

Thermal ecology of the Aeolian wall lizard, *Podarcis raffonei*. What about body temperatures in microinsular lizards?

MASSIMO CAPULA^{1*}, CLAUDIA CORTI², PIETRO LO CASCIO³, LUCA LUISELLI⁴

¹ Museo Civico di Zoologia - Via Aldrovandi 18, 00197 Roma, Italy

² Museo di Storia Naturale dell'Università di Firenze, Sezione di Zoologia "La Specola"
Via Romana 17, 50125 Firenze, Italy

³ Associazione Nesos - Via Vittorio Emanuele 24, 98055 Lipari (ME), Italy

⁴ Centro di Studi Ambientali Demetra s.r.l. - Via Olona 7, 00198 Roma, Italy

*Corresponding authors: massimo.capula@comune.roma.it and plocascio@nesos.org

Abstract. In this paper some aspects of the thermal ecology of *Podarcis raffonei*, a lacertid lizard endemic to the Aeolian Archipelago (NE Sicily, Tyrrhenian Sea) which is on the verge of extinction and is now considered as one of the most endangered lizard species in Europe, are provided. Field body temperatures were recorded on adult lizards from two islets (Scoglio Faraglione and Strombolicchio) which are separated each other by a long and deep sea channel and are characterized by different landscape. The range of the body temperatures registered in *P. raffonei* is congruent with the field body temperatures known for some lacertid lizard species occurring on other Mediterranean small islands. *Podarcis raffonei* seems to adopt a strictly heliothermic strategy. The studied lizard populations were not thermoconformers, as they do actively bask and keep their temperatures regardless of the environment thermal conditions. Despite thermal conditions were identical on the two islets, mean and median body temperatures were higher on Scoglio Faraglione than on Strombolicchio. The difference in body temperatures observed in the investigated populations could be explained taking into account some operating natural selection factors (different genetic and morphological characteristics of the studied populations; different geological, pedological and vegetation cover characteristics of the two islets; different morphology and sun exposure of the rocky slopes of the islets).

Keywords. *Podarcis raffonei*, Lacertidae, thermal ecology, Aeolian Islands, Sicily.

INTRODUCTION

Field records of body temperatures are essential to understand how lizards interact with their thermal environment (see e.g. Huey et al., 1977; Van Damme et al., 1989; Adolph, 1990). However at present there are no available data on thermal biology for many threatened or endangered lizard species, and this lack of information may be counter-producing for designing correct conservation programs. In this respect it must be noted that in reptiles the role of thermoregulation for maintenance of optimal physiological functions is unequivocally linked to habitat selection (e. g. Huey, 1991; Reinert, 1993), and thus understanding the thermal ecology characteristics of lizards may help to secure proper management of their

habitat (Angilletta, 2000; Huang and Tu, 2008, 2009; Angilletta et al., 2009). This is especially true for lizards inhabiting Mediterranean microinsular habitats, which are generally affected by extreme poorness of trophic resources and strong temporal changes in both abiotic and biotic conditions (see Pèrez-Mellado, 1989; Castilla and Bauwens, 1991; Lo Cascio, 2006; Lo Cascio and Capula, 2011).

In Europe most of the endangered lizard species, i.e. those which are particularly prone to extinction and should be considered of prior importance for conservation programmes, are known to occur on small Mediterranean islands. Among the lizards inhabiting small Mediterranean islands, *Podarcis raffonei* (Mertens, 1952) is considered to be one of the most threatened lizards in Europe and certainly the most endangered lizard species in Italy, being at present on the verge of extinction (Capula et al., 2002; Corti and Lo Cascio, 2002; Capula, 2004; Capula and Lo Cascio, 2006, 2011).

Podarcis raffonei is endemic to the Aeolian Archipelago (NE Sicily, S Tyrrhenian Sea), where it occurs with four relict populations on three tiny islets (La Canna, Scoglio Faraglione, Strombolicchio), each with an area less than 2 ha, and on a very small area (<5,000 m²) on Vulcano island (Capula and Lo Cascio 2006, 2011). All populations consist of a very small number of individuals, and currently the abundance of the species in the whole range is estimated to be ~ 920-1380 individuals (Capula et al., 2002; Lo Cascio, 2010; Capula and Lo Cascio, 2011).

