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The Spreading of the Invasive Italian Wall Lizard on Vulcano, the Last Island Inhabited by the Critically Endangered Aeolian Wall Lizard

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***Abstract*.—The Aeolian Wall Lizard (*Podarcis raffoneae*) is an endemic species of the Aeolian Archipelago of Italy (Mediterranean Sea). Its distribution is limited to three islets and two relict populations on a relatively large island: Vulcano (a population on the summit of Gran Cratere volcano and another on Capo Grosso promontory). The critically endangered Aeolian Wall Lizard is threatened by the introduction of the Italian Wall Lizard (*Podarcis siculus*), which successfully competes and hybridizes with the endemic lizard. The invasive lizard is widespread on Vulcano, although the literature does not provide the exact distribution. Our first aim was updating the distribution of the Italian Wall Lizard on Vulcano, with special attention to the last enclaves of the Aeolian Wall Lizard. Our second purpose was investigating the factors determining this distribution range. In the spring of 2016, we surveyed the Italian Wall Lizard distribution on Vulcano, considering 10 human-related and 10 natural areas, including Gran Cratere volcano and Capo Grosso promontory. We recorded the presence of the invasive Italian Wall Lizard in each survey area. As a consequence, the Aeolian Wall Lizard populations of Vulcano face an imminent extinction risk. The main factors increasing the presence probability of this invasive lizard on Vulcano were the nearness to the harbor (the introduction gateway) and the urbanization degree (the invasion pathway). Therefore, we suggest the implementation of a control plan simultaneously acting on the areas of sympatry (mostly Capo Grosso promontory), the introduction gateway (Vulcano harbor), and the source populations (urban areas).**

***Riassunto*.—La Lucertola delle Eolie (*Podarcis raffoneae*) è una specie endemica dell'Arcipelago Eoliano (Italia, Mar Mediterraneo). La sua distribuzione è limitata a tre isolotti e due popolazioni relitte in un'isola relativamente grande: Vulcano (una popolazione sulla sommità del vulcano Gran Cratere e un'altra sul promontorio di Capo Grosso). La Lucertola delle Eolie, una specie in pericolo critico d'estinzione, è minacciata dall'introduzione della Lucertola Campestre (*Podarcis siculus*), a causa della competizione e della possibilità di ibridazione. La Lucertola Campestre è ormai diffusa su tutta l'isola di Vulcano, ma la letteratura scientifica non fornisce l'esatta area di distribuzione. Il primo obiettivo di questo studio è attualizzare l'area di distribuzione conosciuta della Lucertola Campestre su Vulcano, prestando speciale attenzione alle ultime enclavi della Lucertola delle Eolie. Il secondo obiettivo è comprendere i fattori che determinano l'attuale area di distribuzione di questa specie nella nostra area di studio. Nella primavera del 2016, abbiamo monitorato la distribuzione della Lucertola Campestre su Vulcano, considerando 10 aree antropizzate e 10 aree naturali, includendo il vulcano Gran Cratere e il promontorio di Capo Grosso. Abbiamo registrato la presenza della Lucertola Campestre in ogni area monitorata. Come conseguenza, le popolazioni di Lucertola delle Eolie di Vulcano affrontano un rischio d'estinzione imminente. I principali fattori che influenzano positivamente la probabilità di presenza della Lucertola Campestre su Vulcano sono la vicinanza al porto (il portale d'entrata di questa specie) e il grado di urbanizzazione. Quindi, suggeriamo l'implementazione di un piano di controllo che agisca simultaneamente nelle aree di simpatria (soprattutto Capo Grosso), nel portale d'entrata (il porto di Vulcano), e sulle popolazioni sorgente (nelle aree urbane).**

Key Words.—biological invasions; introduction gateway; invasion pathway; invasive species; narrow-endemic species; *Podarcis raffoneae*; *Podarcis siculus*; small-range species.

