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Ethology Ecology & Evolution
Publication details, including instructions for authors and subscription information:
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Version of record first published: 19 May 2010.

To cite this article: M. Sará & B. Busalacchi (2003): Diet and feeding habits of nesting and non-nesting ravens (Corvus corax) on a Mediterranean island (Vulcano, Eolian archipelago), Ethology Ecology & Evolution, 15:2, 119-131

To link to this article: http://dx.doi.org/10.1080/08927014.2003.9522677

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Ethology Ecology & Evolution 15: 119-131, 2003

Diet and feeding habits of nesting and non-nesting ravens (*Corvus corax*) on a Mediterranean island (Vulcano, Eolian archipelago)

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Received 21 February 2002, accepted 19 March

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The almost complete absence of information on the trophic ecology of *Corvus corax* for Mediterranean areas prompted the present research on the small island of Vulcano. Focal observations allowed us to survey the population, which is divided into four territorial pairs and one non-nesting flock (mean n = 23.6 ± 16.3). This flock roosted preferentially near a rubbish dump. Ravens on Vulcano proved to be omnivorous and to feed upon a wide range of food items, with the differences in diet found to be more quantitative than qualitative and related to the season and to the social system. The flock birds consumed more vegetable matter, carrion of domestic animals, other organic matter (eggshells, fish and birds) and rubbish than the pairs. They live in a restricted volcanic area, some 6 km^2, unsuitable for predation and therefore show a more pronounced scavenging strategy, also travelling to neighbouring islands to feed at other dumps. The pairs have access to unlimited food resources, i.e., *Rattus rattus* and *Oryctolagus cuniculus*; as proved by field estimation of those mammal populations. Ravens highly select for black rats (B_i = 0.75) and include more food items related to predation in their diets. The frequency of black rats exploited by pairs (38.7%) is the highest so far recorded over the entire species' range. The diet of the pairs has a more marked seasonal fluctuation than that of the flock.

KEY WORDS: ravens, diet analysis, food preference, Mediterranean island.

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INTRODUCTION

The raven (*Corvus corax*) is widespread through the Holoarctic realm, but despite this large distribution, investigation regarding its trophic ecology is poor. Since the frequency of remains in raven pellets is not directly proportional to the quantities of the various foods eaten, one cannot assess the exact diet and/or food preference from pellets alone. Pellets are, however, the basic material used to investigate the raven's diet. Many of these studies come from America (see NELSON 1934 and references in KNIGHT & CALL 1980) and Great Britain (COOMBS 1978, MARQUISS et al. 1978, NEWTON et al. 1982) and deal with spring and early summer diet. Very few, indeed, are analyses of year-round diet (MARQUISS & BOOT 1986, ENGEL & YOUNG 1989, NOGALES & HERNÁNDEZ 1997). The species' feeding habits are mainly omnivorous in the majority of the occupied habitats (HARLOW et al. 1975, COOMBS 1978, CUGNASSE & RIOLS 1987, NOGALES & HERNÁNDEZ 1997), but some studies (CRAIGHEAD & CRAIGHEAD 1956) consider the raven to be a predator, whereas others found it to be strongly dependent on carrions (RATCLIFFE 1962, WHITE & CADE 1971) and dumps (BENT 1946). Diet studies in island habitats are available only for the Canary archipelago (NOGALES 1994; NOGALES & HERNÁNDEZ 1994, 1997), and Sardinia (ROLANDO 1995).

The raven is a sedentary breeding species in continental and insular Italy, with a continuous distribution in the Alpine and pre-alpine arc and with a scattered presence in the Apennines, where it is mostly concentrated in the Southern range. It is also present in Sicily and Sardinia and in several other small islands (Elba, Egadi and Eolian archipelagos) (LO VALVO et al. 1993, MESCHINI & FRUGIS 1993, ROLANDO 1995).

The raven, like other Corvidae, has a social system in which territorial pairs are clearly separated from groups of non-territorial and non-breeding birds (MARQUISS & BOOT 1986, CRAMP & SIMMONS 1994). Food and nest-site availability are the major factors limiting density in these two fractions of the population (see review in NEWTON 1998). Non-breeding birds, in Sicily and the surrounding islands, concentrate in flocks of 50-150 individuals, very often near dumps (LO VALVO et al. 1993, SARÀ pers. obs.).