According to Amori et al. (2012) the probability of extinction for an endemic species is 80% for islands smaller than 3,120 km². This is just the area of each of the three Aeolian islets inhabited by *P. raffonei* (see above), and thus the species is likely threatened by extinction. It is currently listed as Critically Endangered by the IUCN (2012) because its area of occupancy is less than 10 km², its distribution is severely fragmented, and the number of mature individuals is continuously declining, particularly on Vulcano Island (Capula et al., 2002; Capula and Lo Cascio, 2006, 2011; IUCN, 2012).

With the exception of a few preliminary data (see Lo Cascio, 2006), there is no available information on field body temperatures of the species to date. In this paper some aspects of the thermal ecology of *Podarcis raffonei* are provided. Body temperatures were recorded on adult lizards from two islets (Strombolicchio and Scoglio Faraglione) which are separated each other by a long and deep sea channel and are characterized by different landscape.

MATERIALS AND METHODS

Study area

Scoglio Faraglione and Strombolicchio are two uninhabited islets of the Aeolian Archipelago (Fig. 1). Both are of volcanic origin and are composed by basaltic lavas. The two islets were chosen to study body temperatures of lizards on the basis of two main factors: 1) they host lizard population densities a little bit higher than those known for La Canna Islet and Vulcano Island, (2) because of the access which

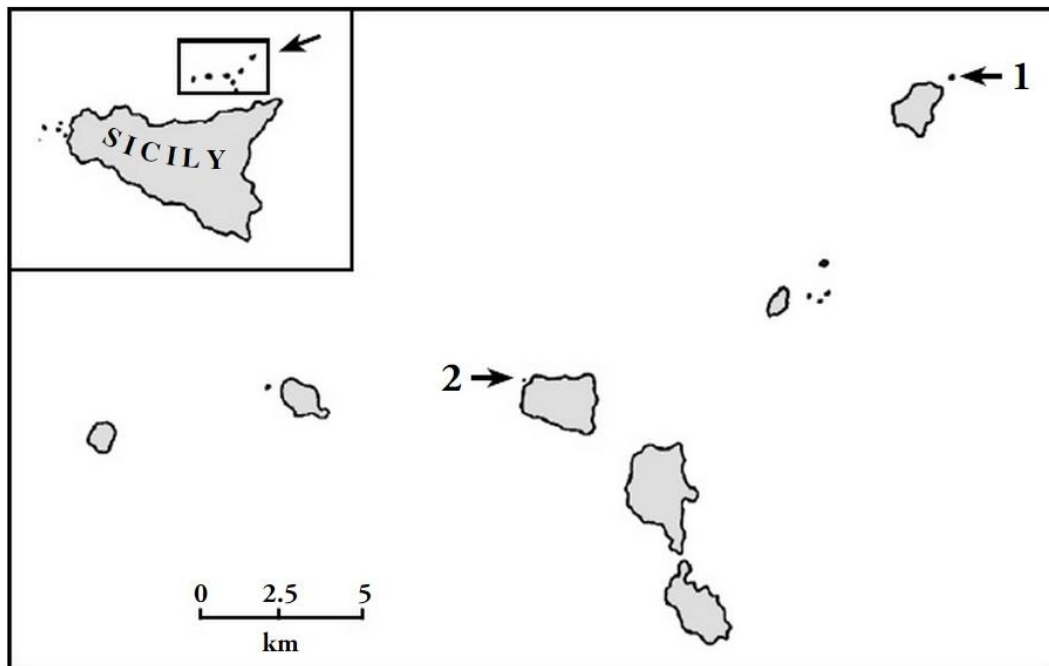


Figure 1. Map of the Aeolian Islands. Study areas: **1**, Strombolicchio Islet (1.5 Km NE of Stromboli Island); **2**, Scoglio Faraglione (300 m W of Salina Island). Insert shows location of the Aeolian Archipelago.

is much more easier than that of La Canna (an islet characterized by vertical rock cliffs), and the area of Vulcano Island where the species at present lives.

Scoglio Faraglione ($38^{\circ}34'77''\text{N}$ - $14^{\circ}48'08''\text{E}$, 300 m off the W coast of Salina Island; hereafter SFA) has a surface of 5,765 m² and a maximum altitude of 35 m a.s.l. The top of the islet is covered by dense shrub vegetation characterized by *Senecio cineraria bicolor*, *Dianthus rupicola aeolicus* and *Lotus cytisoides*, while the rocky slopes of the basal belt, often affected by small landslides and occupied by debris conoids, harbour halo-chasmophytic plant communities characterized by *Limonium minutiflorum* and *Inula crithmoides*.

