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Research Article

The masked invader strikes again: the conquest of Italy by the Northern raccoon

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Abstract

The Northern raccoon *Procyon lotor* is a species native to North and Central America, but alien populations have established in Europe, several Caribbean islands, Azerbaijan, Uzbekistan and Japan, being introduced for fur farming, hunting, or as pets/attraction in animal parks. In the introduced range, raccoons may impact on breeding birds and amphibians, exert crop damages and transmit pathologies to wild species and humans. The species has been introduced also in Italy, where the only known reproductive population is observed since 2004 in Lombardy, along the Adda river. We reconstructed the current distribution range of the Northern raccoon in Italy, collecting information from scientific papers, articles in newspapers and books, as well from experts and local reporters. A total of 53 occurrence points were collected from observation sites. Since 2008, records from Lombardy increased, and sporadic observations were reported from seven other regions. A complete lack of records from the Northernmost provinces of Lombardy (Varese, Como and Sondrio) suggests that the only Italian population does not derive from a range expansion from Switzerland, but it should be considered as an independent, new introduction. Accidental observations of single individuals possibly escaped from captivity are often ignored, and only few animals were removed from the wild. An analysis of the potential distribution of the species was performed in a species distribution modeling framework (MaxEnt). A global model was built up considering the occurrences of reproductive populations from the native range and introduced areas in Europe and Japan and then projected to Italy. The model suggested a good suitability for the plains in Central-Northern Italy and a very low suitability of the Alpine region, thus providing support to the hypothesis that the Italian population did not derive from dispersal from Switzerland. If escapes or releases of raccoons will continue, there is a risk that the species could colonize other areas, making its containment more difficult.

Introduction

A growing global evidence identifies the impact of alien species as one of the main cause of the current biodiversity crisis (Wonham, 2006). In Europe, more than 12000 alien species have been recorded to be present (DAISIE; www.europe-aliens.org/aboutDAISIE.do); many of them may exert a negative impact on biodiversity, environment, human health and economics (Vilà et al., 2010; Scalera et al., 2012; Mazza et al., 2014). About 10-15% of these species exert damages for about 12 billion Euro per year (Kettunen et al., 2008).

The Northern raccoon *Procyon lotor* is listed within the 100 of the worst invasive alien species in Europe (DAISIE, 2009). The species is a medium-sized carnivore, naturally distributed from Southern Canada to Central America (Timm et al., 2008). Introduced populations have been established in Japan, several Caribbean islands, Azerbaijan, Uzbekistan, as well as in many European countries (Lorvelec et al., 2001; Ikeda et al., 2004; Timm et al., 2008; Beltràn-Beck et al., 2012; Garcia et al., 2012). Diet spectrum of the Northern raccoon is very wide as it may feed on a huge variety of invertebrates, fishes, amphibians, birds and small mammals (Hayama et al., 2006; Bartoszewicz et al., 2008; Garcia et al., 2012). Seasonally, vegetables and cultivated fruits are an important part of the diet, as well as carrion and garbage in urban and suburban areas (Hayama et al., 2006; Bartoszewicz et al., 2008). Growing evidence also suggests a role of raccoons as disease vectors (e.g. rabies, nematode-mediated pathologies) with possible transmission to the native fauna, domestic animals and even humans (Arjo et al., 2005; Bartoszewicz et al., 2008; Puskas et al., 2010; Vos et al., 2012; Beltràn-Beck et al., 2012; Hulme, 2014).

In Europe, raccoons were imported for fur farming, hunting or as pets/attraction in animal parks. They were observed in the wild for the first time in Germany (Hessen) in 1927 (Hohmann and Bartussek, 2001). In 30 years, the German population of raccoons doubled (Hohmann and Bartussek, 2001), conquering and invading neighboring countries. Signs of presence of the raccoon in Switzerland date back to the 1970s, when the first individuals appeared near the German border. Thenceforth, recordings of raccoons have been reported from all regions of Switzerland except for the Southern and Southeastern part. The current distribution pattern found in Switzerland could be explained by erratic expansion of individuals combined with the presence of escaped or released animals (S. Capt, Centre Suisse de Cartographie de la Faune, *personal communication*, 2014). A similar story occurred in Austria, where first raccoons were seen in 1980s (Aubrecht, 1985). In the second half of the 1990s, Austrian population expanded mainly northward and reached Bohemia, Czech Republic (Mlíkovsky

