House Sparrow (*Passer domesticus*) density explained with the factors food availability, breeding site availability, shelter availability and predation pressure as limiting factors.

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Capsule The House Sparrow density is related with the factors *food availability* and *shelter availability*. The factors *breeding site availability* and *predation pressure are not related in the selected locations.*
Aims To identify the impact of the *factors food availability, shelter availability, breeding site availability* and *predation pressure* on sparrow densities in urbanized areas in The Netherlands.
Methods In 61 locations of around one hectare in the city of Leiden in The Netherlands, the amount of food, shelter, possible nesting places, predators and House Sparrows were estimated. Part of the data collecting was done by field work; part was done by using aerial photos. For the amount of *food* we measured the amount of grass, herb and shrub on the location and the distance to large external food sources. For the factor *shelter availability* we measured the amount of shrub, ivy, hedges, conifers and deciduous trees. Because *breeding site availability* can be found in both vegetation as in buildings, we measured the amount of hedge, ivy and conifer and measured in addition the type of roof tile and the percentage of the area that was built. For the *predation and competition pressure* we counted the number of magpies, jays, crows, Sparrow hawks, cats and jackdaws. For the data analysis we had three approaches. First we investigated the single role factors play on the sparrow density and we investigated the sparrow density when the factors were combined. Secondly, we compared the locations with the highest and the lowest House Sparrow density for twenty-one variable. Third, we analyzed the twenty-one variables with a Principal Component Analysis.
Results The first approach: the factors *food availability* and *shelter availability* are correlated positively with the sparrow density, *predation pressure* is correlated negatively. There is enough *breeding site availability* in all the locations. When the factors are united as a function, sparrow density decline when both *food* and *shelter availability* is low. The second approach: the sparrow density is correlated with the vegetation density, but in many locations the House Sparrow density is low while the vegetation density is high. The results of the Principal Component Analysis were unclear.
Conclusion The House Sparrow density is related with the factors *food availability* and *shelter availability*. The factors *breeding site availability* and *predation pressure* seems to be not related. The amount of vegetation positively correlates with the sparrow density. However, the sparrow density in many locations cannot be explained. Apparently, the method was incorrect or the investigated parameters were not the only factors affecting the sparrow density. A possible factor can be the amount of invertebrate food as suggested by Vincent (2005).

Introduction

The House Sparrow (*Passer domesticus*), formally the most abundant bird in the urban parts of The Netherlands, shows a sharp decline in number of breeding pairs. Since 1990, the species has started to retreat from the city as well as from the farmland, resembling the remarkable trend in other parts of Western Europe (Klok *et al.*, 2006). The causes on the farmland are mainly ascribed to increased intensity of farming practice, causing for instance loss of seed resources (Crick *et al*. 2002; Hole, 2002 and Robinson, 2005). However, Summers-Smith showed in 2003 and 2005 that the mechanisms underlying the decline in urbanized environments are different. Most frequently mentioned possible causes are an increased predation pressure (Churcher and Lawton, 1987; Woods *et al.*, 2003; MacLeod, 2006) and food shortness (Crick *et al.*, 2002; Robinson, 2005). Summers-Smith (2003) enumerate in addition possible causes like loss of potential breeding sites due to modern building, but also causes like diseases and increased traffic. Despite these possible causes, Chaimberlain (2007) and Klok *et al*. (2006) considered that strong evidence to support any of these causes is still lacking and Robinson (2005) suggested that the decline is caused by an interaction of several of these factors. Chaimberlain of the British Trust for Ornithology (BTO) in Great Britain analyzed data collected for the BTO House Sparrow Survey to identify key habitats for the House Sparrow. He found out that the amount of houses with gardens was the best predictor of House Sparrow abundance and acknowledged the importance of allotments as food sources. Urban green spaces were found to be important, also emphasized by other researchers (e.g. Van Damme-Jongsten & Sparrius, 2002; Vincent, 2005; Wilkinson, 2006).
Klok *et al*. (2006) conclude for the Dutch situation, which may differ from other parts of Western Europe (BirdLife, 2005), that most likely both survival and reproductive success have decreased since 1989, but no strong conclusions were drawn about the possible causes. To be

