

Descriptive epidemiology of a scabies epidemic in chamois in the Dolomite Alps, Italy

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Abstract In 1995, the hitherto *Sarcoptes*-free alpine chamois (*Rupicapra rupicapra*) of the Dolomite Alps (Italy) were affected by scabies for the first time after the spread of the disease from a neighbouring focus in Austria. Since then, four Agencies cooperated to warrant monitoring of the spatial and temporal progress of the outbreak and further active surveillance was carried out within an intensive study area. In ten years, 15 meta-populations numbering 10,000 chamois and 210,000 ha were encompassed with a maximum distance of 55 km from the index case. “Oil spot” advancement of the epidemic was observed together with “jumps” of 9 to 20 km followed by spreading of the infection to the intervening population units. Demographic decline of the four meta-populations so far affected for a minimum of six years ranged between 49 and 77%

($x = 62.5 \pm 13.5$), whereas similar post-epidemic densities of 1.1 to 1.7 heads/100 ha ($x = 1.5 \pm 0.27$) were recorded. Contiguous resistant and sensitive herds with similar pre-epidemic density were detected on a smaller population scale, suggesting complementary mechanisms intervening besides density-dependence as determinants of the outbreak outcome. No sex or age class showed a higher sensitivity to scabies out of a sample of 1,696 infected chamois. A peak prevalence of free-ranging chamois bearing overt scabietic lesions was observed in January and February. Cases were only sporadically diagnosed in other sympatric wild ruminants (*Cervus elaphus*, *Capreolus capreolus* and *Ovis gmelini musimon*), whereas all four alpine ibex (*Capra ibex ibex*) herds living in the surveyed area suffered from scabies-induced decline.

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Introduction

Scabies by the burrowing mite *Sarcoptes scabiei* is a contagious disease affecting humans and a wide range of mammalian hosts on a worldwide scale (Walton et al. 2004). Scabies epizootics with variable effects on population size, hence variable conservation consequences, have been reported in wildlife (Pence and Ueckermann 2002). Amongst wild Caprinae hosts, high scabies-induced mortality in the short-term has been documented in the Pyrenean chamois (*Rupicapra pyrenaica*), Pyrenean ibex (*Capra pyrenaica*) and the introduced barbary sheep (*Ammotragus lervia*) in Spain (Fernandez-Moran et al. 1997; Gonzales-Candela et al. 2004; Leon Vizcaino et al. 1999), in the alpine chamois (*Rupicapra rupicapra*) and ibex (*Capra ibex*) in Austria,

Slovenia and Italy (Ondersheka et al. 1968; Rossi et al. 1995; Schaschl 2003). Notwithstanding, only limited information is available on the “ecological epidemiology” of scabies in these hosts (Forchhammer and Asferg 2000). This information would be of pivotal interest (1) to develop sound simulation models of scabies, permitting in turn to generate hypotheses on spatiotemporal and demographic patterns of the disease (2) to help proper management of the affected populations. To contribute filling this gap, since the onset of a scabies epidemic in chamois in a previously unaffected zone in the Dolomite Alps, Italy, four major Agencies charged of wildlife management decided to coordinate their efforts to monitor the spread and demographic impact of the disease and granted exchange of data on a regular basis. In addition, active surveillance was carried out within an Intensive Study Area (ISA). This paper presents 10 years of monitoring and surveillance results.

Materials and methods

Study area

The survey was conducted on a wide area of approximately 500,000 ha (11°6' to 12°7'E and 46°2' to 46°7'N) comprising a significant part of the Dolomite Alps, in the provinces of Belluno, Bolzano and Trento, Italy, at the border with Eastern Tyrol and Carinthia, Austria. Approximately 85% of the study area is above 1,000 m a.s.l. (range 600–3,300 m a.s.l.) and 45% is covered by forests. Mean annual temperature ranges between 6 and 8°C at 1,000–1,200 m a.s.l., whereas mean annual rainfall ranges from 1,025 to 1,400 mm, with relatively dry winters and most of the precipitation occurring during summer and early autumn. Presence of snow usually exceeds 150 days at 1,000 m a.s.l.

The fauna includes several of the mammalian species listed amongst the hosts of *S. scabiei* in Europe (Bornstein et al. 2001), namely the red fox, beech marten (*Martes martes*), stone marten (*Martes foina*), badger (*Meles meles*), alpine chamois, alpine ibex, roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*) and the introduced Sardinian moufflon (*Ovis aries*). The wild boar (*Sus scrofa*), European lynx (*Lynx lynx*) and brown bear (*Ursus arctos*) are signalled sporadically. Local and transhumant cattle are still abundant in the study area, whereas the presence of sheep and goats is negligible.

Host population and demographic data

For the purposes of this study, 15 meta-populations of *R. rupicapra* numbering approximately 10,000 heads were outlined within the larger Dolomite population (Fig. 1). Cri-