Strombolicchio ($38^{\circ}49'07''\text{N}$ - $15^{\circ}15'13''\text{E}$, 1.5 km off NE coast of Stromboli Island; hereafter STB) has a surface of 7,623 m² and a maximum altitude of 49 m a.s.l. The top of the islet was partially destroyed in the early 20th Century because of the building of a lighthouse. The surroundings of this artificial flat area are covered by few *Euphorbia dendroides*, while the cliffs are composed mainly by steep and bare lavas, sparsely covered by *Dianthus rupicola aeolicus* and *Hyoseris taurina*.

Average annual rainfall (on the main islands of the archipelago) is about 600 mm, with a peak in December and a minimum in July; average temperatures range from 13.3 °C (January) to 29.8 °C (August) (Cicala, 1997).

The two islets differ in terms of micro-climatic and vegetation characteristics: SFA, as a consequence of being very close to the main island (Salina), which makes it partially protected from the sea winds, is characterized by a more dense and well-structured vegetation and by a less xeric environment than STB.

Study lizards

Podarcis raffonei is a medium-sized lizard. The studied microinsular populations are characterised by brownish (SFA) or very dark brown (STB) dorsal coloration, and by ventral parts pearl-grey (SFA) or reddish (STB). SFA and STB populations are referred, respectively, to the ssp. *alvearior* (Mertens, 1955) and to the nominal form; the latter is genetically and morphologically very differentiated from the other known populations (see Capula, 2004, 2006; Capula et al., 2009). Lizard population densities are similar on both islets (SFA: 200-400 individuals; STB: 500-600 individuals; Lo Cascio, 2010). Lizards are active mainly from March to November, but activity can be observed also in sunny days during the cooler season. As usual for the Mediterranean lizards, the activity pattern is bimodal in summer and uni-modal in spring and autumn (Capula and Lo Cascio, 2011).

Field protocol

Field work was undertaken between April and September on SFA (April 5, 2010; May 11, 2010; June 4, 2010; September 8, 2010), and between March and September on STB (March 30, 2010; July 2, 2010; September 10, 2010). Body temperatures (T_b) were taken in the middle of the day (between 11.00 a.m. and 3.00 p.m.) from adult active lizards noosed or captured by hand on the top areas of the islets, using a quick reading cloacal thermometer “Miller & Weber” ($\pm 0.2^\circ$ C of accuracy) and taking care to minimise heat flow during handling. Due to the overall rarity of this species (see above), sample sizes were not randomly small. Each individual was sexed, measured (Snout-Vent Length, SVL) using a calliper (± 0.1 mm of accuracy), and released after examination. Air temperature (T_a) was recorded 2 cm above the soil surface with a shaded bulb. Substrate temperature (T_s) was measured from just below the soil surface, with about one layer of soil particles covering the top of the bulb.

Statistical analyses

All parametric tests were performed after having verified normality and homoscedasticity, with alpha set at 5% and tests being two-tailed. When data normality was not achieved, non-parametric tests were used (Zar, 1984). Since on both islets T_a and T_s were highly positively correlated, we utilized the residuals of the general regression of T_a versus T_s as a surrogate of these two variables to avoid redundancy in statistical analyses. Averages of the residuals from the two study islets were compared by Student t-test in order to verify whether the ‘thermal environment’ was similar at the two sites; means of body temperatures between sites were compared by Student t-test, and medians by a Monte Carlo median test with 5000 iterations. Correlations between T_b and the residuals of T_a and T_s , and between T_b and SVL were analyzed by Pearson’s correlation coefficient. Heterogeneity of the slopes of two regression lines was assessed by one-way Analysis of Covariance (ANCOVA). Means are presented as ± 1 Standard Deviation. All statistical tests were done with Statistica version 11.0 package.

RESULTS

Overall, 76 adult lizards were sampled (37 individuals on SFA, 39 on STB). Mean SVL of the lizard samples from SFA was 71.5 ± 2.1 ($n = 24$) for males, and 63 ± 2.6 mm ($n = 13$) for females; mean SVL of the lizard samples from STB was 83.8 ± 3.5 ($n = 22$) for males, and 75.2 ± 5.1 mm ($n = 17$) for females. These data are in agreement with the morphometric analyses carried out by CAPULA et al. (2009) and clearly indicate that the individuals from STB are considerably larger than those from SFA.

