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NON-CRUELTY ERADICATION OF EUROPEAN RABBIT (*ORYCTOLAGUS CUNICULUS*) FROM A SMALL MEDITERRANEAN ISLAND (ISOLA DELLE FEMMINE, ITALY)

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Abstract: European rabbit is, among mammals, one of the most widespread species almost worldwide, introduced on over 800 islands. In microinsular habitats, the introduction of alien species represents a major threat to biodiversity, and the European rabbit is included in the IUCN published list of the 100 worst invasive species. In 2008, an eradication plan was launched on "Isola delle Femmine", a small and uninhabited island of about 14.5 ha, located in the Mediterranean basin and established as a nature reserve in 1997 to protect its flora and vegetation. The present work was conducted to evaluate the effectiveness of a non-cruelty intervention through the trapping and translocation of live animals, avoiding the use of poisons or hunting in a sensitive microinsular habitat. The European rabbit eradication plan began in December 2007 and ended in 2016, with the complete eradication of the species achieved in 2012. During the 5 yr in which trapping took place on the island, a total of 799 rabbits were trapped and translocated. A significant positive correlation ($r=0.986$; $P=0.014$) was observed between the number of catches made during the year and the estimated rabbit density in July (considered the highest of the year). The method used showed considerable efficacy for the management of rabbit populations in microinsular environments, highlighting the possibility of intervention with these methods when control using poison or direct culling is impractical or inadvisable.

Key Words: rabbit, alien invasive, animal trapping, island restoration.

INTRODUCTION

The introduction of alien species represents a major threat to native fauna and flora, especially in microinsular habitats, causing declines and extinctions due to the lack of natural defences against invaders (Atkinson, 1989; 2001; Williamson, 1996; Courchamp *et al.*, 2003). Significant impacts may occur because of the introduction of plants (Affre *et al.*, 2010), predators (Croll *et al.*, 2005; Fukami *et al.*, 2006; Towns *et al.*, 2009) and herbivores (Martín-Esquivel *et al.*, 2020), by alteration of the structure and function of ecosystems.

European rabbit (*Oryctolagus cuniculus*) is one of the most widespread mammal species almost worldwide. It is native to the Iberian Peninsula and, probably, southern France (López-Martínez, 1989, 2008; Rogers *et al.*, 1994; Kaetzke *et al.*, 2003), and its spread and distribution have mainly been influenced by humans (Clutton-Brock, 1981; Flux,1994; Callou, 1995), especially for its traditional importance as a small game species. It is present in Europe, North Africa, South America, Australia and New Zealand (Ferrand, 2008) and has also been widely introduced on over 800 islands (Flux and Fullagar, 1992), where it is highly destructive (Flux and Fullagar, 1992; Williams *et al.*, 1995; Courchamp *et al.*, 2003). At the same time, in certain geographical areas where the European rabbit has been

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introduced historically, it has become a keystone species over time. In Sicily, for example, the European rabbit is the preferred prey for some endangered species, such as Bonelli's eagle (*Aquila fasciata*) (Di Vittorio *et al.*, 2019) and the European wildcat (*Felis silvestris*) (Anile *et al.*, 2019).

As a pest species, European rabbit is included in the IUCN (International Union for the Conservation of Nature) published list of the 100 worst invasive species (Global Invasive Species Database, 2020), and several attempts have been made to eradicate it from some islands to benefit local biodiversity and ecosystem recovery (Priddel *et al.*, 2000; Murphy *et al.*, 2010, Capizzi 2020). European rabbit can indeed alter natural habitats through its ecosystem engineering activity, with direct effects on vegetation cover and accelerating erosion processes (Chapuis *et al.*, 1994; Copson and Whinam, 1998; Priddel *et al.* 2000; Gálvez-Bravo *et al.*, 2011).

