*Folia Zool.* – 58(3): 309–326 (2009)

# Otter *Lutra lutra* population expansion: assessing habitat suitability and connectivity in southern Italy

Anna LOY[1]*, Maria Laura CARRANZA[1], Carmen CIANFRANI[1], Evelina D'ALESSANDRO[1], Laura BONESI[2], Piera Di MARZIO[1], Michele MINOTTI[1] and Gabriella REGGIANI[3]

[1] *Università del Molise, Contrada Fonte Lappone, I-86090 Pesche, Italy; e-mail: a.loy@unimol.it*

[2] *Università di Trieste, Via Weiss 2, I-34127 Trieste, Italy*

[3] *Istituto di Ecologia Applicata, Via Cremona 71, I-00161 Roma, Italy*

Received 26 March 2008; Accepted 15 June 2009

Abstract. The Eurasian otter is one of the most endangered mammals in Italy and its distribution is now restricted in two isolated portions in southern Italy. However, in recent times, this species has shown a tendency to expand its range, especially northwards. It is therefore important to identify suitable areas on the border of its expansion range where the species can establish and disperse, so that these areas can be targeted for conservation actions. To this aim, the distribution, quality and connectivity of habitats of seven river catchments located in the northern portion of the current otter range in Italy were assessed. Catchments included both rivers where the otter currently occurs and where it is likely to expand in the short-medium term. An expert-based Habitat Suitability (HS) model was developed and validated using otter presence-absence data based on standard field surveys. Fine scale riverbank land cover, extra-riparian coarse scale land cover, altitude, bank slope, and human disturbance were considered as the main factors in the HS model. These variables were available or newly created in the form of digital maps (layers) and the HS model was built by sequentially filtering these layers. Connectivity was assessed within and between river basins through landscape algorithms by taking into account variables that could influence otter dispersal. The results indicated that the seven rivers considered are heterogeneous both in terms of habitat suitability and in terms of connectivity. Among these, one river in particular (the river Volturno), where otters are currently present, showed one of the largest extensions of suitable habitats and the best connectivity both within the river and between the river and the neighbouring catchments, suggesting that this river could play a strategic role in the survival and expansion of otters in the surrounding areas.

**Key words:** potential distribution, deterministic models, dispersal, GIS

## Introduction

The Eurasian otter (*Lutra lutra* L.) is a semi-aquatic carnivore that underwent a strong decline in Europe between the 1960s and the 1980s (Mason & Macdonald 1986, Mason 1989, Macdonald & Mason 1994). Several factors have been suggested to explain this decline, including the reduction of food supply, pollutants, human persecution, and the destruction of riparian vegetation (Mason & Macdonald 1986, Macdonald & Mason 1994, Conroy & Chanin 2000, Kruuk 2006). The decrease in the concentration of harmful pollutants in the environment due to more stringent regulations (Pacyna 1999) and the enactment of legal protection have allowed otter populations to gradually recover since the 1980s in several European countries (Conroy & Chanin 2000, Roos et al. 2001, Mason & Macdonald 2004, Romanovski 2006). Compared to other populations in Europe, the Italian population has recovered rather slowly,

* Corresponding author

and signs of the species expanding its range have only recently started to become apparent (P r i g i o n i et al. 2007). Despite the fact that the IUCN Red list and the European Mammal Assessment consider the Eurasian otter as *near threatened* (R e u t h e r & H i l t o n - T a y l o r 2004, T e m p l e & T e r r y 2007, 2009, Ruiz-Olmo et al. 2008), this animal is still considered a critically endangered species in Italy (B u l g a r i n i et al. 1998). At present, the Italian range of the otter is confined to the southern part of the Italian peninsula (Fig. 1), while originally the species was distributed all over the country (C a g n o l a r o et al. 1975). The residual population is relatively small (P r i g i o n i et al. 2006a, b) and it is geographically isolated and genetically differentiated from other European populations (R a n d i et al. 2003). Furthermore, this population is currently separated into two isolated subpopulations (Fig. 1): the largest one located in southern Italy and the smallest one, only

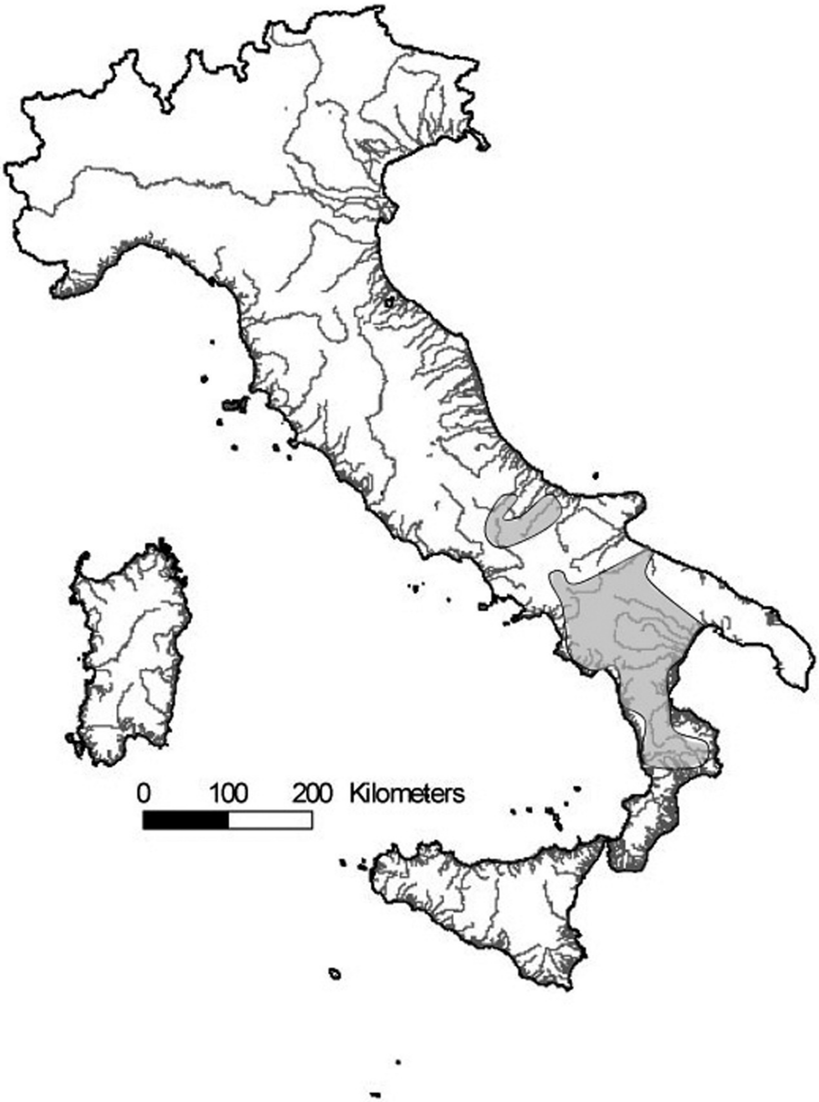


**Fig**. **1**. Distribution range of the otter *Lutra lutra* in Italy.

recently discovered, located in south-central Italy (Loy et al. 2004, Fusillo et al. 2004, 2007, Prigioni et al. 2007).

The subpopulation of south-central Italy is currently expanding northward (De Castro & Loy 2007) while there is no indication that otters are currently colonising the gap that separates the two subpopulations. Given the small size and the current expansion trend of the south-central subpopulation, it is important to identify rivers that can potentially host otters in the area and also to identify the rivers and land areas through which the species could disperse to better target conservation actions aimed at promoting the recovery of the species.

In this study, an approach combining a fine scale Habitat Suitability (HS) model and connectivity analysis was adopted to identify areas where the otter could potentially expand in the short-medium term within and around the south-central subpopulation. The HS model was also used to identify rivers with particularly suitable habitats that could provide source populations. HS models for otters have been produced on different geographic scales (Ottino et al. 1995, Prigioni 1995, Prenda & Granado-Lorencio 1996, Antonucci 2000, Reggiani et al. 2001, Barbosa et al. 2001, Boitani et al. 2002) with a resolution which is usually greater than 1 km. However, fine scale approaches are still lacking. The fine scale approach is particularly critical for otters, as some important habitat requirements such as riparian vegetation cover may not be related to the available coarse scale environmental GIS variables usually used to build HS models.

