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Research Article

Good for management, not for conservation: an overview of research, conservation and management of Italian small mammals

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Abstract

Small mammals (Rodentia, Soricomorpha and Erinaceomorpha) play a crucial ecological role for their distribution and importance in food chains, as well as for being considered environmental bioindicators. Thus, they represent excellent models for understanding the evolutionary processes of ecosystems, population dynamics under changing environmental conditions, and habitat vulnerabilities. However, some rodents may help the spread of human diseases and are responsible for impacts on agriculture, forestry, and ecosystems. Consequently, small mammal species are often neglected in conservation biology, and only a few of them are protected according to national and European laws and directives. In this work, we summarize open questions related to Italian small mammals and analyze conservation issues linked to these species. We address research, management and conservation priorities by considering ongoing activities and the novelties as regards the taxonomy and zoogeography. In Italy, 39 native species, including four out of six Italian endemic mammal species and one questioned as native, and 10 alien species are currently included within the category "small mammals". Although several studies revealed that small mammals may be heavily impacted by habitat loss and fragmentation as well as forest management, only three rodents are listed in IUCN red list as "Near Threatened", the remaining being "Least Concern". We suggest that this may be due to the fact that pertinent information, is not translated in assessments in line with those of other taxonomic groups (e.g. bats). Conservation strategies are still inadequate, impacts of alien species still partly unknown or neglected. Thus, wide monitoring projects, ecological studies and general public involvement in conservation effort should be implemented, with the aim to amend national legislation, thus providing native small mammals with adequate protection status.

Introduction

Small mammals represent a polyphyletic assemblage which typically applies to any non-flying mammal weighing less than a threshold value (e.g. <1 kg). However, the presence of some rodent species heavier than 1 kg (e.g. *Marmota marmota*, *Hystrix cristata*, *Myocastor coypus*) would make it difficult to establish a weight limit. Here, we consider as "small mammals" all the Soricomorpha, Erinaceomorpha and Rodentia species present in Italy, regardless of their weight.

Small mammals constitute a key component of ecosystems, contributing to many functions: they can act as seed (Steele et al., 2005) and fungal spores dispersers (Janos et al., 1995; Bertolino et al., 2004) and help pollination (Dickman, 1999). Furthermore, most of them are important prey for a wide range of predators and many species are efficient predators themselves (Capizzi and Luiselli, 1996a; Dickman, 1999). Small mammals are also considered as bioindicators of sustainable forest management, as they respond to habitat disturbance (Capizzi and Luiselli, 1996b; Pearce and Venier, 2005; Leis et al., 2008; Mortelliti et al., 2010, 2011) and to environmental contaminants (Talmage and Walton, 1991; Shore and Douben, 1994), thus enabling the detection of environmental trends. The interactions between rodents and the environment are sometimes so deep that these species are considered as ecosystem engineers for their ability to change the physical states of the areas where they inhabit (e.g. by burrowing activities of fossorial rodents, Meadows and Meadows, 1991, changes in water flow by beaver dams, Naiman et al., 1986).

On the other hand, some rodent species may have an impact in the spread of zoonotic diseases and on agriculture production, forestry and other human activities (e.g. food industries). Furthermore, they may also negatively affect other species and/or ecosystems (Capizzi et al., 2014). Therefore, the role of small mammals in providing ecosystem services is overwhelmed by the fact that few species are regarded as pests and targeted for control throughout the world, both in native and introduced ranges (Sieg, 1987; Delibes-Mateos et al., 2011; Capizzi et al., 2014). This is perhaps the foundation of the perception that most, if not all, rodent species are pests and do not need any protection. For this reason, small mammals are often neglected in conservation planning (Amori and Gippoliti, 2000). Among other mammals, carnivores and artiodactyls receive much more attention than rodents, despite the latter account for nearly 40% of the world mammal species (Amori and Gippoliti, 2000). In such a situation, the conservation of these species is far from being an easy issue, given also that they are rarely taken into account by the legislation: only very few small mammal species are currently protected according to national and European laws and directives.

Within this general framework, aims of our review were to: 1) summarize open issues related to Italian small mammals; 2) analyze conservation issues concerning small mammals to better address conservation priorities; 3) review currently ongoing management activities, stating whether they are based on documented and/or assumed impacts

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Table 1 – Native Italian small mammals: * endemic species; ** species with a range centred in Italy and extended for a small part to neighbouring countries; *** considered as introduced. National red list reports the IUCN categories for Italy: LC = Least Concern; NT = Near Threatened; DD = Data Deficient.

Family	Species	Vernacular name	National Red List
Erinaceidae	*Erinaceus europaeus*	European hedgehog	LC
	Erinaceus roumanicus	White-breasted hedgehog	LC
Talpidae	*Talpa europaea*	European mole	LC
	Talpa romana *	Roman mole	LC
	Talpa caeca **	Blind mole	DD
Soricidae	*Sorex alpinus*	Alpine shrew	LC
	Sorex antinorii **	Valais shrew	DD
	Sorex minutus	Eurasian pigmy shrew	LC
	Sorex samniticus *	Apennine shrew	LC
	Suncus etruscus	White-toothed pygmy shrew	LC
	Neomys anomalus	Southern water shrew	DD
	Neomys fodiens	Eurasian water shrew	DD
	Crocidura leucodon	Bicolored shrew	LC
	Crocidura pachyura	North African white-toothed shrew	DD
	Crocidura sicula *	Sicilian shrew	LC
	Crocidura suaveolens	Lesser white-toothed shrew	LC
Sciuridae	*Sciurus vulgaris*	Eurasian red squirrel	LC
	Marmota marmota	Alpine marmot	LC
Gliridae	*Dryomys nitedula*	Forest dormouse	LC
	Eliomys quercinus	Garden dormouse	NT
	Glis glis	Edible dormouse	LC
	Muscardinus avellanarius	Hazel dormouse	LC
Cricetidae	*Arvicola amphibius*	European water vole	NT
	Arvicola scherman	Fossorial water vole	DD
	Chionomys nivalis	European snow vole	NT
	Microtus agrestis	Field vole	LC
	Microtus arvalis	Common vole	LC
	Microtus brachycercus *	Calabria pine vole	LC
	Microtus liechtensteini	Liechtenstein's pine vole	LC
	Microtus multiplex **	Alpine pine vole	LC
	Microtus savii **	Savi's pine vole	LC
	Microtus subterraneus	European pine vole	LC
	Myodes glareolus	Bank vole	LC
Muridae	*Apodemus agrarius*	Striped field mouse	LC
	Apodemus alpicola	Alpine field mouse	LC
	Apodemus flavicollis	Yellow-necked field mouse	LC
	Apodemus sylvaticus	Long-tailed field mouse	LC
	Micromys minutus	Eurasian harvest mouse	LC
Hystricidae	*Hystrix cristata* ***	Crested porcupine	LC