The eradication method is highly critical, especially in vulnerable environments such as small islets where the methods usually used are poisoning, trapping or hunting (Capizzi, 2020; Castaño *et al.,* 2022). In particular, the risk to non-target wildlife during eradications by poisoning on islands is a function of hazard and exposure, whereby hazard is the relative toxicity of the poison used to the animal, and exposure is how much and how often an animal is exposed to the poison (Castaño *et al.,* 2022). Likewise, eradication by hunting, especially during the reproductive periods of non-target species, can cause a great disturbance to non-target wildlife. Conversely, eradication through trapping may require longer times and a greater presence of operators in the field, but an almost zero impact on the non-target species. Therefore, the costs and the benefits of non-cruelty eradication must be carefully considered if there are particularly sensitive conditions. Isola delle Femmine is a small island in the Mediterranean basin, established as a protected area in 1997 for the conservation of flora and vegetation. After the Second World War, as well as a small herd of sheep, several rabbits belonging to the subspecies *O. cuniculus* (Lo Valvo *et al.*, 2014; 2017) had been voluntarily introduced on this island by humans for hunting purposes. After their introduction, the density of rabbits on the island was kept low because of hunting, but the establishment of the protected area resulted in a hunting ban, in addition to the end of competition for access to trophic resources caused by the eradication of domestic livestock. Therefore, given the combined absence of natural predators and the abundant presence of herbaceous plants, the European rabbit population reached and maintained high densities. This has resulted in a significant negative impact on the natural vegetation and soil morphology due to burrowing and grazing, with a deterioration in the conservation status of the protected area.

To avoid the detrimental effect caused by European rabbit on conservational goals of the protected area, since 2008 a rabbit eradication programme has been in place on the island. To avoid the undesirable effects of poisons and firearms in a small island with fragile ecosystems, we only used the method of non-lethal trapping and translocation to areas of Sicily where the European rabbit can be considered an ecological and socio-economic resource. In this work, we describe the methods and summarise the results obtained from a best practices perspective.

MATERIAL AND METHODS

Isola delle Femmine (Sicily, province of Palermo, Southern Italy: 38.211°N 13.235°E), formed of stratified Mesozoic limestone (Catalano *et al.*, 2013), is a small uninhabited island of about 14.5 ha (0-36.8 m a.s.l.), located 400 m away from the northwest coast of Sicily (Figure 1). It can only be reached by a small boat in favourable sea conditions. Since 1997, the entire island has been a dedicated Nature Reserve, established by the Regional Sicilian Government. It is also a "Special Area of Conservation", protected under European Union Directive 92/43/ EEC, better known as the "Habitat Directive" (code SAC/ZSC ITA020005).

The island is almost totally covered with forbs and scrubs typical of Mediterranean scrubland, including *Pistacia lentiscus*, *Thymelaea hirsuta* and *Chamaerops humilis* (Di Martino and Trapani, 1964; Caldarella *et al.*, 2010). Vascular plants of the island mainly include therophytes (~62%), hemicryptophytes (~20%), geophytes (~9%), chamaephytes (~5.5%), nanophanerophytes (~2.3%) and phanerophytes (~1.8%). Regarding chorotypes, the Mediterranean one is the most widespread (~33%). There is a wide range of floristic components (cosmopolite, subcosmopolite and xenophyte species), with 39 entities, 17.8% of the total plant taxa on the island. The endemic and sub-endemic contingents are represented by six taxa, i.e. 2.7% of the total (e.g. endemic taxa of north-western Sicily: *Limonium bocconei* and *Romulea linaresii* subsp. *linaresii*). Other endemic taxa have a regional (e.g. *Allium lehmani*), extra-