able to prevent a further decline of the House Sparrow in urban areas in The Netherlands more insight in this problem is needed.
The viability of a population depends on survival rate and reproductive success. The recent decline is related to a disruption of one or both of these two factors (Crick et al., 2002). (1) Survival of adult sparrows is determined by food availability (seeds), shelter availability against predators, predation pressure and organisms or toxins that are harmful for their health. (2) Reproductive success is determined by breeding site availability, food intake (insects), predation pressure and organisms or toxins that are harmful for the health of the brood.
The current study addresses the relationship between a selection of the named determinants and House Sparrow density. Because *food availability, shelter availability and breeding site availability* were measurable with a similar method, by measuring the amount and type of vegetation, these factors were selected. And because the method for estimating the sparrow density compares with estimating predator density the factor *predation or competition pressure* was also selected. Diseases and toxins were not included in this research for the reason that it was not easily combined with the two methods mentioned.
The aim of this research is to investigate to what extend the factors *food availability, shelter availability, breeding site availability and predation or competition pressure* play a role in the decline of the house sparrow. However, the *decline* of the House sparrow can only be investigated with a longitudinal research design; for the sake of time our research was transversal. The research question is: can the House Sparrow density be explained when one looks at *food availability, shelter availability, breeding site availability and predation or competition pressure?*
We hypothesize that the factors *food availability* and *breeding site availability* are limiting factors on the sparrow density. The factor *shelter availability* limits the sparrow density when the *predation pressure* is high. The factor *predation pressure* limits the sparrow density when *shelter availability* is low.
This research was conducted by the Center of Environmental Science Leiden and compared locations in Leiden in The Netherlands. During fieldwork (from April 2007-June 2007), observations were done on sparrow density and the factors *predator density, food abundance, shelter availability* and *breeding site availability* were estimated.

METHODS

The species

The House Sparrow's diet depends for 90% on seeds. During breeding season insects are also included in the diet. The seeds of grasses (*Graminae*), rushes (*Juncidae*) and herbs form the primary food source. Besides seeds House sparrows also eat green plant parts, buds and blossom (BirdLife The Netherlands, 2005). In this research we therefore estimated *food availability* by measuring low vegetation.
The nesting site preference of the sparrow is under roof tiles, in holes and gaps, in ivy (*Hedera helix*), Russian Vine (*Fallopia baldschuenica*), hedges, shrubs and conifers (Van Damme-Jongsten & Sparrius, 2002). For the factor *breeding site availability* we measured vegetation above two meter from the ground.
The vegetation elements that give shelter are presumably shrubs, conifers, hedges and ivy. Middle-high vegetation was measured for this factor. Sparrow or sparrow egg predators are domestic cats (*Felis catus*) (Churcher and Lawton 1987; Woods *et al.* 2003*; Baker et al.* 2005), magpies (*Pica pica*), jays (*Garrulus glandarius*), crows (*Corvus corone*) and Sparrow hawks (*Accipiter nisus*) (Tinbergen, 1947, Summers-Smith, 2003), although real influence on the sparrow density is not shown. Jackdaws (*Corvus monedula*) might cause nest site competition (Van Damme-Jongsten & Sparrius, 2002).

Study area

The city centre of Leiden was built in the 16th century. The centre is characterized by its high building density, most of which built in the 17th century. Gardens are small or absent and there is little public vegetated area. Outside the city centre most of the houses were constructed in the thirties or sixties of the 20th century. Gardens are larger and there is more public vegetation. Two large districts were built in the eighties. In Leiden no House Sparrow trend data is available. There is, however, no reason to assume that the situation of the House Sparrow in Leiden is different. Citizens often told stories about the abrupt absence of the sparrows in their gardens. The assumption is that the situation of the sparrow in Leiden compares to that in other urban parts of The Netherlands.
We selected stratified random locations in Leiden (n=61), each of approximately one hectare. Locations were selected in the old, vegetation poor centre of the city, in the intermediate vegetation rich part and locations in the young district at the edge of Leiden to increase the diversity among the locations. We selected housing blocks and only housing blocks where the roofs were covered with roof tiles.

Measured variables

We assume that the *amount of food, shelter, potential nest sites* and *predators* estimated at the location compares to the surrounding area. Therefore, the *amount of food, breeding site availability, shelter availability and predators* was estimated only *at* the location. For *food availability* however, the presence of a large external food source is likely. Therefore we also estimated the distance to a large external food source like an allotment or park.