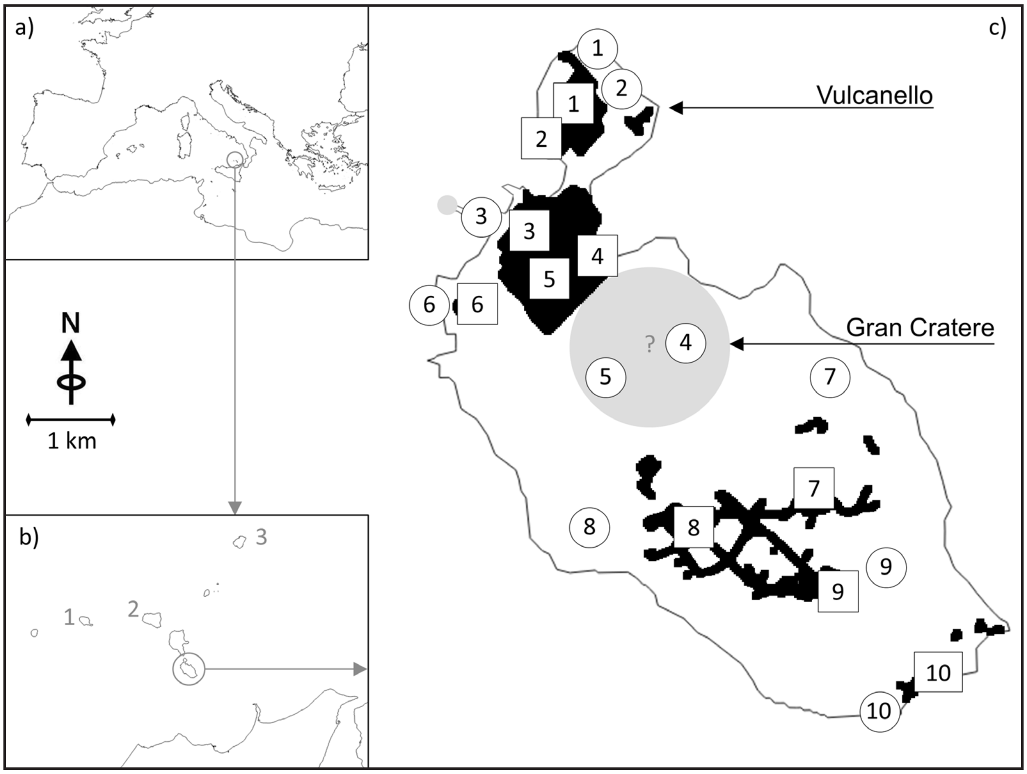

Figure 1. Study area: (a) Aeolian Islands of Italy in the central Mediterranean Sea; (b) Vulcano (38°24’N 14°58’E), in the middle of the Aeolian Islands (in this panel we also show the location of the three islets hosting Aeolian Wall Lizard (*Podarcis raffoneae*) populations: 1 - La Canna; 2 - Scoglio Faraglione; and 3 - Strombolicchio; (c) The distribution (in grey) of the Aeolian Wall Lizard on Vulcano (Gran Cratere distribution range is doubtful). The main urban settlements are in black. The numbers in squares are the human-related survey areas for the Italian Wall Lizard (*Podarcis siculus*): 1–2) Vulcanello village (inland and coast); 3–5) Vulcano town (near Capo Grosso, harbor and town center); 6) Monte Lentia village; 7–8) Piano village (eastern and western), 9–10) Gelso village (inland and coast). The numbers in circles are natural survey areas for the Italian Wall Lizard: 1–2) Vulcanello (coastal cliffs and peak); 3) Capo Grosso proximal cliffs; 4–5) Gran Cratere (peak and western slopes); 6) Monte Lentia (coastal cliffs); 7) Capo Grillo (peak); 8) Monte Saraceno (peak); 9–10) Monte Aria (peak and coastal cliffs).

Introduction

Endemic species are worldwide considered as a conservation priority (Myers et al. 2000; Stattersfield et al. 2005), especially narrow-endemic and insular organisms (Kier et al. 2009; Harvey et al. 2011). One of these intrinsically endangered taxa is the Aeolian Wall Lizard (*Podarcis raffoneae*), a small-range species whose distribution is restricted to three small islets (each one < 0.02 km^2) and only one relatively large island (Vulcano; about 21 km^2) of the Aeolian Archipelago of Italy in the Mediterranean Sea (Capula 1994; Lo Cascio and Corti 2006; Fig. 1). The Aeolian Wall Lizard is listed as Critically Endangered by the International Union for the Conservation of Nature (IUCN; Corti et al. 2009; Rondinini et al. 2013), and it is probably the most threatened lizard in Europe and one of the most endangered vertebrates in Italy (Capula et al. 2002; Gippoliti et al. 2017). The populations of Aeolian Wall Lizard inhabiting Vulcano have strongly declined in the last century (Capula et al. 2002), mainly due to inter-specific competition and also hybridization with the introduced Italian Wall Lizard (*Podarcis siculus*; Capula 1993, 2006; Lo Cascio 2010; Spatz et al. 2017; Fig. 2). Such interactions are the result of a relatively common invasion pattern in which the spread of an introduced habitat-generalist species, potentially successful in human environments, threatens the persistence of a native and evolutionarily closely related taxon (Rieseberg and Gerber 1995; Fowler et al. 2008; Carretero and Silva-Rocha 2015). This invasion pattern is especially frequent on islands, as in the case of the introduced Mallard (*Anas platyrhynchos*) threatening the native Hawaiian Duck (*Anas wyvilliana*) on the Hawaiian islands (Fowler et al. 2008) and the ornamental Birch-Leaf Mountain Mahogany (*Cercocarpus betuloides*) threatening the native Santa Catalina Island Mountain Mahogany (*Cercocarpus traskiae*) off the coast of California, USA (Rieseberg and Gerber 1995). As a further and more relevant example, the Italian Wall Lizard is currently threatening other island populations of native *Podarcis* species, such as the Dalmatian Wall

Figure 2. Typical color pattern phenotypes of the Italian Wall Lizard (*Podarcis siculus*) on the island of Vulcano, Italy, which is an introduced and invasive species on the island. (Photographed by Francesco Paolo Faraone and Marcello D'Amico).