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and Styblo, 2006). Currently, breeding populations are known to occur in 18 European countries (Beltràn-Beck et al., 2012; Alda et al., 2013). Single individuals were sporadically observed in Great Britain, Denmark, Norway and Sweden (Beltràn-Beck et al., 2012), while the current status in Slovenia is unknown (Kryštufek, 2011). Despite this wide distribution range of introduction, a huge gap in knowledge still occur, as no study has been assessed yet to quantify the impact of the raccoon on native biodiversity and environment, e.g. very few research on diet (cf. Garcia et al., 2012). By contrast, sanitary impacts have been more deeply described (Michler and Michler, 2012; Vos et al., 2012).

As for Italy, the first reproductive population of Northern raccoon has been established since 2004 in Lombardy (Northern Italy), along the Adda river and its tributary canals (Canova and Rossi, 2008)). It has been hypothesized that this species colonized Italy through a dispersal route, which links Switzerland to the Adda river basin (Canova and Rossi, 2008). With an expanding range and a large array of potential impacts on native ecosystems, a synthesis of the distribution of the Northern raccoon in Italy is required. Thus, aims of our work were (i) to update the current distribution of this species in Italy ten years after the first observation and (ii) to determine its potential range expansion through a Species Distribution Model based on climatic variables.

Materials and Methods

Species data

Published and unpublished data on the presence and distribution of the Northern raccoon in Italy were collected. The main source of information were: (i) scientific papers on raccoon distribution; (ii) generic articles reporting the presence and distribution of this species; (iii) data collected through citizen science and (iv) direct observations carried out by experts in several Italian regions.

Occurrences from the native area and from the introduced part of the range were also collected. In detail, data from Switzerland were provided by Centre Suisse de Cartographie de la Faune, those from Japan were provided by M. Ishiguro, those from native range, France, Luxembourg, Poland and Germany were taken from iNaturalist (http://www.inaturalist.org), VertNet (http://portal.vertnet.org), Arctos (http://arctos.database.museum) and GBIF Database (http://www.gbif.org).

Species Distribution Model

Species distribution models represent a reliable and widely used tool to evaluate risks and sites of future invasions by alien species (Beaumont et al., 2009; Ficetola et al., 2007; Di Febbraro et al., 2013). The model for the raccoon was calibrated using Maxent (Phillips et al., 2006; Phillips and Dudìk, 2008), a machine-learning method that estimates species distributions using environmental predictors together with species occurrences. This algorithm, based on an application of the maximum entropy principle in an ecological context (Jaynes, 1957), calculates the distribution probability in order to satisfy a set of constraints derived from environmental conditions at presence sites. These constraints impose that the expected value of each environmental predictor falls as close as possible to the empirical mean of that predictor measured over the presence records. Among all the possible distributions satisfying these constraints, the algorithm chooses the closest to the uniform, thus maximizing the entropy. Maxent has generally shown to perform better than other similar techniques, especially in predicting invasive species distributions outside their native ranges (Elith et al., 2006; Heikkinen et al., 2006; Ficetola et al., 2007; Di Febbraro et al., 2013).

Recent studies have shown that including records from native and invasive ranges in model building increase its performance in respect to considering only records from the native range (Beaumont et al., 2009; Di Febbraro et al., 2013). Therefore, we included in our model a total of 1403 occurrences from the native range (N=1119) and from naturalized reproductive populations in Germany, Poland, Luxembourg, France, Switzerland, Northern Italy and Japan (N=294: Fig. S1). Isolated occurrences in Italy, Austria and Slovenia were not included in the analysis to avoid incorrect estimates.