The almost complete absence of information on the raven's basic ecology and trophic habitat for both continental and insular Italy prompted the present research. The high density reached by ravens on Vulcano (Eolian archipelago) is probably recent (cf. MOLTONI & FRUGIS 1967). These circumstances created ideal field conditions for a year-round analysis of the species' diet and for assessing the differential use, if any, of the main food resources, by the nesting and non-nesting ravens.

MATERIALS AND METHODS

Study area

Vulcano, is the third largest Eolian Island (21 km^2), reaching 500 m a.s.l. A large central plateau (Il Piano) abruptly descends with steep cliffs to sea level on the south-western coast (Fig. 1). The volcanic activity of the Gran Cratere is today limited to gas emissions around the crater borders and on the Vulcanello peninsula. This latter is a crater relict joined to the main island by a narrow isthmus.

Vulcano, as all the other Eolian islands, is heavily anthropized, with a 20-30 fold increase in human presence, reaching 8-10,000 tourists per day, during summer.

The terrestrial vertebrate species living in the area are few. Six reptiles (the endemic *Podarcis raffonei*, and the widespread *Podarcis sicula*, *Tarentola mauritanica*, *Hemidactylus turcicus*, *Hierophis viridiflavus*, plus the recent immigrant *Vipera aspis francisciredi*); 21 birds and 3 mammals (*Oryctolagus cuniculus*, *Rattus rattus*, *Mus domesticus*), have also been catalogued (Massa & Di Palma 1988, Lo Cascio & Navarra 1997, Sarà 1998).

Data collection

Inspection from some focal points allowed the detection and continuous tracking of the raven population. One flock of birds roosted preferentially in or nearby a rubbish dump, so it was possible to collect their pellets (n = 425) over 16 monthly visits, from March 1998 to August 1999. During the same visits, inspection below the roosts and the nest-sites of pairs allowed us to gather a sample of their pellets (n = 93). The dispersion of pellets and the difficulties in cliff climbing produced an underestimation of this sample. Nevertheless, both the samples were assumed to reflect the feeding habits of the nesting and non-nesting birds.

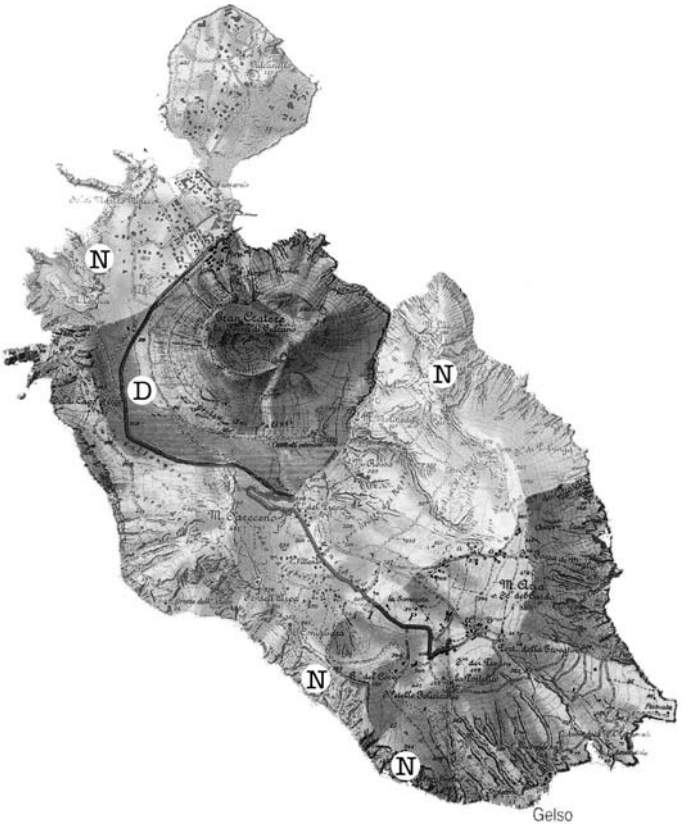

Fig. 1. — The island of Vulcano (Eolian archipelago, 1: 250,000) with the territories utilised by ravens (*Corvus corax*). D = dump site and in bold print the flock territory; N = nest sites and the territory of the four pairs.