and identifying future intervention priorities; 4) examine the recent acquisitions in taxonomical and zoogeographical terms; 5) propose legislative measures to promote conservation and management of Italian small mammals.

1. Are conservation priorities properly set?

More endemic species than all mammals

The list of Italian small mammals was compiled using Amori et al. (2008) and Rondinini et al. (2013) as references. Currently, 39 native species grouped in seven families are included within the category "small mammals" in Italy (Tab. 1): Erinaceidae (n=2), Talpidae (n=3), Soricidae (n=11), Sciuridae (n=2), Gliridae (n=4), Cricetidae (n=11), Muridae (n=5), and Hystricidae (n=1). According to genetic, archeozoological, and paleontological evidences the crested porcupine *Hystrix cristata* could be considered as introduced from North Africa, maybe as a game species during the Middle ages (Trucchi and Sbordoni, 2009; Masseti et al., 2010; for a review, see Mori et al., 2013; but see Angelici et al., 2003 for an alternative hypothesis). The Udine shrew *Sorex arunchi* is not recognized anymore as a valid species, as morphological (Wilson and Reeder, 2005) and genetic (Yannic et al., 2012) differences between this species and the Valais shrew *S. antinori* are weak. Accordingly, the validity of *Arvicola scherman* as a proper species is currently debated, but we retained it in our screening, as no definitive explanation has been claimed yet (Kryštufek et al., 2014). Recently, Gippoliti (2013), in a thoughtful and provocative paper, based on a screening of the published literature, proposed to increase to 131 species the list of the Italian mammals, with 20 introduced, and 15 possible endemic species. According to this paper, Italian small mammals would arise to 56 species. Although some of the putative species identified by Gippoliti (2013) are likely to represent only isolated populations and not good species, there is no doubt that the current taxonomic knowledge of the Italian small mammals needs a thorough revision.

Rodents and Soricomorpha include four out of six Italian endemic mammal species (Tab. 1); the others are the Apennine hare *Lepus corsicanus* and the Sardinian long-eared bat *Plecotus sardus*. Three rodents (*Eliomys quercinus*, *Arvicola amphibius*, *Chionomys nivalis*) are included in the category Near Threatened in the Italian red list (Tab. 1); however, for five Soricomorpha (*Crocidura pachyura*, *Talpa caeca*, *Neomys anomalus*, *N. fodiens*, *Sorex antinorii*) and one rodent (*Apodemus alpicola*), the knowledge on abundance and distribution was considered as being too limited to assess their conservation status and thus they were included in the category Data Deficient (Fig. 1a). The Eurasian red squirrel *Sciurus vulgaris* is still included in the category Least Concern in the Italian red list, although it is currently threatened in at least five Italian regions (Piedmont, Liguria, Lombardy, Veneto and Umbria), where introduced populations of the competitive grey

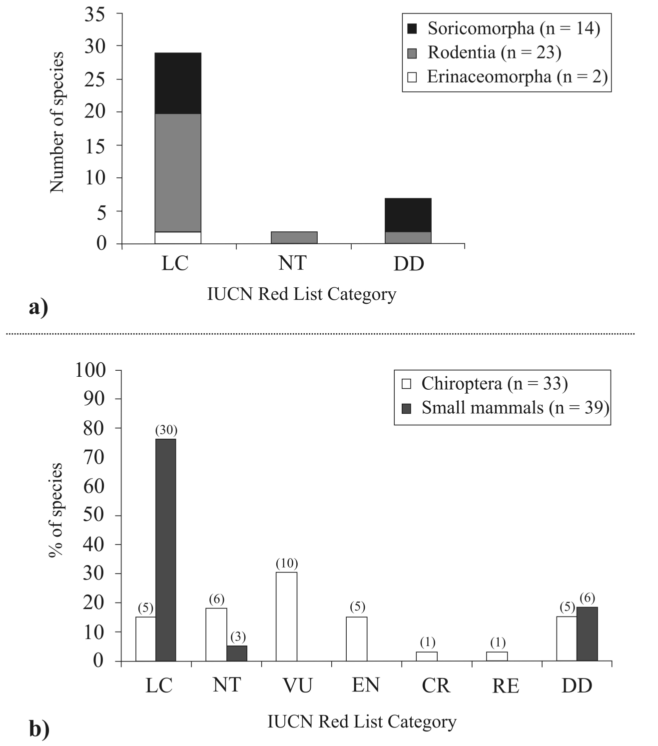

Figure 1 – IUCN Red List categories for a) Italian native small mammals; b) Italian native small mammals and Chiroptera (in percentages). Number in parentheses are referred to the number of species with each threat category in each mammal group. LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; RE = Regionally Extinct; DD = Data Deficient.

squirrel *Sciurus carolinensis* are expanding (Martinoli et al., 2010; Bertolino et al., 2014a); therefore, its IUCN status may change in the next future in the absence of an effective management strategy of the grey squirrel.