From the ecological point of view, the Northern raccoon has a high water requirement, thus occurring in a low number in arid environment (Stuewer, 1943; Hoffmann and Gottschang, 1977; Rosatte, 2000). Moreover, trunk cavities, badger and fox burrows are often used for reproductive purposes, emphasizing the importance of forests for this species (Kamler and Gipson, 2003; Henner et al., 2004; Beasley et al., 2007; Bartoszewicz et al., 2008; Hermes et al., 2011). Notwithstanding this, raccoons also explore suboptimal habitat types, although possibly at lower population densities (Hermes et al., 2011).

High altitudes may represent a limit for the range expansion of the Northern raccoon in Europe, because it reduces its activity during snow cover and winter survival is strictly linked to the amount of fat deposited during the previous autumn (Folk et al., 1968; Mugaas and Seidensticker, 1993). The altitudinal range of Northern raccoon in the native range starts from the sea level up to a maximum of 1520 meters a.s.l. in the USA and 2743 meters a.s.l. in Southern Mexico (Goldman, 1950). Raccoons do not hibernate and select preferentially areas not covered by snow (Lotze and Anderson, 1979; Zeveloff, 2002; Kamler and Gipson, 2003; Beasley et al., 2007). Although they are not impenetrable barriers, ridges represent an important hindrance to raccoon movements (Puskas et al., 2010), and valleys represent the preferred dispersal way.

No published data are available yet for the introduced range, with the only exception of Germany (Tomaschek, 2008), but we know from the occurrences that raccoon may reach over 1000 meters a.s.l. in Switzerland, Japan and in Germany as well.

According to these biological requirements, we chose the following six climatic predictors, derived from the WORLDCLIM dataset, at a resolution of 2.5 arc-minutes ($\approx$ 5 km) (Hijmans et al., 2005): mean temperature of the warmest quarter, mean temperature of the coldest quarter, annual precipitation, precipitation of the driest month, precipitation of the warmest quarter and precipitation of the coldest quarter. The collinearity between the predictors was assessed with a VIF (Variance Inflation Factor) analysis, setting a maximum VIF value of 10 (see Zuur et al., 2010 for further details). The VIF analysis resulted in the exclusion of annual precipitation from the initial set of environmental variables.

We randomly split the occurrence data into two subsets to obtain a reliable evaluation of the model, using 70% of records to calibrate the model and the remaining 30% to evaluate it. This procedure was replicated 10 times, each time randomly selecting different 70–30% portions of occurrence data. The final model was obtained by averaging the 10 runs. We evaluated predictive performance of the model for each replicate by calculating the Area Under the Curve (AUC) of a receiver operating characteristic plot (ROC; Fielding and Bell, 1997), the True Skill Statistic (TSS; Allouche et al., 2006), and the related standard deviations (SD). The evaluation scores were then averaged.

The final model was projected in a geographic area encompassing Italy and borders with neighboring countries.

Results

A total of 38 sites of observation of Northern raccoon has been collected for Italy between 1987 and 2014, corresponding to 53 occurrences. Among those, 25 sites were located in Southern Lombardy and referred to the only known reproductive Italian population (Fig. 1). All the other occurrences represented accidental individuals possibly escaped from captivity or from wildlife recovery centres. Three of them were found dead and only three other individuals were captured and removed from the wild (Fig. 1).

The Species Distribution Model reached a good predictive performance with an AUC of 0.812 (SD=0.001) and a TSS of 0.478 (SD=0.019). Main suitable areas in Italy are represented by the Po plain, the North-Eastern coastline, the internal plain areas of Central Italy and the foothills of the Alps in Lombardy, characterized by dense river networks. By contrast, the Alps and the main Apennine peaks represented areas with low climatic suitability for raccoons, as well as the xeric areas of Southern Italy (Fig. 1).