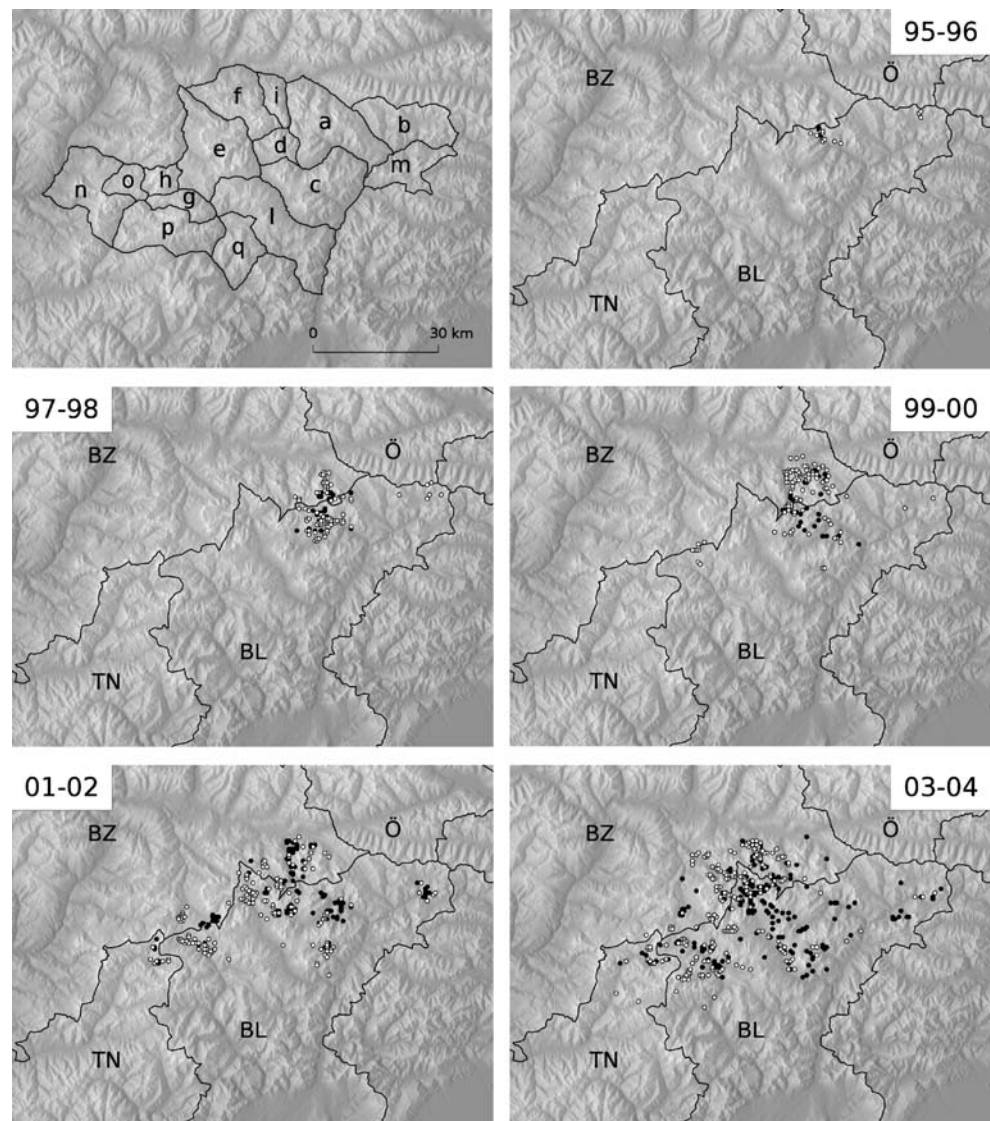
teria were the presence of natural or artificial barriers (deep valleys, large rivers, lakes, high traffic roads) supposed to limit dispersal movements (Loison and Menaut 1999). Range inhabited by the aforementioned meta-populations extended over 5,556 to 35,249 ha ($x=18,647$; SD 10,747). In addition, an Intensive Study Area (ISA) of approximately 4,000 ha was outlined within the massif harbouring the first affected meta-population (Dolomiti di Sesto).

Demographic data were obtained from different sources, namely harvest-based estimates and block counts (Bourliere 1969) by cooperating Agencies. Estimates were obtained for meta-populations, which were either not counted on a regular basis or counted over only a part of the occupied range. Block counts were carried out by teams of professional gamekeepers and park wardens, supported by instructed volunteers. Briefly, each team of two to four operators is assigned a fixed itinerary within a zone of 50 to 250 ha, according to cover and terrain morphology. Chamois are observed by means of 8–10× binoculars and 20–60× telescopes and recorded on the census form into five classes: kids, yearlings, adult males, adult females, undetermined. Putative double counts are deleted by the census manager in the following 24 h. All meta-populations were monitored on a yearly basis until 2005 by means of a single summer (July or August) block census over the whole or part of the occupied range. In the ISA, a 1-day block census was repeated for a minimum of three times from late June to early September, between 1996 and 2001. The highest count was assumed as the “minimum certain number” of chamois in that particular year. Density of chamois was calculated dividing counted individuals by the surface of the area (in square kilometers) inhabited by the corresponding meta-population.

Scabies cases

Spatial and temporal patterns of the epidemic were described from the database of all overt cases of disease until December 2004, confirmed either by a diagnostic laboratory, a veterinarian or trained professional gamekeepers and park wardens. The aforementioned cases are scabietic chamois of the following groups: (1) culled for control purposes or during sport hunting, (2) found moribund or dead in the frame of surveillance, and (3) found moribund or dead in the frame of specific investigation within the ISA, carried out between the onset of the epidemic and December 1998. Two experienced Hannover bloodhounds were profitably used to improve localization of Group 3. Carcasses were aged by observing tooth eruption and counting horn rings (Habermehl 1985). All cases in the database were geographically referenced in the form of Universal Transverse Mercator coordinates, based on direct-hand information by field personnel. Further cases

Fig. 1 Two-yearly geographical distribution of 1,696 scabietic chamois recorded in the Dolomite Alps, Italy, since October 1995 (onset of the outbreak) to December 2004. *Full dots* correspond to odd years, *open dots* to even. The outbreak area and the affected meta-populations are outlined in the *upper left map* (a Dolomiti di Sesto, b Alpi Carniche, c Marmarole, d Cristallo, e Fanes-Tofane, f Sennes-Croda Rossa, g Migon, h Sella, i Picco di Vallandro, l Pore-Nuvolau, m Dolomiti del Comelico, n Catenaccio-Sciliar, o Sassolungo, p Marmolada, q Civetta, BZ Bolzano, Ö Austria, BL Belluno, TN Trento)



are included in a separate database referred to scabietic chamois observed from a distance with the aid of 20–60× telescopes. A case is intended here as a chamois showing association of pruritic behaviour (scratching and gnawing) and alopecic areas. These observations were carried out in the ISA along five fixed transects covered at regular intervals between November 1995 and October 1997. A subset of 425 November–April observations during a shorter period (until April 1997) were used to describe the pre-epidemic sex and age ratios of the chamois herd in the ISA.