## Study Area

The study area comprised seven river catchments of south-central Italy (Sangro, Biferno, Trigno, Fortore, Saccione, Sinarca, and the upper part of the River Volturno) located mostly in the Molise region (Fig. 2). These catchments comprise both rivers where otters are currently present and neighbouring rivers where otters are likely to expand in the near future.

The total length of the water courses considered in the study was 1 943 km. A standard survey run in the years 2000-2004 (Fusillo et al. 2004, Loy et al. 2004) revealed that otter occurrence was restricted to the Biferno and upper Volturno catchments. Sporadic records of otters were also reported for the river Fortore, while otters were seemingly absent from the rivers Sangro, Trigno, Saccione, and Sinarca (Fig. 2). A more recent survey in 2006 revealed signs of otter occupation on the river Sangro, which is located in the north-western part of the study area (De Castro & Loy 2007).

## Material and Methods

### Habitat Suitability model development

The HS model was expert-based, rather than inferential. There were two reasons behind this choice: 1) an inferential approach applied on the peripheral areas of an expanding species' range may fail to discriminate between suitable and unsuitable areas because suitable areas may not yet be occupied (Jason et al. 2002, Clevenger et al. 2002, Ottaviani et al. 2004); 2) European otters have been thoroughly studied and many of the factors that influence their biology and ecology are well known (Mason & Macdonald 1986, Mason 1989, Beja 1992, Madsen & Prang 2001, Bonesi & Macdonald 2004, Kruuk 2006).

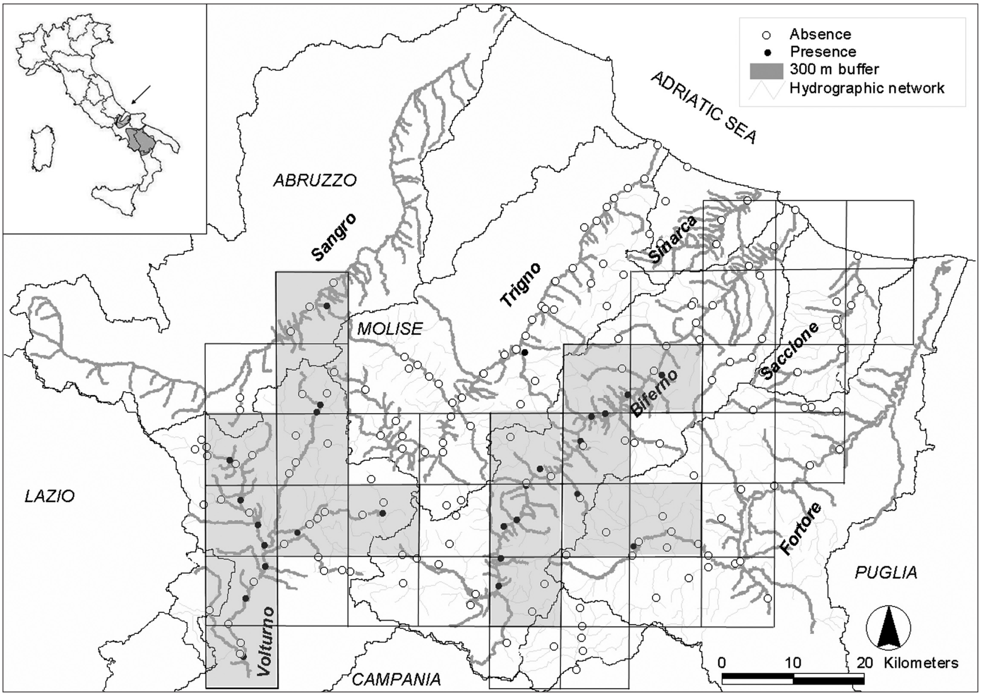


**Fig. 2**. Map of the study area with the seven river catchments. Only the southern tributaries of the river Trigno and Sangro were considered, as the standard survey was limited to the river basins of the Molise region (see text). The map also shows the UTM grid cells of 10x10 km used to validate the HS model. Shadowed cells indicate otter presence. The white circles report negative otter sites, while the black ones report positive otter sites (Loy et al. 2004).

As availability of water represents a main ecological factor affecting otter occurrence (Beja 1992, Prenda et al. 2001, Bonesi & Macdonald 2004, Kruuk 2006) the model was developed on those river stretches that were likely to have water all year round. Main river courses and first and second order tributaries were selected from the national hydrographical network (1:250 000 map obtained from the national environmental agency, ISPRA) and included in the model. Spatial information on the distribution of the otter's resources and disturbance factors was derived from existing digital maps. However, for the "bankside fine scale land cover" variable, a specific spatial data set was developed. Each variable was inserted into a G.I.S. system as a different layer and all categories within each variable were reclassified according to their suitability for otters (Appendix and Fig. 3). More specifically, the following variables were considered:

**Bankside fine scale land cover** (1:5 000). Many studies have found relationships between the number of otter signs and bank side cover (Jenkins & Burrows 1980, Macdonald & Mason 1982, 1985, 1988, Bas et al. 1984, Adrian 1985, Prauser 1985, Delibes et al. 1991). As this parameter is not detectable from the usual coarser CORINE land cover maps, data were obtained by digitising land cover categories derived from aerial photos taken in 2005 and considered at a resolution of 20 m. This variable was considered on a 300 m large buffer around the water course. The categories used were those of the CORINE land cover classification scheme at the third level of detail (European Commission 1993). The procedure of assessing land cover from aerial photos at a scale of 1:5 000 allowed us to gain a good representation of the riparian vegetation on and around the river banks. The role of riparian vegetation was then considered according to its use in providing breeding dens, enhancing the filtering of pollutants and promoting fish productivity (Jenkins & Burrows 1980, Green et al. 1984, Macdonald & Mason 1994, Rader 1997, Morrow & Fischenich 2000). The CORINE land cover categories were then re-classified accordingly (Appendix – layer 1 in Fig. 3).

**Bank slope**. A slope layer was derived from the Digital Elevation Model at a resolution of 20 x 20 m. Cells within the buffer area with a slope of 70° or more were considered as evidence of rock cliffs, potentially providing good sites for resting and breeding dens (Chanin 2003), and were classified as highly suitable (Appendix – layer 1 in Fig. 3).

**Altitude**. This variable is important because otters are rarely found above 2000 m a.s.l., probably due to the scarcity of food available at high altitudes (Ruiz-Olmo 1998, Kruuk 2006). We used the 20 m resolution Digital Elevation Model to classify the area into four altitudinal ranges of decreasing suitability (Appendix), producing a new layer (layer 2 in Fig. 3).

**Human density**. This variable can potentially affect the presence of otters negatively (Barbosa et al. 2001, Chanin 2003) and was derived by considering the density of people in each municipality within a buffer of 1 km surrounding the river (Appendix – layer 4 in Fig. 3).

**Coarse scale extra-riparian CORINE land cover** (1:100 000 map, year 2000). Extra-riparian disturbance was considered within a buffer of 1 km surrounding the river. The presence of land types such as urban settlements and intensive agricultural areas were considered to have a potentially negative affect on the presence of otters (Barbosa et al. 2001, Boitani et al. 2002). Land cover maps were rasterized to 1 x 1 km grid cells and reclassified according to presence/absence of a negative effect (Appendix – layer 4 in Fig. 3).

All GIS layers described above and saved in a raster format at a resolution of 20 x 20 m were then integrated following the scheme presented in Fig. 3 to produce the final layer of habitat suitability for the otter. First of all, the bank slope layer was overlapped to the bank side fine scale land cover layer. Cells with bank slopes which were steeper than 70° were given a high suitability value (three). When a cell had a bank-slope value of three, this figure was retained irrespective of the value of the bank side fine scale land cover, to take into account the fact that when rock cliffs are present the surrounding land cover matrix may have little influence on otter presence. The resulting layer was characterized by 20 x 20 cells with HS integer values ranging between zero and three (layer 1). This layer was then combined with the altitude layer (layer 2) to produce four synthetic suitability classes ranked between zero (not suitable) and three (most suitable) through a logical overlay operation. This operation assigned a suitability class value to each 20 m cell by choosing the lowest value between those of the two input layers (1 and 2). The new layer (layer 3) so created was also made of integer numbers ranging between zero and three (Fig. 3). Human disturbance was then taken into consideration by subtracting values of 0.25 or 0.50 from this new layer if, respectively, one or both disturbance factors (human density and unfavourable land cover) were present (layer 4). If no disturbance was present, the layer retained its original value. The maximum number of final suitability classes resulting from this procedure was ten, ranging in values from zero (unsuitable) to three (high suitable) (Fig. 3) and these values were assigned to each 20 x 20 m cell within a buffer of 300 m surrounding the river.