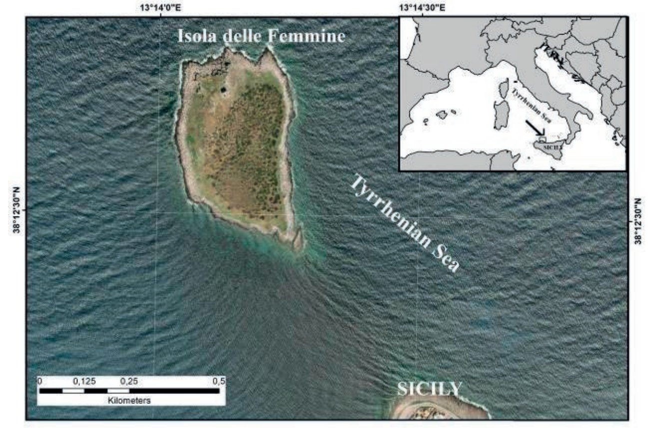

Figure 1: Map of the location of the nature reserve "Isola delle Femmine" (Sicily, Southern Italy).

regional Tyrrhenian (*Biscutella maritima*) or South Italian distribution (*Carlina sicula* subsp. *sicula*). Other rare species, whose extent of occurrence is not limited to Sicily, include *Delphinium emarginatum* subsp. *emarginatum*, *Galium verrucosum* subsp. *halophilum*, *Jacobaea delphinipholia* and *Ononis pendula* subsp. *boissieri* (Caldarella *et al.*, 2010).

The only building on the island is a late-medieval tower ruin, along with a few stone tanks for fish keeping (Riggio and Raimondo, 1992), dating back to the 4th century B.C. (La Rocca, 2004) and today no longer used.

Since 1988, the Mediterranean yellow-legged gull (*Larus michahellis*) has been breeding on the island (Lo Valvo *et al.*, 1993), with a current estimated 500 pairs (LIPU, 2007). Among other vertebrate species, other than the introduced species of Norway rats (*Rattus norvegicus*) and European rabbits, the Italian wall lizard (*Podarcis siculus*) and the black whip snake (*Hierophis viridiflavus*) are present.

The European rabbit eradication programme was carried out exclusively using the live-trapping method. This technique was chosen to avoid the use of firearms and hunting dogs, and the circulation of poison within the delicate microinsular ecosystem, and because the control of fauna by the use of poison is prohibited by regional legislation. The programme was approved by the national Istituto Superiore per la Protezione e Ricerca Ambientale (ISPRA) and applied for the first time in Italy.

The commencement of trapping activities was determined by the marine weather conditions, which had to remain good for prolonged periods of time to allow easy and constant landing on the island. For each annual session, trapping activities were only interrupted after the prolonged absence of catches (at least 10 consecutive days) or when rainfall stimulated vegetative recovery of the herbaceous flora or when autumn weather conditions (September) prevented regular visits to the island.

Steel trap cages, measuring 30×30×70 cm and with a snap closure mechanism activated by a tilting platform at the bottom of the trap (Figure 2), were evenly distributed over the entire surface of the island, at an average distance of about 40 m from each other. The position of each trap was geo-referenced with GPS to facilitate its location and to facilitate cartographic positioning. Each trap was covered with shade netting to avoid stress to the trapped animals as a result of the strong sunlight and to ensure a protected environment before translocation.

The traps were set with fresh fruit, replaced periodically every 2–3 d. In particular, according to seasonal availability, Canary melons, apples or grapes were used. Starting from the third year of trapping, the traps were placed taking into account the presence of traces on the ground of the presence of rabbits (faecal pellets, burrows), taking care to change the position of traps that did not catch for more than 10 d.

Figure 2: Trap model used by catching of European rabbit.

On the island, captured animals were initially housed in pet carriers in a shaded and protected collection point. Once the control session of all traps was concluded, the captured animals were transferred to a temporary breeding and storage centre for fauna on the mainland (Istituto Zootecnico Sperimentale per la Sicilia) before being used, after the appropriate health checks, for restocking interventions on the Sicilian territory, where the species, considered para-autochthonous, has been undergoing a strong decline in recent decades (Lo Valvo *et al.*, 2017; Di Vittorio *et al.*, 2019).

