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Ecology of the raccoon (*Procyon lotor*) from western Poland

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Preliminary results on the ecology of raccoon in Poland are presented. The use of space (by radiotelemetry), diet composition and parasite infections (both by scat analysis) were investigated. The home-range size of the raccoon in western Poland averaged 1 km^2 in suburban areas ($n = 5$ individuals), 10 km^2 in the Warta Mouth National Park wetland area ($n = 5$), and 60 km^2 for a single individual studied inhabiting woodlands. Space use patterns in relation to habitat type were also studied. About 44% of the biomass consumed by raccoons were mammals, 41% other vertebrates, 12% invertebrates, 2% plant material and only 1% eggs. Three species and one genus of helminths, e.g. the humans pathogen parasite, *Baylisascaris procyonis*, were identified.

Introduction

Besides loss or degradation of habitat, introduction of exotic species is one of the major threats to native communities (IUCN 2004). Exotic predators can cause massive changes in prey and predator/competitor, communities in newly invaded habitats. Therefore, there is a need for immediate assessment of the impact of a new invader on an ecosystem.

Rapid spread of exotic carnivorous species, like the raccoon *(Procyon lotor)* or the small Indian mongoose (*Herpestres javanicus*), has recently been observed (Hohmann *et al*. 2001, Hays & Simberloff 2006). The raccoon is a North American carnivore which was introduced to Europe in the 20th century. Raccoon were first released in Germany in the 1930s (Müller-Using 1959), in Russia in 1936, and in Belarus in 1954 (Chesnokov 1989). Most introductions of the raccoon in eastern Europe did not succeed. In the western and middle parts of the continent, however, the raccoon successfully founded a wild population (Stubbe 1999) and, since the 1980s, a rapid expansion has been observed (Hohmann *et al*. 2001). In Germany, the largest populations occur in the middle of the country and in Brandenburgia, near the border with Poland

(Lutz 1996, Hohmann 2000).

Although the raccoon has been present in Europe for 70 years, the body of knowledge on various aspects of its biology is relatively limited. This species has only been investigated in forest and urban environments in Germany (Lutz 1980, 1984, 1996, Hohmann 2000, Hohmann *et al*. 2000, 2001). There are no data on the ecology of the raccoon invading other important habitats, especially wetlands, or data on possible competition between the raccoon and other medium-sized native carnivores. Furthermore, only scarce information is available on the impact of the raccoon on the native fauna.

In Poland, the raccoon was declared a game species in 2004, with the hunting season being between 1 July and 31 March. Knowledge on the species' distribution, numbers, and trends in Poland is poor. Actually, the raccoon population remains out of control and most hunters are still not aware of the presence of this carnivore (Pielowski 2007).

In this paper we present data on the spatial patterns of the raccoon in relation to habitat type, its diet and parasite load. Possible impacts of this alien predator on the native fauna, especially birds protected in important wetland site of the Warta Mouth National Park, are also assessed. Additionally, the potential for further range expansion and transmission of pathogen parasites is discussed.

Material and methods

The study was conducted in 2005–2007 in the northwestern part of Poland close to the Odra river. Three study areas with differing habitat features were selected. The first site was the Warta Mouth National Park (Ramsar Convention and Natura 2000 site, 52°34´N, 14°43´E), which covers about 80 km^2 of the Warta River valley close to the German border. Floodplains comprise about half of this area. It is a mosaic of marshy meadows, willow thickets (*Salix* spp.) and old river beds, shallow lakes and land improvement canals with overgrown plants. This area is very important for breeding and migrating waterfowl (Majewski 1983). During the autumn and spring migrations as many as 250 000 water birds arrive in the park. The second study area, located about 10 km from the first one, along the Postomia River in the Forest Inspectorate of Osno Lubuskie, is a dry woodland dominated by beech (*Fagus sylvatica*), oak (*Quercus* spp.), and pine (*Pinus sylvestris*). The third area is a suburban environment of the city of Kostrzyn (about 17 000 inhabitants), located about 1 km from the national park's border. This area is located at the junction of the mouths of the Warta and Odra Rivers, where gardens and allotments occur alongside meadows. On the edge of the area at the German–Polish border is a zone of high human activity surrounded by petrol stations, restaurants and a hotel. This area is located about 1 km from the national park wetlands.