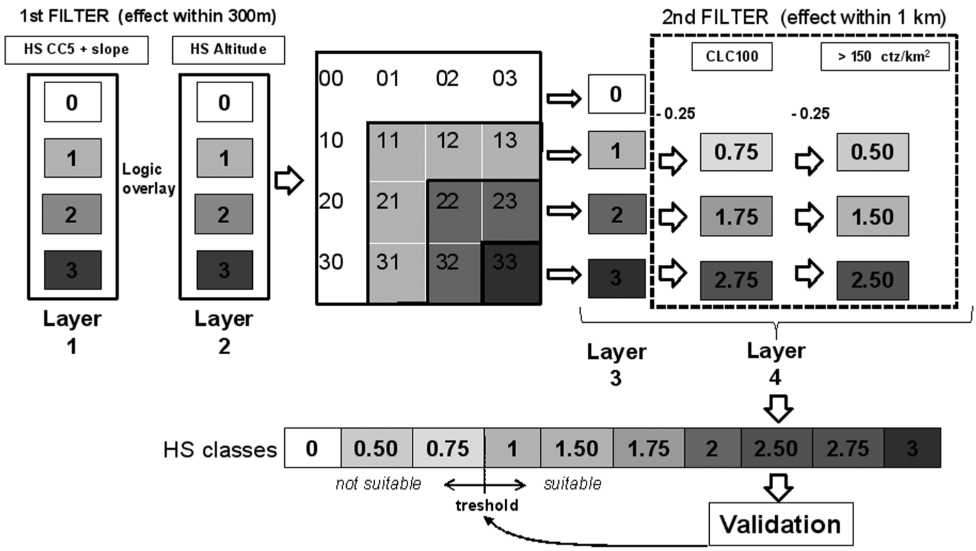


**Fig. 3**. Flow chart of the procedure used to create the 10 HS suitability classes. The first number in each cell of the square matrix in the middle represents layer 1, while the second number represents layer 2. The dotted square on the right represents the process of subtracting human disturbance (human density and land cover derived from the CORINE 1:100 000) from layer 3.

## Habitat Suitability Model validation

Validation of the HS map resulting from the application of the model described above was performed using available data on the presence and absence of otters in the area derived from a standard otter survey (Loy et al. 2004). Otter presence/absence was reported in UTM grid cells of 10 x 10 km, considering only the river basins of current otter occupancy, for a total 42 UTM grid cells (Fig. 2). The river Trigno was excluded from the validation analyses as it was the furthest away from areas with otter presence. Hence, it is likely that the absence of otters along this river is due to the fact the species has yet to arrive there rather than to the characteristics of the river. The UTM grid cells were classified as positive (17 out of 42) if they contained at least one positive site where otter signs (spraints or footprints) had been recorded. Both presence and absence data were considered for the validation of the model. It must be stressed that absence data obtained for this species using the standard surveys are considered to be more reliable than for other species for which absence is more likely to mean non detection (Reuther et al. 2000). The percentage of the 300m buffer around the river covered by each of the ten suitability classes was computed within each UTM grid cell of 10 x 10 km. The percentage area covered by each HS class was then compared between 10 x 10 km UTM grid cells which were positive or negative for otters through a non parametric Mann–Whitney U-test.

Accuracy of the model was then tested through a sensitivity analysis for HS classes showing significant differences either for presence or absence of otter signs. Sensitivity analysis was performed by applying the ROC (Receiver Operating Characteristics) technique (Fielding & Bell 1977, Swets 1998, Manel et al. 1999, Greiner et al. 2000, Osborne et al. 2001). The suitability classes that successfully passed the test were used to define a threshold between two large categories of suitable and not suitable habitats.

Connectivity analysis

Otter habitats tends to develop along linear features of the landscape, namely the hydrographical systems (Philcox et al. 1999, Kruuk 2006). Analyses examining the connectivity of the landscape along linear features such as rivers are relatively new (Bennett 1999, Wiens 2002, Schick & Lindley 2007) and pose some specific problems in that both longitudinal and lateral connectivity must be evaluated (van Langevelde et al. 1998). Longitudinal connectivity refers to otters moving within one river system, while lateral connectivity refers to dispersal movements toward neighbouring rivers, which contribute to range expansion and the maintenance of gene flow among populations living in different river basins. As river catchments can be considered as closed systems, the longitudinal connectivity can be simply evaluated through the distribution of suitable habitat patches, while the lateral connectivity must also consider the resistance (permeability) of the land matrix to dispersal by otters between catchments (Schumaker 1996, Tischendorf 2001).

**Longitudinal connectivity** along rivers was analysed by summarising two classical spatial pattern statistics of suitable habitat distribution (McGarigal & Marks 1995, McGarigal et al. 2002). More specifically, the extension and fragmentation of suitable patches, as identified by the HS model, within the 300 m buffer along rivers were evaluated through the number of patches (NUMPs) and the mean patch size (MPSs). These parameters were evaluated considering the mean distance covered by an otter during its daily movements in Italian river catchments, which was respectively 10 km for males and 6 km for females (Di Marzio 2004).

**Lateral connectivity** was assessed by evaluating the resistance of the land matrix between neighbouring catchments to otter movements, i.e. dispersal. The following layers of the land matrix were considered to be relevant in evaluating resistance to otter dispersal: slope, land cover, altitude, human density and road networks (Philcox et al. 1999, Janssens et al. 2006). The analysis was performed within the region Molise area, for which all GIS layers were available. Source of data for slope, altitude and land cover were the same as those specified for the HS model; road networks were derived from a 1:250 000 digital map of the National Environmental Agency (ISPRA). Specifically, slopes were considered to be impermeable when greater than 45° (Cortés et al. 1998, Saavedra & Sargatal 1998, Saavedra 2002, Janssens et al. 2006); altitude, CORINE land cover map at scale 1:100 000, and roads were reclassified for permeability as listed in Appendix. All the reclassified layers were then rasterized at a resolution of 20 x 20 m. The logical overlay of the considered layers allowed the identification of areas which were permeable to otter dispersal between catchments. A group of contiguous 20-meter permeable cells formed a permeable patch. The efficacy of each permeable patch was analysed considering its extension and the number of river tributaries connected within it. To this aim, we considered the whole hydrographical network at a resolution of 1:250 000 (source ISPRA), rather than only the main course and main tributaries as in the HS model.

## Results

HS model results and validation

Of all the ten HS classes resulting from the HS model, only three held sufficient data for the validation analysis (Fig. 4). The Mann–Whitney U-tests revealed significant differences

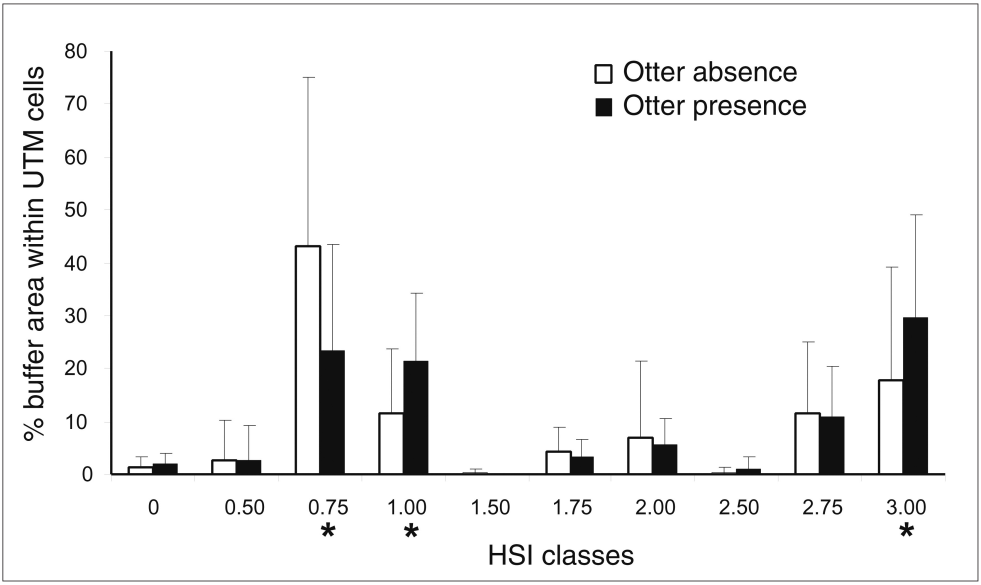


**Fig. 4**. Mean and SD of suitable (filled bars) and unsuitable (empty bars) areas computed for HS classes within each UTM cell shown in Fig. 2. Asterisks indicate HS classes showing significant differences between presence-absence UTM cells (Mann-Withney U, p < 0.05).

between positive and negative UTM cells for the HS classes with values of 0.75, 1 and 3 ($p < 0.05$ for all pairwise comparisons). HS classes 1 and 3 were found to be significantly associated with the presence of otters, while the 0.75 class was significantly associated with their absence. No significant difference was reported for the other HS categories, which is probably due to their small sample size.