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Pellets were dry-opened, their content was identified to the lowest possible taxonomic rank, by comparison with reference guides and collections held in the Zoological Museum of the University of Palermo. Specialists determined plant and insect remains. Pellet content was quantified by the frequency of occurrence (i.e., the percentage of the total number of pellets containing a specified food item), and classified, according to their composition, as the result of: (a) "predatory action" i.e., those containing only food items that can be obtained by a direct predatory activity, such as rodents, lizards, insects; (b) "scavenging action" i.e., those containing only carrion, chicken and egg-shells remains, fish and other marine animals, etc.; (c) "mixed action" i.e., those containing items of both the first two categories plus vegetables.

Since active predation on rabbits (*Oryctolagus cuniculus*), by ravens, has often been debated, we treated their bones and fur (some fur of domestic animals was also found) by dividing the sample in two. Half of the sample was considered the result of predation and the other half, of scavenging.

To analyse the selection of the food resource represented by rabbits and black rats, we used the index of selection $B_i = (u_i/m_i)/\Sigma(u_i/m_i)$; where u_i = no. of units in category i in the sample of used units; m_i = no. of available units in category i in the sample (where i = 1, 2, …, I); and the related statistic: $\chi^2_L = 2\Sigma\, u_i \log_e(u_i/u_+\pi_i)$, (Manly et al. 1993).

The frequency of the two mammals in pellets gave us the sample of used units, whereas to check for their availability we did some field estimations in spring 1996 and summer 1997. The relative frequency of rabbits was assessed by counting their faecal pellet piles in 100 plots of 1 m^2; that of the black rats by live-trapping. The DAT% index = [no. of animals/(no. traps × no. nights of capture) × 100], allowed an estimation of the relative frequency of black rats. Both samplings were made in the four main island habitats: (a) garrigue; (b) open low maquis < 0.5 m; (c) dense high maquis > 0.5 m; (d) artificial thickets of *Pinus* spp. and *Eucalyptus* spp.

RESULTS

The ravens

From some focal points, it was relatively easy to follow each pair, which lived mostly on the seaside cliffs, and to discover their old or active nests and roosts. The pairs' patrolling and chasing off of raptors or other ravens allowed the mapping of their territory boundaries. Four pairs were found to have stable territories on the island (Fig. 1). At least one bred in 1998, two in 1999, with the three pairs fledging two young each.

On Vulcano, we also recorded a second group of non-nesting ravens; these birds lived in a flock, in the volcano area (Gran Cratere) near one rubbish dump where they roosted (Fig. 1). The non-nesting flock was, on average, formed by 23.6 ± 16.3 (min-max: 0-70; n = 16) birds. On four occasions, it was possible to observe some of them (n = 4-18) flying from the Vulcano dump area to the Lipari dump area. For the rest of the archipelago, other inter-island movements among the dumps were also recorded (L. Russo in verbis).

The social system on the Eolian islands, based on territorial nesting pairs and non-nesting flocks, was thus equal to that recorded on inland Sicily and elsewhere in the species' range.

Food estimates

Rabbits and black rats are very abundant and spread over the entire island without any evidence of habitat preference. The Student's t test for rabbit dropping

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piles gave significant results only in the garrigue vs high maquis ($t = 2.22$; $P < 0.05$) and in the high maquis vs artificial thicket ($t = 2.54$; $P < 0.05$) cross-comparisons. This finding is better explained by the difficulties associated with counting them in the high maquis vegetation rather than in terms of a real difference in distribution.

Also the live-trapping of black rats did not indicate significant differences in distribution across the habitats. DAT% indices ranged from 32% to 54%, less than those observed on Stromboli (65-90%: SARÀ unpublished), but much higher than on Sicily (8.6% and 10.3%: SARÀ & CASAMENTO 1993 and SARÀ unpublished) or on other Mediterranean islands (Pantelleria = 11.1%: SARÀ unpublished; Tilos = 1%: MASSETI & SARÀ unpublished).

