Available online at www.sciencedirect.com
SCIENCE DIRECT®

Veterinary Parasitology 122 (2004) 15–26

veterinary parasitology

www.elsevier.com/locate/vetpar

Use of remote sensing and geographical information systems to identify environmental features that influence the distribution of paramphistomosis in sheep from the southern Italian Apennines

G. Cringoli [a,*], R. Taddei [b], L. Rinaldi [a], V. Veneziano [a], V. Musella [a], C. Cascone [a], G. Sibilio [b], J.B. Malone [c]

[a] *Dipartimento di Patologia e Sanità Animale, Università degli Studi di Napoli "Federico II", CREMOPAR Regione Campania, Naples, Italy*
[b] *Dipartimento di Biologia Vegetale, Università degli Studi di Napoli "Federico II", Naples, Italy*
[c] *Department of Pathobiology, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA 70803, USA*

Received 16 October 2003; received in revised form 25 February 2004; accepted 8 March 2004

Abstract

A geographic information system (GIS) was constructed using remote sensing (RS) and landscape feature data together with *Calicophoron daubneyi* positive survey records from 197 georeferenced ovine farms with animals pasturing in a 3971 km^2 area of the southern Italian Apennines. The objective was to study the spatial distribution of this rumen fluke, identify environmental features that influence its distribution, and develop a preliminary risk assessment model.

The GIS for the study area was constructed utilizing the following environmental variables: normalized difference vegetation index (NDVI), land cover, elevation, slope, aspect, and total length of rivers. These variables were then calculated for "buffer zones" consisting of the areas included in a circle of 3 km diameter centered on 197 farms.

The environmental data obtained from GIS and RS and from data taken by the veterinarians on the field (stocking rate and presence of streams, springs and brooks on pasture) were analyzed by univariate (Spearman and ANOVA) and multivariate (discriminant) statistical analyses using the farm coprological status (positive/negative) as the dependent variable.

Sheep on 32 of the 197 (16.2%) farms, were positive for *C. daubneyi*, with an average intensity of 52 epg.

* Corresponding author. Tel.: +39-081-451802; fax: +39-081-451729.
E-mail address: cringoli@unina.it (G. Cringoli).

0304-4017/$ – see front matter
doi:10.1016/j.vetpar.2004.03.011

A multivariate stepwise discriminant analysis model was developed that included moors and heathland, sclerophyllous and coniferous forest vegetation, autumn–winter NDVI and presence of streams, springs and brooks on pasture.

The variables entered in the model were also correlated with *C. daubneyi* positive farms in the univariate tests and are consistent with the environmental requirements of *C. daubneyi* and its snail intermediate host.

Keywords: Paramphistomidae; *Calicophoron daubneyi*; Sheep-trematoda; Epidemiology; Remote sensing; Geographical information systems

1. Introduction

Paramphistomum daubneyi Dinnik, 1962 was renamed *Calicophoron daubneyi* after the revision of the genus *Calicophoron* by Eduardo (1983). This rumen fluke has been reported in Europe, Asia, Africa and Oceania (Szmidt-Adjidè et al., 1996), and has been reported in Italy by Cringoli et al. (1993).

The spatial distribution of paramphistomosis is a function of the interaction between abiotic and biotic environmental factors.

Diseases have natural habitats in the same way as a species: they are found in focal areas where the spatial distribution of the parasite, host, vector and required environmental conditions coincide (Pavlovsky, 1966). Inside the distribution range, there are favorable zones where a high level of abundance is maintained. The boundaries of distributions are not strictly fixed and may fluctuate with climate and other components of the environment (Malone et al., 1998). For snail-borne diseases, such as paramphistomosis, the crash-boom growth pattern of snail host populations and the asexual parasite multiplication phase within snails leads to a high degree of environmental sensitivity (Malone et al., 1997).

Geographic information systems (GIS) and remote sensing (RS) technologies are being used increasingly to study the spatial and temporal patterns of disease (Brooker and Michael, 2000). GIS can be used to complement conventional ecological monitoring and modeling techniques, and provide a means to portray complex relationships in the ecology of disease (Yilma and Malone, 1998).

In addition, the use of GIS and RS to identify environmental features allows determination of risk factors and delimitation of areas at risk, permitting more rational allocation of resources for cost-effective control (Beck et al., 2000).