Listing species as "threatened" in the IUCN Red List requires to evaluate the reduction in the geographic range and population size of the species. These data are in many cases not available for small mammals. Even the knowledge on the ecology and biology of these species is still scanty (Amori et al., 2008). Many species are extremely elusive (e.g. *Neomys* spp.; Churchfield et al., 2000; Čepelka et al., 2011), hard to be trapped (e.g. *Talpa caeca*; Di Febbraro and Loy, 2014), occurring at low densities (e.g. *E. quercinus*, Bertolino et al., 2001; *S. vulgaris*, Wauters et al., 2008), and/or have nocturnal habits (*E. quercinus*, Bertolino, 2007; *H. cristata*:, Mori et al., 2014a), all aspects which make field studies challenging. This lack of data makes it difficult any quantitative assessment of populations and geographical ranges; thus, conservation ranking for this group of species is mainly based on expert judgement (Temple and Terry, 2007). Bertolino et al. (2014b) proposed a new ranking system for small mammals, based on their degree of vulnerability and their conservation value, which could be used when species needs to be evaluated for further investigation or conservation actions.

A legal perspective

From a legal perspective, the currently available tools for species conservation are largely unsatisfactory. For small mammals, Italian national law N. 157/1992 recorded as especially protected (Art. 2.4) only the species listed in the Bern Convention (Annex II, *H. cristata*) and in the Habitat Directive 92/43/CEE (All. IV: *Crocidura sicula*, *Muscardinus avellanarius*, *Dryomys nitedula* and *H. cristata*), as well as those identified as endangered by possible special decrees by the President of the Council of Ministers. The same Italian law declares as "protected" all mammals and birds living in Italy. However, these standards explicitly exclude from the legal protection moles, rats, mice and, voles (Art. 2.2). Accordingly, the Near Threatened *E. quercinus* is excluded from the "especially protected" species, and many introduced species (e.g. *S. carolinensis*) are more safeguarded than native ones. Only in 2014 the law was amended indicating that introduced species should be managed toward eradication or control, also removing legal protection to coypu. Indeed, the near endemic blind mole *T. caeca* and the rarest (or at least poorly known) Italian voles (*A. amphibius*, *A. scherma*n and *C. nivalis*) are excluded from any form of legal protection, and no permission is required for their numerical control.

Similar gaps, different concerns: the case study of small mammals and bats

In spite of the same knowledge gaps shared with small mammals, Chiroptera, including 33 species distributed throughout Italy, are especially protected. All species are listed in both the Bern Convention (Annex II, with the exception of *Pipistrellus pipistrellus*) and in the Habitats Directive (Annexes II and IV), being also especially protected by the National Law 157/1992. Moreover, Italy adhered to the European Bat Agreement for the conservation of European bats population, through the National Law 104/2005. An analytical comparison of Red List Categories assessed for Italian Chiroptera and small mammals (Rodentia, Soricomorpha and Erinaceomorpha) (Fig. 1b) revealed that: 1) the relative proportion of Data Deficient species is very similar between Chiroptera and small mammals (15.1% and 18.4% respectively), and did not differ statistically (Yates corrected $\chi^2_{(1)}$=0.09, p=0.76); 2) The number of RE (Regionally Extinct) species is only slightly higher for Chiroptera (1 and 0 respectively); it is noteworthy that the only RE species is *Rhinolophus blasii*, a Balcanic species, with only a marginal occurrence in Italy (Jacobs et al., 2008); 3) building a 2×2 contingency table with the frequencies of Chiroptera and small mammals species in the LC (Least Concern) category against those in the remaining threat categories (i.e. Near Threatened, Vulnerable, Endangered, and Critically Endangered), revealed the presence of statistically significant differences (Yates corrected χ^2=33.5, p<0.0001). Therefore, in spite of similar knowledge gaps and extinction rates, the allocation of the threat categories was significantly skewed in favour of bats.

2. A conservation perspective

According to the IUCN assessment, the most important threat to European terrestrial mammals is habitat loss and degradation, followed by pollution and human disturbance (Temple and Terry, 2007); habitat loss is the most severe threat also at the global level followed by human environmental exploitation (Viè et al., 2009). To evaluate the main pressure that may affect the Italian small mammals, we checked both national and global IUCN red lists reporting threat factors identified by experts for each species.

In detail, Italian threats have been reported only when different from the global ones (Tab. 2). We also checked the last Italian report (2013), produced within the framework of the Habitat Directive, which includes three rodents and one Soricomorpha. Threats are listed for 8 (20.5%) out of 39 species according to the global red list, for 26 (66.7%) according to the Italian red list; respectively, 23 (59.0%) and 10 (25.6%) species are considered not affected by serious threats, and 8 (20.5%) and 3 (7.75%) are listed as data deficient. For two species (*Apodemus alpicola* and *Arvicola scherman*), data are lacking both at the global and Italian scale.

The main threat is represented by habitat alteration, affecting 18 species (46.2%), immediately followed by environmental pollution, affecting the survival of 14 species (35.9%). The first category includes both habitat loss and fragmentation, in terrestrial and freshwater environments. For instance, deforestation mainly threaten arboreal species, such as the red squirrel, edible and hazel dormice (Capizzi et al., 2002, 2003; Mortelliti et al., 2009, 2014; for a review see Mortelliti et al., 2010), while spatial and temporal allocation of logging may affect the survival of forest shrews, mice and voles (Capizzi and Luiselli, 1996b; Mortelliti and Boitani, 2009). Species typical of meadows and prairies (e.g. wild mice, harvest mice and blind moles) are impacted by mowing and/or cattle grazing or, conversely, by the disappearance of the pastures because of the re-colonization of the forest. On the other

Table 2 – Threat factors listed in the Italian (IT) and global (GL) IUCN red lists and in the last Habitat Directive Assessment (Hab). Threats in the Italian red list are reported only when different from the global red list. Question marks underline potential threats.

