aeruginosus*), Osprey (*Pandion haliaetus*), Hobby (*Falco subbuteo*) and short-distance migrants: Hen Harrier (*Circus cyaneus*), Goshawk (*Accipiter gentilis*), Eurasian Sparrowhawk (*Accipiter nisus*), Common Buzzard (*Buteo buteo*), Rough-legged Buzzard (*Buteo lagopus*), Common Kestrel (*Falco tinnunculus*), Merlin (*Falco columbarius*), Peregrine Falcon (*Falco peregrinus*). Another categorical predictor was "Flight" within soaring flight species: Honey Buzzard, Common Buzzard, Rough-legged Buzzard and flapping flight raptors: Marsh Harrier, Hen Harrier, Goshawk, Eurasian Sparrowhawk, Osprey, Common Kestrel, Merlin, Hobby, Peregrine Falcon. We also used one continuous predictor "Median" (median migration date, presented as day of year).

The mixed model was fitted using maximum likelihood and the number of degrees of freedom were estimated using the Satterthwaite approximation. Statistical analyses were done using IBM SPSS Statistic version 20 software. We considered results with $p < 0.05$ to be statistically significant.

3. Results

During the four years of this survey, a total of 22 bird of prey species were observed on the Vistula

Table 1. Numbers of raptors recorded on the Vistula Spit during the autumn migration in 2008–2011. Averaged phenology parameters are shown for the most numerous species.

Species	2008	2009	2010	2011	Median date	Date of first 5%	Date of first 95%	Length of central 90%
Honey Buzzard	37	20	63	92	4. Sep	22. Aug	16. Sep	25
Marsh-harrier	54	107	171	187	5. Sep	21. Aug	30. Sep	40
Hen-harrier	915	383	549	683	24. Oct	2. Oct	7. Nov	36
Goshawk	102	76	110	72	25. Oct	28. Aug	8. Nov	72
Eurasian Sparrowhawk	6,272	3,729	5,732	8,320	16. Oct	13. Sep	2. Nov	50
Common Buzzard	4,571	2,372	3,639	2,099	24. Oct	31. Aug	9. Nov	70
Rough-legged Buzzard	415	127	403	176	2. Nov	16. Oct	10. Nov	25
Osprey	5	12	14	38	12. Sep	22. Aug	1. Oct	40
Common Kestrel	28	27	156	120	19. Sep	29. Aug	17. Oct	48
Merlin	46	97	80	151	6. Oct	13. Sep	28. Oct	45
Eurasian Hobby	132	131	498	317	12. Sep	25. Aug	30. Sep	36
Peregrine Falcon	69	115	106	170	4. Oct	7. Sep	25. Oct	48
Black Kite	0	1	0	0				
Red Kite	1	1	3	2				
Unidentified Harrier	0	0	0	1				
Pallid Harrier	1	0	3	8				
Montagu's Harrier	1	2	3	8				
Levant Sparrowhawk	0	0	1	0				
Lesser Spotted Eagle	1	0	10	0				
Greater Spotted Eagle	0	0	1	1				
Golden Eagle	0	0	0	1				
Red-footed Falcon	0	8	2	10				
Saker Falcon	1	0	0	0				
Unidentified Falcon	1	0	0	1				
Total number	12,652	7,208	11,543	12,457				

Spit with a mean number of 10,965 individuals per year (Table 1). The most numerous species was the Eurasian Sparrowhawk, which exceeded the threshold of 50% individuals. The next two were the Common Buzzard and Hen Harrier (29% and 6%, respectively).

Taking into account the breeding population sizes, seven species on the Vistula Spit exceeded 1% of the population originating from Fennoscandia and eight species exceeded that of the Baltic states (Table 2). The Peregrine Falcon and Hen Harrier were the most important migrants, as their numbers at the Vistula Spit were higher than the breeding populations of the Baltic states. For the next two species, i.e. the Merlin and Eurasian Sparrowhawk, the numbers were 66% and 23% respectively of the birds nesting in the Baltic states (Table 2).

The linear mixed model showed that "Median" positively affected the Difference Index (Table 3). Late migrants occurred in relatively larger numbers at Vistula Spit compared to Falsterbo. In this group, three species: Goshawk, Hen Harrier and Peregrine Falcon had positive mean value of the Difference Index. However, Honey Buzzard, Osprey and Marsh Harrier were noted relatively early and in low numbers on Vistula Spit. In contrast, two later migrants (Rough-legged Buzzard and Common Buzzard) had negative Difference Index and one early species (Hobby) was numerous on the Vistula Spit. The average Difference Index for all later migrants was higher than for early migrants (–0.46 and –2.17 respectively; implying a ca 5.5 times higher ratio exp[$D_{i,j}$] for later migrants).