In previous parasitological surveys in southern Italy, GIS has also been used to develop sampling procedures in selected geographical areas, and create different types of parasitological maps (Cringoli et al., 1996, 2001, 2002a,b). The purposes of the present study were to: (1) map the distribution of paramphistomosis in pastured sheep in a selected area of the southern Italian Apennines; (2) relate the distribution to environmental features using RS and GIS, and (3) develop a preliminary GIS forecast and risk assessment model for paramphistomosis based on environmental determinants.

2. Materials and methods

2.1. Study area

The study was conducted in a 3971 km^2 area of the southern Italian Apennines (Fig. 1) that contains 92 contiguous municipalities located in portions of the 3 southern Italian regions, Campania, Apulia and Basilicata (40°39′–41°22′N, 14°50′–16°01′E). The area is mainly hilly, with small areas of either mountainous or flat land and extends from 100 to 1800 m above sea level. There are no lakes. However, a few rivers, some streams and many brooks run through the area; the latter two hold water only from autumn to late spring. The climate is Mediterranean with dry summers and rainy winters.

In this area there is a strong impact by man and the small agrozootechnical farms are widely distributed with and average area of approximately 50 ha. Small pasture areas are dispersed throughout the zone, which is mainly cultivated with cereal crops. Animals graze

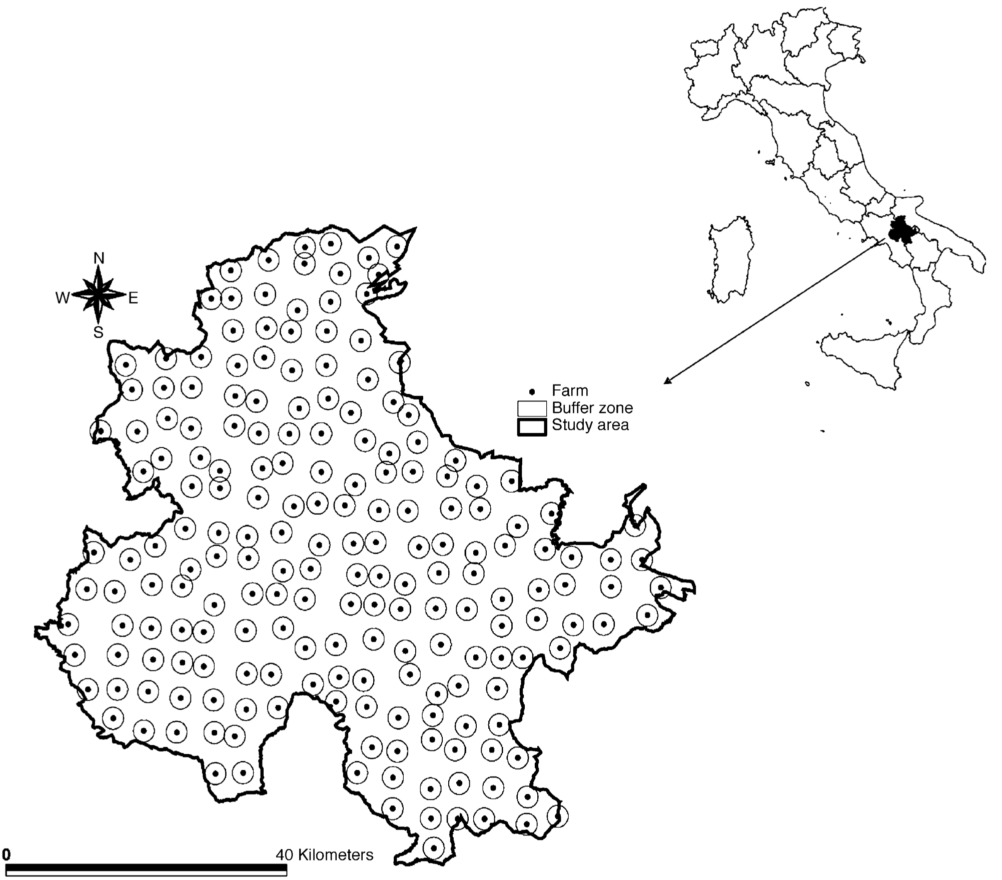

Fig. 1. The study area, showing location of the ovine farms tested for paramphistomosis and buffer zones used to extract data on environmental features.

mainly in areas of uncultivable elevation. In the past 50 years, some of these areas have been planted with coniferous trees.

2.2. Sample size and distribution

The survey was conducted on 197 ovine farms. This sample size was calculated using the formula proposed by Thrusfield (1995) inserting the following values: study population (6864 ovine farms), expected prevalence of paramphistomosis (5%), confidence interval (95%), and desired absolute precision (3%). Only farms with pastures (occasional/seasonal/permanent pasturing) and 50 or more sheep were included in the study population.