Species	Threats								Notes
	Habitat loss/ fragmentation	Environmental pollution	Population control	Alien species	Poaching	Road-killing	No serious threat	No data	
Erinaceus europaeus		IT				IT ?	GL		Use of biocides and chemical products in agriculture (locally)
Erinaceus roumanicus						IT ?	GL		
Talpa europaea		IT					GL		Use of biocides and chemical products in agriculture (locally)
Talpa romana		IT ?					GL		Use of biocides and chemical products in agriculture (locally)
Talpa caeca	IT							GL	
Sorex alpinus	IT	IT					GL		Use of biocides
Sorex antinorii	IT ?	IT ?						GL	
Sorex minutus							GL		
Sorex samniticus		IT					GL		
Suncus etruscus		IT					GL		Use of biocides and chemical products in agriculture (locally)
Neomys anomalus	IT ?	IT ?						GL	Use of biocides and water pollution
Neomys fodiens	IT ?	IT ?						GL	Use of biocides and water pollution
Crocidura leucodon		GL					IT		Use of biocides
Crocidura pachyura	IT			IT ?				GL	Interaction with rats
Crocidura sicula	IT/Hab	IT/Hab					GL		Use of biocides in smaller islands around Sicily
Crocidura suaveolens	IT	IT					GL		Use of biocides
Sciurus vulgaris	GL/IT			IT					Competition with *Sciurus carolinensis*
Marmota marmota							GL/IT		
Dryomys nitedula	GL/IT							Hab	Deforestation and forest burning
Eliomys quercinus	GL/IT								Particularly for populations in islands
Glis glis	GL/IT								Unknown status for Sardinian population
Muscardinus avellanarius	GL/IT/Hab								Deforestation and forest burning
Arvicola amphibius	GL/IT	GL							Water pollution
Arvicola scherman								GL/IT	
Chionomys nivalis	IT						GL		
Microtus agrestis							GL/IT		
Microtus arvalis							GL/IT		
Microtus brachycercus							IT	GL	
Microtus leichtensteini							GL/IT		
Microtus multiplex							GL/IT		
Microtus savii			GL/IT						Crop damages
Microtus subterraneus							GL/IT		
Myodes glareolus							GL/IT		
Apodemus agrarius	IT						GL		
Apodemus alpicola								GL/IT	
Apodemus flavicollis							GL/IT		
Apodemus sylvaticus	IT	IT ?					GL		Habitat loss by cattle grazing
Micromys minutus	IT						GL		Habitat loss by mowing
Hystrix cristata					IT	IT	GL		

hand, water quality affects the survival of the sensitive water shrews (Greenwood et al., 2002) and water voles (Barreto et al., 1998; Rushton et al., 2000), although data for these species from Italy are still lacking. Alien species may also play an important role for the conservation of some small mammal species. Grey squirrels *Sciurus carolinensis* are replacing the native red squirrel *Sciurus vulgaris* (Bertolino et al., 2014a)), while interaction with rats may threaten the survival of Mediterranean shrew *Crocidura pachyura* in Pantelleria and possibly in Sardinia (http://www.iucn.it/scheda.php?id=-344640608). Introduced American minks *Neovison vison* exert a strong predation upon water voles *Arvicola amphibius* in Great Britain (Woodroffe et al., 1990; Rushton et al., 2000); this alien carnivore is also present in at least four Italian regions (Iordan et al., 2012) where it may affect the local populations of the water vole. Population control regards only the Savi's pine vole (Caroli et al., 2000), which exerts damages in orchards and is not protected by any law. Although legally protected, the crested porcupine is still subjected to a strong local poaching pressure, for both its meat and damages to crops (Mori et al., 2014b).

Table 3 – Divergent lineages of Italian small mammals.

Species	Localization of divergent lineage	Justification	Bibliography
Erinaceous europaeaus	Restricted to Sicily	Allozimic and molecular data	Filippucci and Simson, 1996 ; Santucci et al., 1998; Seddon et al., 2001
Talpa caeca	Italian peninsula	Chromosome and molecular data	Meylan, 1966; Colangelo et al., 2010
Talpa europaea	Italian peninsula	Molecular and morphological data	Corti and Loy, 1987; Feuda et al., 2015
Sorex minutus	Italian peninsula	Molecular and morphological data	Vega et al., 2010
Neomys fodiens	Restricted to Calabria	Molecular data	Castiglia et al., 2007
Sciurus vulgaris	Restricted to Calabria	Molecular data	Grill et al., 2009
Myodex glareolus	Restricted to Calabria	Molecular data	Colangelo et al., 2012
Microtus arvalis	Northern Italy and Switzerland	Molecular data	Tougard et al., 2008
Microtus savii	Monophyletic lineage restricted to Sicily	Molecular data	Castiglia et al., 2008
Arvicola amphibius	Italian peninsula	Molecular data	Taberlet et al., 1998
Apodemus sylvaticus	Monophyletic lineage restricted to Sicily	Molecular data	Michaux et al., 2005
Eliomys quercinus	Italian peninsula, Sicily, Sardinia and Corsica	Chromosome and molecular data	Gornung et al., 2010

IUCN red lists are endorsed by the Ministry of Environment and they are therefore the main reference to evaluate the status of the species. The lack of data on the population trends prevents a thoughtful assessment for many species. When data are scanty, species may be wrongly considered safe because there is no indication of decline; nation-wide monitoring programs on small mammals are still lacking in Italy.

Increasing urbanization, large infrastructure construction, agricultural intensification and widespread habitat erosion in the last decades have produced a wide-scale land use change to Italian landscape whose potential effects on local fauna should be investigated. A number of recent studies focused on the effects of forest fragmentation on rodents (Capizzi et al., 2002, 2003; Mortelliti et al., 2009, 2011, 2014) and shrews (Mortelliti et al., 2007; Mortelliti and Boitani, 2009) pointing out that habitat loss negatively affects many species that probably need protection and management interventions.