Raccoons were live-trapped with wire-box traps, immobilized with 1.5–2.0 ml Domitor (medetomidine) (Pfizer), and fitted with VHF radio-collars (Advanced Telemetry Systems, USA). After the collars were fitted, raccoons received 1.2–1.5 ml Antisedan (atipamezole) (Pfizer) as a reversal agent. Animals were located (triangulation with a minimum of two bearings) with a portable receiver (Yaesu, Japan) and 3-element Yagi antenna. One or two diurnal locations (between sunrise and sunset) were taken at least once a week. Additionally, 4–12 hour, continuous night radiotracking sessions (with radiolocations taken at 15-min intervals) were conducted at least once a month. In total, 1728 radiolocations were taken. During the day we determined the location of an animal as accurately as possible in order to identify resting sites. Telemetry locations were plotted on 1:10 000 maps. The minimum-convex-polygon (MCP) method (100% of locations included) and adaptive kernel with 95% of locations were used to estimate home-range sizes (calculated with the TRACKER software; A. Angerbjörn, Radio Location Systems, Sweden). Home range overlap percentage between two individuals was calculated as the area of overlap compared with the smaller home-range size (calculated as MCP) from the pair. Analyses were performed on pooled data from two seasons: spring–summer (April–September) and autumn–winter (October–March).

We used scat analysis to determine raccoon diet. Most of the scat were collected within latrines located high on trees and scat were distinguished on the basis of size, shape and smell characteristics. Prey species were identified from bone remains and microscopic characteristics of hair and feathers according to published identification keys (Teerink 1991). Diet composition was expressed in two ways: (1) as the percentage of occurrence, and (2) as the percentage of biomass consumed. The percentage of occurrence in scats was defined as the number of scats with remains of a particular prey compared with the total number of scats (being 100%). The percentage of fresh biomass consumed was obtained by weighing all dry food remains and then multiplying by the corresponding coefficient of digestibility. We used a coefficient of digestibility for the raccoon dog *Nyctereutes procyonoides* from Jędrzejewska and Jędrzejewski (1998).

The intestinal parasites of raccoons were assessed using fecal analysis to determine the level of infection with helminth eggs. Collected samples (about 2–4 grams) were preserved in 4% formalin. We used water decantation and a zinc sulfate centrifugal flotation concentration technique to detect parasite ova. Eggs were identified to genus and species levels based on morphology as well as on biometric parameters (Thienpont *et al*. 1986, Foreyt 2001). According to Bush *et al*. (1997), prevalence (%) and intensity of infection (range) were used to estimate level of infection.

Results

In 2005–2007, 11 individuals were trapped: 5 in the wetlands, 5 in the suburban area and one in the woodland (Table 1). Excluding one woodland individual with an extremely large home range (M1), there was no correlation between the number of locations and seasonal home-range size ($r = -0.11$, $n = 15$, NS). Nonparametric ANOVA using the Scheirer-Ray-Hare extension of the Kruskal-Wallis test (Sokal and Rohlf 1995) for the size of the seasonal home range showed significant variation between habitats ($H_2 = 10.09$, $p < 0.01$ for MCP 100% and $H_2 = 10.95$, $p < 0.01$ for kernel 95%) but not between seasons ($H_1 = 1.38$, NS for MCP 100% and $H_1 = 0.001$, NS for kernel 95%). Raccoons occurring in the suburban habitat (M4, M5, M6, M7, F2) utilized the smallest home ranges: 1.5–4.2 km^2 (Table 1). They usually stayed in suburban allotments (communal gardens) with a small pond and only occasionally ventured along rivers (Warta, Odra) or in wetlands within the National Park. Home ranges of these individuals overlapped extensively (on average 80%; Fig. 1). Raccoons that inhabited the floodplains of the lower Warta River valley (M2, M3, M8, F16, F4) showed intermediate home-range sizes: on average 8.4 km^2 in autumn–winter and 4.4 km^2

Table 1. Total and seasonal raccoon home-range sizes (km^2) in the north-western Poland studied in 2005–2007. Seasons: Autumn–winter (AW: October–March); Spring–summer (SS: April–September); MCP = minimum convex polygon with 100% of locations; Kernel = adaptive kernel with 95% of locations; M = male, F = female. Total home range sizes were calculated only for individuals tracked for longer than one season. * home range not used for statistical calculation due to low numbers of locations.