Evidence of the quantity of rubbish in the dump is only circumstantial, i.e., it was assumed to be strongly correlated to tourism and thus to increase in summer and decrease in winter.

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Diet analysis

The frequency of occurrence of the food items is found in Table 1 and shows the quantitative differences between the territorial pairs and the flock. The χ^2 test gives an overall statistical significance among the food items used by the two fractions of population.

The flock birds consumed more vegetable matter than the territorial pairs, mostly seeds and the peels of Solanaceae and Rosaceae, whereas a relatively higher percentage of Graminaceae was found in the pair pellets. In addition, the flock birds consumed more organic matter (eggshells, fish and birds) than the pairs. Regarding the eggs eaten, we did not found any sign of nest predation on the three marine species present on the island.

The frequency of occurrence of marine molluscs and crustaceans as well as of terrestrial insects eaten is similar. Within this category, however, we noted that the flock birds ate more Coleoptera and the pairs more Orthoptera and Hymenoptera. Details of the plant and insect taxa eaten are presented in Appendix 1. Reptiles and mammals are found more often in the pellets of territorial pairs, but a marked difference exists in the last food item. Bones of *Oryctolagus cuniculus*, *Rattus rattus* and *Mus domesticus* prevail in the pair pellets, whereas the remains of domestic animals is higher in the flock pellets (Table 1).

As expected from the collection of pellets around the dump, paper, plastic and other rubbish occurs more frequently in the composition of the flock pellets.

Seasonal variation of diet

The division of pellets per season reveals statistically significant differences in all the food items used, except for birds and rubbish (Fig. 2). The ravens gathered in the flock eat vegetables and other organic matter more or less constantly during the year, together with rubbish. Mammal frequency rises in autumn and decreases in spring and that of insects varies conversely, being low in winter and high from spring to autumn. During the summer, ravens eat a relatively higher frequency of fish, reptiles and marine animals.

The seasonal diet of the pairs shows a more marked fluctuation, in that many items decrease (mammals, fish, vegetables, insects and rubbish) or are absent

Table 1.

List of the raven's (*Corvus corax*) main food categories (PFI = frequency of occurrence) found in pellets on Vulcano (Eolian archipelago). Difference among totals is statistically significant (χ^2 = 49.94; df = 10; P = 0.000); differences within categories are reported in the table.

Prey items	No. flocks	No. pairs	PFI flocks	PFI pairs	χ^2	df	P
Seeds and peels other than tomato	101	13	23.76	13.98			
Graminaceae	11	8	2.59	8.60			
Leaves and inflorescences	14	2	3.29	2.15			
Solanum lycopersicum	43	4	10.12	4.30			
Vegetables not determined	201	47	47.29	50.54			
Total vegetable matter (1)	370	74	87.06	79.57	14.50	4	0.006
Egg-shells	132	12	31.06	12.90			
Chicken	2	1	0.47	1.08			
Fragmented bones not det.	22	8	5.18	8.60			
Total other organic matter	156	21	36.71	22.58	9.32	2	0.009
Marine molluscs and crustaceans *	16	3	3.76	3.23			
Hymenoptera	23	8	4.65	8.60			
Coleoptera	48	2	9.70	2.15			
Lepidoptera	1	1	0.20	1.08			
Orthoptera	7	4	1.41	4.30			
Insects not determined	51	12	10.30	12.90			
Total insects (1)	130	27	30.59	29.03	12.23	4	0.02
Fish	118	16	27.76	17.20			
Podarcis spp.	7	5	1.65	5.38			
Reptiles not determined	2	0	0.47	0.00			
Total reptiles	9	5	2.12	5.38			
Birds (passerines)	26	3	6.12	3.23			
Oryctolagus cuniculus	52	18	12.24	19.35			
Rattus rattus	28	36	6.59	38.71			
Mus domesticus	3	5	0.71	5.38			
Carrion (feral dog, cat, goat, sheep)	22	1	5.18	1.08			
Mammals not determined	65	7	15.29	7.53			
Total mammals	170	67	40.00	72.04	45.68	4	0
Paper	309	31	72.71	33.33			
Plastic	117	17	27.53	18.28			
Other garbage	57	8	13.41	8.60			

(1) See Appendix 1 for further details. * = Mussels, cephalopods, crabs.