3. New discoveries and long-standing issues: know we do not know?

The contribution of molecular biology to the assessment of diversity of animal species gave a new boost to different disciplines from taxonomy and systematics to ecology, biogeography and evolutionary biology. The increase of genetic studies on mammals has provided a most accurate information on the genetic structure of populations and on evolutionary relationships among taxa. Such information has been used for the reconstruction of the phylogeographic history of many taxa, as well as for the identification of cryptic species (Ferguson, 2002).

Molecular techniques proved to be especially useful in the study of small mammals diversity. Small mammals, representing most of the total mammalian species described till now (Reeder et al., 2007), still harbour an undisclosed diversity for the presence of subspecies or populations that will likely be considered as valid species in the future. Within rodents it has been estimated that many species have still to be described in the next years (Reeder et al., 2007) and genetics and molecular biology, including the new genomic approaches, will probably play a fundamental role.

Many recent studies focused on the assessment of genetic diversity in the South European areas, which played a central role in the colonization and diversification of mammals in Europe (Randi, 2007). In spite of this, few studies focused on the description of genetic diversity in Italy, and most studies performed at an European scale took into consideration Italy only marginally (often a few localities in the northern or central Italy: e.g. Berggren et al., 2005; Ruiz-Gonzalez et al., 2013). By contrast, a number of recent works raised up the importance of the genetic study for a better knowledge of taxonomic and genetic diversity of Italian small mammals (Castiglia et al., 2008; Grill et al., 2009; Vega et al., 2010; Colangelo et al., 2012; Mouton et al., 2012). The case of *Microtus savii* which, as currently defined, is a paraphyletic taxon on the basis of mtDNA and may include more than one species, is emblematic (Castiglia et al., 2008). The presence of divergent lineages in Calabria (Southern Italy) was identified both for *S. vulgaris* (Grill et al., 2009) and *Myodes glareolus* (Colangelo et al., 2012). In particular, the latter species shows a high level of genetic divergence (based on mtDNA) from other Italian bank voles, hard to be considered only as intraspecific variability and comparable to levels of genetic divergence observed among good species within the genus *Myodes* (Colangelo et al., 2012). Recent genetic analyses seem to confirm the evidence that *M. glareolus* from Calabria should be considered as a distinct species (Markovà et al., 2014). For many other small mammals, genetic analyses highlighted the distinctiveness of the Italian populations (Taberlet et al., 1998; Feuda et al., 2015) reinforcing the view of the Italian peninsula as one of the hot-spot of diversity and an endemism-rich area (Randi, 2007).

More recently, the use of multidisciplinary approaches which combine mitochondrial DNA phylogeography, ecological niche modelling and morphometrics (Vega et al., 2010) proved to be very useful to give an insight in mechanisms which originated the diversity of Italian small mammals. Furthermore, the combination of genetic and morphometrics gives also the opportunity to fill the gaps between the new DNA taxonomy and the "old" taxonomy, thus potentially allowing the use of collections available in the Italian and European natural history museums (Gippoliti et al., 2014) which, if possible, should be used as reference points for the assessment of small mammal diversity. The description of new species poses also a conservation issue related to the need to protect those taxa which are restricted endemism, declining, or of an uncertain status and not yet taken into account by national laws and international directives. The importance of species recognition for conservation purposes is well reflected in recent debates on the implications of different species concepts for the identification of conservation units (Gippoliti and Groves, 2013; Gippoliti et al., 2013; Zachos et al., 2013; Zachos and Lovari, 2013).

Despite the definition of a clear, unambiguous and operatively valid species concept, remains a central issue in evolutionary biology and taxonomy, from a conservation perspective, the use of genetic tools to identify "units of diversity" irrespectively of the taxonomic level (at species level or below it) for which it is necessary to define conservation actions is more interesting. For this reason, in the last two decades the concept of Evolutionary Significant Unit (ESU) become central in conservation biology (Moritz, 1994). The purpose of defining ESUs is to ensure that evolutionary heritage is recognized and protected (Moritz, 1994) by posing the attention on genetically distinct lineages. By preserving isolated and diversified lineages, conservation actions can ensure that the evolutionary potential of a species is preserved. From this perspective, genetic analyses highlighted how several small mammals lineages from Italy represent distinct lineages (see Tab. 3 and Gippoliti, 2013). Also in absence of a clear taxonomic revision, in many cases the Italian divergent lineages may represent ESUs of high interest for the definition of management units for conservation.

Table 4 – Small mammals introduced and naturalized in Italy.

Family	Species	English name	Origin	First introduction	Pathways
Sciuridae	*Sciurus carolinensis*	Eastern grey squirrel	North America	1948	Pet trade
	Callosciurus finlaysonii	Finlayson's squirrel	Asia	1980s	Pet trade
	Callosciurus erythraeus	Pallas's squirrel	Asia	2000s	Pet trade
	Tamias sibiricus	Siberian chipmunk	Asia	1980s	Pet trade
Hystricidae	*Hystrix cristata**	Crested porcupine	Africa	Middle Ages	Game species
Cricetidae	*Ondatra zibethicus*	Muskrat	North America	1990s	Fur farming
Muridae	*Mus musculus*	House Mouse	Asia	-6000	Transported by humans
	Rattus norvegicus	Brown rat	Asia	1700	Transported by humans
	Rattus rattus	Black rat	Indian Peninsula	-200/-400	Transported by humans
Myocastoridae	*Myocastor coypus*	Coypu	South America	1928	Fur farming

* The origin of this species is still debated.