Analysis of data

The coordinates of each scabietic chamois were used to create maps showing their distribution in the study area by using Quantum GIS (<http://www.qgis.org>) and digital maps. Spatial analyses were carried out of the same data using the

open source software tools, namely the Geographical Information System GRASS (<http://grass.itc.it>) connected with the R statistical environment (<http://www.R-project.org>). The surface of the scabies-affected area in a particular year was calculated using the minimum convex polygon method by R package version 1.2. Nominal data such as season, sex and age were analysed by the Chi-squared test for association, using a statistical significance level of $\leq .05$. Finally, using generalised linear models, we tested the relationship between (a) time (x =years since onset of the outbreak) and the spatial advancement of the outbreak by previously transforming the affected areas into circular surfaces and computing the corresponding radial equivalents (y =radial equivalent of the affected areas) and (b) pre-epidemic density and the outcome of scabies in naïve hosts, by comparing the pre-epidemic density of affected meta-populations and the corresponding post-outbreak density gap. Data from a previously published paper (Meneguz et

Table 1 Yearly advancement of the scabies epidemic amongst chamois in the Dolomite Alps, Italy

Year	Affected area		Maximum distance from the index case (km)			
	In hectares	Yearly increase (x)	NE–SE	SE–SW	SW–NW	NW–NE
1995	47	–	–	1.4	–	1.7
1996	7,839	166.8	24.3	1.5	1.1	2.6
1997	19,894	2.5	24.3	7.2	8.0	5.1
1998	34,629	1.7	28.4	7.3	8.0	9.5
1999	45,878	1.3	28.4	7.3	9.3	12.4
2000	94,672	2.1	28.4	13.8	32.1	14.8
2001	122,515	1.3	28.4	14.1	43.3	18.7
2002	147,739	1.2	28.4	20.3	44.7	21.0
2003	178,739	1.2	28.7	21.6	51.4	33.2
2004	209,359	1.2	28.7	21.6	55.0	33.2

The linear distances from the index case in October 1995 are measured within quadrants centred on the four cardinal points.

al. 1996) were used in addition to original data to explore the last point.

Results

A total of 1,696 confirmed scabietic chamois were registered since the onset of the outbreak, including 1,471 of known sex and age, 183 sex-undetermined (52 of them kids), 42 sex- and age-undetermined. Cases refer to 585 chamois culled during sport hunting or for control purposes (Group 1); 916 found moribund or dead in the frame of passive surveillance (Group 2); 195 found moribund or dead in the ISA (Group 3).

The index case of the epidemic—an 8-year-old female—was diagnosed on 25 October 1995 in the northern part of the Belluno province (Val Cengia, Auronzo di Cadore). This location is 14 km far from the border with Eastern Tyrol, Austria, where scabies is signalled since the early 1960s. Three geographically separate cases (24 km apart from the index case) were registered in January and February 1996, in the Carniche Alps at the border with Carinthia, Austria. The two putative foci coalesced in 1997. Successively, scabies spread along a principal SW axis, with three major “jumps” of the epidemic front being observed in 2000, 2001 and 2003 (20, 11 and 9 km, respectively). As per December 2004, maximum distance from the index case was 55 km, corresponding to an average advancement of 5.5 km/year (± 7.08 SD, range 0–22.8; $N=9$). A slower spread of between 2.2 and 3.3 km/year ($x = 3.04 \pm 5.14$, range 0–12.2; $N=27$) was observed in the remaining quadrants. Yearly advancement of the epidemic and the corresponding affected area are reported in Table 1. A linear model ($y=2.8031x+0.9785$; $\rho=0.993$) provided the best fit to the expanding scabies affected area.

The total number of registered scabietic chamois is reported by month and 12-month rolling average (to de-

seasonalise the time series; Fig. 2). Cases increased during the investigated decade (from 6 in 1995 to 407 in 2004) in parallel with the spread of the epidemic. The yearly distribution of cases was investigated further at a local (ISA) and a meta-population scale (Table 2). At the wider scale, cases were expectedly distributed in a larger interval, data showing that not even the first affected meta-populations have completely cleared of scabies at the moment. On average, the number of cases peaked during the fifth or sixth year after the index case ($x = 5.75 \pm 0.95$ years, range: 5–7; $N=4$) and declined afterward, though less abruptly than observed in the ISA. So far, no cluster of cases suggesting a second wave of the epidemic was observed in any section of the study area.