Lizard (*Podarcis melisellensis*) on Adriatic Islands and the Lilford's Wall Lizard (*Podarcis lilfordi*) on Balearic Islands (Nevo et al. 1972; Carretero and Silva-Rocha 2015).

Currently, there are only two populations of Aeolian Wall Lizard on Vulcano (Capula et al. 2002; Lo Cascio 2010). The first population is restricted to the only active volcano of the island (Gran Cratere; Fig. 1), but the last published sightings date back to some field campaigns of around the year 2000 (Capula et al. 2002). Two German amateur herpetologists have recently confirmed the persistence of this population on the summit of the volcanic cone (Birgit Oefinger and Peter Oefinger, unpubl. report). The second population is restricted to a small promontory called Capo Grosso, which is 0.005 km^2 in extent (Lo Cascio 2010; Fig. 1). This population is virtually isolated in the distal area of the promontory, which can be almost considered as an islet because its access is barely above sea level (Lo Cascio 2010). As evidence of this isolation, Capo Grosso lizards are typically colored differently compared to the other Aeolian Wall Lizards inhabiting Vulcano (Lo Cascio 2010). A third population was present until the recent past on the volcanic peninsula of Vulcanello (Fig. 1), but there have not been sightings of this lizard there in the last 20 y (Capula 1993, 1994; Capula et al. 2002; Lo Cascio 2010).

The Italian Wall Lizard was probably introduced on Vulcano at the end of 19^{th} Century (Corti et al. 1999), but until the 1990s its distribution was mostly limited to human-related habitats (Capula et al. 2002). In the last two decades, the Italian Wall Lizard has spread into the natural environments representing the last enclaves for the endemic Aeolian Wall Lizard, such as the lowest elevations of both Gran Cratere and Vulcanello (Capula 1993, 1994; Capula et al. 2002; Lo Cascio 2010). Currently, the Italian Wall Lizard is widespread throughout human-related and natural habitats of Vulcano (Capula et al. 2002; Lo Cascio 2010), although the available literature does not provide the exact range of this distribution. For this reason, the first aim of the present study was updating the knowledge about the distribution of the Italian Wall Lizard on Vulcano. We paid special attention to the last enclaves of the Aeolian Wall Lizard on this island, because the presence of the Italian Wall Lizard in these areas would entail an ultimate threat for this critically endangered endemic species.

The second purpose of our study was to investigate the factors determining the current distribution of the Italian Wall Lizard on Vulcano. We tested different hypotheses related to introduction gateway and invasion pathway potentially explaining the spreading of this introduced lizard on Vulcano. In our first hypothesis, the current distribution of the Italian Wall Lizard would depend on the distance to the main introduction gateway: the harbor (see Corti et al. 1999). Our prediction is that the probability of the Italian Wall Lizard being present will be higher at the harbor surroundings and will decrease according to the distance from the harbor. In our second hypothesis, this distribution would be related to the environmental factors that, considering the species biology, might facilitate the invasion pathway, such as the presence of human settlements, the habitat type and the topographic elevation. Our prediction is that the probability of the Italian Wall Lizard being present will be higher in human environments at low elevations. We also considered several combinations of these hypotheses. The approach of the present study, focused on determining at the same time the distribution of the invasive species and the factors facilitating its spreading, can be useful to determine where concentrate our conservation efforts. The expected results can be relevant for the identification of the invasion pathways of potentially synanthropic species, with the final purpose to prevent their establishment.

Materials and Methods

Study site.—Our study was on Vulcano, a volcanic island of the Aeolian Archipelago of Italy, in the Tyrrhenian Sea (38º24’N, 14º58’E; Sicily; Fig. 1). Climate in the island is typically Mediterranean, with mild winters and hot summers. The northern area of the island is Vulcanello, a peninsula with a volcanic cone (123 m) without activity in the last 600 y (Fig. 1). In the middle of the island there is the only active volcano, Gran Cratere (386 m; Fig. 1). The southern area of the island is composed of partially collapsed old volcanic cones (Monte Aria, 501 m; Monte Saraceno, 481 m; Monte Luccia, 188 m; Fig. 1).