The 197 ovine farms that comprised the sample were selected to be uniformly distributed throughout the study area. For this purpose, the study area was divided into 197 equal sub-areas, and the centroid of each sub-area was identified. The sampling areas of the present study were circular areas of 3 km diameter centered on the centroides. In each sampling area, the specific farm to be studied was randomly selected by local veterinarians and designated by the number associated with that area.

2.3. Faecal samples

Between June 2000 and May 2001, faecal samples were collected per rectum from animals on the selected ovine farms.

Fecal samples were collected from 20 animals in each farm. The total number of faecal samples collected from the 197 ovine farms was 3940 (560 lambs and 3380 adult sheep). Eleven private veterinarians working in the study area were each assigned a portion of the 197 ovine farms from which to collect the study samples.

In order to randomly select study farms within the 3 km in diameter sampling area, each veterinarian was given a map (Universal Transverse Mercator projection, scale 1:100.000) of the study area within his/her responsibility and a handheld geographic positioning system (GPS GARMIN 12XL, Garmin International Inc. Olathe, KS, USA) to identify the precise geographical location of the farms selected with an accuracy of <40 m. In addition, the veterinarians were required to record information on the field regarding stocking rate and presence of streams, springs and brooks on pasture.

2.4. Laboratory procedures

Laboratory coprological examination of the ovine samples employed the modified McMaster technique (MAFF, 1986) with a sensitivity of 10 eggs/g (epg) of faeces. A zinc sulfate plus potassium iodomercurate solution (specific gravity = 1.450) was used. In addition, in positive samples, a sedimentation technique (Ambrosi, 1991) was used to differentiate the paramphistomes eggs from those of *Fasciola hepatica*.

2.5. GIS construction

A GIS for the study area was constructed utilizing datalayers on the following environmental features: normalized difference vegetation index (NDVI), land cover, elevation, slope, aspect, and total length of rivers. These variables, not collected from field, describe, in an exhaustive way, the habitat complexity for the studied species (Clark et al., 1993).

Data on each of these variables were then extracted for 'buffer zones' consisting of the area included in a circle of 3 km diameter centered on 197 georeferenced farms (points). Three kilometers is the minimum diameter in which at least one farm was found in the study area.

2.5.1. NDVI

NDVI index is particularly discriminating for vegetation cover classes because it is based on the combined use of the red band and the near infrared (nir) band for which vegetation has a unique spectral 'signature': plants absorb completely the red radiation (0.65–0.7 μm) used by leaves for chlorophyllian photosynthesis and they reflect the radiation in the nir radiation (0.7–1.3 μm), that would have the tendency to overheat the leaves and reduce their vital functions (Malingreau, 1989):

$$\mathrm{NDVI} = \frac{\mathrm{nir} - \mathrm{red}}{\mathrm{nir} + \mathrm{red}}$$

NDVI was obtained from Landsat-5 TM images (spatial resolution $= 30\,\mathrm{m} \times 30\,\mathrm{m}$). Using six NDVI images for dates distributed throughout the year, a sinusoidal model for NDVI annual profile proposed by Taddei (1996) was applied to make it possible to produce annual NDVI integrals (Fig. 2). This sinusoidal model takes into account: time,