Simultaneously, censuses of the rabbit population were conducted using the faecal bullet count method (Eberhardt and Van Etten, 1956; Moreno and Villafuerte, 1995; Redondo, 2009) to assess and monitor density changes during the trapping phase of each year. This methodology consists of counting the number of excrement in fixed detection stations scattered randomly in the study area. The data may provide information on population size and numerical trends over time. This method has been confirmed successful for the good correlation between the number of excrements and the density of animals (Wood, 1988; Palomares, 2001). To obtain an estimation of the density of animals (D) in an area of identified surface, knowing the number of excrements deposited daily by the animal (r) and the period of time in which these have been deposited (t), we applied the formula of Eberhardt and Van Etten (1956):

$D = d/rt$, where d is the mean density of excrement per sampling station. Due to the lack of experimental data for Sicily, r was considered equal to 350, the value reported by Moreno and Villafuerte (1992) for Mediterranean environments. The parameter (t) is instead the number of days between the cleaning of stations and counting.

Pearson correlation coefficient (r) was used to measure a linear correlation.

RESULTS

The European rabbit eradication plan began in 2008 and ended in 2016, with the complete eradication of the species already achieved in 2012. In fact, since 2013, no rabbits have been caught or observed, and no traces (faeces or active burrows) have been found. To verify the absence of rabbits on the island, inspections were carried out between 2013 and 2016 with hunting dogs equipped with “anti-venom bites” to prevent negative interactions with wildlife. These inspections confirmed the absence of the target species.

Trapping periods were between April and October, consistent with weather and sea conditions suitable for landing on the island in reasonable safety. During the eight years of activity, a variable number of trap cages was used, from a minimum of 47 traps to a maximum of 104 traps, in relation to the estimated frequency of catches, with a variable density of 3.2 to 6.9 traps/ha.

Table 1: Start and end dates of trapping activities, total number of rabbits caught and of traps used, and trapping effort.

Year	Start	End	Rabbits caught (A)	n. days (B)	n. traps (C)	trapping effort (B*C)	trapping efficiency (A/B/C)
2008	1 April	22 September	133	174	47	8.178	0.02
2009	8 April	21 September	106	166	67	11.122	0.01
2010	17 May	1 October	297	137	72	9.864	0.03
2011	18 June	28 September	263	102	100	10.200	0.03
2012	28 May	21 September	0	118	104	12.272	0.00
2013	6 September	2 October	0	27	97	2.619	0.00
2014	1 August	15 September	0	46	98	4.508	0.00
2015	22 July	21 August	0	31	98	3.038	0.00
2016	3 August	12 September	0	41	98	4.018	0.00

During the 5 yr in which trapping took place on the island, a total of 799 rabbits were trapped and translocated. The start and end dates of trapping activities, the total number of animals caught and traps used, together with the trapping effort, are shown in Table 1.

During application of the European rabbit eradication plan, apart from the capture of a single individual blackbird (*Turdus merula*), individuals of Mediterranean yellow-legged gull (*Larus michahellis*) and Norway rat (*Rattus norvegicus*) were also captured (Table 2). After capture, the gulls and blackbird were released, whereas the rats were generally found dead when trying to escape.

The monthly values of population densities, estimated during the years inwhich catches were made by applying the Moreno and Villafuerte (1995) algorithm, are shown in Table 3. In all years, decreases were observed, with densities at the end of the campaign (September) always lower than 2.5 ind/ha.

A significant positive correlation (r=0.99; P=0.014) was observed between the number of catches made and the estimated rabbit density in July (considered to be the highest of the year). When possible, the number of rabbits removed, calculated as the differences between the estimate mean density, obtained by Eberhardt and Van Etten (1956), between two temporally consecutive counts, was correlated with the number of rabbits really caught, and therefore subtracted from the island's population during the same time range, and the correlation value Pearson's was statistically significant (r=0.83; P=0.003) and the linear regression showed in Figure 3.