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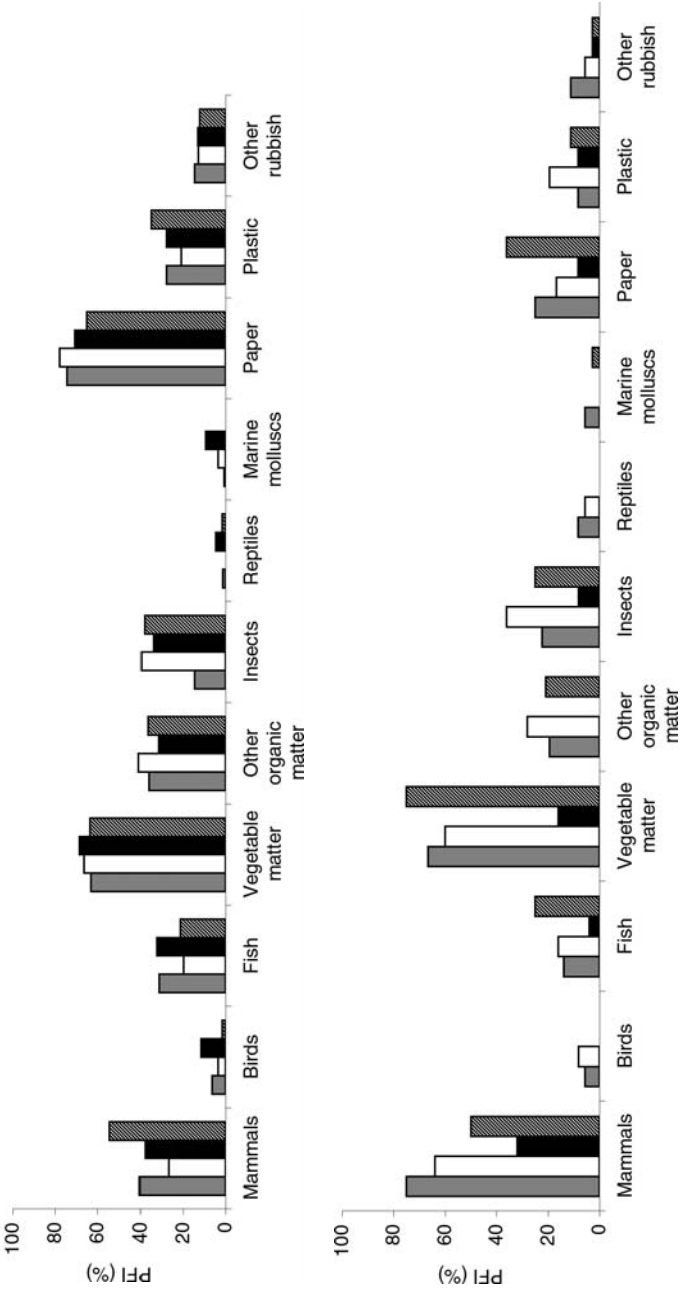

Fig. 2. — Seasonal frequency of occurrence in raven pellets on Vulcano (Eolian Islands), flock (above) and nesting pairs (below). The χ^2 tests among each food item eaten in the four seasons by the flock and pairs were all significant, except for birds and rubbish: mammals $P < 0.05$; fish $P < 0.01$; vegetables $P < 0.001$; other organic matter $P < 0.05$; insects $P < 0.05$; reptiles $P < 0.05$; marine animals $P < 0.01$; paper $P < 0.001$; plastic $P < 0.05$.

(birds, other organic matter, reptiles, marine animals) in the summer and autumn compared to winter and spring. Some of these items (except for birds and reptiles) show an increase during the autumn when the presence of vegetables reaches its annual peak. The insects and the other organic matter (plus plastic remains) are eaten more in the spring, the months in which a high frequency of vegetables, fish, birds and mammals is also consumed.