As per August 2005, the whole surveyed chamois population had suffered an estimated 27.4% demographic decline, with obvious differences amongst meta-popula-

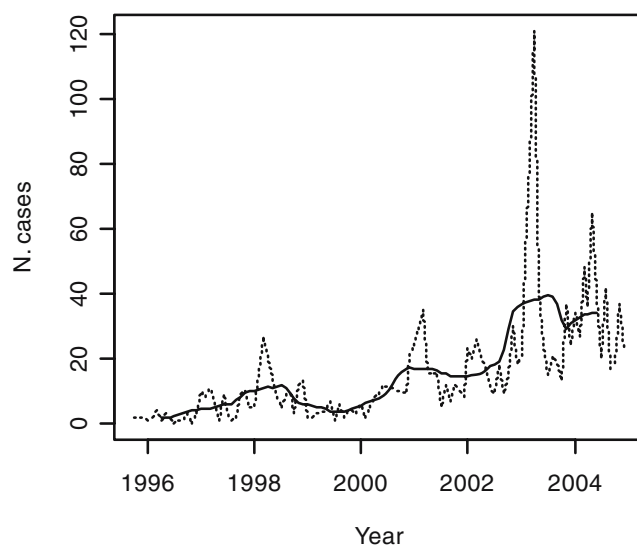


Fig. 2 Total number of registered scabietic chamois in the Dolomite Alps, Italy, reported by month (*dashed line*) and 12-month rolling average (*solid line*)

Table 2 Yearly distribution of the cases of scabies in the Dolomite Alps, Italy

Code	Massif	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
ISA	Dolomiti di Sesto	6	17	60	108	9	4	3	1	1	1	210
A	Dolomiti di Sesto ^a		1	13	25	25	78	50	17	9	9	227
B	Alpi Carniche		3	0	6	0	2	11	5	6	2	35
C	Marmarole-Antelao			1	3	4	8	51	35	88	24	214
D	Monte Cristallo					3	10	41	36	82	4	176
E	Fanes-Tofane						12	21	89	115	149	386
F	Sennes-Croda Rossa							5	26	124	130	285
G	Migon							3	6	14	31	54
H	Sella							3	1	2	13	19
I	Picco di Vallandro							1	0	1	22	24
L	Pore-Nuvolau								1	15	10	26
M	Dolomiti del Comelico									10	2	12
N	Catinaccio-Sciliar									1	2	3
O	Sassolungo									1	0	1
P	Marmolada									1	20	21
Q	Civetta										3	3

Cases refer to the Intensive Study Area (ISA) and the 15 meta-populations affected so far. Entries in bold denote peak values in the cohorts affected for a minimum of 6 years.

A–Q Meta-population code as in Fig. 1

^aThe ISA is excluded.

Table 3 Demographic decline in 15 meta-populations of chamois affected by a scabies outbreak in the Dolomite Alps, Italy

Code	Meta-population	Surface (ha)	Index case (year)	Pre-epidemic		Current		Decline rate (%)	Recorded cases of scabies (N.)
				Stock ^a (heads)	Density (heads/km ²)	Stock ^a (heads)	Density (heads/km ²)		
A	Dolomiti di Sesto	31,862	1995	1,650	5.2	500 ^b	1.6	70	437
B	Alpi Carniche	20,964	1996	425	2.0	225	1.1	47	35
C	Marmarole-Antelao	30,507	1997	1,125	3.7	500	1.6	56	214
D	Monte Cristallo	7,172	1999	550	7.7	125	1.7	77	176
E	Fanes-Tofane	31,040	2000	1,750	5.6	900	2.9	49	386
F	Sennes-Croda Rossa	20,079	2001	1,950	9.7	850	2.7	56	285
G	Migon	7,290	2001	550	7.5	325	4.4	41	54
H	Sella	5,556	2001	200	3.6	100	1.8	50	19
I	Picco di Vallandro	6,137	2001	750	12.2	375	6.1	50	24
L	Pore-Nuvolau	35,249	2002	425 ^c	2.7	250 ^c	1.6	41	26
M	Dolomiti del Comelico	14,016	2003	275	2.0	250	1.8	NA	12
N	Catinaccio-Sciliar	25,382	2003	850	3.3	850	3.3	NA	3
O	Sassolungo	6,219	2003	75	1.2	75	1.2	NA	1
P	Marmolada	23,693	2003	1,475	6.2	1,300	5.5	NA	21
Q	Civetta	14,149	2004	200	1.4	200	1.4	NA	3

NA Not applicable, A–Q meta-population code as in Fig. 1

^aApproximated to the nearest 25

^bMinimum stock recorded in 2003

^cPartial counts over 16,000 ha

Table 4 Demographic decline in small units of the chamois population affected by a scabies outbreak in the Dolomite Alps, Italy

Population unit	Meta-population	Surface (ha)	Density (heads/km ²)	Pre-epidemic stock (heads)	Post-epidemic stock (heads)	Decline rate (%)
Canazei—Lasties	Sella	1,480	4.8	71	66	9.3
Livinallongo—Boè Cherz	Sella	2,092	4.9	103	47	64.1
Canazei—Vial del Pan	Migon	1,872	6.5	122	98	19.7
Livinallongo—Mesola	Migon	2,174	5.4	119	62	47.9
Roccapietore—Sass da Roi	Migon	3,077	11.2	346	164	52.6
Calalzo—Val d'Oten	Marmarole	2,174	8.5	187	146	21.7
P.N. Somadida	Marmarole	1,720	12.9	220	50	77.3
P.N. Regole di Ampezzo—Cristallo	Monte Cristallo	1,475	14.5	214	93	56.6
P.N. Regole di Ampezzo—Fanes	Fanes-Tofane	2,407	7.5	180	40	77.8
P.N. Regole di Ampezzo—Tofane Sud	Fanes-Tofane	2,095	9.5	199	38	81.0
P.N. Regole di Ampezzo—Tofane Nord	Fanes-Tofane	2,531	4.4	109	14	87.2
P.N. Regole di Ampezzo—Croda Rossa	Sennes-Croda Rossa	3,419	23.9	816	96	88.2
ISA	Dolomiti di Sesto	3,982	6.9	275	67	75.6

Block counts of the 13 selected units were carried out on a yearly basis for a minimum of 5 years after the index case in the corresponding meta-population. Neighbouring units and corresponding data are presented in bold.

tions (Table 3). Expectedly, low to null decline rates characterise the recently affected herds, whereas figures referring to meta-populations whose decline has now halted after the impact of the epidemic wave (coded A–D in Table 3) range between 47 and 77% ($x = 62.5 \pm 13.5$; $N=4$). In addition, highly variable decline rates were registered amongst 13 smaller population units currently in a post-epidemic phase (Table 4). Based on confirmed cases of scabies and the estimated pre- and post-epidemic number of chamois in the meta-populations affected by scabies for a minimum of 3 years, we infer that a very high proportion of the carcasses of scabietic chamois ($\geq 68.5\% \pm 12.6$, range ≥ 55.0 – 93.5% ; $N=9$) were lost to surveillance. The estimated proportion is remarkably lower ($\geq 26.4\%$) in the ISA,

where trained personnel and special dogs were dedicated to this task.