The second factor "Flight" nearly significantly influenced the Difference Index. In line with our prediction, the Difference Index was lower for soaring raptors in comparison to flapping species (the average value was –2.35 and –0.78, respectively; implying a ca 4.8 times higher ratio for flapping species). However, "Migration Distance" did

Table 2. Comparison of the mean numbers (± SE) of the most numerous birds of prey counted during the autumn migration on the Vistula Spit (VS, Poland) and the percentage of the numbers of the most numerous birds of prey migrating along the Vistula Spit vs. the estimated population sizes of potential breeding areas (according to Birdlife International 2004). Fennoscandia includes Sweden and Finland, the Baltic states include Lithuania, Latvia and Estonia. Species numbers exceeding 1% of the population estimates are marked in bold.

Species	Vistula Spit	Fennoscandia		Baltic countries	
		Pop. estimate	VS	Pop. estimate	VS
Honey Buzzard	53.0 ± 15.72	25,200–31,200	0.2	9,300–13,800	0.5
Marsh Harrier	129.8 ± 30.60	5,775–6,600	**2.1**	12,705–18,480	0.8
Hen Harrier	632.5 ± 112.39	7,130–13,640	**6.7**	480–697	**>100**
Goshawk	90.0 ± 9.42	25,200–37,800	0.3	11,520–17,280	0.6
Eurasian Sparrowhawk	6,013.3 ± 943.62	99,900–129,500	**5.3**	21,090–35,890	**22.6**
Common Buzzard	3,170.3 ± 574.94	90,000–126,000	**3.0**	78,000–97,500	**3.7**
Rough-legged Buzzard	280.3 ± 75.04	9,500–34,200	**1.9**	0	0
Osprey	17.3 ± 7.18	15,015–17,820	0.1	561–775	**2.6**
Common Kestrel	82.8 ± 32.73	20,250–29,250	0.3	2,700–4,275	**2.5**
Merlin	93.5 ± 21.90	24,800–34,800	0.3	100–240	**66.2**
Hobby	269.5 ± 87.82	14,060–19,240	**1.6**	4,810–9,990	**4.2**
Peregrine Falcon	115.0 ± 20.86	717–875	**14.5**	3–35	**>100**

not affect the differences between the Vistula Spit and Falsterbo significantly (Fig. 2).

4. Discussion

Our study shows that the southern Baltic coastline is an important migration corridor for raptors. Closely associated with the Western European Flyway, it is used by up to eleven thousand birds of prey every autumn. In comparison with estimated breeding raptor populations from Fennoscandia and the Baltic states, we counted relatively high numbers of Eurasian Sparrowhawks, Hen Harriers, Peregrine Falcons and Merlins. Most of the known wintering grounds of the Eurasian Sparrowhawk from north-eastern Europe are in its western part (Cramp 1977), which tallies with ringing recoveries from the Baltic area (Saurola 1981, Busse *et al*. 2012) and indicates that this species migrates over short distances from northern to western Europe. According to ring recovery data obtained at the "Operation Baltic" sites on the Polish coast (e.g., Nowakowski *et al*. 2005), most recaptured Sparrowhawks originated from breeding grounds in Finland, but fewer from the Baltic states, Russia and Sweden. They were found overwintering mainly in Germany and France. Hen Harriers migrate to wintering grounds in western Europe, although some individuals could spend the winter in southern or central Europe (Cramp 1977). According to this information, the Vistula Spit appears to be located on an important migration bottleneck for this species, given the

Table 3. Results from linear mixed model, explaining variation in the Difference Index.

Parameters	Estimate ± SE	Test statistic	*P*-value
Intercept	–15.071 ± 5.453		
Flight (flapping vs. soaring)	2.024 ± 0.966	$F_{1,9}$ = 4.387	0.066
Median	0.044 ± 0.018	$F_{1,44}$ = 5.972	**0.019**
Migration distance (long vs. short)	0.334 ± 1.100	$F_{1,17}$ = 0.092	0.765
Variance for Year	1.920 ± 0.983	Z = 1.954	0.051
Variance for Species	0.418 ± 0.100	Z = 4.178	**< 0.001**