On both islets T_a and T_s were highly positively correlated (SFA: $r = 0.591$, $n=39$, $P<0.0001$; STB: $r = 0.959$, $n = 30$, $P<0.00001$). The residuals of the general regression of T_a versus T_s for SFA and STB were not significantly different ($t = 0.001$, $df = 66$, $P = 0.998$), which means that the bioclimatic conditions on the two islets were nearly identical. Because of the similarity in thermal characteristics of the environments, any eventual difference in thermal biology of the two lizard populations would have been particularly noteworthy. Mean T_b was $34.7 \pm 1.8^\circ\text{C}$ ($n = 37$) on SFA, and $33.2 \pm 3.1^\circ\text{C}$ ($n = 30$) on STB; the difference between the two averages was statistically significant ($t = -2.493$, $df = 66$, $P = 0.0151$). Median T_b was also higher on SFA than on STB (34.8°C versus 33°C ; Monte Carlo $P = 0.0145$). There was no statistically significant positive relationship between residuals of the regression T_a on T_s and T_b (SFA: $r = 0.003$, $n = 39$, $P = 0.987$; STB: $r = 0.257$, $n = 30$, $P = 0.170$; Fig. 2), indicating that both lizard populations were not thermoconformers. In addition, the two regression lines did not differ significantly (ANCOVA on slopes: $F_{1,67} = 1.265$, $P < 0.265$), showing a similar relationship between body and environment temperatures in both lizard populations. On SFA there was no significant correlation between SVL and T_b ($r = -0.110$, $n = 39$, $P = 0.517$), and the same was true on STB ($r = 0.216$, $n = 30$, $P = 0.250$).

DISCUSSION

The range of the body temperatures registered in *P. raffonei* (SFA: mean $T_b = 34.7^\circ\text{C}$; STB: mean $T_b = 33.2^\circ\text{C}$) is congruent with the field body temperatures known for some lacertid lizard species occurring in the Mediterranean area (mean T_b ranging between 31.9 and 35.5°C ; Castilla et al. 1999; Lo Cascio 2006, 2010). Similarly to other Mediterranean lizards, *P. raffonei* seems to adopt a strictly heliothermic strategy. Although the thermal environment available to lizards is very similar on SFA and STB islets, the two lizard populations revealed some intriguing peculiarities in terms of their relationships with the thermal environment, beyond a general and expected similarity in thermal ecology. The lack of correlation between lizard T_b and environment temperatures clearly shows that both lizard populations are not thermoconformers, as they do actively bask and keep their temperatures regardless of the environment thermal conditions. These results are similar to those reported by Lo Cascio (2010) for a population of the scincid lizard *Chalcides ocell-*