House Sparrows rarely fly more than a couple of hundred meters from their nests. During the breeding season they fly even less (Bower, 1999 as mentioned in BirdLife, 2005). The maximum distance between a location and a potential food source is therefore set at 500 meters.
To estimate the amount of a factor on a location we made a connection between the factor and habitat element that would provide this factor. Table 1 lists the habitat elements per factor. Per element we thought over the relative importance for a factor. Since no literature was available to improve this measure of importance we were forced to base this only on assumptions. For *breeding site availability* we made a distinction between roof tiles that provide a lot of breeding sites (type 1) and less breeding sites (type 2). The squared meter built up times the type of roof tiles calculated the number of potential breeding sites in the houses.

Collecting data

Data was collected during twelve weeks of fieldwork in the breeding season of the House Sparrow. All locations were visited four times with an observation period of ten minutes. During visits, number of chirping male sparrows, number of predators and competitors were recorded. The volume of the leaf part of the trees and the coverage of ivy in squared meters were estimated during the last visit. Using aerial photos made by the Belgian Aerodata and available by the city council, the percentage of vegetation and the type of vegetation were measured. The photos were processed with ArcView GIS 3.2.

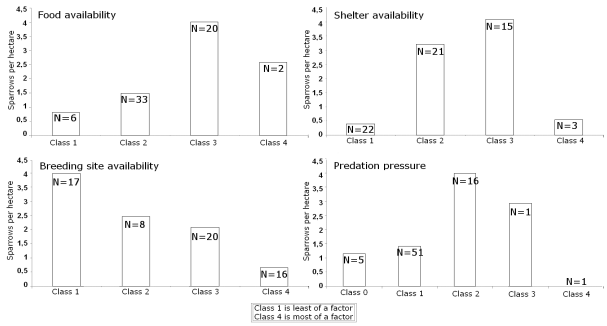
Data analyses

Analyzing the data was done in three different ways. The central question of the first approach was: do the factors *food availability*, *shelter* and *breeding possibility* and *predation and competition* play a role in explaining the sparrow density? Simplified: does every single factor limit the population size? First we made a relative measure for the factors as shown in Table 1, column 'Weight'. Habitat elements were counted which makes us able to express factors in numbers. Per factor we made four classes of which class one was the lowest amount of a factor and class four the highest, and finally subdivided these classes in *small/large amount*.
The second approach, a descriptive approach, compared locations with the *highest* (more than 7 sparrows per hectare) and the *lowest* density (no sparrows at all) for twenty-one variables (e.g. the amount of grass). The other locations were called *intermediate* locations. The statistics was done by making PivotCharts in Excel.
In the third approach, the Principal Component Analysis reduced the twenty-one variables into components that explain most of the variances for the data. This was done in SPSS 15.0.

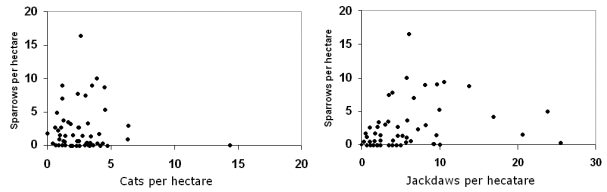
RESULTS

Approach 1: Analysis of limiting factors

First we made an analysis in which the sparrow density was related to each single factor, see Graph 1. There is a clear positive correlation between the sparrow density and the amount of food. The factor *food* can thus be a limiting factor in the locations. The sparrow density is surprisingly most when the *breeding site availability* is low. Shelter availability shows a positive correlation, regardless of predation pressure. *Predation* itself shows no strong correlation and also the domestic cat density is not strongly correlated with the sparrow density (Graph 2). Because the Sparrow hawk was only seen once, the Sparrow hawk was excluded from the analysis. *Competition* by jackdaws shows a positive correlation (graph 2). The most likely explanation for that is accordance in habitat preference.



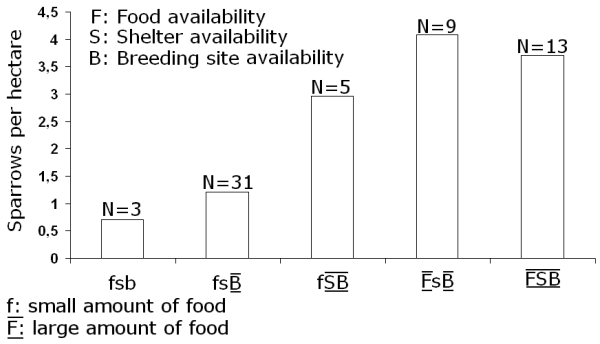
Graph 1: the relation between the House Sparrow density and the factors food availability, shelter availability, breeding site availability and predation pressure.