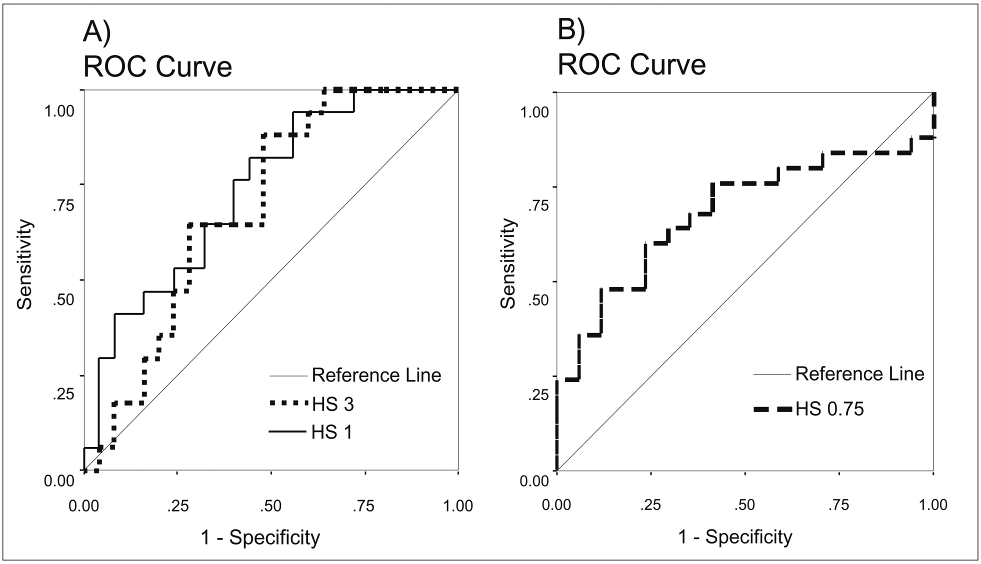


**Fig. 5**. A – ROC plot for the HS values 1 and 3, testing the accuracy to predict the presence of otters. B – ROC plot for the HS value 0.75, testing the accuracy to predict the absence of otters.

The three significant HS classes with values of 0.75, 1 and 3 were subjected to a sensitivity analysis using ROC curves. For HS class 1 and 3, the Area Under the ROC Curve (AUC) had, respectively, the values of 0.74 and 0.69, suggesting that they were able to discriminate the presence of otters relatively well (Fig. 5A). The ROC plot to test for the sensitivity of the HS class 0.75 was used to evaluate its ability to predict otter absence, rather than presence (Fig. 5B). Also in this case, an AUC value of 0.68 suggested a good probability of a correct prediction.

Based on the above results, we considered 0.75 as a threshold value and a new HS map was hence produced by reclassifying all 20 x 20 m cells as non-suitable or suitable, according to whether they were, respectively, above or below this HS value (Fig. 6).

The river Biferno, followed by the river Sangro, Trigno and Volturno were identified by the HS model as the ones with the highest suitability for otters (Figs. 6 and 7). Suitable areas were concentrated in the upper and medium course of the rivers, while the lower plains were generally unsuitable for otters. A small concentration of suitable areas was also found in the upper river Fortore, where scattered otter signs were found, whilst its lower course and the whole course of the rivers Sinarca and Saccione were classified as unsuitable for otters.

### Connectivity analysis

The analysis of the distribution and extension of suitable patches along rivers (longitudinal connectivity) indicated that the river Volturno had the best connectivity having the largest extension of suitable patches and the most connected patches (Fig. 7). The rivers Biferno, Trigno and Sangro had also, overall, a relatively large extension of suitable patches, but their distribution was quite different from the suitable patches on the Volturno. Indeed, on these three rivers suitable patches tended to be numerous but highly fragmented.

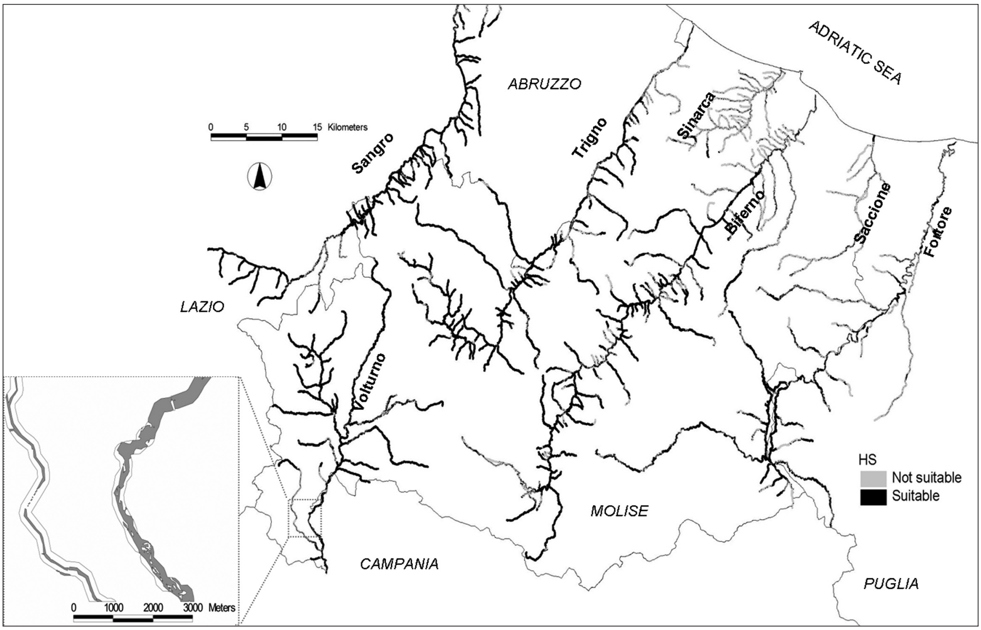


**Fig. 6**. Map showing the distribution of suitable (HS ≥1) and unsuitable (HS < 1) habitat patches for the seven river catchments of the study area.

The map in Fig. 8 reports the results for lateral connectivity and highlights a concentration of areas of the land matrix that are likely to be permeable to otter movements located between the upper river Volturno and the river Sangro, Trigno and Biferno, whilst permeable areas between the other catchments are less extended and more fragmented. The high permeability around the upper reaches of the Volturno probably allowed the recent otter expansion to the Sangro river basin (De Castro & Loy 2007), and will likely lead to the recolonization of the river Trigno in the short term.