The landscape on Vulcano is a mosaic of urban and rural areas (Fig. 1), with gardens, orchards, and old fields. More natural environments are restricted to cliffs, peaks of volcanic cones and some volcanic slopes, especially the coastal slopes. On cliffs and on the summit of Gran Cratere, the only vegetation is limited to pioneer species such as Tyrrhenian Broom (*Genista tyrrhena*). Mediterranean shrubland (including some threatened endemic species, such as Aeolian Broom (*Cytisus aeolicus*), is the main habitat on the other volcanic peaks and slopes, with some woody patches (almost exclusively composed by introduced species: eucalypts, pine and thorn trees).

Data collection.—In March 2016, we surveyed for the presence of the Italian Wall Lizard on Vulcano Island. We established 20 survey areas across the island, half of them in human-related environments and the other half in natural environments. The human-related areas were Vulcanello village (inland and coast), Vulcano town (near Capo Grosso, harbor and town center), Monte Lentia village, Piano village (eastern and western), and Gelso village (inland and coast; Fig. 1). The natural areas were Vulcanello (coastal cliffs and peak), Capo Grosso proximal cliffs (distal cliffs, inhabited by the Aeolian Wall Lizard, are not accessible by land), Gran Cratere (peak and western slopes), Monte Lentia (coastal cliffs), Capo Grillo (peak), Monte Saraceno (peak), and Monte Aria (peak and coastal cliffs; Fig. 1). Within each survey area we randomly established five circular 25-m-wide observation plots in which we actively searched for the presence of Italian Wall Lizards for 15 min. Each observation plot was located at a minimum distance of 25 m to other observation plots, and it was also characterized according to its main habitat: urban, semi-urban (gardens and orchards), woodland, shrubland (old fields and natural scrublands), and rocky ground (cliffs and volcanic areas). We used Geographic Information Systems (QGIS Development Team, version 2.18) to further characterize observation plots (distance to the nearest urban area, from the center of the observation plot to the nearest border of the nearest urban area; distance to the harbor, from the center of the observation plot to the nearest border of the survey area of Vulcano town harbor; and topographic elevation of the center of the observation plot).

Data analysis.—We used Generalized Linear Mixed Models (GLMM; Procedure GLIMMIX, SAS software, version 9.3) and evaluated the performance of models using Akaike Information Criterion (AIC). For each model, the response variable was the presence/absence of the Italian Wall Lizard in the observation plot, with the survey area as a random factor. We used a binomial error distribution and a logit link function. With the aim to explain the spreading of the Italian Wall Lizard on Vulcano, we considered two different hypotheses related to introduction gateway and invasion pathway, respectively. In our first hypothesis, the response variable depended on the distance to the harbor (Table 1), which has been suggested to be the main introduction gateway for this invasive lizard on Vulcano. In our second hypothesis, the response variable was related with an environmental factor characterizing the observation plot, such as the amount of urbanization (urban vs natural environments), the distance to the nearest urban area, and the habitat or the topographic elevation (Table 1). We also included a null model without predictors and three other models that considered several combinations of the aforementioned variables (Table 1). We selected the most supported models using AIC, and calculated Akaike weights (wAIC) to estimate the relative support for each model (ranging from 0 to 1, with larger numbers

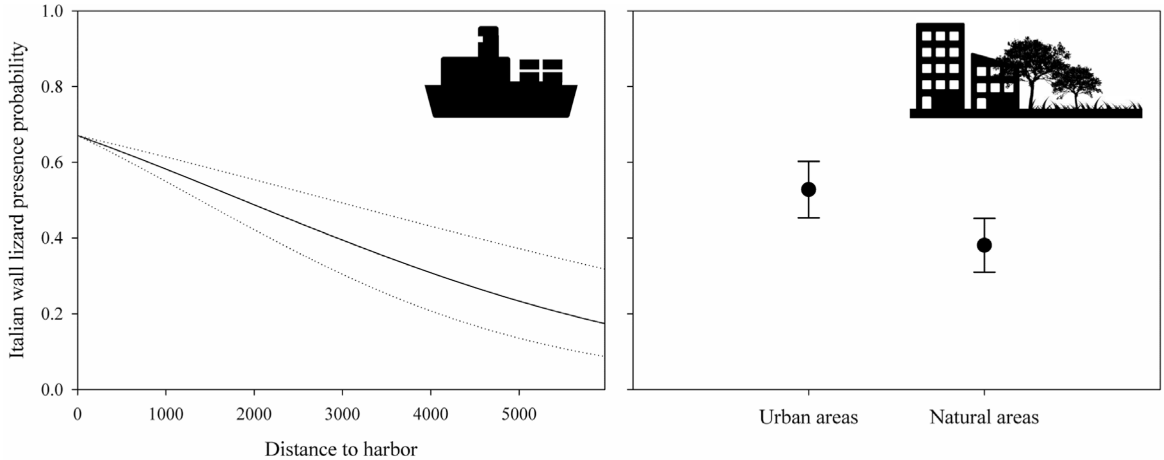

Figure 3. Factors affecting the presence probability of the Italian Wall Lizard (*Podarcis siculus*) in the observation plot. Left: the probability decreases according to the distance to the harbor (dotted lines are upper and lower standard errors. The graph data were fitted from the second GLMM, the best supported model). Right: the probability is higher in urban areas than in natural areas (the graph data were fitted from the seventh GLMM, the second ranked model and the best one including the urbanization variable).

indicating greater support; Burnham and Anderson 2002). We considered as plausible all models with ΔAIC < 2 (Burnham et al. 2011).