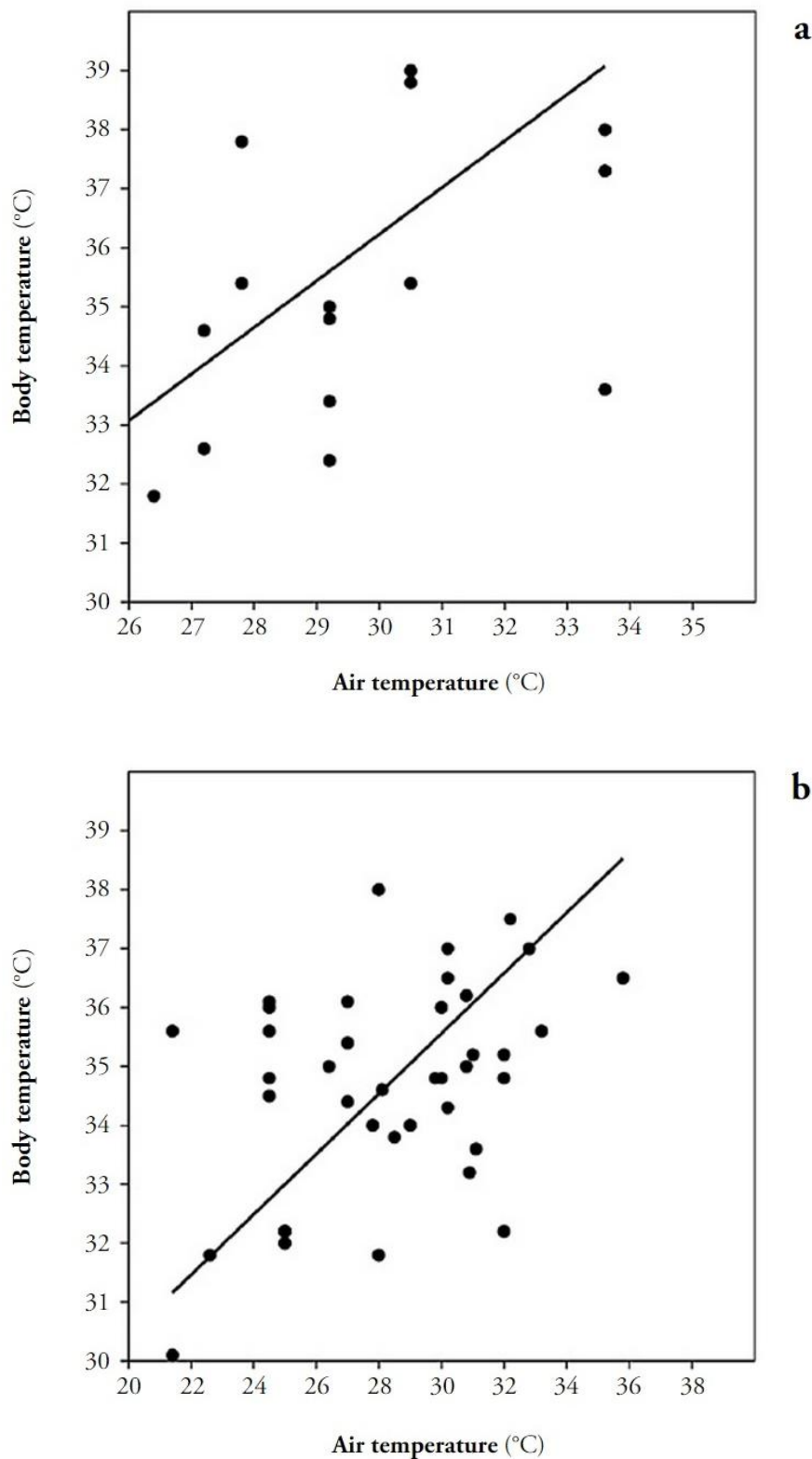


Figure 2. Relationships between T_a and T_b at the two study islets, STB (**a**), and SFA (**b**). For statistical details, see the text.

latus (Forskål, 1775) from a small Mediterranean island (Linosa). In addition, the homogenous slopes of their regressions T_b versus residuals of environment thermal conditions indicate that the thermoregulation strategy of both populations is quite

similar, despite evident differences in body size and coloration, STB lizards being darker and larger than those occurring on SFA (see above). On the other hand, the population from SFA exhibited a consistent trend for a T_b higher than that of the STB population. The results of previous studies concerning the relationship between lizard thermoregulation and melanistic coloration (e.g. Lanza et al., 1986; Tosini et al., 1991) suggest that melanistic coloration would not influence the rate of body heating or the maintenance of different body temperature ranges; hence, the differences observed in the body temperatures of the lizard populations from SFA and STB would be not explained on the basis of their different coloration pattern. However, it must be noted that the results by Lanza et al. (1986) and Tosini et al. (1991) were not confirmed by other studies on melanism in reptiles (see e.g. King, 1987; Madsen and Stille, 1988; Luiselli, 1992; Capula and Luiselli, 1994), and thus we think that the role of melanistic coloration in influencing the rate of lizard body heating should be reconsidered and further explored by ad-hoc experiments in the Aeolian wall lizard populations.

Although our study patterns were inferred from correlational evidence (see Zar 1984) and based on the present data it is not possible to give any firm conclusion, some operating natural selection factors are listed below that could explain in some way the difference in body temperatures observed in the investigated populations. First, it must be noted that some differences between the two islets do exist concerning morphology and sun exposure of their rocky slopes. In particular, Strombolicchio is entirely surrounded by vertical cliffs and seems more settled than Scoglio Faraglione, whose perimetral slopes are less steepy and are affected by an intense erosive process. Moreover, it must be stressed that, as reported above, the lizards from Strombolicchio are genetically and morphologically very differentiated from those inhabiting Scoglio Faraglione. As it is well known that the interactions between lizards and their thermal environment are strictly related to size and genetic traits of the lizards themselves (see Huey and Kingsolver, 1989; Adolph, 1990; Grant and Dunham, 1990), we can hypothesize that the differences in the observed body temperatures may be also explained on the basis of the different genetic characteristics of the studied populations, as these may constrain biochemical and physiological performances of lizards.