No significant correlations were found between the number of rabbit catches and the number of traps used (r=–0.80; P=0.198), between the number of catches and the number of trapping days (r = 0.63; P = 0.368) and between the number of catches and trapping effort (days x traps) (r = 0.05; P = 0.954). Similarly, no significant correlations were found between the total number of catches of all species caught and the number of traps used (r = –0.58; P = 0.418), between the total number of catches of all species caught and the number of trapping days (r = 0.32; P = 0.679) and between the number of catches and trapping effort (days×traps) (r = –0.35; P = 0.645).

Table 2: Species and number of specimens captured during the application of the European rabbit (*Oryctolagus cuniculus*) eradication plan.

	2008	2009	2010	2011
Rabbits (*Oryctolagus cuniculus*)	133	106	297	263
Rats (*Rattus norvegicus*)	122	0	0	0
Gulls (*Larus michahellis*)	26	60	97	69

Table 3: Trend of densities and estimated European rabbit (*Oryctolagus cuniculus*) population (density population*ha island) during trapping years.

	2008		2009		2010		2011		2012	
	rabbit/ha	estimated population	rabbit/ha	estimated population	rabbit/ha	estimated population	rabbit/ha	estimated population	rabbit/ha	estimated population
April	12.18	177								
May	8.37	121							0.43	6
June	7.14	104			18.61	270	14.35	208		
July	6.47	94	4.83	70	10.07	146	9.41	136		
August	3.58	52	1.63	24	3.69	54	3.61	52		
September	2.32	34	0.71	10	0.80	12	1.70	25		

DISCUSSION

Globally, several European rabbit eradication efforts have been carried out on islands (Clout and Williams, 2009; Genovesi and Carnevali, 2011). Using the Database of Island Invasive Species Eradications (DIISE, 2018), there have been 137 rabbit eradication attempts globally on islands, of which 108 have been successful. The methods used to eradicate rabbits have been diverse, used in combination in 87% of cases, and have mainly involved the use of poison (48), firearms (23), pathogen input (11), traps (14) and others unknown (39). Only in three cases was trapping used as the only method for rabbit eradication: Montana Clara Island (Canary, Macaronesia) (Martín, 2002), Kauai Island (Hawaii, United States) (Hess and Jacobi, 2011) and Molara Island (Sardinia, Italy) (Sposimo *et al.*, 2010). Unfortunately, no detailed information is reported for any of the three that would allow a comparison, but it is possible to notice that in case of use of only one method the success is of 83% for poisoning, 30% for firearms, 60% for pathogen input and 100% for trapping.

As far as Isola delle Femmine is concerned, although Capizzi (2020) writes of failure, the eradication of the European rabbit using only the trapping method was successful. Although the plan was applied for eight consecutive years, eradication was achieved definitively after five years, and to date, there are no more rabbits on the island.

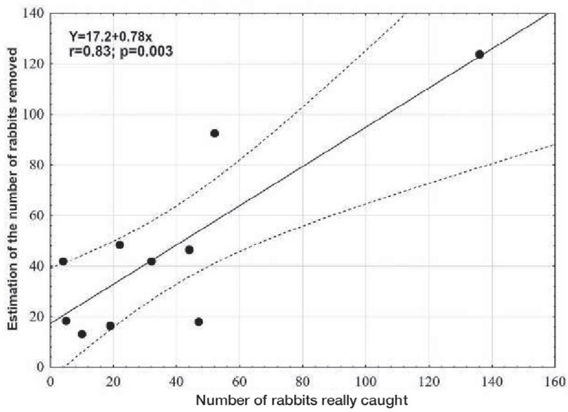

Figure 3: Linear regression between the number of rabbits really caugh and the estimate of the number of rabbits removed, calculated as the differences between the mean density, obtained by algorithm of Eberhardt and Van Etten (1956), between two temporally consecutive counts (§ material and methods). Solid lines represent the fitted linear regression, dashed lines indicate the 95% confidence intervals for the regression.