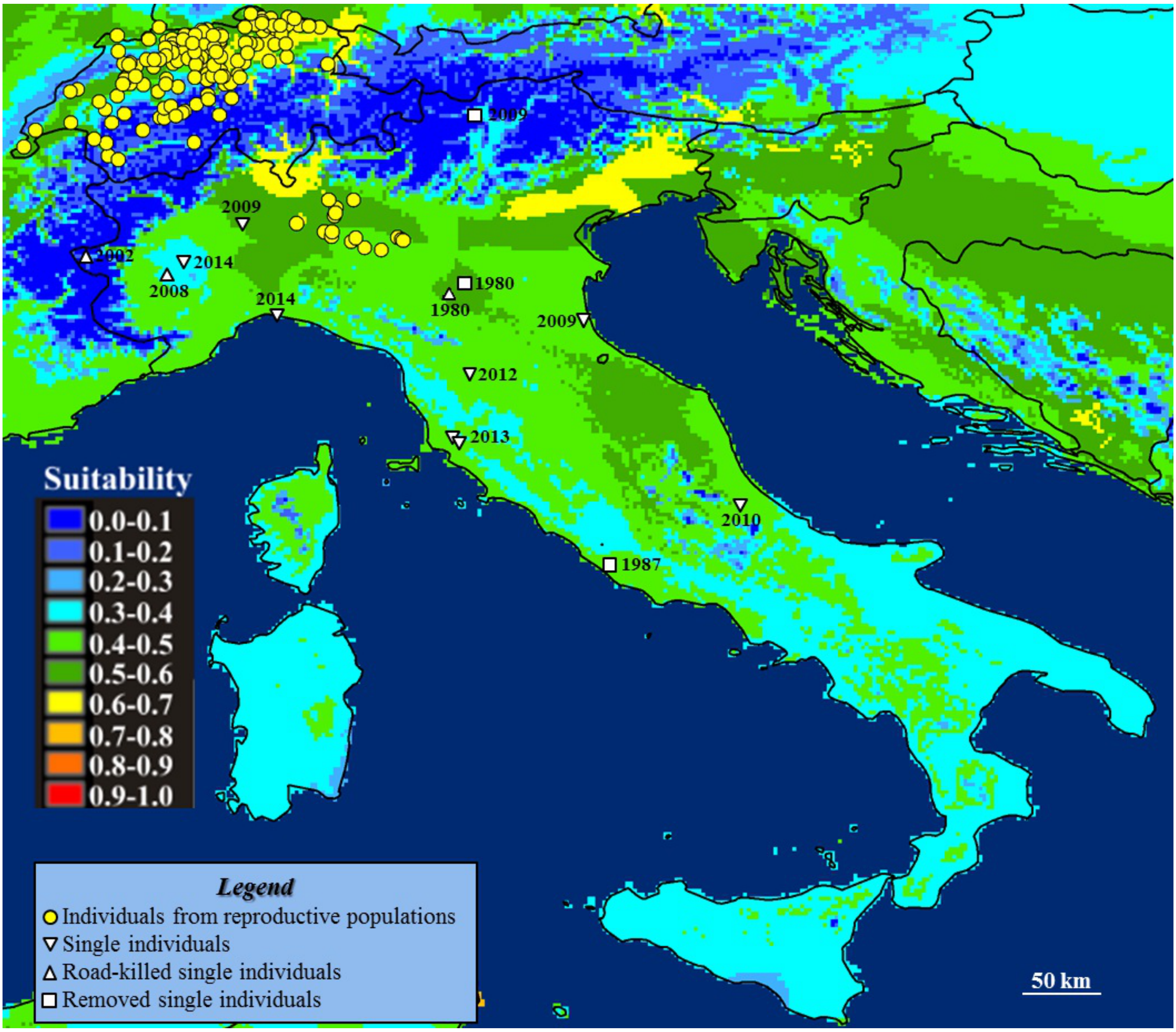

Figure 1 – Current distribution and climatic suitability for Northern raccoon in Italy.

Population of Lombardy markedly increased its range since the first assessment of 2008 (Canova and Rossi, 2008: Fig. 2), and now the animals are observed in the Adda basin, as well as in the Southern floodplains of Lambro and Oglio rivers, and up to the North of the Po river (provinces of Bergamo, Monza-Brianza, Milan, Cremona and Lodi). The current distribution of the species in this region, calculated on the two minimum convex polygon (2008 and 2014) encompassing all the occurrences, is now 138% wider than it was in 2008.

Discussion

Our work provided new evidence on the current status and invasion risk of Northern raccoon in Italy. Although records of this carnivore have been reported from eight Italian regions, evidence of reproduction are currently available only for Southern Lombardy. With respect to the first assessment (Canova and Rossi, 2008), the area with records is more than doubled.