Females were slightly more abundant than males amongst scabietic chamois (803 vs 695; ratio 1:0.87) and the same applies to the cohort of adult individuals (619 vs 547; ratio 1:0.88). A higher proportion of adult females than males were present in culled scabietic chamois than in those found moribund or dead (56.9 vs 50.8%; $N=432$ and 734 ; $\chi^2=4.10$; $P=0.043$). The female to male ratio of the herd surveyed in the ISA was notably similar as in the scabietic chamois collected in the same zone (1:0.69 vs 1:0.71; $N=231$ and 120 ; $\chi^2=0.02$; $P=0.897$). The distribution of cases according to three age classes (adults, yearlings and kids) and the age pyramid designed from the whole

Table 5 Age structure of different cohorts of scabietic chamois in the Dolomite Alps outbreak, Italy and comparison with the pre-epidemic age structure of chamois in ISA

Cohort	N.	% Age classes			Kids/adult females	Yearlings/adult females
		Adults	Kids	Yearlings		
Scabietic (total)	1,605	76.1	9.5	14.4	0.23	0.36
Scabietic (group 1)	571	75.8	10.5	13.7	0.24	0.32
Scabietic (group 2)	839	77.0	8.2	14.8	0.21	0.39
Scabietic (group 3)	195	72.8	12.3	14.9	0.30	0.36
Healthy (ISA)	425	61.2	23.6	15.2	0.65	0.42

Group 1, culled for control purposes or during sport hunting; group 2, found moribund or dead in the frame of passive surveillance; group 3, found moribund or dead in the Intensive Study Area, ISA

database are reported in Table 5 and Fig. 3, respectively. No difference was found in the age structure of scabietic chamois that were culled (group 1) compared with those found moribund or dead (groups 2 and 3; $\chi^2=4.35$; $P<.360$), whereas the structure of group 3 chamois differed from the transect-derived structure of the corresponding herd in that kids were under-represented in the former (12.3 vs 23.6%; $\chi^2=8.60$; $P=0.014$). The kid to adult female ratio amongst scabietic chamois observed from a distance in the ISA (0.38; $N=62$) was lower than the ratio derived from all observed chamois, but the difference was not significant ($\chi^2=2.85$; $P=0.091$).

A distinct seasonal pattern of cases distribution was observed. Based on the whole database, cases were most abundant in spring (38.2%, the peak months corresponding to March and April) and relatively rare in summer and fall (18.9% in both; $\chi^2=182.42$; $P<.0001$). Differences came apart between the cohorts of chamois that were culled or found dead, the autumn cases being most abundant in the former (36.5%) and the spring cases in the latter (46.4%; Pearson's Chi-square=205.49; $P<.0001$; Fig. 4). Similarly, the prevalence of scabietic chamois observed from a distance, as determined along transects in the ISA, fluctuated according to season ($\chi^2=182.42$; $P<.0001$), with the minima recorded in April to July and the maxima in January and February, during which approximately one-third of the chamois (35.5 and 31.4%, respectively) showed overt signs of the disease (Fig. 5). Monthly frequency distribution of scabies cases significantly differed between chamois observed from a distance and those found moribund or dead in the ISA (Pearson's Chi-square=278.21; $P<.0001$), a couple of months separating the corresponding peak months

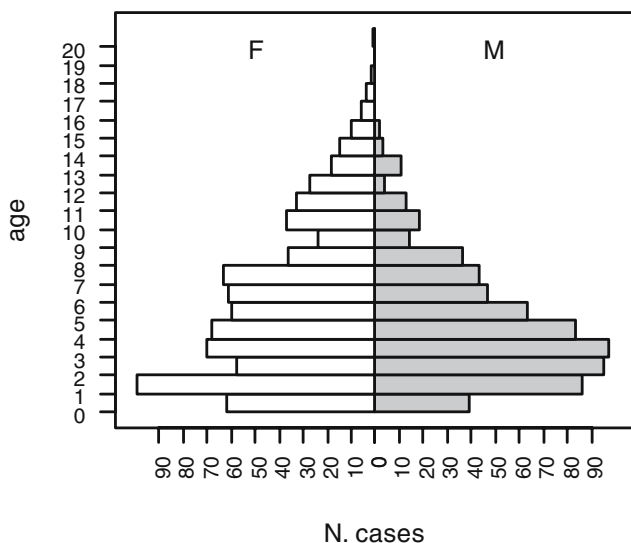
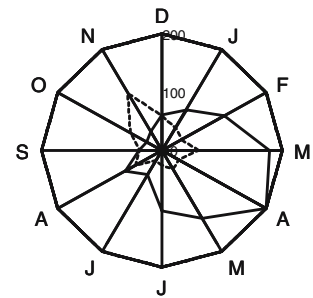


Fig. 3 Age structure of 1,471 scabietic chamois of known sex and age recorded in the Dolomite Alps, Italy, from October 1995 to December 2004 (M males, F females). Of the remaining 153 chamois of unknown sex, 52 were kids, 46 yearlings and 55 adults

Fig. 4 Radar plot of the monthly distribution of recorded scabietic chamois in the Dolomite Alps, Italy. Solid line Cohort of individuals found moribund or dead ($N=1,111$), Broken line cohort of individuals culled for control purposes or sport hunting ($N=585$)



(January and March, respectively). Finally, no season-related difference was found in the distribution of index cases in each of the investigated meta-populations ($N=15$). In fact, three occurred in the autumn and four in the winter, spring and summer, respectively.