4. Unwanted guests

Rodent invaders: alien species introduction in Italy

Overall, at least 10 rodent species are introduced to Italy, six of them in the last century (Tab. 4). They represent nearly one third (31%) of the rodents present in Italy. Ancient introductions are the now ubiquitous *R. rattus* and *Mus musculus*, while *R. norvegicus* was transported by humans more recently; *Ondatra zibeticus* and *M. coypus* were imported in Europe for fur farming (Amori et al., 2008). The presence of the coypu in Italy originated from individuals escaped or released from fur farms, while *O. zibeticus* spontaneously colonized north-eastern Italy from Slovenia (Lapini and Scaravelli, 1993). The populations of three squirrel species originated from animals imported as pets and then intentionally released or escaped (Bertolino, 2009; Martinoli et al., 2010). A fourth squirrel species, *Callosciurus erythraeus*, has been recently discovered in Lombardy (A. Martinoli and L. Wauters personal communication 2014).

Molecular data may play a pivotal role in integrating ecological data in the context of biological invasions (Dlugosch and Parker, 2008; Fitzpatrick et al., 2011; Handley et al., 2011) and in the identification of introduction dynamics of alien species. Multiple introductions of alien species pose a major obstacle to eradication programs, by promoting an increase of genetic diversity and thus of the adaptive potential of alien species to the newly invaded environment (Alda et al., 2013); this may represent a crucial issue for species with high reproductive rates, as small mammals, and particularly for their management as pests. Genetics may reveal the exact geographical origin of alien populations (Ficetola et al., 2008; Forcina et al., 2012), or specific attribution where morphology by itself is not enough (Moralee et al., 2000; Allendorf et al., 2012). For instance, according to genetics, population of grey squirrel in Umbria was founded by translocations of animals from Piedmont, where the species has been established since 1940s (Signorile et al., 2014). The anthropogenic origin of the Molara island reinvasion by *R. rattus* was established by comparing the DNA of invading with that of eradicated population (Ragionieri et al., 2013). The historical introduction of *R. rattus*, which presence was recorded since 3000 b.p. in the western Mediterranean (Kotsakis and Ruschioni, 1984; Ruffino and Vidal, 2010), was also investigated by means of mtDNA markers. Despite the potential multiple introduction expected for this commensal species, the observed genetic diversity unexpectedly fits with a pattern of single introduction (Colangelo et al., 2015) opening interesting perspectives in understanding the ecology and ethology of this species.

Knowing the invaders

The impacts the ten rodent species introduced to Italy may exert to ecosystems and human activities are reported with relative references in Tab. 5. These were divided into five broad categories, considering impacts to (i) native species, (ii) natural vegetation, (iii) agriculture (including arable crops and orchards), (iv) animal husbandry and (v) other impacts. Finally, the potential for a species to be (vi) vector of parasites and diseases was also considered. Impacts confirmed for Italy are highlighted in bold. *R. rattus*, *R. norvegicus* and *M. musculus* are characterized by widespread impacts which cover all categories, followed by *S. carolinensis* and *M. coypus*, which may have negative effects on other animal species, natural vegetation, agriculture, and may also be reservoir of parasites and pathogens. *Myocastor coypus* and *Ondatra zibethicus* could weaken riverbanks with their burrowing activities; this impact is especially important for the first species (Panzacchi et al., 2007). Introduced squirrels may affect forestry and orchards, as well as other animal species, mainly birds and mammals (Bertolino, 2009; Bertolino and Lurz, 2013), even replacing native species (i.e. the competition between *S. carolinensis* and *S. vulgaris*, Gurnell et al., 2004; Wauters et al., 2005). For three species, *C. erythraeus*, *Tamias sibiricus*, *O. zibethicus*, no information on the impacts produced in Italy is available; however, it should be stressed that these species still have a restricted distribution in the country.

Facing the invader

A national or European strategy aiming at reducing the risks posed by introduced species should be based on a three-stage hierarchical approach which includes prevention of new introductions, early detection and rapid response when prevention failed, and a mitigation of impacts with the eradication, containment or control of populations (Genovesi and Shine, 2004).

Prevention

Prevention against new introductions should be based on the identification of the pathways of entry (e.g. pet trade, fur farming, escapes from zoos) and the implementation of effective measures to avoid or reduce arrivals. For instance the importation of pets followed by either a deliberate release or the escape from captivity is the main source of squirrel introductions (Bertolino, 2009; Martinoli et al., 2010). A regulation of the pet trade should thus be considered to avoid a further proliferation of new species and populations. This has been already done but only for few species.

The importation of three squirrel species (*S. carolinensis*, *Sciurus niger*, *C. erythraeus*) in the European Union is suspended since 2012, after having listed them within the Annex B of the EU Regulation 338/1997 (the European Union Wildlife Trade Regulation that enforces CITES within the European Union). It is now forbidden to import live specimens of these species in the EU, even though there are no restrictions to their movement within the boundaries of EU. A further request aiming to establish restrictions to possession and movement of live specimens within the European countries was denied. A more stringent regulation has been recently adopted by Italy. A decree signed by the Ministers of the Environment, Agriculture and Economic Development and published on 2nd February 2013 in the Official Journal of Italian Republic forbids trading, raising and keeping the three squirrel species.

It should be stressed that the inclusion of few species in these lists is a reactive approach: species are proposed for trade restriction when are already established and proven to be invasive. An alternative option is to encourage a voluntary ban of the trade of high-risk species or to evaluate a complete trade restriction except for authorized species (Davenport and Collins, 2011; Takahashi, 2006).

Table 5 – Species introduced to Italy and their impacts. References in bold refers to Italian studies; other references are from the international literature.