ID no.	No. of locations AW/SS	Period of tracking	Autumn–winter		Spring–summer		Total		Habitat type
			MCP	Kernel	MCP	Kernel	MCP	Kernel	
M1	388/34	17 Feb. 2006–7 Aug. 2007	57.86	23.09	13.75	37.61	60.51	20.07	Woodland
M2	16/–	3 Mar. 2006–25 Jan. 2007	1.68*	12.16*	–	–	–	–	Wetland
M3	–/89	20 Apr. 2006–20 Aug. 2007	–	–	5.11	8.53	–	–	Wetland
	42/57		14.35	24.62	7.12	9.15	19.44	14.17	Wetland
F16	190/157	6 Dec. 2005–20 Aug. 2007	1.77	0.98	5.26	3.44	–	–	Wetland
	137/103		7.74	6.77	2.17	2.69	10.59	5.90	Wetland
F4	65/51	14 Nov. 2006–2 Aug. 2007	9.64	6.76	3.59	5.13	10.90	5.44	Wetland
M8	–/33	4 Apr. 2007–16 Aug. 2007	–	–	3.00	6.34	–	–	Wetland
M4	58/–	24 Oct. 2006–13 Feb. 2007	1.55	3.35	–	–	–	–	Suburban
M5	60/–	24 Oct. 2006–28 Feb. 2007	1.53	3.00	–	–	–	–	Suburban
M6	96/12	24 Oct. 2006–16 Aug. 2007	2.08	1.66	0.99*	5.01*	2.32	1.37	Suburban
M7	98/–	25 Oct. 2006–30 Mar. 2007	4.22	2.63	–	–	–	–	Suburban
F2	28/–	24 Oct. 2006–19 Dec. 2006	0.16	0.17	–	–	–	–	Suburban

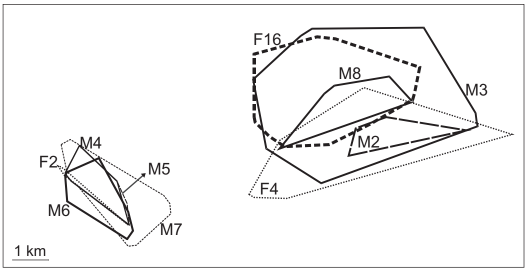

Fig. 1. Home ranges of 5 raccoons from the suburbs (M4, M5, M6, M7, F2) and 5 raccoons from wetlands (F4, F16, M2, M3, M8) studied in northwestern Poland in 2005–2007.

in spring–summer. Home ranges of these individuals also extensively overlapped (on average 65%; Fig. 1).

The solitary captured individual (M1) inhabiting the woodland area had the largest home range, 57.9 km^2 in autumn–winter and 13.7 km^2 in spring–summer (annually 60 km^2, Table 1). However, this male utilised only part of this large area, as locations are clumped in three areas (Fig. 2). This male moved up to 15 km during one night between shelters and feeding places in spring–summer.

We localised and described 95 diurnal resting sites (*n* = 71 for wetland and suburban raccoons together and 23 for woodland animals out of about 650 diurnal locations). Raccoons used various resting sites depending on the habitat present. In the wetland and suburbs, raccoons mainly used outside shelters on the ground (55%), such as reed beds, thickets and sedges close to water. In 24% of cases, they used tree holes, 11.2% wooden bird boxes, and occasionally animals resided in unoccupied beaver's lodges and fallen trees. Raccoons inhabiting forests spent days mainly in hollows of oaks (43%), in dense vegetation on the ground (39%), and in a nest of a sea eagle *Haliaeetus albicilla* on the top of an oak tree (about 35 m high) several times.

During severe winters, when daily temperatures were below –10 °C, raccoons did not leave their shelters for up to 1.5 months. During the study period, snow cover did not exceed 5 cm, so this factor probably has no effect on the winter activity of raccoons.

Mammals, mainly rodents (34% of the biomass consumed) and carcasses of wild boar *Sus*

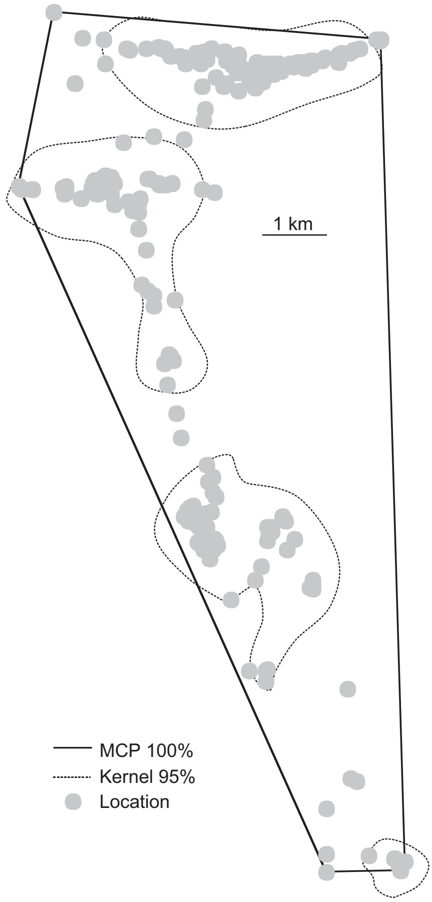

Fig. 2. Home range of a male raccoon (M1) from a woodland studied in northwestern Poland in 2006–2007. Home ranges were calculated as a minimum convex polygon (MCP) including 100% of the location and as an adaptive kernel including 95% of the locations (kernel 95%).