Results

We recorded the presence of the introduced Italian Wall Lizard in all survey areas (n = 20), including both human-related and natural environments. The three survey areas in Vulcano town (harbor, town center and near Capo Grosso) were heavily invaded, with Italian Wall Lizards present in 80% of observation plots. In most survey areas (including Vulcanello peak, Capo Grosso proximal cliffs, and Gran Cratere peak), this invasive species was detected in 40–60% of observation plots. Overall, we surveyed 100 observation plots, recording the presence of the Italian Wall Lizard in almost half of them (n = 46). See Appendix 1 for raw data and Appendix 2 for more details on species detectability in different habitats.

The AIC model selection highlighted three supported models. The first supported model was the only GLMM concerning the Introduction Gateway hypothesis, whereas both second and third supported models were related to the combination of Introduction Gateway and Invasion Pathway hypotheses (Table 1). These three models together represented 87% of wAIC, and there were no significant differences among them (the ΔAIC among them was < 2). All of the models included the variable distance to the harbor, which is also included in the fourth ranked model, and therefore appears to be the most relevant predictor of the presence probability of the Italian Wall Lizard in the observation plot. This probability decreased according to the distance to the harbor (Table 2), being approximately three times higher in the harbor proximities than in the farther

Table 1. Factors affecting the presence probability of the Italian Wall Lizard (*Podarcis siculus*) in the observation plot (with survey area as a random factor) and model ranks by AIC weights. ΔAIC is the relative difference of a given AIC value compared to the smallest AIC value. The supported models (ΔAIC < 2) are highlighted in grey. AIC weights indicate the relative support for every model (the weights of all the models in the candidate set have the sum of 1). The DF column indicates degrees of freedom for each model and ER is the evidence ratio, which is the ratio of wAIC comparing the best-supported model with every competing one.

Hypothesis	Model	AIC	ΔAIC	wAIC	DF	Rank	ER
Null	-	140.0	6.9	0.01	19	-	-
Introduction gateway	harbor distance	133.1	0.0	0.37	79	1	1.0
Invasion pathway	urbanization	139.5	6.4	0.01	80	-	-
	urban distance	140.2	7.1	0.01	79	-	-
	habitat	140.5	7.4	0.01	76	-	-
	elevation	138.3	5.2	0.03	79	-	-
Combinations	harbor distance + urbanization	133.2	0.1	0.34	79	2	1.1
	harbor distance + habitat	136.8	3.7	0.06	75	-	-
	harbor distance + elevation	134.7	1.6	0.16	78	3	2.3

Table 2. Factors affecting presence probability of the Italian Wall Lizard (*Podarcis siculus*) in the observation plot (with survey area as a random factor) and parameter estimates for supported models. For parameter estimates, values in parentheses are standard errors (± 1 SE). The last column shows the 95% confidence intervals (CI) for each explanatory variable.

Hypothesis	Model	Explanatory variables	Variable categories	Parameter estimates (± SE)	95% CI
Introduction gateway	1st ranked	intercept	-	0.7117 (± 0.3611)	
		harbor distance	-	-0.0004 (± 0.0001)	-0.0006, -0.0001
Combinations	2nd ranked	intercept	-	0.9942 (± 0.4239)	
		harbor distance	-	-0.0004 (± 0.0001)	-0.0006, -0.0001
		urbanization	urban areas	0	
			natural areas	-0.5991 (± 0.4242)	-0.2281, 1.4422
	3rd ranked	intercept	-	0.7544 (± 0.3657)	
		harbor distance	-	-0.0003 (± 0.0001)	-0.0006, -0.0001
		elevation	-	-0.0009 (± 0.0014)	-0.0037, 0.0018

observation plots, which were located almost 6 km away from the harbor (Fig. 3). The second supported model additionally included the variable urbanization degree and the third supported model, the variable topographic elevation (Table 1). The presence probability of the Italian Wall Lizard in the observation plot was higher in urban than in natural environments (Fig. 3), and also at low elevations compared to high elevations (Table 2). Nevertheless, considering the 95% confidence intervals of these variables in their best supported models, both urbanization degree and topographic elevation appeared to be not so relevant in determining the presence probability of the Italian Wall Lizard in the observation plot (Table 2).