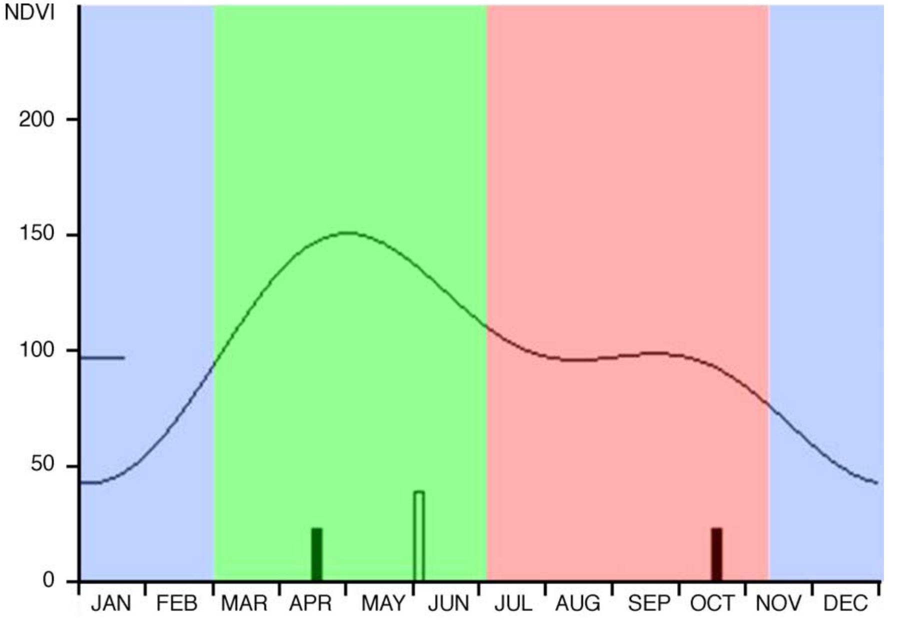

Fig. 2. NDVI profile obtained using the sinusoidal model for a generic pixel. Dark bar and white bar are the amplitude and phase of 6-month and annual cycles, respectively.

annual average of NDVI, amplitude and phase at annual and 6-month cycles (Eqs. (1) and (2)):

$$\text{Polar form}: \quad \mathrm{NDVI}(t) = M + \mathrm{Aa}\cos(t - \mathrm{Fa}) + \mathrm{As}\cos(2t - \mathrm{Fs}) \tag{1}$$

$$\begin{aligned}\text{Euclidean form}: \quad \mathrm{NDVI}(t) = {} & M + \mathrm{Aa}\sin(\mathrm{Fa})\sin(t) + \mathrm{Aa}\cos(Fa)\cos(t) \\ & + \mathrm{As}\sin(\mathrm{Fs})\sin(2t) + \mathrm{As}\cos(\mathrm{Fs})\cos(2t)\end{aligned} \tag{2}$$

where t is the time (Radiants); M the annual average of NDVI; Aa, Fa the amplitude and phase of annual cycle; As, Fs the amplitude and phase of 6-month cycle, respectively.

This profile describes phenology of vegetation canopy and climate conditions in a generic pixel of the image of study area during the year. For each pixel (30 m × 30 m) of each “buffer zone” we have calculated the NDVI average and standard deviation in three periods of 4 months: November–February (autumn–winter), March–June (spring), July–October (summer).

NDVI range varies from −1 to 1. As other Authors do, we have transformed negative values into 0 and rearranged positive values from 0 to 255, so that they could be contained in 1 byte.

For this reason, in the present study, NDVI was ranked within the value range of 0 to 255.

2.5.2. *Land cover*

Land cover of the study area was obtained from the Corine Land Cover map (1:100.000) (European Commission, 2000), that describes land cover (and partly land use) of according to a nomenclature of 44 classes.

The study area land cover map had 24 classes (pixel values correspond to class numbers). The hectares of each class were calculated for each “buffer zone”, overlaying the “buffer zone” grid to the land cover grid.

2.5.3. *Elevation, slope and aspect*

Data on elevation, slope and aspect of the study area were obtained from the Digital Elevation Model (DEM) (spatial resolution = 100 m) (source = Cartographic Office of the Campania Region).

The elevation was divided into the following four classes: low (0–500 m); medium (500–1000 m); high (1000–1500 m); very high (>1500 m). Aspect was divided into the following eight classes: north (337.5–360° and 0–22.5°), north-east (22.5–67.5°), east (67.5–112.5°), south-east (112.5–157.5°), south (157.5–202.5°), south-west (202.5–247.5°), west (247.5–292.5°), and north-west (292.5–337.5°). Slope was divided into the following four classes: flat (0°), low (0–15°), medium (15–30°) and high (30–54°).

Utilizing the above data for each “buffer zone”, the following variables were calculated: number of pixel of each elevation class, average and S.D. of elevation; number of pixel of each aspect class, average and S.D. of aspect; average and S.D. of slope.

2.5.4. River length

Total length of rivers in the study area was obtained from Digital Chart of the World (DCW—1:1.500.000) (ESRI, Italia).

Applying a new intersection of “buffer zones” with study area hydrographic network, the total length of the rivers in each “buffer zone” was calculated.

More precise data regarding the presence of watercourses smaller than rivers (streams, springs and brooks) were recorded in the field, since they were not detectable from DCW or Landsat images.

All GIS databases were developed using Arc-View 3.2 GIS (ESRI, Redlands, CA, USA) and IDRISI (Clark University, Worcester, MA, USA).