Year-round (Fig. 3), the pairs ate more black rats than the flock ($P < 0.001$) but a similar frequency of rabbits (P = NS). Pairs select for black rats ($B_i = 0.75$) 4 times more than the flock ($B_i = 0.17$) and this difference is highly significant ($\chi^2_L = 70.77$; $P < 0.001$). In the case of rabbits, the expected frequencies are more or less similar to that used, the B_i index being 0.48 for flock and 0.52 for pairs, but the slight preference of pairs is not statistically significant ($\chi^2_L = 0.28$; P = NS).

The pairs ate a statistically significant quantity of rats over rabbits. Black rat frequency in their pellets varies from 50% in spring to 74.1% in winter and only in summer this is less than the rabbit frequency.

The flock birds would apparently eat more rabbits than rats (Fig. 3), but their seasonal occurrence is not statistically significant, in spite of the increase from winter to autumn, and of the very few black rats eaten during spring (4.3%).

Inter-annual variation of diet

Comparable samples of pellets were available only for the flock in the winter, spring and summer of 1998 and 1999. Differences are negligible, and not statistically significant, according to the χ^2 test, in both the spring and summer of 1998 compared to those of 1999. Only during the winter of 1999, with respect to the winter of the previous year, do some items appear to be in higher percentage, e.g., mammals (F in 1998 = 32% vs 50% in 1999), fish (26% vs 38%), insects (6% vs 24%), and vegetables (50% vs 79%), but the overall diet differences in the 2 years is still not statistically significant.

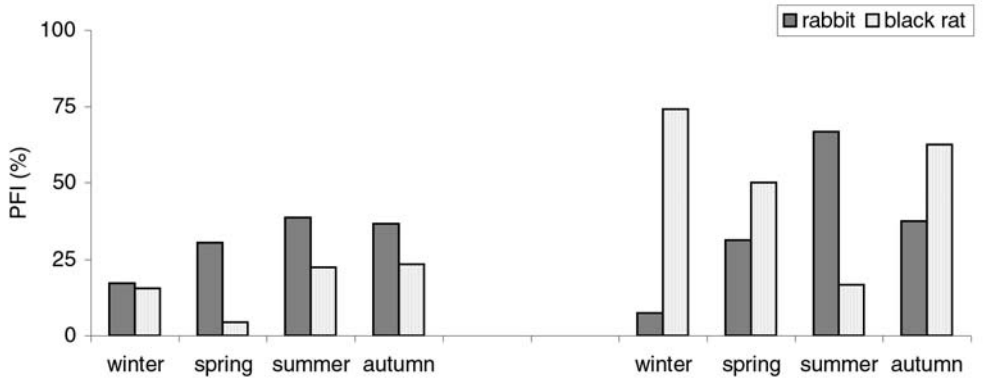

Fig. 3. — Year-round occurrence of rabbit and black rat preyed upon by the flock (left) and territorial pairs (right). Differences are statistically significant only between the seasonal PFI of rabbit and black rat eaten by the pairs, ($\chi^2 = 15.68$; df = 3; $P < 0.001$) and between PFI of black rat eaten by the flock and by the pairs, ($\chi^2 = 15.60$; df = 3; $P < 0.001$).

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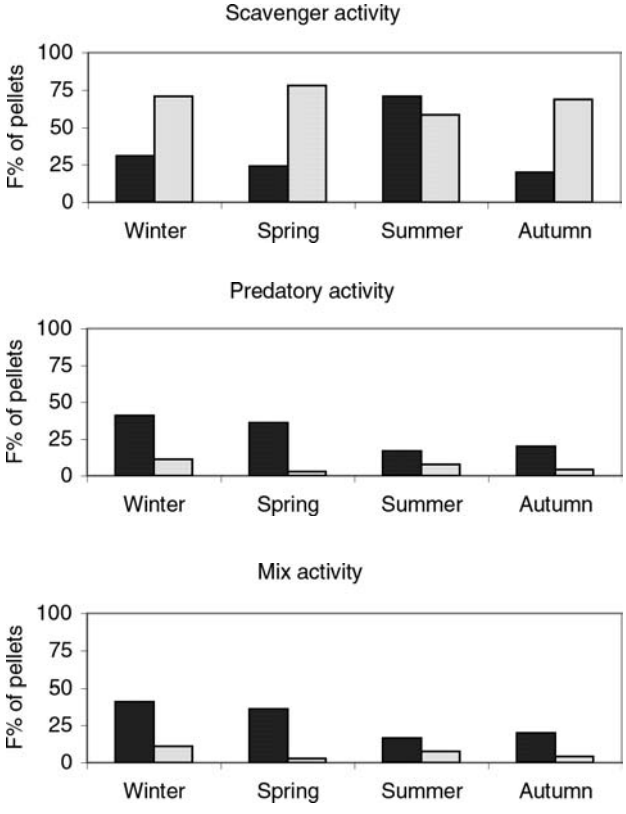