Discussion

The present study confirmed, for the first time with quantitative data, the widespread invasion of the introduced Italian Wall Lizard on Vulcano, the only relatively large island still inhabited by the critically endangered Aeolian Wall Lizard. These findings depict an alarming scenario for this narrowly endemic species, which is now facing an imminent extinction risk. The invasive Italian Wall Lizard has been previously described to be widespread throughout the island of Vulcano, including the lowest elevations of both Gran Cratere and Vulcanello (Capula 1993, 1994; Capula et al. 2002; Lo Cascio 2010). The competitive pressure of this introduced species appears to have forced the last populations of the endemic Aeolian Wall Lizard to the summit areas of Gran Cratere (Lo Cascio 2010; Birgit Oefinger and Peter Oefinger, unpubl. report) and Vulcanello (where it appears to be now extinct; Capula et al. 2002), in addition to the small population on the distal cliffs of Capo Grosso promontory (Lo Cascio 2010). We found, for the first time, several individuals of the invasive Italian Wall Lizard on those summit areas of Gran Cratere and Vulcanello, and also on the proximal cliffs of Capo Grosso promontory. The renewed threats of the competitive pressure, together with the hybridization risk (Capula 1993, 1994; Capula et al. 2002), and the absence of control plans for the invasive lizards, suggest that the population of Aeolian Wall Lizards on Gran Cratere may be considered virtually extinct at this time. Overall, the persistence of the last relatively viable population of the endemic Aeolian Wall Lizard on Vulcano only depends on the inaccessibility of the distal area of Capo Grosso promontory. A stochastic event such as a rockslide could connect the distal and the proximal areas of the promontory, and consequently the populations of Aeolian and Italian Wall Lizards would no longer be separated. This likely would results in the extinction of the endemic lizard from the only relatively large island of its distribution range.

At present there is a compelling need for establishing a control plan focused on the eradication of the Italian Wall Lizards from the area of Capo Grosso promontory, but also from the summit areas of Gran Cratere and Vulcanello. This control should be ideally performed at the same time as the establishment of exclusion fences (see, for example, Toda et al. 2010). On the other hand, our model selection highlighted that the distance to the harbor is the most relevant factor in determining the presence of this invasive species on Vulcano, with more presence probability in the harbor surroundings. The harbor has been previously suggested to represent the main introduction gateway of the introduced Italian Wall Lizard on Vulcano (Corti et al. 1999) and also in other invaded areas (Podnar et al. 2005). As a consequence, any program aiming to control the invasive Italian Wall Lizard on Vulcano should establish a biosecurity procedure focused on avoiding the introduction of stowaway individuals travelling on cargo and passenger ships, as suggested by others in similar cases (Chapple et al. 2016; Silva-Rocha et al. 2016; Spatz et al. 2017). At the same time, our results highlighted that the urbanization degree was not so relevant in determining the current distribution of the invasive lizards on Vulcano. However, previous literature described that until the 1990s, the distribution of the Italian Wall Lizard was mostly limited to human-related habitats (Capula et al. 2002). We recorded the presence of this species in all survey areas (including both human-related and natural environments), so this species may now too widespread to highlight an invasion pathway related to urbanization gradients.

The Italian Wall Lizard is a habitat-generalist species, which is able to successfully persist in urban and semi-urban areas (e.g., Mangiacotti et al. 2013; Vignoli et al. 2017), especially when these areas coincide with the introduction gateways (Silva-Rocha et al. 2012; Kolbe et al. 2013; Lillo et al. 2013). Overall, human environments appear to host the source populations of the Italian Wall Lizard on Vulcano, and any program aiming to control an invasive species should also focus on undermining the source populations (Hampton et al. 2004; Simberloff 2009). Furthermore, a control program in urban and semi-urban areas would entail simple logistics and less probability to accidentally target native non-synanthropic species (van Heezik et al. 2008; D'Amico et al. 2013), in this case the endemic Aeolian Wall Lizard.

We aimed to determine simultaneously the distribution of an alien species and the factors facilitating its invasion pathway. We suggest the need to implement a control program acting on the introduction gateway (the harbor of Vulcano), the source populations (urban and semi-urban areas), and the most critical invaded areas. These areas include Capo Grosso promontory, where the Italian Wall Lizard might threaten the endangered Aeolian Wall Lizard, and Gran Cratere and Vulcanello summit areas, two of the last areas in which the endemic lizard was observed. At the same time, we reiterate the need to accomplish the conservation recommendations previously suggested for the narrow-endemic Aeolian Wall Lizard: establishment of legal protection for this species and the creation of a captive-breeding program (Capula et al. 2002; Lo Cascio 2006, 2010; Gippoliti et al. 2017). We think this is probably the last chance to recovery the most important populations of this critically endangered lizard.

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Appendix 1. Both human-related areas (hra) and natural areas (hn) are listed in the survey area column. Each survey area includes five observation plots. For presence, 0 is study species absent and 1 is study species present. Harbor distance, urban distance, and elevation are in meters. Urbanization is 1 for human-related areas (hra) and 0 for natural areas (hn). Habitat categories are: ur = urban areas; su = semi-urban areas (gardens and orchards); wo = woodlands; sh = shrublands (old fields and natural scrublands); cl = cliffs; and vo = volcanic areas.