2.6. Statistical analyses

Environmental data obtained from RS and GIS (autumn–winter, spring and summer NDVI, land cover, elevation, slope, and aspect) and from the field data (stocking rate and presence of streams, springs and brooks on pasture) were analyzed by univariate and multivariate statistical analysis using the farm paramphistomes coprological status (positive/negative) as the dependent variable.

Since the variables were not normally distributed, a Spearman non-parametrical correlation analysis was run to state relationships among the variables sampled in the study area and the dependent variable.

A one-way ANOVA was also performed in order to state significative differences in the average values of variables between positive and negative “buffer zones”.

The variables that showed significance in the Spearman non-parametrical correlation and one-way ANOVA analyses were used to perform a stepwise discriminant analysis. This latter was used to derive a model predicting the likelihood of presence or absence of paramphistomes. All the statistical analyses were performed using SPSS 11 software.

3. Results

Sheep on 32 of the 197 farms (16.2%), were positive for *C. daubneyi*, with an average intensity of 52 epg (range 10–340). The distribution of ovine farms with infections of *C. daubneyi* is shown in Fig. 5.

The maps obtained from the GIS are shown for autumn–winter (Fig. 3a), spring (Fig. 3b) and summer NDVI (Fig. 3c), land cover (Fig. 3d), elevation (Fig. 4a), aspect (Fig. 4b), slope (Fig. 4c) and length of rivers (Fig 4d).

Spearman correlation analysis indicated that positive farms were positively related to the environmental variables shown in Table 1.

The ANOVA results are shown in Table 2. The predictor variables entered into the discriminant model and their function coefficient are shown in Table 3. The model correctly classified the 83.1% of the field data set (89.4% of negatives and 53.1% of positives). Comparison between the field data and prediction data is reported in Fig. 5.

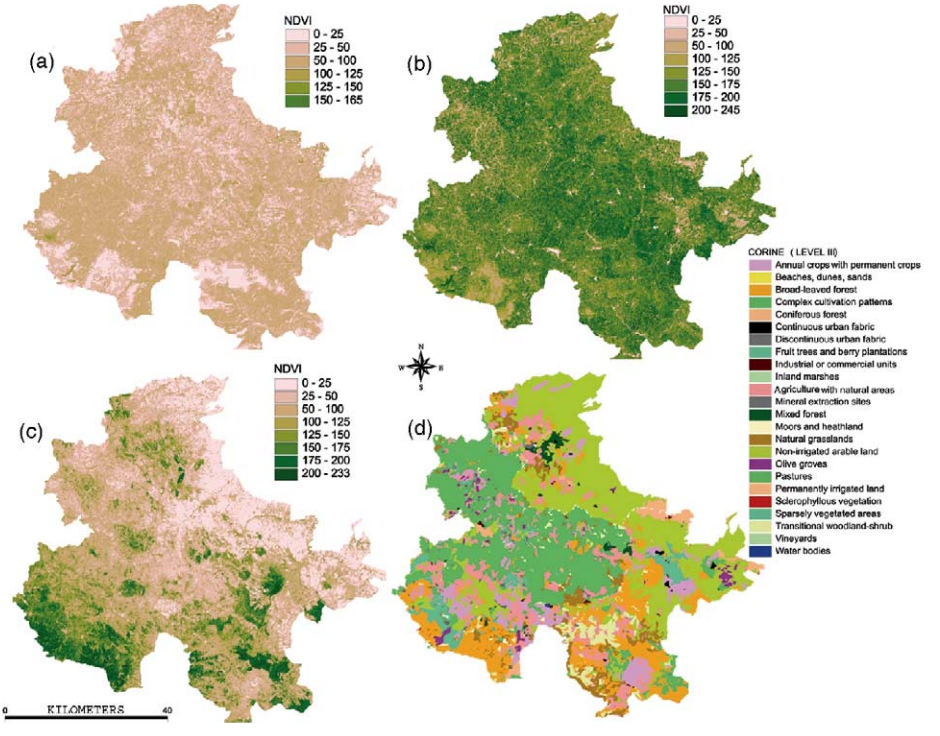

Fig. 3. Maps of the study area obtained from the GIS: (a) autumn–winter NDVI; (b) spring NDVI; (c) summer NDVI; (d) land cover.