Species	Native species	Natural vegetation	Agriculture	Animal husbandry	Vector of parasites and diseases	Other impacts
Sciurus carolinensis	*S. vulgaris* (**Gurnell et al., 2004; Wauters et al., 2005**); Birds	(Mayle, 2005)	(**Currado, 1993**; **Currado et al., 1997**)		Reservoir of squirrel poxvirus (Sainsbury et al., 2000) Tompkins et al., 2002)	Damage to electric cable and other manufactures (**Bertolino and Genovesi, 2005)**
Callosciurus finlaysonii	Birds (Bertolino and Lurz, 2013)	(**Bertolino et al., 2004; Aloise and Bertolino, 2005**)	(**Bertolino et al., 2004; Aloise and Bertolino, 2005**)			Damage to electric cable and other manufactures **(Bertolino and Genovesi, 2005)**
Callosciurus erythraeus	Birds (Bertolino and Lurz, 2013)	(Bertolino and Lurz, 2013)			Vector of parasites (Bertolino and Lurz, 2013)	Damage to electric cable and other manufactures (Bertolino and Lurz, 2013)
Tamias sibiricus	Birds?				Reservoir of *Borrelia* spp., vector of Lyme disease (Vourch et al., 2007)	
Ondatra zibethicus	Invertebrates, Vertebrates (Nummi et al., 2006; Hulme et al., 2010)	(Skyrienė and Paulauskas, 2012)			Reservoir of *Leptospira interrogans*, *Francisella tularensis*, *Echinococcus multilocularis* (Meerburg et al., 2009)	
Mus musculus	Invertebrates, Vertebrates (Wanless et al., 2007; Angel et al., 2009)	(Jones et al., 2003)	(Brown and Singleton,1998; **Capizzi and Santini, 2007**)	(Leirs et al., 2004; **Capizzi and Santini, 2007**)	Reservoir of diseases and parasites infectious to humans (Meerburg et al., 2009)	Damage to manufactures and stored food; commensal populations need to be controlled by rodenticides toxic to non target species (Capizzi et al., 2014)
Rattus norvegicus	Invertebrates, Vertebrates (Atkinson, 1985; Long, 2003)	(Towns et al., 2006; Harris, 2009)	(**Capizzi and Santini, 2007**; Lambert et al., 2008)	(Leirs et al., 2004; **Capizzi and Santini, 2007**)	Reservoir of diseases and parasites infectious to humans (Meerburg et al., 2009)	Damage to manufactures and stored food; commensal populations need to be controlled by rodenticides toxic to non target species (Capizzi et al., 2014)
Rattus rattus	Invertebrates, Vertebrates (**Baccetti et al., 2009**; **Capizzi et al., 2010**; Long, 2003)	(Towns et al., 2006; Harris, 2009)	(Horskins et al., 1998; **Capizzi and Santini, 2007**)	(Leirs et al., 2004; **Capizzi and Santini, 2007**)	Reservoir of diseases and parasites infectious to humans (Meerburg et al., 2009)	Damage to electric cable and other manufactures; damage to stored food; commensal populations need to be controlled by rodenticides toxic to non target species (Capizzi et al., 2014)
Hystrix cristata		**(Santini, 1980)**	(Tweheyo et al., 2005; **Capizzi and Santini, 2007**; **Mori et al., 2014b**)			
Myocastor coypus	Birds (**Bertolino et al., 2011**; **Angelici et al. 2012**)	(**D'Antoni et al., 2002**; **Bertolino et al., 2005**)	(**Panzacchi et al., 2007**; **Bertolino and Viterbi, 2010**)		Reservoir of *Leptospira* (**Arcangeli, 2002**; **Bollo et al., 2003**)	Burrowing can weaken riverbanks (**Panzacchi et al., 2007**)

Early detection and rapid response

Early detection of introduced animals is essential to start a rapid action before significant populations are established. Italy does not have an early warning system and reaction of authorities is limited, often starting with a large delay. A call for the eradication of the grey squirrel was published in 1987, the first action plan was prepared in 1997 but it was stopped by a recourse to the court from animal right groups; a new management project started only in 2010, 62 year after the first introduction of the species in Italy (Bertolino and Genovesi, 2003; Bertolino et al., 2014a). The Finlayson's squirrel was introduced in urban areas of Acqui Terme and Maratea in the 1980s but the presence of the animals in these two areas was reported to local authorities with a delay of 18-20 years (Bertolino et al., 1999; Aloise and Bertolino, 2005).

Eradication and control

The only successful removals of mammals in Italy have been rat eradications from small islands. Since the late 90s, many islands have been released by rats, with the goal of protecting target species (i.e. nesting seabirds, mainly shearwaters) and, more generally, island ecosystems. Although two rat species are present on Italian islands, *R. rattus* is largely the most widespread on Mediterranean islands (Baccetti et al., 2009). Islands were selected according to their importance in terms of seabird nesting pairs as well as the monetary cost for the implementation of the eradication (Capizzi et al., 2010). Furthermore, the risk of rat reinvasion was also taken into account. On the whole, between 1999 and 2014, rats were eradicated from 11 islands, in areas ranging between 1 ha and 1000 ha (Montecristo), but 6 of them were reinvaded (see Ragionieri et al., 2013 for the case of Molara island). Monitoring of seabird reproductive success confirmed the positive effect of rat removal on target species (Baccetti et al., 2009).

As previously mentioned, an early attempt to eradicate the grey squirrel was halted at the stage of a first trial when radical animal rights groups took the responsibles for the project to the court (Bertolino and Genovesi, 2003). The two officers involved were acquitted by the Appeal Court, but no other action was implemented till a recent new attempt started in 2010 which is still ongoing (Bertolino et al., 2014a).

The only introduced rodent species widely controlled in Italy is the coypu. The management of the species is a current practice in many regions of north-central Italy, though control activities seem to be ineffective at a large scale. During a six-years period (1995-2000), despite the removal of 220,688 coypu with a cost of € 2,614,408, the damage produced to agriculture and riverbanks increased to € 11,631,721 (Panzacchi et al., 2007). However, coypu populations were locally managed in an effective way, with reduction of economic losses (Bertolino and Viterbi, 2010) and preservation of biodiversity (Bertolino et al., 2005). An important feature of these projects was an adequate level of trapping effort, which was maintained constant or even increased after first results were achieved (Bertolino and Viterbi, 2010). It should also be stressed that the cost for a successful 11-years eradication project in England was largely exceeded by the cost related to few years of permanent control campaign in Italy, demonstrating that a timely eradication could be cost-effective in respect to a long-term control campaign (Panzacchi et al., 2007).