## Discussion

The fine scale HS model adopted in this study was well able to discriminate between areas with and without signs of otters for the subpopulation living in the northern portion of the

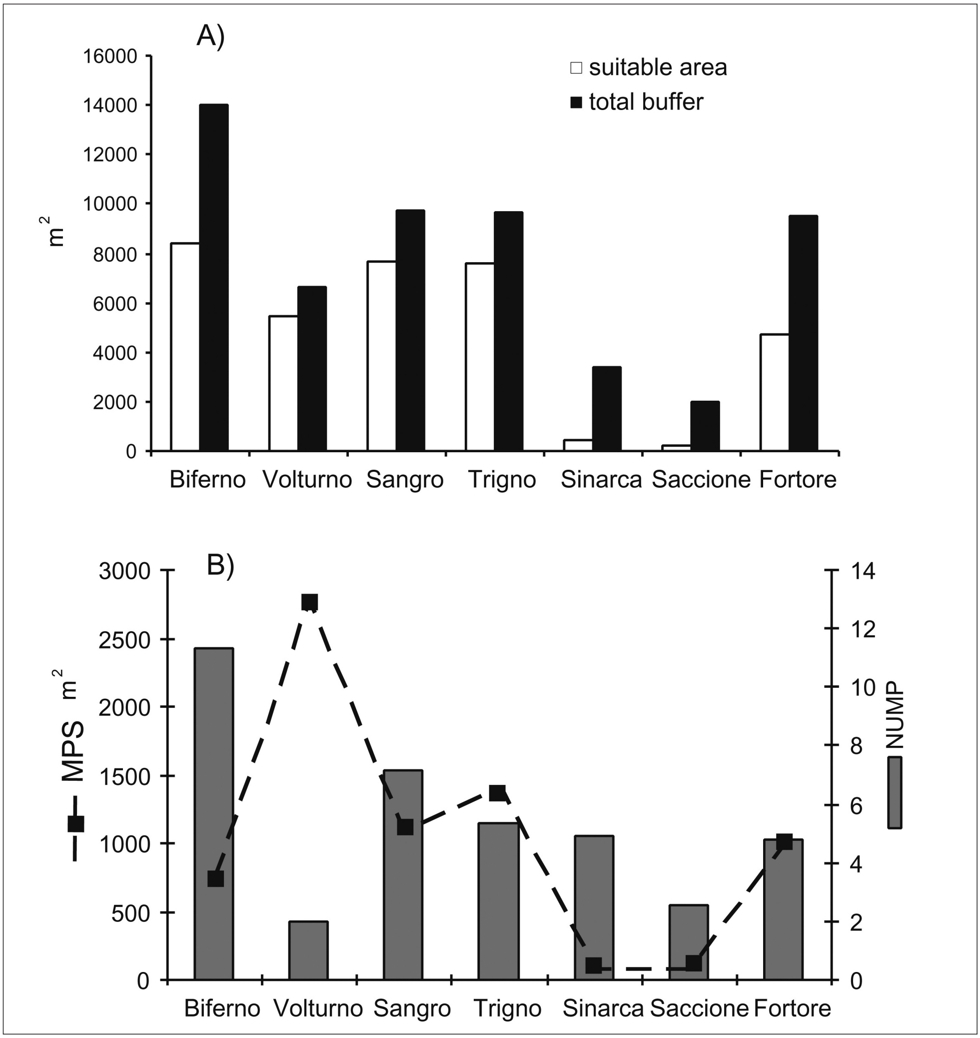


**Fig. 7**. A – Comparison of the total buffer extension and total surface of suitable habitat for each river basin. B – Mean size (MPS) and number (NUMP) of suitable patches for the same river basins.

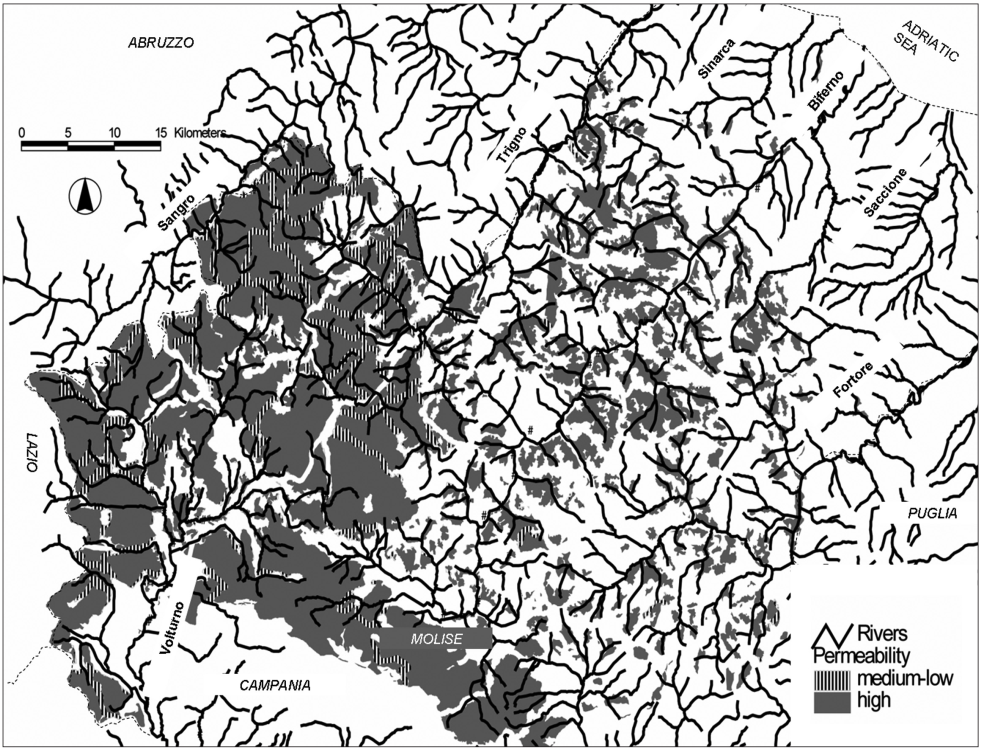


**Fig. 8**. Results of the lateral connectivity analysis for the river catchments within the region Molise. Patches are shaded according to the degree of permeability to otter moving across the watersheds.

Italian otter range, suggesting that riparian vegetation cover (fine scale land cover), bank slope, altitude, and human disturbance (human density and extra-riparian land use) can be useful factors for assessing the probability of otter presence or absence in an area.

Riparian vegetation may be important for otters for several different reasons: it provides resting and breeding dens, provides cover during movements, enhances filtering of pollutants, and promotes fish productivity (Jenkins & Burrows 1980, Green et al. 1984, Macdonald & Mason 1994, Rader 1997, Morrow & Fischenich 2000). It is possible that in Italy vegetation cover may play a particularly important role in protecting the animals from human and human-related disturbance. Indeed, human disturbance is likely to be particularly important in constraining the distribution of otters in southern and central Italy because otters are still illegally killed (Laura Bonesi, unpublished data), rivers are often surrounded by areas with a relatively high human population density, and feral dogs, that are known to be a threat to otters (Marjana Hönigsfeld, pers.obs.), are often present. While these threats are still also common in other Mediterranean countries (e.g. Robitaille & Laurance 2002), all or most of them are often absent from areas or countries, like for example the UK, where otters are known to live along rivers with scarce or absent riparian vegetation and which even frequent urban environments (Crawford 2003). Similarly to riparian vegetation, steep rocky banks, which are taken into account in the model with the variable "bank slope", may be important as they provide protection from disturbance because they are not easily accessible overland by both humans and dogs. Ruiz-Olmo et al. (2005) in their study of female otters with cubs in northeast Spain also found that otters, in particular older cubs, tended to be concentrated around areas which were well protected by steep rocky cliffs. Finally, altitude may play a role as usually the upper reaches of the streams that are found at higher altitudes tend to host a less diverse community of fish and fish biomass is less abundant (Ruiz-Olmo 1998). Compared to other HS models developed for otters (Ottino et al. 1995, Prigioni 1995, Prenda & Granado-Lorencio 1996, Antonucci 2000, Barbosa et al. 2001, Reggiani et al. 2001, Boitani et al. 2002), our model was based on a much finer scale as it considered habitat variables at a resolution of 20 x 20 m. We think that working at this fine scale resolution may provide a management tool that allows an accurate identification of specific sites along rivers which could benefit from special protection or from specific improvements that may favour the otter. The model of matrix permeability was able to identify overland areas where corridors which would favour otter dispersal are more likely to occur within and between catchments, thus offering a tool for the management of the extra-riparian landscape for otter conservation. The identification of suitable habitat patches for otters within rivers, along with the assessment of the permeability of the land matrix to dispersal, provide a general framework to interpret the otter's movements within and between river basins and to make an assessment of each catchment in terms of its ability to host source or sink populations. Among all the seven catchment considered, one river in particular (the river Volturno), where otters are currently present, showed one of the largest extensions of suitable habitats and the best connectivity both within the river and between the river and the neighbouring catchments. These evidences suggest that this river could play a strategic role in the survival and expansion of otters in the surrounding areas, and in the joining of the two isolated portions of otter range.

In fact, otters at present occur in two portions of this river basin, the upper Volturno in the south central range, and one of its tributary in the southern range (Panzacchi et al. 2009). Thus the colonization of the medium course of this river will likely allow the joining of the two ranges in the short-medium term.