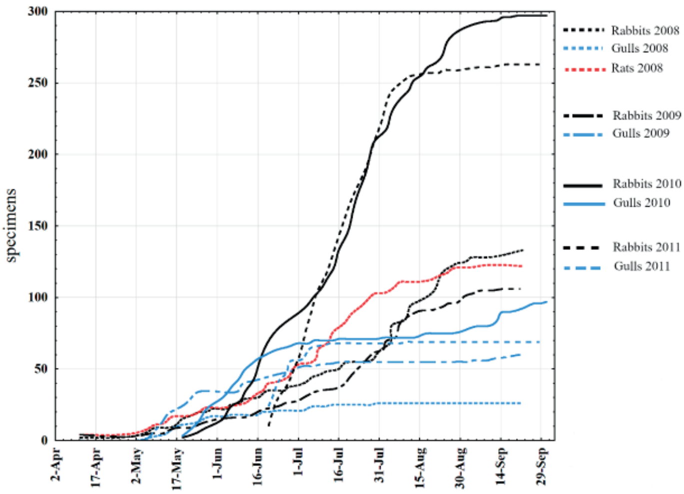

Figure 4: Trends in European rabbit (*Oryctolagus cuniculus*), rat (*Rattus norvegicus*) and gull (*Larus michahellis*) catches during the rabbit eradication plan in the nature reserve "Isola delle Femmine" (Sicily, Italy).

The longer time taken to achieve complete eradication, compared to other interventions where other techniques were used (DIISE, 2018), was rewarded by not having to use poison, which could have had possible negative effects on the ecosystem of a microinsular protected area, and by avoiding the killing of the animals, with possible negative reactions from the public as the captured rabbits were used for restocking purposes.

The experience gained over the years has made it possible to reduce the trapping effort, developing more effective methods in term of the number of catches made during the summer months. In fact, trapping actions have proved to be of little or no benefit in the presence of rain and mild temperatures, combined with the availability of fresh pasture. Under these conditions, rabbits were unlikely to be enticed by the bait in the traps.

The lack of a significant correlation between the number of catches and trapping effort could be due to the low number of degrees of freedom, but probably, even more so, to the different numbers of rabbits in the population among the years in which the catches were made. For example, on the island, in July 2011, the number of rabbits (136) was estimated to be almost double (70) the number estimated for the same month in 2009 (Table 3).

Instead, trapping effort is likely to affect trapping efficiency in general. As Figure 4 shows, since 2009, the increase in trapping probability as a result of Norway rat eradication (Canale *et al.*, 2019) has been offset by the increase in the capture of herring gull individuals, especially juveniles, which are captured in abundance until mid-July. When both juvenile and adult gulls drastically reduce their frequentation of the island, the number of traps available to catch rabbits increases. The constant movement of the traps in relation to the signs of presence seems to have been decisive for the success, resulting in an average daily trapping efficiency per trap of 0.03 rabbits (see Table 1), which was therefore sufficient for the eradication of a population with a density of between 15 and 18.5 animals per hectare. The correlation values and significance levels obtained using the number of captures, variations in the number of captures during the eradication programme and densities estimated with the Moreno and Villafuerte algorithm (1995) confirm that the pellet count technique is a reliable method for absolute estimation of this species.

CONCLUSIONS

In conclusion, under certain conditions in a microinsular environment, the trapping method using strategically placed traps in relation to signs of presence alone can be an effective management method for the control or eradication of feral rabbit populations, particularly when the use of poison or firearms is impractical or inadvisable. Non-lethal eradication may require longer periods to achieve the same objectives attainable with lethal methods. However, it helps to avoid the undesirable negative impacts that may fall on fragile ecosystems, in addition to preventing negative reactions from the public towards the killing of iconic animals that elicit feelings of empathy.

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Authors contribution: Lillo F.: conceptualization, data curation, writing – original draft and writing – review & editing. Di Dio V.: investigation, project administration and funding acquisition. Lo Valvo M.: conceptualization, formal analysis, writing – original draft, writing – review & editing, visualization and supervision.

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