Graph 2: the relation between the House Sparrow density and the variable cat density and jackdaw density.

However the results as shown before can easily be interpreted wrongly since interaction between the factors is not shown in the graphs. *Breeding site availability* for instance shows a negative correlation which might indicate a negative correlation with the building density. The other explanation is that another factor, for instance *food* is limiting the sparrow population size in class two, three and four. Therefore we combine the factors to see whether the sparrow population can be explained in this way.

For Graph 3 we made a code for the *amount of food, shelter* and *available nesting sites*. *Predation pressure* is not included anymore because the pressure is high in only two locations. The letters of the code represent a factor; small letters represent a low amount of a factor present in the locations, under and over lined capitals represent a large amount of a factor. To make a distinction between small and large amounts we putted an imaginarily line at 3.5 sparrows per hectare. Classes three of *food* and of *shelter* were called large amounts. For *breeding site availability* class one and upwards is already a large amount. There were three locations were the roofs contain a bird screen. The amount of potential nesting sites in those three locations was called a small amount.
Graph 3 tells us that the sparrow density is positively correlated with the amount of the factors present. When locations are *food* or *shelter* poor sparrows can still survive. But, when locations are *food* as well as *shelter* poor, sparrows are nearly absent.

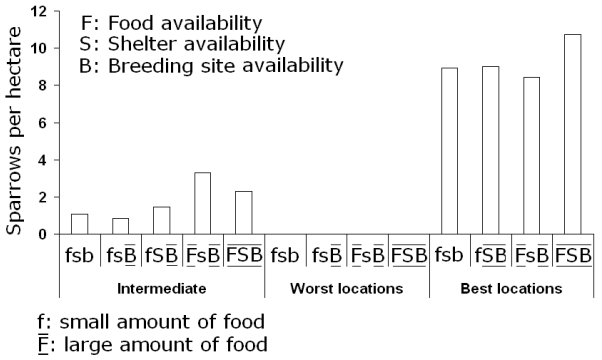


Graph 3: the relation between the House Sparrow density and the three factors combined.

Approach 2: Best versus worst locations

Apparently *food* and *shelter availability* can have an effect on the House Sparrow population but perhaps we might get more insight when we focus on the habitat elements that were combined in the factors; the twenty-one variables. We therefore made a comparison between the *best* and the *worst* locations for these twenty-one variables and then for the three factors. Nine locations had a sparrow density higher than seven sparrows per hectare (on average 9,4 sparrows per hectare), in twenty locations there were no sparrows at all. Sixteen out of twenty *worst locations* were in the centre of the city. The nine *best locations* were in the intermediate part or at the edge of Leiden. There were 32 locations called *intermediate*, with an average of 1,7 sparrows per hectare.
The *best locations* differ from the *worst locations* in the amount of, ivy, shrub, hedge, herb, grass, small and large deciduous trees, conifers, crows, jays, magpies, jackdaws, which is for all the elements in the *best locations* more. In other words: the total amount of vegetation and predators.

When the *best* locations were compared with the *intermediate* locations, only the amount of grass, hedge, predators (crow, jay, magpies) and jackdaws is larger in the *best locations.*
Apparently, vegetation elements are in some way related to the sparrow density, confirming the results of approach 1. However, when the *best* and the *worst* locations are compared with the *intermediate* locations, this correlation does not explain the striking difference in sparrow density. Locations with a high vegetation density can still have a low sparrow density. Graph 4 also shows the unexplainable difference in sparrow densities when one looks at the factors. The sparrow density differs although the amount of the factor that is present is the same.