In spite of the ability of the HS model to predict relatively well presence and absence of otters at a 10 x 10 km resolution, there are, however, a number of limitations to our model. First of all, the model is based on the distribution of spraints and not on the distribution of the actual animals, but there are two factors that may mitigate this limitation. First, in otters, spraints are likely to be used to signal the use of resources such as food and dens, rather than reproductive status or aggressive encounters, at least when they live in groups such as on the Shetland coast (Kruuk 1992). In freshwater areas, otters live at lower densities than in coastal areas and tend to be more solitary, although their home ranges may still overlap, especially between males and females (Kruuk 2006). If in freshwater areas, spraints are also used to signal the use of resources. Therefore the distribution of spraints may be considered as an acceptable surrogate for the distribution of otters in HS models which consider variables that are directly linked to the use of resources or disturbance, such as ours. Second, to validate the model, we considered a spatial scale of 10 x 10 km, which is in the order of magnitude of an otter's home range, i.e. 10–20 km (Antonucci 2000). Probably due to the fact that we considered relatively large validation cells of 10 x 10 km and a relatively large study area with enough variability, the use of spraints as surrogates for otter distribution was not particularly limiting because the suitability of a relatively large area around the 600 m sites with signs of otters was considered.

Another limitation to our model was that we were unable to take into account one of the most important resources for otters: fish availability (Kruuk et al. 1993, Jeņdrzejewska et al. 2001, Lanszki & Sallai 2006). Reliable data on fish community composition and biomass are difficult to obtain over large areas. Moreover, translating these data into actual availability of fish for otters is a further obstacle. However, for five of the seven catchments considered in this study (Sangro, Biferno, Volturno, Fortore and Trigno) data on fish biomass collected at 54 sampling stations (Regione Molise 2004) were available (Loy et al. 2008). On average, a fish biomass of 13.08 gr/$m^2$ was registered across these five catchments (range: 0.01–98.60 g/$m^2$, SD = 4.08, n = 54 sampling stations). Kruuk et al. (1993) demonstrated that otters could successfully exploit oligotrophic streams populated mainly by salmonids with fish biomass between 9 and 14 g/$m^2$, while Ruiz-Olmo (1998) noted that otters were present at sites with biomass values of 10–20 g/$m^2$. Taking all studies that relate otter distribution with fish biomass into consideration, Chanin (2003) proposed that, as a rule of thumb, otter populations can survive and breed where fish biomass exceeds 10 g/$m^2$. Therefore, the values that are reported for five of the seven catchments considered in this study would seem to be sufficient, on average, to support a population of otters. It was, however, not possible to incorporate these values into the model because of the relative scarcity of sampling stations for fish biomass relative to the whole study area.

The application of the HS model to the six catchments (the Trigno was excluded) resulted in only three of the ten HS classes being significantly related to the presence-absence of the species. This is probably due mainly to the fact that only these three classes were significantly represented in our sample, all the other classes being found at a relatively low frequency.

The planned extension of this approach to study the southern Italian subpopulation, together with the development of an inferential approach and the implementation of more sophisticated algorithms for longitudinal and lateral connectivity analysis, currently in progress, will probably help to improve the prediction ability of the HS and connectivity models and to offer better insights into the areas of potential range expansion of otters in Italy and into the likelihood that the two subpopulations will become connected in the future.

Acknowledgements

We'd like to specially thank two anonymous reviewers for their extensive revision and fruitful comments that highly improved the first draft of this manuscript. We are also grateful to Marco Ottaviano for his constant and generous support with G.I.S. techniques. This work is part of the project 'Rete ecologica della lontra – Fase 1' funded by the Italian Ministry of Environment MATTM - Ministero dell'Ambiente, del Territorio e del Mare to Anna Loy. Laura Bonesi was sponsored by the program 'Incentivazione alla mobilità di studiosi stranieri e italiani residenti all'estero'.

## LITERATURE

Adrian M.I. 1985: Otter distribution and agriculture in southwestern Spain. *Trans. Int. Union Game Biol. 7: 519–526.*

Antonucci A. 2000: Analisi ambientale per un rilascio sperimentale della lontra (*Lutra lutra* L.) nel bacino idrografico Aterno Pescara. *Thesis, Università degli studi dell'Aquila.*

Barbosa A.M., Real R., Marquez A.L. & Rendon M.A. 2001: Spatial, environmental e human influences on the distribution of otter (*Lutra lutra*) in the Spanish Provinces. *Divers. Distrib. 7: 137–144.*

Bas N., Jenkins D. & Rothery P. 1984: Ecology of otters in northern Scotland. V. The distribution of otter *Lutra lutra* faeces in relation to bankside vegetation on the River Dee in summer 1981. *J. Appl. Ecol. 21: 507–513.*

Beja P.R. 1992: Effects of freshwater availability on the summer distribution of otters *Lutra lutra* in the southwest coast of Portugal. *Ecography 15: 273–278.*

Bennett A.F. 1999: Linkages in the landscapes. The role of corridors and connectivity in wildlife conservation. *IUCN, Gland.*

Boitani L., Corsi F., Falcucci A., Maiorano L., Marzetti I., Masi M., Montemaggiori A., Ottaviani D., Reggiani G. & Rondinini C. 2002: Rete Ecologica Nazionale. Un approccio alla conservazione dei vertebrati italiani. *Università di Roma "La Sapienza", Dipartimento di Biologia Animale e dell'Uomo; Ministero dell'Ambiente, Direzione per la Conservazione della Natura; Istituto di Ecologia Applicata. http://www.gisbau.uniroma1.it/REN*

Bonesi L. & Macdonald D.W 2004: Differential habitat use promotes sustainable coexistence between the specialist otter and the generalist mink. *Oikos 106: 509–519.*

Bulgarini F., Calvario E., Fraticelli F., Petretti F. & Sarrocco S. 1998: Libro rosso degli animali d'Italia. Vertebrati. *WWF Italia, Roma.*

Cagnolaro L., Rosso D., Spagnesi M. & Venturi B. 1975: Inchiesta sulla distribuzione della lontra (*Lutra lutra*) in Italia nei cantoni Ticino e Grigioni (Svizzera) 1971 – 1973. *Ric. Biol. Selv 63: 1120.*

Chanin P.R.F. 2003: Ecology of the Eurasian otter. *Conserving Natura 2000 Sites Rivers Ecology Series N° 10. English Nature, Peterborough.*

Clevenger A.P., Wierzchowski J., Chruszcz B. & Gunson K. 2002: Gis-generated, expert-based models for identifyng wildlife habitat linkages and planning mitigation passages. *Conserv. Biol. 16: 503–514.*

Conroy J.W.H. & Chanin P.F. 2000: The status of the Eurasian otter (*Lutra lutra*) in Europe – A review. In: Conroy J.W.H., Yoxon P. & Gutleb A.C. (eds.), Proceedings of the first otter toxicology conference, Isle of Skye, September 2000. *Journal of the International Otter Survival Fund No 1: 7–28.*

Cortés Y., Fernandez-Salvador R., Garcia F.J., Virgos E. & Llorente M. 1998: Changes in otter *Lutra lutra* distribution in Central Spain in the 1964-1995 period. *Biol. Conserv. 86: 179–183.*

Crawford A. 2003: Fourth otter survey of England 2000-2002. *Environment Agency, Bristol.*

De Castro G. & Loy A. 2007: Un nuovo censimento della lontra (*Lutra lutra*, Carnivora, Mammalia) nel fiume Sangro (Abruzzo): inizia la ricolonizzazione dell'Italia centrale? *68° Convegno Unione Zoologica Italiana, Lecce, 23-25 Settembre 2007. Abstract Volume*: *105.*

Delibes M., MacDonald S.M. & Mason C.F. 1991: Seasonal marking, habitat and organochlorine contamination in otters (*Lutra lutra*): a comparison between catchments in Andalucia and Wales. *Mammalia 55: 567–578.*

Di Marzio M. 2004: Rilascio sperimentale di lontra europea (*Lutra lutra* L.) nel bacino idrografico Aterno-Pescara: analisi ecologica ed eto-biologica mediante tecniche radiotelemetriche. *Thesis, Università degli Studi dell'Aquila - Facoltà di Scienze MM.FF.NN.*

European Commission 1993: CORINE Land Cover Guide technique. *CECA-CEE-CEEA. Bruxelles.*

Fielding A.H. & Bell J.F. 1977: A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environ. Conserv. 24: 38–49.*

Fusillo R., Marcelli M. & Boitani L. 2004: Progetto di ricerca sulla ecologia della lontra nel Parco Nazionale del Cilento e Vallo di Diano. Relazione delle attività di ricerca. AA 2003-2004. *Università degli Studi di Roma "La Sapienza", Parco Nazionale del Cilento e Vallo di Diano.*