In detail, we suggest that the hypothesis that the Italian population derive from individuals in natural dispersal from Switzerland (Canova and Rossi, 2008) should be discarded. The aspect of the raccoon is unmistakable and well-known by the general public; we suggest that the absence of data in the intermediate area between Switzerland and the Adda river basin might be due to a real discontinuity in the distribution range rather than to a lack of reports; records from Southern and South-Eastern part of Switzerland, near the border with Italy, are few too and in an early phase of colonization (S. Capt, *personal communication*, 2014).

The linear distance between these two populations of raccoons is about 270 km. Although in Germany a marked individual was caught 285 km straight line from its release point (Michler and Köhnemann, 2010), dispersal distances reported for the species are on average of lesser extent (Lynch, 1967; Puskas et al., 2010). Even if Puskas et al. (2010) claimed that dispersal of raccoon is mainly associated with valleys and that ridges are basically not selected, the complete absence of records from climatically suitable areas (e.g. Province of Varese, Northern Lombardy) bring us further support to the hypothesis that different introduction events may have occurred in Switzerland and in Italy. A different hypothesis would be that no signs/citizen science data do not necessarily mean absence and some individuals may be present at low densities between Italian and Swiss populations. Genetic analyses of both the Swiss and the Italian population would be useful to clarify this issue.

Although being ecologically generalist, according to habitat types and food selection, the Northern raccoon has specific requirements in terms of climate, preferring the immediate surroundings of rivers or water courses, possibly because of food requirements, and avoiding the