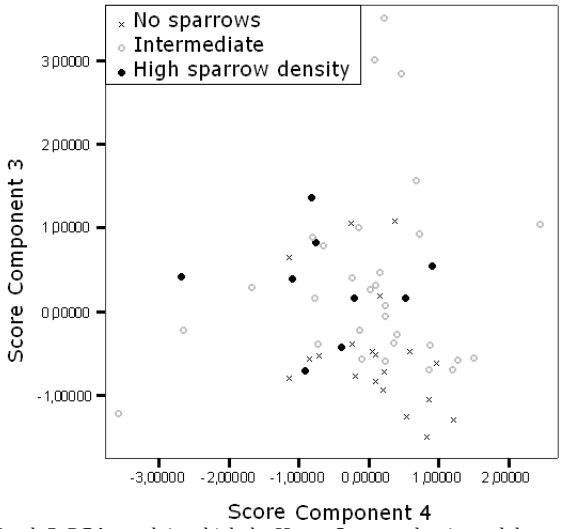


Graph 4: the relation between the House Sparrow density and the three factors combined in the best, intermediate and worst locations.

Because the *worst* locations were concentrated in the centre and the *best* locations at the edge or the intermediate region of the city, we finally made for this approach a descriptive comparison between the three areas in Leiden. In the centre of Leiden the sparrow density is approximately 0,2 sparrows per hectare. The houses and roof tiles are old, the building density high; *possible nesting places* is no limiting factor here. The total amount of vegetation is nearly three times smaller than at the edge of Leiden. A shortage of food or shelter possibility is possible. In the centre of Leiden the number of crows, jays and magpies is three times smaller than at the edge, cats, at the other hand, are the most present predators here.
The sparrow density in the intermediate region of Leiden is more difficult to explain. There is more *food* supplying vegetation than at the edge of Leiden (with a sparrow density of 4.3), but the sparrow density is much lower (approximately 2.5 sparrows per hectare in the intermediate region). At the edge of Leiden the *shelter* supplying vegetation is more or less the same as in the intermediate region. The *predation and competition pressure* is lowest in the intermediate region.

Approach 3: Principal component analysis

As shown in Approach 1 en 2 the selected factors or variables cannot fully explain the sparrow density and therefore a Principal Component Analysis was done. Twenty-one parameters were reduced to seven components, of which two components were significantly correlated with the logarithm of the number of sparrows per hectare. A scatter plot of these two components, shown in Graph 5, make a distinction between locations with a high and a low sparrow density. High sparrow density locations had a higher score of component 3, and a lower score of component 4. However, the meanings of component 3 and 4 are not easily explained. Component 3 seems to be related with trees and the number of potential nesting sites, component 4 with the number of jays per hectare. A low score for component 4 is than related with the number of jackdaws and the distance to an unexploited field (see Table 2).



Graph 5: PCA-graph in which the House Sparrow density and the two components are combined. A clustering of locations with a high sparrow density and locations with no sparrows is visible.

DISCUSSION

After many reports on the decline and even the addition of the House Sparrow on the Red List of threatened birds on November 2004 (www.minlnv.nl), we are becoming curious about possible causes. There has been a lot of speculation, but no relation has been proven so far.

This research indicated in the first place that *breeding site availability* might not be a limiting factor in the selected locations. Apparently, a decline in *breeding site availability* cannot be the explanation of the decline of sparrow breeding pairs, as seen in the last decades. *Food* and *shelter availability* on the other hand, can be limiting factors in the selected locations. *Predation pressure* might have a negative effect on the population size, but no conclusions can be drawn based on this research. Because only one sparrow hawk was counted, we draw no conclusions on the role of this predator. Neither the role of the jackdaw can be explained.

The second conclusion that can be drawn, both derived from approach 2 and 3, is that vegetation does play a role, not surprising. What is more surprising is that the sparrow density cannot be explained by the amount of vegetation in many locations. Sparrows are both present and absent in various vegetation rich habitats. It is very likely that there is another factor limiting the sparrow population size.

The conclusion can be made that the sparrow density cannot be explained well enough with the factors *food availability*, *breeding site availability*, *shelter availability* and *predation pressure*. There are two possible explanations for this phenomenon. The first thing we must consider is the possibility that the factors were not formed adequately. In that case, when sparrows do suffer from food shortage, it is not reflected in our parameters. The method thus causes inexplicable results. One can discuss the way the factors were formed. In specific, the weight of every variable in the factors was determined quite clumsily. Due to lack of the needed scientific knowledge, we still do not know how to improve this method.