Survey area	Observation plot	Presence	Harbor distance	Urbanization	Urban distance	Habitat	Elevation
1 hra	1	1	915	1	0	ur	15
1 hra	2	0	970	1	0	ur	20
1 hra	3	1	1075	1	0	ur	25
1 hra	4	1	770	1	0	su	10
1 hra	5	0	790	1	0	ur	10
2 hra	1	1	745	1	0	su	0
2 hra	2	1	780	1	0	su	0
2 hra	3	0	845	1	0	ur	5
2 hra	4	1	890	1	0	ur	5
2 hra	5	0	820	1	0	ur	5
3 hra	1	1	1170	1	0	su	10
3 hra	2	0	1125	1	0	ur	10
3 hra	3	1	1020	1	0	su	5
3 hra	4	1	945	1	0	su	5
3 hra	5	1	910	1	0	ur	5
4 hra	1	0	0	1	0	ur	5
4 hra	2	1	90	1	0	ur	5
4 hra	3	1	130	1	0	ur	5
4 hra	4	1	200	1	0	ur	5
4 hra	5	1	225	1	0	ur	5
5 hra	1	1	300	1	0	ur	5
5 hra	2	1	690	1	0	ur	15
5 hra	3	1	510	1	0	ur	5
5 hra	4	0	500	1	0	ur	10
5 hra	5	1	285	1	0	ur	5
6 hra	1	0	1920	1	0	su	140
6 hra	2	0	1850	1	0	su	145
6 hra	3	0	1775	1	0	su	160
6 hra	4	1	1680	1	0	su	175
6 hra	5	1	1820	1	0	su	145
7 hra	1	1	3685	1	0	su	360
7 hra	2	1	3705	1	0	ur	370
7 hra	3	0	3740	1	0	ur	380
7 hra	4	0	3730	1	0	ur	380
7 hra	5	0	3780	1	0	su	380
8 hra	1	0	3570	1	0	su	330
8 hra	2	1	3600	1	0	su	330
8 hra	3	1	3640	1	0	ur	335
8 hra	4	0	3665	1	0	ur	335
8 hra	5	0	3680	1	0	su	335
9 hra	1	0	4405	1	0	su	410
9 hra	2	0	3400	1	0	ur	410
9 hra	3	1	4410	1	0	ur	415
9 hra	4	0	4315	1	0	ur	400

Appendix 1 (Continued). Both human-related areas (hra) and natural areas (hn) are listed in the survey area column. Each survey area includes five observation plots. For presence, 0 is study species absent and 1 is study species present. Harbor distance, urban distance, and elevation are in meters. Urbanization is 1 for human-related areas (hra) and 0 for natural areas (hn). Habitat categories are: ur = urban areas; su = semi-urban areas (gardens and orchards); wo = woodlands; sh = shrublands (old fields and natural scrublands); cl = cliffs; and vo = volcanic areas.

Survey area	Observation plot	Presence	Harbor distance	Urbanization	Urban distance	Habitat	Elevation
9 hra	5	1	4170	1	0	ur	390
10 hra	1	0	5970	1	0	su	5
10 hra	2	0	5895	1	0	su	5
10 hra	3	1	5830	1	0	ur	0
10 hra	4	0	5845	1	0	ur	0
10 hra	5	0	5820	1	0	ur	55
1 na	1	0	1310	0	120	cl	5
1 na	2	0	1300	0	160	cl	5
1 na	3	1	1235	0	130	sh	10
1 na	4	1	1575	0	50	sh	20
1 na	5	0	1660	0	150	sh	15
2 na	1	0	1320	0	80	sh	60
2 na	2	0	1280	0	85	sh	75
2 na	3	1	1250	0	220	sh	100
2 na	4	0	1335	0	330	sh	100
2 na	5	1	1290	0	305	sh	115
3 na	1	0	1300	0	290	sh	15
3 na	2	1	1270	0	260	sh	20
3 na	3	1	1240	0	230	sh	30
3 na	4	0	1220	0	130	sh	25
3 na	5	1	1220	0	120	sh	30
4 na	1	0	1430	0	1080	vo	390
4 na	2	1	1470	0	1060	vo	380
4 na	3	1	1400	0	1050	vo	370
4 na	4	0	1200	0	995	vo	300
4 na	5	0	1500	0	875	vo	380
5 na	1	1	955	0	145	sh	62
5 na	2	1	1170	0	215	sh	95
5 na	3	0	1200	0	290	sh	120
5 na	4	1	1300	0	340	sh	140
5 na	5	0	1415	0	480	sh	170
6 na	1	0	1970	0	170	sh	90
6 na	2	0	1975	0	105	sh	95
6 na	3	1	1995	0	95	sh	80
6 na	4	1	2060	0	120	sh	70
6 na	5	0	2115	0	200	sh	30
7 na	1	1	3090	0	320	su	365
7 na	2	0	3120	0	335	sh	370
7 na	3	0	3150	0	340	sh	375
7 na	4	0	3120	0	350	wo	360
7 na	5	0	3150	0	310	wo	370
8 na	1	1	3440	0	240	su	360
8 na	2	0	3335	0	350	wo	400
8 na	3	0	3200	0	490	wo	435