Fig. 4. — Occurrence of pellets (black = pairs; grey = flock) resulting from predatory, scavenger and mixed actions divided per season, over the total sample (n = 518).

Feeding strategies

By rearranging the number of pellets according to food collection activity (i.e., predatory, scavenger or mixed), it is possible to further separate the feeding strategy of territorial pairs from that of the flock (Fig. 4). The flock birds have shown constant scavenger activity throughout the year, whereas the pairs show high scavenging only during the summer. The reverse applies to the predatory activity that is always low in the flock and high in pairs but with a decrease during the summer and autumn. The mixed activity of the pairs rises in autumn. The peak of scavenging in both fractions of the population does not correspond to a significant decrease in the occurrence of mammals in the diet (for pairs: r = – 0.71; *P* = NS; for flock: r = – 0.36; *P* = NS).

DISCUSSION

The species on the island of Vulcano proved to be omnivorous and to feed upon a wide range of food items. Ravens, according to availability, opportunistical-

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ly feed on plants and animals, killing the latter with their powerful bill or scavenging them as carrion. For example, when ravens live in an area of intensive agriculture such as Idaho, cereal grains become the main food (Engel & Young 1989). In the Guadalquivir marshes (Spain) high frequencies of water birds and their eggs are eaten (Amat & Obeso 1989), which also occurs for the marine colonial species in the Orkneys (Marquiss & Boot 1986) and in the Shetlands (Ewins et al. 1986). This food resource is completely lacking on Vulcano, because ravens cannot prey upon the underground nesting Calonectridae or upon the large and powerful *Larus cachinnans*.

Overabundant rabbits and black rats are the main biomass eaten on Vulcano, together with the other mammals and vertebrates. The frequency of black rats exploited by pairs (38.7%) is the highest so far recorded, while total vertebrate occurrence (87.3% in the flock and 97.8% in pairs) is among the highest (Coombs 1978, Marquiss & Boot 1986, Nogales & Hernández 1994, Mattingley 1995, and review in Nogales & Hernández 1997).

Although the ravens studied on Vulcano showed qualitatively similar diets, there were considerable quantitative differences determined by their social system. The territorial pairs have access to fields rich in rabbits and black rats, where these animals are not a limiting resource. They positively select for the black rat and, in general, include more items related to predation (i.e., higher percentages of reptiles and other rodents) in their diet. Predation decreases in summer and autumn and is replaced by ground foraging vegetables, insects and scavenging dead fish and other organic matter. Thus, the location and the number of suitable nest-sites along the cliffs, and ultimately, the size (area per altitude a.s.l.) of the island, would be the factors limiting the density of this population. Raven density (3.8 km^2 per pair) reached on Vulcano, is evidence of saturation of the entire available habitat. Similarly, on Stromboli, with its higher volcano (900 m a.s.l.), ravens have occupied all available cliffs, reaching a density of 2.6 km^2 per pair (L. Russo unpublished, Sarà pers. obs.). Nogales (1994) recorded the highest island density (2.9 km^2 per pair) on El Hierro (Canary islands), which is also the second highest value over the entire species' distribution area and is comparable to those found in the Eolian archipelago. Density in Sicily is much lower, ranging from 32.3 km^2 (Massa 1985) to 50.3 km^2 per pair (Sarà unpublished) and is comparable to that of several continental sites reviewed in Nogales (1994).

The lack of territorial competition with large raptors for nesting cliffs and the abundant food supply represented by the black rat, seem to be the major factors leading to the high density on the Eolian islands and to the difference from the larger island of Sicily.