Finally, it is likely that the activity pattern, body temperatures, and temporary use of micro-refuges by lizards are influenced by the geological, pedological and vegetation cover characteristics of the two islets (see Materials and Methods, Study area, for relative detailed information). For instance, according to our field observations (Lo Cascio, 2010; Capula and Lo Cascio, pers. obs.) on SFA lizards occur almost exclusively in shaded refuges within the dense vegetation on the top of the islet, while on STB lizards generally alternate stays on the top of the islet, which is characterized by scarce vegetation and high exposure to sun, with frequent shifts in the partially shaded cliffs.

Acknowledgments. The field work was performed in the frame of the Research Project “Studio dell’erpetofauna della R.N.O. Le Montagne delle Felci e dei Porri e di altre aree dell’Isola di Salina”, which was funded by the Regional Province of Messina (D.P. n. 167, 30/12/2004). The authors wish to express their gratitude to Dr. Maria Letizia Molino, director of the Natural Reserve of Salina Island, for her support and assistance during fieldwork.

REFERENCES

- Adolph, S.C. (1990): Influence of behavioral thermoregulation on microhabitat use by two *Sceloporus* lizards. *Ecology* **71**: 315-327.
- Amori, G., Gippoliti, S., Luiselli, L. (2012): Ecological correlates of threatened endemic island rodents. *Mammalia* **76**: 15-20.
- Angilletta, M.J. (2000): Thermal effects on the energetics of lizard embryos: Implications for hatching phenotypes. *Ecology* **81**: 2957-2968.
- Angilletta, M.J., Pringle, R.M., Sears, M.W. (2009): Spatial dynamics of nesting behavior: lizards shift microhabitats to construct nests with beneficial temperatures. *Ecology* **90**: 2933-2939.
- Capula, M. (2004): Low genetic variation in a critically endangered Mediterranean lizard: conservation concerns for *Podarcis raffonei* (Reptilia, Lacertidae). *Italian Journal of Zoology* **71** (supplement): 161-166.
- Capula, M. (2006): Population heterogeneity and conservation of the Aeolian wall lizard, *Podarcis raffonei*. In: Mainland and insular lacertid lizards: a mediterranean perspective, p. 24-32. Corti, C., Lo Cascio, P., Biaggini, M., Eds., Firenze University Press, Firenze.
- Capula, M., Chiantini, S., Luiselli, L., Loy, A. (2009): Size and shape in Mediterranean insular lizards: patterns of variation in *Podarcis raffonei*, *P. sicula* and *P. wagleriana* (Reptilia, Squamata: Lacertidae). *Aldrovandia, Bollettino del Museo Civico di Zoologia di Roma* **5**: 217-227.
- Capula, M., Lo Cascio, P. (2006): *Podarcis raffonei* (Mertens, 1952) - Lucertola delle Eolie. In: Atlante degli Anfibi e dei Rettili d’Italia, p. 480-485. Sindaco, R., Doria, G., Razzetti, E., Bernini, F., Eds. Polistampa, Firenze.
- Capula, M., Lo Cascio, P. (2011): *Podarcis raffonei* (Mertens, 1952). In: Fauna d’Italia. Vol. XLV, Reptilia, p. 401-407. Corti, C., Capula, M., Luiselli, L., Razzetti, E., Sindaco, R., Eds, Calderini - Edizioni Calderini de Il Sole 24 ORE S.p.A., Bologna.
- Capula, M., Luiselli, L. (1994): Reproductive strategies in alpine adders, *Vipera berus*. The black females bear more often. *Acta Oecologica* **15**: 207-214.
- Capula, M., Luiselli, L., Bologna, M.A., Ceccarelli, A. (2002): The decline of the Aeolian wall lizard, *Podarcis raffonei*: causes and conservation proposals. *Oryx* **36**: 66-72.
- Castilla, A.M., Bauwens, D. (1991): Thermal biology, microhabitat selection, and conservation of the insular lizard *Podarcis hispanica atrata*. *Oecologia* **85**: 366-374.
- Castilla, A.M., Van Damme, R., Bauwens, D. (1999): Field body temperatures, mechanisms of thermoregulation and evolution of thermal characteristics in lacertid lizards. *Natura Croatica* **8**: 253-274.
- Cicala, A. (1997): Nozioni informative di meteorologia con riferimenti alle Isole Eolie. La Grafica, Messina.
- Corti, C., Lo Cascio, P. (2002): The Lizards of Italy and Adjacent Areas. Chimaira, Frankfurt-am-Main.
- Grant, B.W., Dunham, A.E. (1990): Elevational covariation in environmental constraints and life histories of the desert lizard *Sceloporus merriami*. *Ecology* **71**: 1765-1776.
- Huang, S.P., Tu, M.C. (2008): Cold tolerance and altitudinal distribution of *Takydromus* lizards in Taiwan. *Zoological Studies* **47**: 438-444.
- Huang, S.P., Tu, M.C. (2009): Locomotor and elevational distribution of a mountainous lizard, *Takydromus hsuehshanensis*, in Taiwan. *Zoological Studies* **48**: 477-484.