Table 1
Results of the Spearman's correlation analysis: environmental features positively correlated with paramphistome positive farms

Environmental features	Source	Spearman's rho coefficients
Moors and heathland	Land cover	0.217**
Sclerophyllous vegetation	Land cover	0.162*
Coniferous forest	Land cover	0.191**
Number of pixel classes of elevation	DEM	0.180*
Standard deviation of elevation	DEM	0.170*
Medium elevation (500–1000 m)	DEM	0.143*
Standard deviation of aspect (west)	DEM	0.221**
Number of pixel classes of slope	DEM	0.184**
Average slope	DEM	0.179*
Standard deviation slope	DEM	0.179*
Summer NDVI	Landsat	0.196**
Autumn–winter NDVI	Landsat	0.186*
Presence of streams, springs and brooks on pasture	Field data	0.150*

* $P < 0.05$.

** $P < 0.01$.

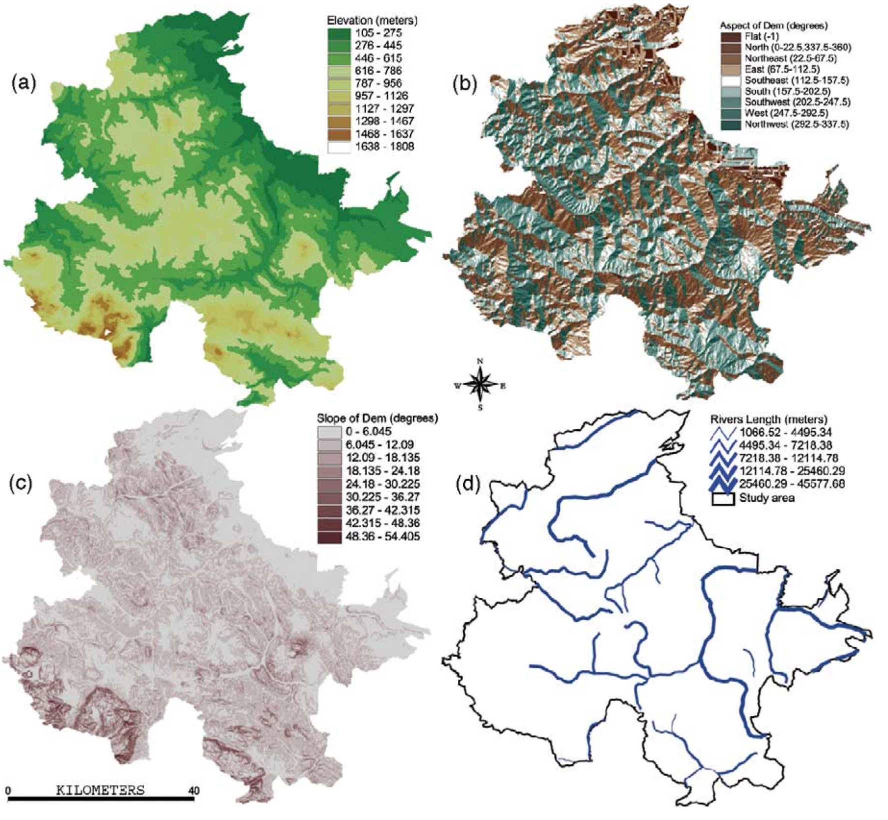

Fig. 4. Maps of the study area obtained from the GIS: (a) elevation; (b) aspect; (c) slope; (d) total length of rivers.

Table 2
Results of the one-way ANOVA analysis

Environmental features	Source	*P*	d.f.[a]
Moors and heathland	Land cover	0.002	1
Sclerophyllous vegetation	Land cover	0.023	1
Coniferous forest	Land cover	0.007	1
Number of pixel classes of elevation	DEM	0.004	1
Standard deviation of elevation	DEM	0.004	1
Medium elevation (500–1000 m)	DEM	0.017	1
Number of pixel classes of slope	DEM	0.004	1
Average slope	DEM	0.004	1
Standard deviation slope	DEM	0.004	1
Summer NDVI	Landsat	0.004	1
Presence of streams, springs and brooks on pasture	Field data	0.035	1

[a] Freedom degree.