scrofa and Cervidae (10% of biomass) were the most important components of the diet of raccoons in the wetland study area. Other vertebrates were less important and their share amounted to 12%–15% of the biomass. Birds comprised 15% of the biomass (Table 2). Insects were also frequently consumed by raccoons (34% of occurrence) and among them there were mainly Coleoptera (of the order Dytiscidae and their larvae) and Carabidae; they however comprised only 8% of the consumed biomass.

In coprological examinations, we detected and identified eggs of the following parasites: *Ancylostoma* spp. (3.7%, 1 egg), *Baylisascaris procynis* (3.7%, from 1 to 5 eggs per sample), *Strongyloides procyonis* (14.8%, 1–75), and an ova which size and morphology have an affinity with the species *Spirocerca lupi* (14.8%, 1–6).

Discussion

These results demonstrate that the raccoon may use small home ranges in areas with high food abundances (suburbs). Furthermore, the observed high home range overlap in the suburbs and in wetland areas suggests that the raccoon population density may be very high. This confirms findings from Germany where the density of raccoons was very high and home ranges were very small in urban habitats. In Hessen, for example, there were up to 1 individual/ha (Hohmann *et al*. 2001) and average home ranges were 1.29 km^2 (Michler *et al*. 2004). Up to 2001, urbanization (urban range expansion) of this species seemed to be restricted to Germany and northern France (Hohmann *et al*. 2001). Now, raccoons have colonized urban areas in Poland and have reached high densities there. Therefore, we can expect a rapid expansion of the raccoon into urban environments, especially in housing estates located near water bodies and deciduous forests throughout Europe.

We now have preliminary data on the use of space by raccoons in European wetlands. The average home range in this habitat was about 10 times larger than in suburban areas, and over 10 times larger than in marshlands of North America (0.88 km^2, Urban 1970). It appears that there are abundant food resources in wetland habitats, but animals also wandered to places located farther from marshes, where food was temporarily available; via the patchy distribution of acorns in oak forests or mating places of frogs.

Radio tracking of the single animal in a woodland (M1) produced very different results. Its seasonal and total home ranges were much larger than those of animals from both the wetlands and the suburbs. This may be the result of dispersed sites that supported rich food resources (small and medium rivers, lakes and fish ponds) within a mosaic of a relatively dry forest and scarcity of proper den sites (hollow trees). Thus, this individual had to cover long distances between locations of food resources and resting sites. Raccoons from German woodlands have comparable home range sizes (Hohmann *et al*. 2000), and this is the largest known measured home range of racoons.

This study showed very high plasticity in the spatial patterning of the raccoon that probably depend on habitat type and local food abundance. Home ranges were smallest in the food-rich suburban area, but we do not have dietary data of the raccoon in this habitat. Our observations of foraging individuals suggest that they eat rodents, water insects, garden fruits and garbage. Raccoons occupied home ranges of intermediate sizes in the wetland area where the abundance of rodents, birds and frogs is relatively high. Raccoons have the largest home ranges in deciduous forest where the abundance of rodents, birds and frogs is much lower. Considering that only one individual was caught and radio-tracked in this habitat, these results should be treated with caution. Similar variation in home-range sizes, depending on habitat, were also observed in other carnivores, such as the stone marten *Martes foina* and the red fox *Vulpes vulpes* (Skirnisson 1986, Voigt & Macdonald 1984).

We noted seasonal changes of resting site types used by wetland raccoons. There is no information on such changeability in forested or urban areas. In German forests, only 6% of hiding places were in dense vegetation (Hohmann 1998), however in urban habitats 17% were "above or below the ground" (Michler *et al*. 2004), but no substantial seasonal changes were observed. Typical day resting sites in the study

Table 2. Diet composition of raccoons in the wetland study area in western Poland in 2005–2006 as determined by scat analyses (n = 150).