The flock has, on the contrary, access only to a limited portion (some 6 km^2) of the island, the Gran Cratere area, where the dump is located. The predatory activities of these birds, restricted to this bare and unsuitable volcanic space, thus depend more heavily on the dump. As a consequence, they feed, by ground foraging, upon vegetable rubbish, other organic matter and the carrion of domestic animals. They also have to defend the Gran Cratere area against the pairs, since we recorded pair incursions in the dump but never the opposite (i.e., flock birds entering pair territory, or if that did happen, flock birds were easily chased off). Non-nesting birds, therefore, may suffer from the winter decrease in rubbish, the lack of sufficient foraging space for each individual in the Gran Cratere, and the intraspecific competition with pairs. This may explain why they need to travel between islands. From the above considerations, we argue that the flock is non-residential

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on the island and is composed of the surplus of non-nesting birds coming from the other nesting populations found in the archipelago.

Regarding the rabbits eaten on Vulcano, both the pairs and the flock do not select for it and direct proof of predation is lacking. Their relative higher frequency in autumn and winter could be related to the easy recovery of young and/or dead or injured animals during the hunting season (cf. MARQUISS & BOOT 1986, HEINRICH 1989, NOGALES & HERNÁNDEZ 1997). We did observe (M. SARÀ), however, ravens plunging into shrubs and taking off with black rats in their bills.

In conclusion, other opportunistic activities determine the inclusion, in the flock and pair diet (in some cases with similar occurrence), of those resources not preyed upon or exclusively found in the dump area: ground foraging for insects and vegetables, scavenging around the harbour and along the seashore for fish or other dead marine animals, or scavenging on other parts of the island for dead migratory passerines.

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ACKNOWLEDGEMENTS

We extend our thanks to Dr L. Russo for his help in the field and for personal data; and to Dr G. Sabella and to Drs G. Turrisi and F. Mondello for insect and plant determination.

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APPENDIX 1

Plant and insect remains found in raven (*Corvus corax*) pellets on Vulcano (Eolian archipelago).

Taxonomical determinations by G. Sabella (insects), F. Mondello and G. Turrisi (plants). SND = specimens of the given taxonomical rank not determined.

Plants

Solanaceae: SND, *Capsicum annuum* L., *Lycopersicon esculentum* Miller
Pedaliaceae: *Sesamum indicum* L.
Lamiaceae: *Rosmarinus officinalis* L.
Moraceae: *Ficus carica* L.
Vitaceae: *Vitis vinifera* L.
Umbelliferae: *Foeniculum vulgare* Miller
Oleaceae: *Olea europaea* var. *europaea* L.
Cactaceae: *Opuntia ficus-indica* (L.)
Graminaceae: SND, *Zea mays* L.
Rutaceae: *Citrus* sp., *Citrus limon* (L.)
Piperaceae: *Piper nigrum* L.

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Rosaceae: *Malus domestica* L., *Pyrus communis* L., *Prunus avium* L., *Prunus armeniaca* L., *Prunus domestica* L.
Fabaceae: *Ornithopus compressus* L.
Asteraceae: *Cynara cardunculus scolymus* (L.), *Lactuca sativa* L.
Cupressaceae: *Thuja orientalis* L.
Cucurbitaceae: *Cucumis melo* L., *Lagenaria siceraria* Standley

Insects

Hymenoptera: SND
Apocrita Aculeata: SND,
Scolidae: SND, *Megascolia* sp., *Megascolia bidens* (L.), *Megascolia flavifrons* (F.)
Formicidae: SND, *Tetramorium* sp.
Vespidea: Polistinae SND, *Polistes* sp.
Apoidea Halictidae: SND
Chrysididae: SND
Sphecidae: SND
Coleoptera: SND
Carabidae Scaritinae: SND
Scarabaeidae: SND
Elateridae: SND
Lucanidae: SND
Curculionide: SND
Cerambycidae: SND
Anobiidae: SND
Lepidoptera: SND
Orthoptera: SND
Ensifera: SND
Acrididae: SND, *Anacridium aegyptium* (L.)

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