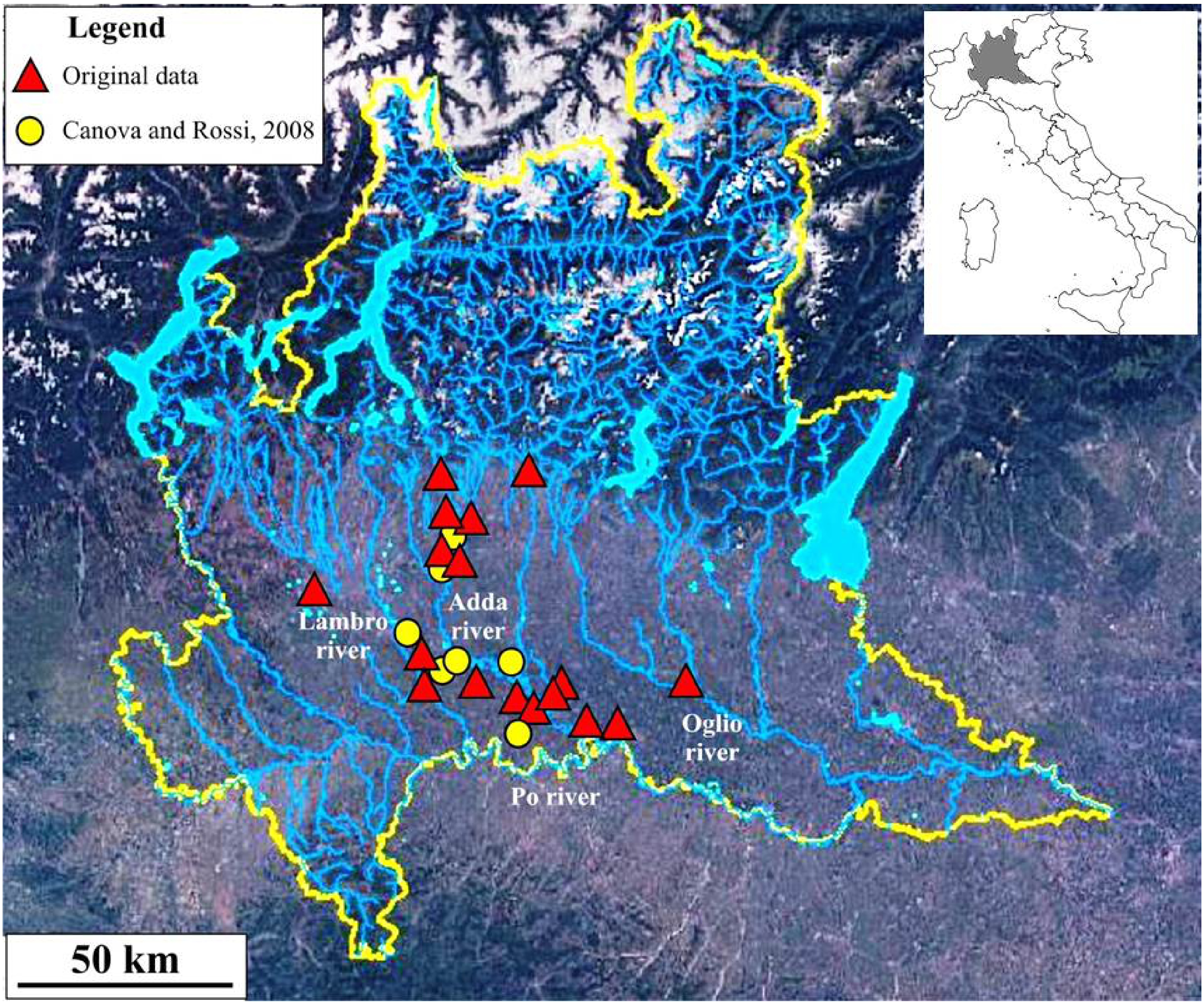

Figure 2 – Current distribution of Northern raccoon in Lombardy (red triangles), with respect to the first detection (yellow circles: Canova and Rossi, 2008). The hydrographic map of Lombardy is available at http://idro.arpalombardia.it/pmapper-4.0/map.phtml (Accessed on 30th November 2014..

coldest areas (Stuewer, 1943; Folk et al., 1968; Mugaas and Seidensticker, 1993; Hermes et al., 2011). According to our model, the Alps does not constitute a climatically suitable environment for the presence of raccoons, representing a potential barrier between the Italian and the Swiss populations. In addition, the Po plain and the Italian coastline may constitute a preferential way for the conquest of Central and Southern regions, where other sporadic observations of Northern raccoon have been reported.

An optimal strategy aiming at reducing the risks posed by introduced species should consider a three-stage hierarchical approach, which includes i) prevention of new introductions, ii) early detection when prevention failed, and iii) a mitigation of impacts with the eradication, containment or control of populations (Genovesi and Shine, 2004; Bertolino et al., 2015). Despite being considered an invasive species in Europe, prevention is failing: the trade of the Northern raccoon is not controlled yet and enclosures do not avoid risk of escapes. If a species is present in a country and occurs free in the wild with some frequency, early detection and rapid response should be adopted. Conversely, only 3 individuals out of 14 recorded outside Lombardy were captured and removed, in addition to other three found road-killed (see Fig. 1). This species easily gains emotional affiliation from the general public (Gilbert, 1982), thus possibly limiting management actions as control and eradication, as it happened for other "attractive" alien species (e.g. grey squirrel *Sciurus carolinensis*: Bertolino and Genovesi, 2003; Bertolino et al., 2014; rose-ringed parakeet *Psittacula krameri*: Menchetti and Mori, 2014). Alien populations of Northern raccoon may be funded by a small number of individuals (Alda et al., 2013; Biedrzycka et al., 2008); if sporadic escapes or releases by private owners or zoo parks will continue, they form new propagule that could establish reproductive populations, leading to greater difficulties in management activity. The invasive potential of the Northern raccoon, also helped by a wide ecological plasticity and by multiple introductions (Alda et al., 2013; Biedrzycka et al., 2008), has been widely observed in its introduced range, both in Europe and in Japan (Bartoszewicz et al., 2008; Hayama et al., 2006; Beltràn-Beck et al., 2012). Our study shows a rapid expansion of the species in Lombardy, suggesting the potential for raccoon invasion in Northern Italy. Considering the experiences from other European countries and Japan (Ikeda et al., 2004; Beltràn-Beck et al., 2012; Garcia et al., 2012), this population should be rapidly removed to avoid further expansion and consequent impacts to biodiversity. At the same time, it is important to activate a response system with the rapid removal of new animals found free in the environment.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Figure S1 Localization of the occurrences used for the model.