There is also a possibility that the number of sparrows and predators were counted inaccurate. A visiting period of ten minutes was nearly too short to record all the selected animals in one hectare. Another point of discussion is that we only estimated food availability *at* the location and the distance to an external food source. We assumed that the amount of food provided by the vegetation at a location equals the amount in the surrounding vegetation. However, it is likely that the food availability differs in some locations from their surrounding areas.

Although these points of discussion can always exert influence on the analysis, there is not much reason to see this as the main cause of inexplicable results. Sparrows are indeed in many locations inexplicable absent. Therefore the second possibility is that factors that are not selected are involved. One can think of the mortality or disturbance due to increased traffic intensity, unknown deceases or the role of the sparrow hawk. Another possible cause is the use of pesticides as mentioned by Summers-Smith (2003), related to a shortage of invertebrate food as investigated by Vincent (2005). Recommendations for further research aim at the possible causes just mentioned.

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Table 1: Factors with relates variables

Factor	Unit	Habitat element	Definition	Unit	Weight
Food availability	Vegetation that provides food per m2	Grass	Lawn	M2	1
		Herb	Vegetation up to 0,5 m	M2	1
		Shrub	Vegetation between 0,5 and 2,5 meter	M2	1
	External food source	Allotment	Distance	M	1
		Rural area	Distance	M	1
		Park	Distance	M	0.5
		Unexploited field	Distance	M	0.25
Breeding site availability	Number of potential breeding sites per m2	Ivy	Measured 1 meter from the ground	M2	0.04
		Conifers	Evergreens	M3	1
		Hedge	Between 1,5-2,5 meter high. 1 meter wide	M2	0,5
		Type 1 roof tile	Old types: many breeding sites possible	M2	M2 built * 0,8
		Type 2 roof tile	New types: less breeding sites possible	M2	M2 built * 0,4
Shelter availability	Number of potential shelter places per m2	Shrub	Vegetation between 0,5 and 2,5 meter	M2	1
		Ivy	Measured 1 meter from the ground and up	M2	0.1
		Small conifers	Evergreens up to 216 m3	M3	4
		Small deciduous	Deciduous trees up to 216 m3	M3	0.5
		Hedge	Between 1,5-2,5 meter high and 1 meter wide	M2	2
Predation pressure	Number of predators per m2	Cats	Domestic cats (individuals)	#	0,5
		Magpies	Individuals and nests	#	1
		Jays	Individuals and nests	#	1
		Crows	Individuals and nests	#	1
		Sparrow hawks	Individuals and nests	#	Excluded
Competition	Number of competitors per m2	Jackdaws	Individuals and nests	#	No weight

Table 2: Component Matrix of the Principal Component Analysis for the twenty-one variables.

Component Matrix

Variable	**Component**						
	1	2	3	4	5	6	7
Ivy	,668	-,319	,271	-,330	,085	-,126	-,262
Shrub	,539	,510	,048	-,193	,035	-,077	,148
Hedge	,685	,045	-,385	-,037	,021	-,274	-,052
Herb	,766	,363	,133	,022	-,167	,017	,072
Grass	,615	,293	,123	,342	-,356	,364	,084
Vegetation Total	,795	,447	,096	,154	-,250	,191	,117
Small deciduous	,549	,354	-,112	-,310	,342	,004	-,256
Large deciduous	,676	-,497	,460	,044	,098	,139	,066
Conifers	,507	,025	,211	,309	,260	-,602	,086
Trees Total	,768	-,386	,424	,027	,179	,051	,027
Building density	-,784	,100	,368	,029	,019	-,014	-,034
Distance to rural land	-,451	,490	-,147	,289	,349	,195	-,108
Distance to allotment	-,033	,087	,088	,290	,646	,473	-,130
Distance to park	-,432	,225	,403	-,089	,146	,063	,318
Distance to unexploited field	-,189	,274	,377	-,541	-,065	,124	,228
Crows per ha	,140	-,100	-,207	,295	,329	-,171	,742
Jays per ha	,183	,323	,160	,620	-,107	-,292	-,338
Magpies per ha	,548	-,435	-,126	,234	-,023	,437	-,013
Cats per ha	-,254	-,300	-,400	,194	-,015	,002	-,004
Jackdaws per ha	,505	,194	-,264	-,330	,416	,019	-,074
Possible nesting sites in roofs	-,457	,024	,674	,179	,111	-,146	-,144

Extraction Method: Principal Component Analysis.