Table 3
Results of the discriminant analysis: predictor variables entered in the forecast model

Predictor variables	Source	Function coefficients
Moors and heathland	Land cover	0.639
Sclerophyllous vegetation	Land cover	0.517
Coniferous forest	Land cover	0.522
Autumn–winter NDVI	Landsat	0.484
Presence of streams, springs and brooks on pasture	Field data	0.373

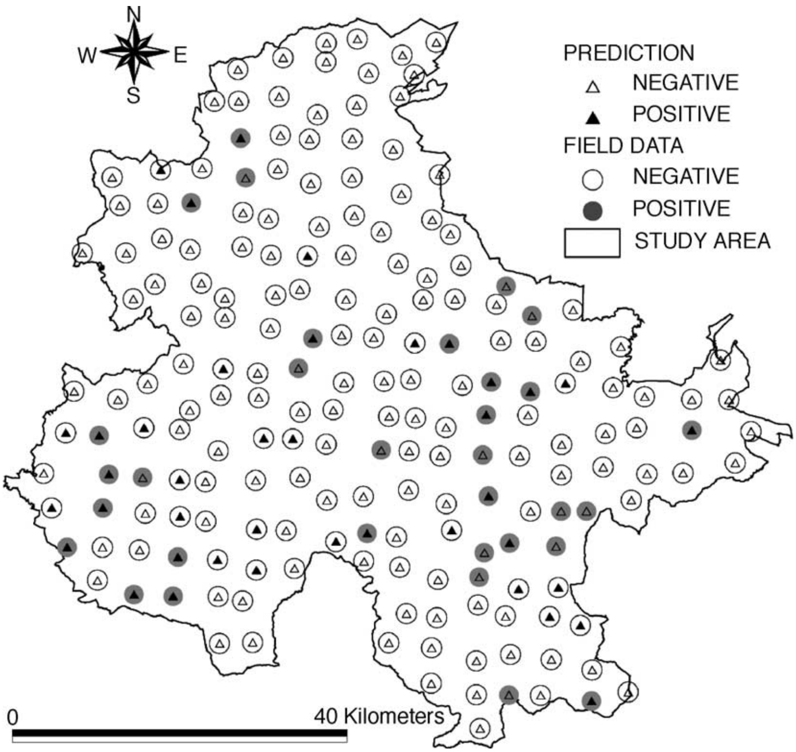

Fig. 5. Comparison between the field data and prediction data.

4. Discussion

The present survey carried out in a selected area of the southern Italian Apennines shows that *C. daubneyi* was present on the tested ovine farms, with a prevalence of 16.2%.

The use of RS and GIS allow us to make a first characterization of the environment suitable for *C. daubneyi*. In most of the buffer zones on positive farms, there were areas with forest canopies mingled with shrubs and undershrubs located at an elevation between 500 and 1000 m, with a slope of greater than 15°. In addition, higher values of autumn–winter and summer NDVI were correlated with farm positivities, indicating the importance of the presence of vegetation during all the year for the rumen fluke and its intermediate host(s).

With the objective of preparing a model based on environmental risk that can be extrapolated to other areas with similar characteristics, a multivariate stepwise discriminant analysis was developed that included moors and heathland, sclerophyllous vegetation, coniferous forest, autumn–winter NDVI and presence or absence of streams, springs and brooks on pasture. In addition to length of rivers from the DCW (1:1.500.000 scale), this latter information was obtained from the field since, for areas as small as our study area, they cannot be reliably detected from DCW or Landsat images.

The variables entered in the model, also correlated to positivities in the univariate tests, are consistent with the environmental requirements of *C. daubneyi* and the snail(s) intermediate host(s).

In particular, the land cover types entered in the model in this area are indicators of marginal uncultivable and sloping zones where typically there is the presence of water (permanently or temporarily).

In addition, since NDVI can be used as an indicator of regional thermal-moisture regime (Malone et al., 2001), the distribution of farms positive for paramphistomosis corresponding to relatively high values of winter and evidence of extended presence of pasture moist zones seen in summer Landsat NDVI values, indicated the presence of adequate moisture and temperatures favorable to the fluke and the snails.

The model generated in the present survey defines suitable conditions for development of the life cycle of *C. daubneyi* in this typology of territory; it represents a first experience of forecasting of snail-borne disease in Italy by remote sensing and GIS. More accurate characterization of the zones where this fluke is found are needed, probably utilizing a larger study area. In addition, since the presence of the intermediate host snail(s) is a key factor regulating the distribution of paramphistomosis, a more accurate knowledge of the distribution and the ecology of vector(s), never investigated before, is needed. Longer term, these studies encourage investigations to develop, by similar methods, environmental risk assessment models for other ruminant parasites that were concurrently recorded during surveys of the same farms in the southern Italian Apennines.

References

Ambrosi, M., 1991. La diagnostica coprologica nelle elmintiasi di allevamento: caso delle distomatosi dei ruminanti. Praxis Vet. 12, 17–20.

Beck, L.R., Lobitz, B.M., Wood, B.L., 2000. Remote sensing and human health: new sensors and new opportunities. Emerg. Infect. Dis. 6, 217–227.