Fusillo R., Marcelli M. & Boitani L. 2007: Survey of an otter *Lutra lutra* population in Southern Italy: site occupancy and influence of sampling season on species detection. *Acta Theriol. 52: 251–260.*

Green J., Green R. & Jefferies D.J. 1984: A radio-tracking survey of otters *Lutra lutra* on a Perthshire river system. *Lutra 27: 85–145.*

Greiner M., Pfeiffer D. & Smith R.D. 2000: Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests. *Prev. Vet. Med. 45: 23–41.*

Janssens X., Defourny P., de Kermabon J. & Baret P.V. 2006: The recovery of otter in the Cevennes (France): a GIS-based model. *Hystrix It. J. Mammal. 17: 5–14.*

Jason W.K, Leona K.S., Heglund P.J., Wright M.N. & Scott J.M. 2002: Species commonness and the accuracy of habitat-relationship models. In: Raven P.H., Scott J.M., Heglund P.J., Morrison M.L. et al. (eds.), Predicting species occurrences: Issues of accuracy and scale. *Island Press, Washington: 573–580.*

Jenkins D. & Burrows G.O. 1980: Ecology of otters in northern Scotland. 3. The use of faeces as indicators of otter (*Lutra lutra*) density and distribution. *J. Anim. Ecol. 49: 755–774.*

Jeņdrzejewska B., Sidorovich V.E., Pikulik M.M. & Jeņdrzejewski W. 2001: Feeding habits of the otter and American mink in Białowieża Primeval Forest (Poland) compared to other Eurasian populations. *Ecography 24: 165–180.*

Kruuk H. 1992: Scent marking by otters (*Lutra lutra*): signalling the use of resources. *Behav. Ecol. 3: 133–140.*

Kruuk H. 2006: Otters ecology, behaviour and conservation. 2 ed. *Oxford University Press, Oxford*.
Kruuk H., Carss D.N., Conroy J.W.H. & Durbin L. 1993: Otter (*Lutra lutra*) numbers and fish productivity in rivers in North-East Scotland. *Symp. Zool. Soc. London 65: 171–191*.
Lanszki J. & Sallai Z. 2006: Comparison of the feeding habits of Eurasian otters on a fast flowing river and its backwater habitats. *Mamm. Biol. 71: 336–346*.
Loy A., Bucci L., Carranza M.L., De Castro G., Di Marzio P. & Reggiani G. 2009: Survey and habitat evaluation for a peripheral population of the Eurasian otter in Italy. *IUCN Otter Specialist Group Bulletin 2004. In press*.
Loy A., Bonesi L., Carranza M.L., Celico F., Cianfrani C., Ciccorelli G., Cimino F., D'Alessandro E., Di Marzio P., Di Martino P., Minotti M. & Reggiani G. 2008: Rete ecologica per la lontra - Fase 1. Rapporto finale. *Dipartimento Scienze e Tecnologie per l'Ambiente e il Territorio Università del Molise e Ministero dell'Ambiente e della Tutela del Territorio e del Mare*.
Macdonald S.M. & Mason C.F. 1982: The otter *Lutra lutra* in Central Portugal. *Biol. Conserv. 22: 207–215*.
Macdonald S.M. & Mason C.F. 1985: Otters, their habitat and conservation in Northeast Greece. *Biol. Conserv. 31: 191–210*.
Macdonald S.M. & Mason C.F. 1988: Observations on an otter population in decline. *Acta Theriol. 33: 415–434*.
Macdonald S.M. & Mason C.F. 1994: Status and conservation needs for the otter in the western Palearctic. *Council of Europe Press, Nature and Environment 67: 1–54*.
Madsen A.B. & Prang A. 2001: Habitat factors and the presence or absence of otters *Lutra lutra* in Denmark. *Acta Theriol. 46: 171–179*.
Manel S., Dias J.-M. & Ormerod S.J. 1999: Comparing discriminant analysis, neural networks and logistic regression for predicting species distributions: a case study with a Himalayan river bird. *Ecol. Model. 120: 337–347*.
Mason C.F. 1989: Water pollution and otter distribution: a review. *Lutra 32: 97–131*.
Mason C.F. & Macdonald S.M. 1986: Otters. Ecology and conservation. *Cambridge University Press, Cambridge*.
Mason C.F. & Macdonald S.M. 2004: Growth in otter (*Lutra lutra*) populations in the UK as shown by long-term monitoring. *Ambio 33: 148–152*.
McGarigal K. & Marks B.J. 1995: FRAGSTATS: Spatial analysis program for quantifying landscape structure. *USDA Forest Service General Technical Report PNW-GTR-351*.
McGarigal K., Cushman S.A., Neel M.C. & Ene E. 2002: Fragstats: spatial pattern analysis program for categorical maps. *University of Massachusetts, Amherst*.
Morrow J.V. & Fischenich C. 2000: Habitat requirements for freshwater fishes. *EMRRP technical note collection (ERDC TN-EMRRP-SR-06), U.S. Army Engineer Research and Development Center, Vicksburg*.
Osborne P.E., Alonso J.C. & Ryan R.G. 2001: Modelling landscape scale habitat use using GIS and remote sensing: a case study with great bustards. *J. Appl. Ecol. 38: 458–471*.
Ottaviani D., Jona Lasinio G. & Boitani L. 2004: Two statistical methods to validate habitat suitability models using presence-only data. *Ecol. Model. 179: 417–443*.
Ottino P., Prigioni C. & Vigna Tagliani A. 1995: Habitat suitability for the otter (*Lutra lutra*) of some rivers of Abruzzo Region (Central Italy). *Hystrix 7: 265–268*.
Pacyna G.M. 1999: Environmental cycling of selected persistent organic pollutants (POPs) in the Baltic region. *Technical report of Environmental and climate research programme N° ENV4-CT96-0214*.
Panzacchi M., Genovesi P. & Loy A. (eds.) 2009: Piano d'azione per la conservazione della lontra. *Ministero per la Tutela dell'Ambiente, del Territorio e del Mare e Instituto Nazionale per la Fauna Selvatica*.
Philcox C.K., Grogan A.L. & Macdonald D.W. 1999: Patterns of otter *Lutra lutra* road mortality in Britain. *J. Appl. Ecol. 36: 748–762*.
Prauser N. 1985: Vorkommen von Fischottern (*Lutra lutra* L. 1758) und ihre Abhängigkeit von der Struktur verschiedener Habitat-Zonen der Wümme-Niedersacsen. *Z. Angew. Zool. 72: 83–91*.
Prenda J. & Granado-Lorencio C. 1996: The relative influence of riparian habitat structure e fish availability on otter *Lutra lutra* L. – sprainting activity in a small Mediterranean catchment. *Biol. Conserv. 76: 9–15*.
Prenda J., Lopez-Nieves P. & Bravo R. 2001: Conservation of otter (*Lutra lutra*) in a Mediterranean area: the importance of habitat quality e temporal variation in water availability. *Aquat. Conserv. 11: 343–355*.
Prigioni C. 1995: Guidelines fo the feasibility study of reintroduction of the otter *Lutra lutra* in Italy. The project of the Ticino valley. *Hystrix, It. J. Mamm. (N.S.) 7: 255–264*.
Prigioni C., Remonti L., Balestrieri A. & Sgrosso S. 2006a: Estimation of European otter (*Lutra lutra*) population size by fecal DNA typing in southern Italy. *J. Mamm. 87: 855–858*.