- Huey, R.B. (1991): Physiological consequences of habitat selection. *American Naturalist* **137** (Supplement): S91-S115.
- Huey, R.B., Kingsolver, J.G. (1989): Evolution of thermal sensitivity of ectotherm performance. *Trends in Ecology & Evolution* **4**: 131-135.
- Huey, R.B., Pianka, E.R., Hoffman, J.A. (1977): Seasonal variation in thermoregulatory behaviour and body temperature of diurnal Kalahari lizards. *Ecology* **58**: 1066-1075.
- IUCN (2012): IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 05 November 2012.
- King, R.B. (1987): Color pattern variation in the Lake Erie water snake, *Nerodia sipedon insularum*. *Evolution* **41**: 241-255.
- Lanza, B., Tosini, G., Bacci, M. (1986): Lizard skin reflectance spectra in relation to microinsular melanism: a preliminary study. *Médecine Biologie Environnement* **14**: 131-134.
- Lo Cascio, P. (2006): Aspetti ecologici e problemi di conservazione di una popolazione di *Podarcis raffonei* (Mertens, 1952) (Reptilia: Lacertidae). *Il Naturalista siciliano* **30**: 495-521.
- Lo Cascio, P. (2010): Attuali conoscenze e misure di conservazione per le popolazioni relitte dell'endemica lucertola delle Eolie, *Podarcis raffonei* (Squamata Sauria). *Il Naturalista siciliano* **34**: 295-317.
- Lo Cascio, P., Capula, M. (2011): Does diet in lacertid lizards reflect prey availability? Evidence for selective predation in the Aeolian wall lizard, *Podarcis raffonei* (Mertens, 1952)(Reptilia, Lacertidae). *Biodiversity Journal* **2**: 89-96.
- Luiselli, L. (1992): Reproductive success in melanistic adders: a new hypothesis and some considerations on Andrén and Nilson's (1981) suggestions. *Oikos* **64**: 601-604.
- Madsen, T., Stille, B. (1988): The effect of size dependent mortality on colour morphs in male adders, *Vipera berus*. *Oikos* **52**: 73-78.
- Pérez Mellado, V. (1989): Estudio ecológico de la lagartija balear *Podarcis lilfordi* (Günther, 1874) en Menorca. *Revista de Menorca* **53**: 455-511.
- Reinert, H.K. (1993): Habitat selection in snakes. In: *Snakes, Ecology and Behavior*, p. 201-240. Seigel, R.A., Collins, J.T., Eds. McGraw-Hill, New York.
- Tosini, G., Lanza, B., Bacci, G. (1991): On the thermoregulatory significance of microinsular melanism in the lizard of genus *Podarcis*. *Selected Symposia and Monographs Unione Zoologica Italiana* **4**: 613-629.
- Van Damme, R., Bauwens, D., Castilla, A.M., Verheyen, R.F. (1989): Altitudinal variation of the thermal biology and running performance in the lizard *Podarcis tiliguerta*. *Oecologia* **80**: 516-524.
- Zar, J.H. (1984): *Biostatistical Analysis*. Prentice-Hall, New Jersey.