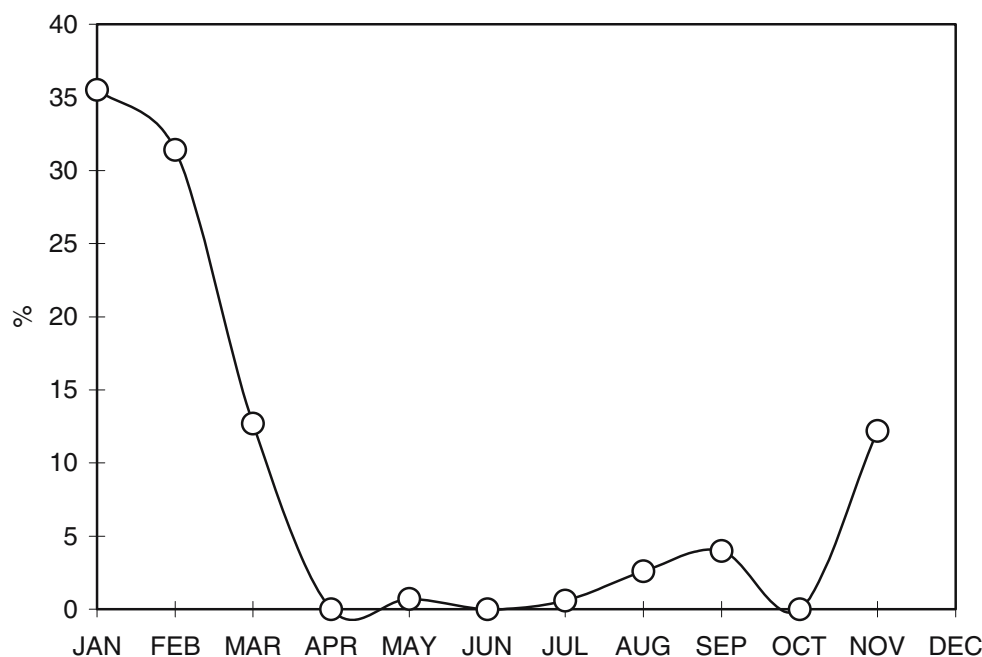
Other wild ruminants were diagnosed with scabies in the Dolomites, namely a roe deer, two Sardinian moufflons, a red deer and 157 alpine ibex. Index cases in these hosts were signalled between 1 and 4 years after the corresponding index case had been reported in sympatric chamois. Interspecific transmission of scabies occurred in all massifs ($N=4$) where ibex shared range with infected chamois. Out of the infected ibex colonies, one experienced limited (estimated 25%) decline, two suffered from severe demographic consequences (>90 and >60% decline rates), and one was only recently exposed. More detailed description of scabies in the alpine ibex in the Dolomites will be the object of a future paper.

Discussion

Out of the scabies epidemics reported so far in chamois on the southern aspect of the Alps, the one described here is no doubt the most important in terms of the total number of cases, size of the affected host population and width of the affected area.

Onset of this outbreak was somewhat unexpected since relatively long distances (>10 km) were separating the index case from the closest known cases in Eastern Tyrol, Austria. Until now, the spread of scabies in the Alps has been described as typically “oil spot”-like with average yearly advancement ranging between 2.4 and 4.5 km (Fuchs et al. 2000; Rossi et al. 1995; Schaschl 2003). However, in this case a jump triggered the outbreak and more jumps were reported afterward, their length ranging from 9 to 20 km. Jumps caused the SW average yearly advancement of the epidemic front (5.5 km) to be longer than previously reported and more similar to values—6 to 7 km/year—from the Cantabrians’ outbreak (Fernandez-Moran et al. 1997). Similarly to the Dolomites outbreak, scabies amongst red foxes in Sweden did not spread along a regularly advancing front; instead, scattered local population units were infested,

Fig. 5 24-month survey of the prevalence of scabietic individuals amongst distance observed chamois in the Intensive Study Area, Dolomite Alps, Italy ($N=1,012$; range: 31–170 observations/months, no transect walked in December)



with a period of up to 4 years elapsing before disease advanced into the gaps between infested areas (Mörner 1992). A similar spreading model was observed in coyotes (*Canis latrans*) in Texas (Pence and Windberg 1994). It may be a matter of debate whether jumps represent the actual localization of an isolated bridgehead of the epidemic deriving from migration of single infected individuals; alternatively, jumps might be only apparent, viz., the first emergence of scabies in population units actually infected on a larger basis. Evidence exists supporting the validity of either hypothesis. Dispersal of young chamois up until 35 km was documented on the Eastern Alps (Lovari, personal communication). Similarly, a proportion of adult chamois were shown migrating on a yearly basis to and from wintering areas located 3 to >20 km apart from the remaining home range (Clarke 1986; Hamr 1984, 1985; Unterthiner 2000). Finally, a proportion of adult males is used to move several kilometers from the usual home range during the rutting season (Hamr 1984; Unterthiner 2000). On the other hand, Rambozzi et al. (2004) reported on the presence of anti-*Sarcoptes* antibodies in healthy chamois from meta-populations neighbouring recognised infected ones. These seroreactors are evidence that a larger area is actually infected than the distribution of carcasses and clinical cases may suggest. Under these circumstances, index cases in a previously scabies-free meta-population would rather mirror the uncertainty of wildlife diseases surveillance in remote mountain areas (Wobeser 2002).