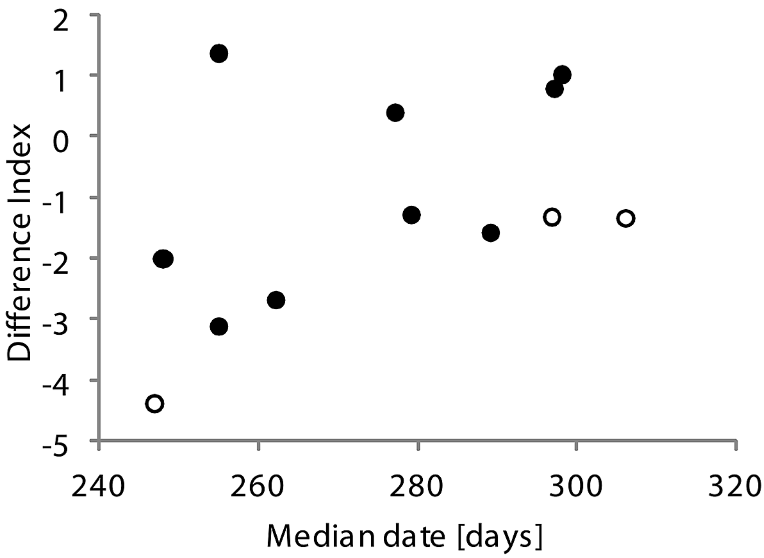

Fig. 2. Average Difference Index (y-axis) for each species (N = 12) against average median date (x-axis); open circles showed the flapping flight type of given species and filled the soaring flight type. The Difference Index was calculated as the natural logarithm of the ratio between the numbers of observed raptors at the Vistula Spit and Falsterbo for each of surveyed species.

significant proportion of the northern population that passes through it. Moreover, the numbers of Hen Harriers on passage exceeded the breeding populations of the nearest countries thus the birds recorded on the Vistula Spit probably came from the large Russian populations. The Vistula Spit is similarly important for Peregrine Falcons and Merlins, in view of the considerable numbers of these species passing through compared with the sizes of their northern populations. Such a migration route has also been confirmed by satellite-tracked Peregrine Falcons: they fly from their northern Russian nesting sites, using the shortest possible route close to the Baltic coast, thereafter following the Western European–West African Flyway, ultimately arriving at their wintering grounds in south-western Europe (Ganusevich *et al*. 2004). Merlins from northern populations overwinter in western and southern Europe as well as in north-western Africa and the Middle East (Cramp 1977, Bildstein 2006). Most of these birds passing along the southern Baltic coast seem to feed the Western European Raptor Flyway.

The southern Baltic flyway is used by relatively large numbers of other species. One of these is the Marsh Harrier, which seems to cross Europe south-westwards on a broader front using the leapfrog migration strategy. Most individuals from north-eastern Europe move south-west, flying along the southern Baltic coast too (Panuccio *et al.* 2013). However, only one recovery, that of an individual originating from Finland, was caught on the Polish coast (Busse *et al*. 2012; J. K. Nowakowski, Operation Baltic Ringing Station, unpublished data). Common Buzzards, Hobbies and Rough-legged Buzzards were also noted in large numbers on the southern Baltic corridor. The first two species probably came from north-eastern populations, and the Rough-legged Buzzards from that species' northern breeding areas. The main part of the Buzzard's European populations heads to western and south-western Europe, but some of these birds overwinter in central Europe (Cramp 1977, Bildstein 2006, Kasprzykowski & Cieśluk 2011). This is in accordance with the westerly/south-westerly direction of passage along the southern Baltic coast and in contrast to the south-easterly oriented migration axis of the Steppe Buzzard (*B. buteo vulpinus*), which follows the Eurasian-East African Flyway in large numbers. The nominative race of this species is also one of the dominant raptors in southern Sweden (Falsterbo FÍgelstation 2012). The Hobby also seems to migrate on a broad front across natural barriers across the Central Mediterranean basin (Strandberg *et al.* 2009a). Satellite-tracked individuals migrated southwards from Germany and overwintered in South Africa (Meyburg *et al*. 2011).

Surprisingly, Honey Buzzards, which are numerous at Falsterbo and use the Western European Raptor Flyway in large numbers (Bildstein 2006, Meyburg *et al*. 2010), turned up in only low numbers on the Vistula Spit. On the other hand, many are also sighted during the autumn migration in Bulgaria (Michev *et al*. 2011) and Israel (Bruderer *et al*. 1994). Thus, most Honey Buzzards do not use the southern Baltic flyway *en route* from north-eastern Europe and western Siberia. Likewise the Osprey, regarded as a long-distance species, does not use the corridor along Vistula Spit. Ospreys from western Fennoscandia migrate along south-western Scandinavia and head south-westwards to west Africa (Strandberg *et al*. 2009b).