Prey category	Biomass consumed (%)	Occurrence (%)
Mammals	44	25
Birds	15	11
Amphibians	13	4
Fish	13	11
Insects	8	34
Molluscs	3	7
Crustacea	1	1
Plant material	2	4
Eggs	1	3

mentioned above were hollow trees. In our study, old hollow trees (mainly willows) in wetlands were also very important for the raccoon during winter and during periods of rising water levels. Our data also showed high plasticity in the selection of resting sites by raccoons, which may suggest that resting sites are not a limiting factor for this species in its colonised range.

Raccoons are generalist predators, and their diet changed in various locations in response to variation of food availability. In the species' original range, North America, raccoons consumed mainly plant material. In summer, when fruits ripen, they comprised up to 78% of the raccoon's food (Zeveloff 2002). Similarly, in Germany, raccoons inhabiting deciduous forests dominated by beech and oak, consume a high proportion of plant material (Hohmann *et al*. 2000). Plants comprised 33% of the raccoon diet, invertebrates 40%, and vertebrates 27% (mainly rodents from the genus *Microtus*) (Lutz 1980). No evidence was found that the raccoon has a serious influence on the native fauna (Lutz 1983). In contrast to other studies, our study shows that plant material made up only a very small proportion of the raccoon diet in wetlands. The major part of the diet consisted of mammals (primarily rodents). The high percentage of ungulate carrion in the diet shows that raccoons can easily adapt to food resources that are locally abundant.

Birds do not appear to be a very significant component of the raccoon diet in the Warta River mouth; they comprised about 15% of the biomass consumed. An investigation into the food habits of the American mink (*Mustela vison*) in the same study area showed that this predator was much more destructive for birds than the raccoon. Birds made up to 60% of biomass consumed by mink during spring and 34% on average, annually (Bartoszewicz & Zalewski 2003). Mink are better adapted to variations in the water level in wetland habitats (thanks to their ecological plasticity), where a high number of birds are available year round. Other carnivores (eg. red fox, raccoon dog, martens *Martes* spp.) during high water levels have to leave the area or stay in trees, risk starvation and death. Similarly, raccoons move to drier areas and select alternative prey when water levels rise, even though birds are still numerous in the wetlands areas (M. Bartoszewicz, unpubl. data). However, it is possible that the additive predation pressure of exotic predators could cause a decrease in the bird population in the near future.

Successive expansion of raccoons in Europe has begun relatively recently, therefore the study of helminth parasites is of great importance for public health (van der Giessen *et al*. 2004). Increasing populations of this carnivore and its expansion into environments where humans live (suburbs, allotments) points to the need to take note of helminths transmitted by raccoons. From among its parasites, the most dangerous for humans and domestic and wild animals is *Baylisascaris procyonis*. Infection is transmitted to people by accidentally ingesting eggs with invasive larvae (Sorvillo *et al*. 2002). Despite the fact that *B. procyonis* occurred only in one sample of our study, this finding may be of great importance to veterinary and medical parasitology. High prevalence of this roundworm (39%) in the neighbouring German raccoon population (Winter *et al*. 2005) suggests the possibility that this rate will increase when studied further. Nematodes of the genus *Ancylostoma* spp. parasitising domestic and wild living carnivores are relatively common in Europe but in this study these nematodes were detected in raccoons in Europe for the first time. *Ancylostoma kusimaense* has previously been detected only in Japanese raccoons (Matoba *et al*. 2006, Sato & Suzuki 2006). The most frequent parasite found in fecal samples was *Strongyloides procyonis*. This nematode was recorded only twice in raccoon: in North America (Little 1965, 1966) and in Japan (Sato & Suzuki 2006), where prevalence was relatively high (25.5%), which corresponds to our results. *Spirocerca lupi* has a relatively wide spectrum of definitive hosts, mainly representatives of the Canidae and Felidae. The life cycle *S. lupi* is complex, and its indirect hosts are coprophagous beetles (fecal eating) including species of the genera *Geotrupes* and *Scarabeus* (Gundłach & Sadzikowski 2004). In our study, insects made up 8% of the raccoon diet that can explain the invasion of *S. lupi* in this carnivore. Since the published literature has never reported *S. lupi* in the raccoon, our result increases the list of definitive hosts of this nematode.

In conclusion, the raccoon is a recently arrived, exotic species that has adapted to various habitat types and shows high plasticity in spatial patterning and in resting site selection. In some habitats, raccoon densities may reach a very high level and, consequently, two main problems may arise. First, it may result in increasing predation pressure on native prey, and secondly there may be increased transmissions of dangerous parasites or diseases (e.g. rabies) to domestic animals and humans. Therefore, further studies of the population dynamics would be necessary to create a strategy for raccoon population management.

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