The area infected by scabies in a decade—approximately 210,000 ha—is remarkably larger than chamois may colonise in the same time interval (Forsyth and Clarke 2001). This is evidence of the high spreading potential of scabies,

provided a geographically continuous, sufficiently abundant and susceptible host population is available, as it currently occurs in the Dolomites. Notwithstanding, the yearly advancement of the epidemic front of scabies and the corresponding infected area compare unfavourably with the rapidly spreading infectious keratoconjunctivitis (IKC) by *Mycoplasma conjunctivae*, another serious epidemic disease affecting the chamois on the Alps. Outbreaks of IKC are typically short-termed, lasting from months to a maximum of a few years; notwithstanding, advancement may be as fast as 15 km/year and several thousands of hectares are rapidly involved accordingly (Giacometti et al. 2002).

The marked seasonal trend of the epidemic is consistent with observations in affected chamois all over the Eastern Alps (Knaus and Schroeder 1983; Kutzer and Ondersheka 1966; Miller 1985; Valentincic 1981). The trend seems primarily determined by seasonal variations in the fertility of *Sarcoptes* mites. Sokolova et al. (1989) showed that maximum egg production by adult female mites occurs in autumn and is low to null during January to July. A winter rise in the number of scabies episodes has been reported worldwide in several wild and domestic hosts and in humans (Bornstein et al. 2001; Burgess 1994; Martin et al. 1998; Mellanby 1944). Higher autumn fertility of the mites, coupled with the November to mid-December timing of the rutting season (when direct contacts are more frequent) and the expected 1-month lag from infection to first symptoms (Lavin et al. 2000; Menzano et al. 2002) is adequate explanation of the January to February rise in clinical cases, as shown in Fig. 5. Moreover, peak mortality in April and May suggests a 2 to 4-month evolution of clinical scabies in most susceptible individuals, confirming field data referred

to other wild caprine hosts, *C. pyrenaica* (Leon Vizcaino et al. 1999) and a limited number of radio-equipped *R. pyrenaica* (Sanchez Corominas 1999). The length of the clinical course is also influenced by the delicate metabolic situation of chamois during winter, when the effects of scabies and food deprivation may add up (Ondersheka et al. 1989). Almost twice the amount of fat reserves were found in healthy compared with scabietic Pyrenean chamois shot at the end of winter in the same study area (Fernandez-Moran et al. 1997).

Literature has reported on the dramatic impact of scabies on previously naive mountain-dwelling ungulates, the decline rate reaching more than 90% on occasion (Leon Vizcaino et al. 1999; Rossi et al. 1995). In the study area, a definite figure is available for a minority of the studied meta-populations, namely, an estimated decline rate of 70 and 77% in A and D, and a lower decline of approximately 50% in B and C. Of the remaining meta-populations, the ones affected for a minimum of 4 years have declined 45–56% hitherto. Based on the above, a bias in previous literature towards high mortality episodes seems likely. On a smaller scale, out of 13 meta-population sub-units counted on a yearly basis, six suffered a high decline rate of 76–88%, four suffered a 48–64% decline, whereas three were only mildly affected ($\leq 22\%$ decline). Interestingly, all the “resistant” sub-units were bordering with one or two sensitive ones (48 to 77% decline, Table 4) within the same meta-population. To the best of our knowledge, patchy distribution of bordering scabies-sensitive and scabies-resistant population units was not emphasised explicitly in any previous description of a scabies outbreak in a wild mammalian host. Notwithstanding, infra-population variations in susceptibility to scabies may be inferred from published data on *C. latrans* in the US (Pence and Windberg 1994) and an unpublished report by one of the authors (G.C.), who described a scabies epidemic occurred in chamois in a different part of Southern Tyrol between 1976 and 1994.

Density is a recognised category exerting an influence on the outcome of transmissible diseases, as suggested by its obvious connection with core epidemiological concepts such as the critical community size and the basic or effective reproductive numbers (Lloyd-Smith et al. 2005; Wobeser 2002). In this survey, only a limited number of meta-populations ($N=4$) suffered from scabies for a sufficient time to permit proper weighing of the category. Notwithstanding, after merging the available data with those ($N=3$) from a previous study in the Giulie Alps, Italy (Meneguz et al. 1996), a tempting linear relationship arose between the pre-epidemic density and the post-outbreak density gap of the corresponding meta-population (Fig. 6). Remarkably, whilst pre-epidemic densities are quite different from each other (range 2.0–22.7 heads/100 ha),

post-epidemic ones are similar (range 1.1–1.7 chamois/100 ha). This suggests that scabies will not spread further into a naive chamois population once a “threshold” density below 2 individuals/100 ha has been attained. A similar threshold density (1.1 chamois/100 ha) was generated in a simulation model of a scabies epidemic in the same host (Guberti and Zamboni 2000), and a recent observational study of a scabies outbreak in a related Caprinae host, *A. lervia*, yielded a threshold density of 1.7 individuals/100 ha (Gonzales-Candela et al. 2004). Such low threshold densities are an expected feature of transmissible diseases characterised by long infectious periods and limited transmission efficiency (Wobeser 2002). Although the concept of threshold density is often stressed in epidemiology (Anderson and May 1991), field-derived values referring to transmissible diseases in wildlife have rarely been published (Lloyd-Smith et al. 2005). Still, they may have important implications from the theoretical (modelling) and practical point of view, namely, when considering the feasibility, degree of public compliance, and likelihood of success of different control options. Incidentally, a threshold density below 2 chamois/100 ha is several folds lower than targeted for conservation or sport hunting purposes based on the estimated carrying capacity of most Alpine massifs. We are aware that the reliability of stock and density data reported in this paper may have suffered from errors usually associated with wildlife counts and estimates conducted under real-world conditions and that more replicates (and more years of monitoring) would be necessary to describe in proper detail the association between host density and disease outcome in the present model. However, even a partial contribution may represent