There are a number of possible reasons why we could have overlooked some raptors during our studies. One reason is the natural oscillation of rodents in northern latitudes, so that some migrating, rodent-eating raptors remain longer in their breeding grounds and undertake their migration relatively late in the autumn, when their food supply has significantly decreased (e.g., Newton 2008). During the study seasons some raptors could have been also missed because of the weather conditions (e.g., Shamoun-Baranes *et al*. 2006). Raptors can sense the local atmospheric pressure, which helps them to avoid cold fronts and low temperatures (e.g., Krüger 2002). Those could have been mainly Buzzards (Common and Rough-legged) and Hen Harriers, which normally migrate across Poland late in the autumn (Tomiałojć & Stawarczyk 2003), and could have been heading to their wintering grounds after our study season had ended. However, the numbers of very late migrants do not appear to be important: only small numbers of raptors were observed here during occasional counts done in late November and December. We assume that this did not affect the general conclusions on the significance of the southern Baltic flyway.

We found that the species composition influenced the median of migration within Vistula Spit. The flyway was characterised by large numbers of some late migrants of high Difference Index which are short-distance raptors. On the other hand, some long-distance species migrate earlier and in much lower number in Vistula Spit than in Falsterbo. These phenomenon could be explain by Day Length Hypothesis (Mellone *et al.* 2011). According to the hypothesis, day length has a positive effect on the distance covered per day, which is especially important for soaring species. In local scale, weather conditions could also modify the timing of autumn raptor migration (Miller *et al.* 2011). Especially soaring and long-distance birds require higher temperature and calmer wind to minimize the energetic costs of flight (Lanzone *et al.* 2012). The likelihood of favorable conditions on Vistula Spit decreases during migration period thus such group of raptors are more represented earlier in the autumn here. Nearly significant differences in the type of flight between Vistula Spit and Falsterbo suggest that the flapping flight style seems to be the most often used on the southern Baltic. This is related to the dominance of small raptors migrating in such a style and to the low number of heavier raptors with better gliding ability (Spaar 1997). Soaring species usually detour around sea barrier because they must undertake powered flight consuming a large amount of energy (Alerstam 2001, Yamaguchi *et al.* 2012). Lower Difference Index noted in the two later Buzzard species confirm the avoidance of crossing water surface by typical raptors exploiting thermals. Therefore, described flyway was mostly used by late raptors without availing themselves of thermals which corresponds with the tendency of raptors to occur along the coastlines (Zalles & Bildstein 2000).

In conclusion, the Vistula Spit on the southern Baltic coast seems to be the most important bottleneck for raptor species. The flyway is of great significance to late migrants using mainly flapping flight. Particularly high numbers of Eurasian Sparrowhawks, Hen Harriers, Peregrine Falcons and Merlins migrate there from north-eastern breeding areas to western and south-western Europe.

Acknowledgements. We would like to thank all the people who participated in the fieldwork and helped in the studies, and also Justyna Kubacka, Agnieszka Piróg, Peter Senn and Marta Ściborska for the language corrections. We also thank Andreas Lindén and an anonymous referee for their useful suggestions and comments on the manuscript. The research was partially supported by the Regional Fund for Water Resources and Protection of the Environment in Gdańsk.

Petolintujen syysmuutto Itämeren etelärannikolla

Euroopassa on tiedossa olevia, mutta puutteellisesti tutkittuja lintujen muuton pullonkauloja.

Laskimme muuttavia petolintuja 1.8.–15.11. vuosina 2008–2011 Veikselin kynnäksellä (Itämeren etelärannikolla, Puolassa). Toteamme kyseessä olevan Euroopan mittakaavassa merkittävä muuttoreitti, jolla vuosittain muuttaa 22 lajia petolintuja noin 11 000 yksilöä. Muuttoreitti on erityisen tärkeä muuttohaukalle, sinisuohaukalle, ampuhaukalle ja varpushaukalle. Tutkiaksemme muuttavien petolintujen lajistoa vertasimme vuosittaisia muuttajamääriä Veikselin kynnäksellä Etelä-Ruotsin Falsterbon määriin. Lineaarinen sekamalli osoitti, että Itämeren etelärannikon muuttava petolintulajisto eroaa Falsterbosta. Muuton ajoittumisen mediaani vaikutti lajistoon merkitsevästi ja lentotavalla oli lähes merkitsevä vaikutus. Reitti on tärkein myöhään muuttaville, lepattavan muuttolentotyylin omaaville petolintulajeille.

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