Appendix 1 (Continued). Both human-related areas (hra) and natural areas (hn) are listed in the survey area column. Each survey area includes five observation plots. For presence, 0 is study species absent and 1 is study species present. Harbor distance, urban distance, and elevation are in meters. Urbanization is 1 for human-related areas (hra) and 0 for natural areas (hn). Habitat categories are: ur = urban areas; su = semi-urban areas (gardens and orchards); wo = woodlands; sh = shrublands (old fields and natural scrublands); cl = cliffs; and vo = volcanic areas.

Survey area	Observation plot	Presence	Harbor distance	Urbanization	Urban distance	Habitat	Elevation
8 na	4	0	3020	0	480	sh	465
8 na	5	0	2925	0	495	sh	480
9 na	1	1	4520	0	50	sh	460
9 na	2	1	4530	0	100	sh	485
9 na	3	0	4540	0	150	sh	490
9 na	4	0	4550	0	160	sh	490
9 na	5	0	4560	0	130	sh	495
10 na	1	0	5900	0	50	cl	5
10 na	2	0	5880	0	90	cl	10
10 na	3	0	5860	0	125	cl	5
10 na	4	1	5840	0	160	cl	5
10 na	5	0	5820	0	200	cl	10

Appendix 2. The presence probability of the Italian Wall Lizard in the observation plot is a proxy of both species abundance and detectability. According to the available literature, species abundance should be higher in urban and semi-urban areas, decreasing in shrublands and rocky grounds (cliffs and volcanic areas), and it should be lowest in woodlands (Capula 1993, 1994; Capula et al. 2002; Lo Cascio 2010). On the other hand, according to the amount of vegetation, the species detectability should be higher in rocky grounds, decreasing in urban and then in semi-urban areas, and it should be lower in shrublands and then woodlands. The presence probability of the Italian Wall Lizard in the observation plot was higher in urban areas than in rocky grounds (Figure), suggesting that our response variable was mostly related to species abundance, and not so related to species detectability. We cannot completely exclude that species detectability can somehow affect the presence probability of the Italian Wall Lizard in the observation plot.

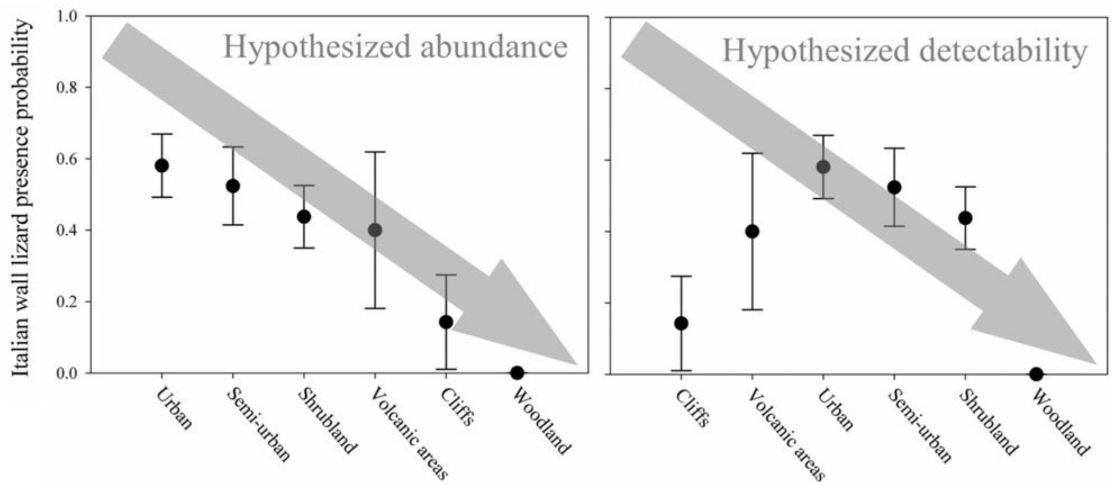

Figure. Relationship between presence probability of the Italian Wall Lizard in the observation plot and habitat, considering the survey area as a random factor. The graph data were fitted from the fifth GLMM, the model including only habitat as explanatory variable. Left, the presence probability is visually compared with the hypothesized abundance of the Italian Wall Lizard in different habitats. Right, the presence probability is visually compared with the hypothesized detectability of the Italian Wall Lizard in different habitats.

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