Prigioni C., Remonti L., Balestrieri A., Sgrosso S. & Priore G. 2006b: How many otters are there in Italy? *Hystrix, It. J. Mamm. (N.S.) 17: 29–36.*
Prigioni C., Balestrieri A. & Remonti L. 2007: Decline and recovery in otter *Lutra lutra* populations in Italy. *Mamm. Rev. 37: 71–79.*
Rader R.B. 1997: A functional classification of the drift: traits that influence invertebrate availability to salmonids. *Can. J. Fish. Aquat. Sci. 54: 1211–1234.*
Randi E., Davoli F., Pierpaoli M., Pertoldi C., Madsen A.B. & Loeschcke V. 2003: Genetic structure in otter (*Lutra lutra*) populations in Europe: implications for conservation. *Anim. Conserv. 6: 93–100.*
Regione Molise - Assessorato Caccia e Pesca 2004: Carta Ittica Regionale. *Regione Molise. Settore Caccia e Pesca, Campobasso.*
Reggiani G., Pittiglio C., Zini R., Marconato E., Bianco P.G. & Boitani L. 2001: La lontra nella provincia di Grosseto: presenza attuale ed idoneità ambientale. *Abstract. III Convegno SMAMP La lontra in Italia: distribuzione, censimenti e tutela. Montella (AV), 30 Nov-2 Dic Dryocopus IV.*
Reuther C., Dolch D., Green R., Jahrl J., Jefferies D., Krekemeyer A., Kucerova M., Bo Madsen A., Romanowsky J., Roche K., Ruiz-Olmo J., Teubner J. & Trindade A. 2000: Surveying and monitoring distribution and population trends of the Eurasian otter (*Lutra lutra*). *Habitat, Band 12.*
Robitaille J.F. & Laurence S. 2002: Otter, *Lutra lutra*, occurrence in Europe and France in relation to landscape characteristics. *Anim. Conserv. 5: 337–344.*
Romanowski J. 2006: Monitoring of the Otter recolonisation of Poland. *Hystrix, It. J. Mamm. (N.S.) 17: 37–46.*
Roos A., Greyers E., Olsson M. & Sandegren F. 2001: The otter (*Lutra lutra*) in Sweden – population trends in relation to DDT and total PCB concentrations during 1968-99. *Environ. Pollut. 111: 457–469.*
Ruiz-Olmo J. 1998: Influence of altitude on the distribution, abundance and ecology of the otter (*Lutra lutra*). *Symp. Zool Soc. Lond. 71: 159–178.*
Ruiz-Olmo J., Margalida A. & Batet A. 2005: Use of small patches by Eurasian otter (*Lutra lutra* L.) females and cubs during the pre-dispersal period. *J. Zool. 265: 339–346.*
Ruiz-Olmo J., Loy A., Cianfrani C., Yoxon P., Yoxon G., de Silva P.K., Roos A., Bisther M., Hájková P. & Zemanová B. 2008: *Lutra lutra*. In: IUCN 2009. IUCN Red List of Threatened Species. Version 2009.1. *<www.iucnredlist.org> Downloaded on 21 September 2009.*
Saavedra D. 2002: Reintroduction of the Eurasian otter (*Lutra lutra)* in Muga and Fluvia basins (north-eastern Spain): viability, development, monitoring and trends of the new population. *Ph. D. Thesis, Universitat de Girona.*
Saavedra D. & Sargatal J. 1998: Reintroduction of the otter (Lutra lutra) in northeast Spain (Girona province). *Galemys 10: 191–199.*
Schick R.S. & Lindley S.T. 2007: Directed connectivity among fish populations in a riverine network. *J. Appl. Ecol. 44: 1116–1126.*
Schumaker N.H. 1996: Using landscape indices to predict habitat connectivity. *Ecology 77: 1210–1225.*
Swets J.A. 1988: Measuring the accuracy of diagnostic systems. *Science 240: 1285–1293.*
Temple H.J. & Terry A. 2007: The status and distribution of European mammals. *Office for Official Publications of the European Communities, Luxembourg.*
Temple H.J. & Terry A. 2009: European mammals: Red List status, trends, and conservation priorities. *Folia Zool. 58: 248–269.*
Tischendorf L. 2001: Can landscape indices predict ecological processes consistently? *Landscape Ecol. 16: 235–254.*
Van Langevelde F., van der Knaap W.G.M. & Claassen G.D.H. 1998: Comparing connectivity in landscape networks. *Planning and Design 25: 849-863.*
Wiens J.A. 2002: Riverine landscapes: taking landscape ecology into the water. *Freshwater Biol. 47: 501–515.*

**Appendix**. Values used for the reclassification of the variables for the HS model and the connectivity analysis. The number in parenthesis after the Land cover class reports its official code. The HS reclassified codes are reported either within the 300m or 1km buffer. In the case of 1km buffer, the value that was subtracted from those of layer 3 is indicated (see text).

| | HS model | | | Permeability model | |
|---|---|---|---|---|---|
| Layer | Value-range/Description | HS: value within 300m buffer | HS: effect within 1km buffer | Values range/ Description | Connectivity: Values of permeability |
| Bank slope | >70° | 3 | - | 0-45°<br>>45° | 1<br>0 |
| **Altitude** m a.s.l. | 0-1000 | 3 | - | | 3 |
| | 1000– 1500 | 2 | - | | 2 |
| | 1500 – 2000 | 1 | - | | 1 |
| | >2000 | 0 | - | | 0 |
| **Human density** citizens/km² | >150 | - | -0.25 | 0-500 | 3 |
| | | | | 500–1200 | 2 |
| | | | | 1200–2600 | 1 |
| | | | | >2600 | 0 |
| | | CORINE 1:5000 | CORINE 1:100000 | | CORINE 1:100000 |
| **CORINE land cover class** | Continuous urban fabric (1.1.1) | 0 | -0.25 | | 0 |
| | Discontinuous urban fabric (1.1.2) | 0 | -0.25 | | 1 |
| | Industrial or commercial units (1.2.1) | 0 | -0.25 | | 0 |
| | Road and rail networks (1.2.2) | 0 | -0.25 | Railways | 3 |
| | | | | Municipal roads | 2 |
| | | | | State and-Province roads | 1 |
| | | | | Highways | 0 |
| | Port areas (1.2.3) | 0 | -0.25 | | 0 |
| | Airports (1.2.4) | 0 | -0.25 | | 0 |
| | Mineral extraction sites (1.3.1) | 0 | -0.25 | | 1 |
| | Dump sites (1.3.2) | 0 | -0.25 | | 1 |
| | Construction sites (1.3.3) | 0 | -0.25 | | 0 |
| | Green urban areas (1.4.1) | 1 | -0.25 | | 2 |
| | Sport and leisure facilities (1.4.2) | 1 | -0.25 | | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | Non-irrigated arable land (2.1.1) | 1 | -0.25 | | 1 |
| | Permanently irrigated land (2.1.2) | 1 | -0.25 | | 1 |
| | Rice fields (2.1.3) | 1 | -0.25 | | 2 |
| | Vineyards (2.2.1) | 1 | -0.25 | | 1 |
| | Fruit trees and berry plantations (2.2.2) | 1 | -0.25 | | 1 |
| | Olive groves (2.2.3) | 1 | -0.25 | | 2 |
| | Pastures (2.3.1) | 1 | -0.25 | | 1 |
| | Annual crops associated with permanent crops (2.4.1) | 1 | -0.25 | | 1 |
| | Complex cultivation (2.4.2) | 1 | -0.25 | | 2 |
| | Land principally occupied by agriculture, with significant areas of natural vegetation (2.4.3) | 1 | - | | 2 |
| | Agro-forestry areas (2.4.4) | 1 | -0.25 | | 2 |
| | Broad-leaved forest (3.1.1) | 3 | - | | 3 |
| | Coniferous forest (3.1.2) | 2 | - | | 3 |
| | Mixed forest (3.1.3) | 3 | - | | 3 |
| | Natural grassland (3.2.1) | 1 | - | | 3 |
| | Moors and heathland (3.2.2) | 2 | - | | 3 |
| | Sclerophyllous vegetation (3.2.3) | 2 | - | | 3 |
| | Transitional woodland/shrub (3.2.4) | 2 | - | | 3 |
| | Beaches, dunes, and sand plains (3.3.1) | 1 | - | | 2 |
| | Bare rock (3.3.2) | 3 | - | | 0 |
| | Sparsely vegetated areas (3.3.3) | 2 | - | | 2 |
| | Burnt areas (3.3.4) | 0 | - | | 1 |
| | Glaciers and perpetual snow (3.3.5) | 0 | - | | 0 |
| | Inland marshes (4.1.1) | 3 | - | | 3 |
| | Peatbogs (4.1.2) | 2 | - | | 3 |
| | Salt marshes (4.2.1) | 3 | - | | 3 |
| | Salines (4.2.2) | 0 | - | | 3 |
| | Intertidal flats (4.2.3) | 1 | - | | 3 |
| | Water courses (5.1.1) | 3 | - | | 3 |
| | Water bodies (5.1.2) | 3 | - | | 3 |
| | Coastal lagoons (5.2.1) | 3 | - | | 3 |
| | Estuaries (5.2.2) | 3 | - | | 3 |
| | Sea and ocean (5.2.3) | 3 | - | | 3 |