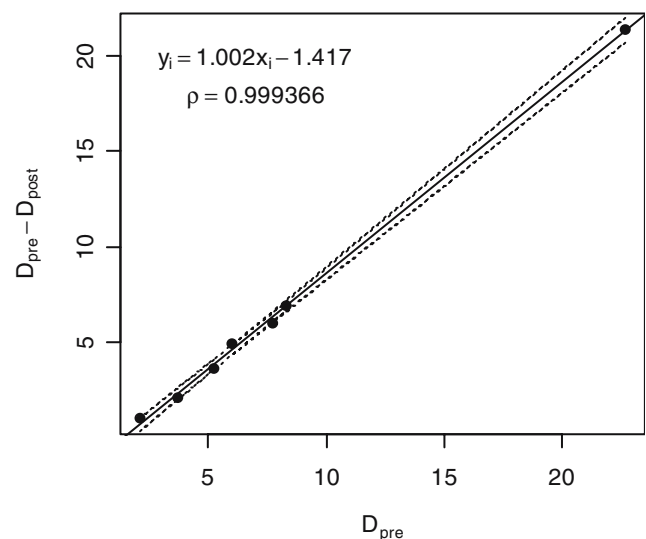


Fig. 6 Relationship between the pre-epidemic density and the post-outbreak density gap in seven chamois meta-populations affected by scabies in the Eastern Alps, Italy (D_{pre} pre-outbreak density, D_{post} post-outbreak density)

an opportunity to fill the current gap between theoretical and empirical understanding of population thresholds and the dependence of wildlife disease on host population abundance (Lloyd-Smith et al. 2005).

Though the observed differences in decline rates between meta-populations may be largely explained by the density-dependent hypothesis (Guberti and Zamboni 2000), viz., in terms of different gaps from the field-derived threshold density, contrasting sensitivity to scabies in smaller sub-units characterised by similar pre-epidemic density suggests the intervention of complementary mechanisms. Variations in the virulence of circulating *Sarcoptes* strains and genetic-based variations in host resistance to scabies have been postulated (Pence and Windberg 1994). Both explanations of the observed patterns are speculative and not mutually exclusive per se. Notwithstanding, based on theoretical predictions by Poulin and Combes (1999), low selective pressure is expectedly exerted on virulence of a pathogen whenever easy encounter and multiplication within the host is warranted, as in the case of mites rapidly spreading into a naïve, dense, and evenly distributed host population. On the other hand, for almost every disease that was intensively and carefully investigated, evidence for host genetic variation in resistance was found (Bishop and Stear 2003). In domestic ruminants, breed-associated resistance to *Sarcoptes* infection was demonstrated in sheep (Sotiraki et al. 2002) by means of experimental infections, and the same applies to the similar *Psoroptes ovis*/sheep and *P. ovis*/cattle models (Bates et al. 2002; Losson et al. 1999). In addition, a spatially explicit stochastic model simulating the spread of a scabies epidemic in a coyote (*C. latrans*) population best-fitted empirical data when selection for inherited host resistance was included (Leung and Grenfell 2003). Similar results were obtained in preliminary simulations of long-term temporal patterns of scabies in chamois (Guberti and Zamboni 2000).

Our data do not support a higher vulnerability to scabies in any sex or age class. In particular, the investigated sex ratios were similar in the cohorts of pre-epidemic and scabietic chamois in the ISA and the age distribution of scabietic chamois was as “long pyramid-shaped” as expected in a standard population of this ruminant (Fuchs et al. 2000). This is consistent with previous observations in *R. rupicapra* (Rossi et al. 1995) and *R. pyrenaica* (Fernandez-Moran et al. 1997). Other authors (Boch and Schneidawind 1988; Kutzer and Ondersheka 1966; Miller 1985; Schaschl 2003) indicated the young age in bucks and the particular stress of their first rutting seasons as important risk factors but no such sex- or age-related vulnerability emerges in a large data set (520 bucks) in a recent paper (Fuchs et al. 2000). Finally, though kids were significantly under-represented amongst scabietic chamois in this study, this seems more of a bias, the small size of carcasses making them easier to remove by

scavengers (Fernandez-Moran et al. 1997; Kutzer and Ondersheka 1966; Rossi et al. 1995; Wobeser 2002).

Spill-over of scabies from *R. rupicapra* to other wild ruminants other than *C. ibex* is confirmed a rare event, in spite of existing opportunities for contacts between roe deer, red deer and Sardinian moufflon and moribund to just dead scabietic chamois in the study area. On the Alps, reported cases in these hosts amount to a couple of dozens compared to some ten thousands in chamois and a few hundreds in *C. ibex* (Schaschl 2003), indicating specialization for caprines of the circulating *S. scabiei* strain. In fact, due to the low density of alternative sympatric wild hosts, mainly chamois-to-chamois transmission has occurred in the Eastern Alps for a minimum of 150 years after putative trigger infection by hitherto abundant domestic goats. Conversely, efficient transmission of scabies from *C. pyrenaica* to sympatric Sardinian moufflon, red deer and fallow deer (*Cervus dama*) occurs in southern Spain (Perez et al. 2002) and relatively frequent cases in red deer and roe deer were observed in northern Spain since the appearance of scabies in *R. pyrenaica* (Fernandez-Moran et al. 1997). Both Spanish outbreaks originated from recent contacts between domestic and wild caprines in mountain zones harbouring also dense populations of Cervids. These circumstances may have prevented, to date, strict specialization for caprines of the corresponding *Sarcoptes* strains.

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