Brooker, S., Michael, E., 2000. The potential of geographical information systems and remote sensing in the epidemiology and control of human helminth infections. In: Remote Sensing and Geographical Information Systems in Epidemiology. Adv. Parasitol. 47, 246–279.

Clark, J.D., Dunn, J.E., Smith, K.J., 1993. A multivariate model of black bear habitat use for a geographic information system. J. Wildl. Manage. 57, 519–526.

Cringoli, G., Capuano, F., Frisiello, M., Maffucci, R., Cecio, A., 1993. *Calicophoron* sp. (Paramphistomidae) in allevamenti bovini della provincia di Avellino: Nota 1. Acta Med. Vet. 4, 165–176.

Cringoli, G., Del Vecchio, U., Capuano, F., Veneziano, V., 1996. Application of geographical information systems (GIS) to parasitology: a case study in southern Italy. Parasitologia 38, 282.

Cringoli, G., Rinaldi, L., Veneziano, V., Capelli, G., 2001. A prevalence survey and risk analysis of filariosis in dogs from the Mt. Vesuvius area of southern Italy. Vet. Parasitol. 102, 243–252.

Cringoli, G., Otranto, D., Testini, G., Buono, V., Di Giulio, G., Traversa, D., Lia, R., Rinaldi, L., Veneziano, V., Puccini, V., 2002a. Epidemiology of bovine tick-borne diseases in southern Italy. Vet. Res. 33, 421–426.

Cringoli, G., Rinaldi, L., Veneziano, V., Capelli, G., Malone, J.B., 2002b. A cross-sectional coprological survey of liver flukes in cattle and sheep from an area of the southern Italian Apennines. Vet. Parasitol. 108, 137–143.

Eduardo, S.L., 1983. The taxonomy of the family Paramphistomidae Fischoeder, 1901 with special reference of the morphology of species occurring in ruminants. III. Revision of the genus *Calicophoron* Nasmark, 1937. Syst. Parasitol. 5, 25–79.

European Commission (DG Agri EUROSTAT, Joint Research Centre (Ispra) e European Environmental Agency), 2000. From Land Cover to landscape diversity in the European Union. http://www.europa.eu.int/comm/agriculture/publi/landscape/index.htm.

MAFF, 1986. Manual of Veterinary Parasitological Laboratory Techniques. Ministry of Agriculture, Fisheries and Food, Reference Book 418. HMSO, London.

Malingreau, J.P., 1989. The vegetation index and the study of vegetation dynamics. In: Toselli, F. (Ed.), Applications of Remote Sensing to Agrometeorology. ECSC, EEC, EAEC, Brussels, pp. 285–303.

Malone, J.B., Abdel-Rahman, M.S., El Bahy, M.M., Huh, O.K., Shafik, M., Bavia, M., 1997. Geographic information systems and distribution of *Schistosoma mansoni* in the Nile Delta. Parasitol. Today 13 (3), 112–119.

Malone, J.B., Gommes, R., Hansen, J., Yilma, J.M., Slingerberg, J., Snijders, F., Nachtergaele, F., Ataman, E., 1998. A geographic information system on the potential distribution and abundance of *Fasciola hepatica* and *F. gigantica* in east Africa based on Food and Agriculture Organization databases. Vet. Parasitol. 78, 87–101.

Malone, J.B., Yilma, J.M., McCarroll, J.C., Erko, B., Mukaratirwa, S., Zhou, X., 2001. Satellite climatology and the environmental risk of *Schistosoma mansoni* in Ethiopia. Acta Trop. 79, 59–72.

Pavlovsky, E.N., 1966. The Natural Nidality of Transmissible Disease. University of Illinois Press.

Szmidt-Adjidè, V., Adjidè, C.C., Rondelaud, D., Dreyfuss, G., Mage, C., 1996. L'ètat des connaissances sur *Fasciola hepatica* Linne, 1758 et *Paramphistomum daubneyi* Dinnik, 1962. GTV 529, 45–54.

Taddei, R., 1996. Modello e algoritmi per i profili NDVI su dati mensili: applicazione alle immagini NOAA-AVHRR sul territorio italiano. Rivista Italiana di Telerilevamento 6, 31–40.

Thrusfield, M., 1995. Veterinary Epidemiology. Blackwell, London, UK, pp. 138–188.

Yilma, J.M., Malone, J.B., 1998. A geographic information system forecast model for strategic control of fasciolosis in Ethiopia. Vet. Parasitol. 78, 103–127.