The future

The Council of the European Union adopted on 29 September 2014 the regulation on the prevention and management of the introduction and spread of invasive alien species. The regulation establishes a framework for tackling invasive species at the European level with the aim to protect biodiversity and ecosystem services, as well as to mitigate the economic and sanitary impacts that these species can have (Genovesi et al., 2014). This will be achieved by focusing resources on priority species and on preventive measures. The proposal is based on a black list of invasive alien species of Union Concern, which will be developed and updated through risk assessment and scientific evidence. Criteria that will be considered are the following: non-native in EU territory, ability to establish and spread, causing such damage so as to deserve EU action. Selected species will be banned from the EU, meaning it will not be possible to import, use, release or sell them.

5. Scattershot, the homemade management of small mammals

Italian law does not protect a number of rodent and mole species (i.e. rats, mice, voles and moles), the main reason being that most of them are regarded as pest species of economic and public health importance. This is of course an opportunity for pest control operators (PCO companies), which can eliminate pest species in many sensitive contexts, food industries, urban areas, agricultural premises and sewers without any legal problem. However, most of the pest control operations are usually carried out in contexts where non-target small mammal species may live (i.e. peripheral or green urban areas, or in rural contexts), thus setting them at risk of primary poisoning and, as consequence, their main predators (e.g diurnal and nocturnal raptors, carnivores, etc) of secondary poisoning.

Main target species are invariably synanthropic rats and mice (*R. rattus*, *R. norvegicus* and *M. musculus*, Capizzi and Santini, 2007). Most pest control operations are carried out largely relying on non-selective anticoagulant rodenticides (Capizzi et al., 2014). The use of trap devices is usually deserved inside buildings or food industries. Toxic baits are placed inside bait stations, distributed without worrying about the possible presence of other non-target species, either non-protected (wood mice, voles) or protected (dormice), which may have access to them.

Contrary to what happens in other European countries, where the most powerful active ingredients are prohibited in outdoor areas (e.g. brodifacoum and flocoumafen in United Kingdom), in Italy there are no restrictions on the active ingredients. Rodent control activities are routinely performed by PCO companies in buildings, food industries, municipalities and green areas. Furthermore, all rodenticides are commonly sold in stores, and anyone can buy them. This implies that rodent control activities can be carried out by anyone without checking out if they are actually managing harmful species or, more likely, hitting anyone walking there (in fact, scattershot). In fact, the impact of rodenticides on non-target small mammals has been well documented (Brakes and Smith, 2005).

Another relevant issue is the risk of secondary poisoning for predators and scavengers (Berny et al., 1997; Fournier-Chambrillon et al., 2004). The risk is strictly depending on the active ingredient used, low (although not irrelevant, O'Connor et al., 2003) for first generation anticoagulants (e.g. warfarin, clorophacinone), high for second generation ones (bromadiolone and difenacoum, Berny et al., 1997), and even higher for the most potent ones (brodifacoum and flocoumafen, Alterio, 1996; Hoare and Hare, 2006). However, as no restriction in outdoor areas exists, the risk is out of control, and no published account is available for Italy. A study performed in Latium on roadkilled birds revealed the presence of anticoagulant residues in about 40% diurnal and nocturnal raptors (Capizzi et al., unpublished data). It is worth noting that the baits are often consumed by invertebrates (snails, ants, cockroaches, grasshoppers), thus endangering other predators.

Rodent control inside buildings is often performed relying on trap devices, either mechanic or glue boards. In both cases, these devices are not fully selective towards synanthropic rats and mice, but may also catch non-target small mammals, such as shrews and dormice (Capizzi and Santini, 2007). The scale of operations is usually very small (group of buildings, small parts of urban areas). When rodent control is applied on a larger scale (municipalities, large urban areas), no attempt of forecasting and modeling rodent presence (e.g. Langton et al., 2001; Traweger and Slotta-Bachmayr, 2005), which may significantly reduce the distribution of rodenticide baits, is planned.

A first attempt to tackle the problem of rodent resistance to anticoagulants is in place (Capizzi et al., 2013). Nowadays, the phenomenon can be localized on a genetic basis (Pelz et al., 2005), and a first monitoring was launched at a national level, in the wake of similar studies at a more advanced stage in other European countries (Pelz, 2007; Buckle, 2011).

6. Not only criticisms and self-pity: an operational proposal for the future

Italian small mammal fauna is composed by species which apparently do not require conservation attention. According to the IUCN red list, only three rodents are Near Threatened. This situation, however, is related more to the absence of adequate information than to a thoughtful evaluation of the species status, based on population and range trends. Six species were classified as Data Deficient, as knowledge about their abundance and distribution is still too limited; the elusiveness of many species and the need to trap them to collect data on their ecology and population dynamics or even on their presence, make it difficult and expensive to start long term studies. In such a situation, the lack of information implies the risk of considering most species as safe, because there is no indication of decline. Furthermore, small mammals are r-strategist and with wide distributions, therefore they end up being considered as Least Concern.

Recent studies highlighted the need of a stronger effort on genetic analyses of small mammals. Almost all the species surveyed till now showed genetic peculiarity respect to the conspecific populations from the rest of Europe (e.g. divergent lineages, cryptic diversity, large genetic diversity) suggesting that some of the divergent lineages found in Italy may represent valid species, thus endemic to Italy and with a conservation status to evaluate. Moreover, any research focusing on conservation of small mammals should take into account that maintaining high genetic diversity (i.e preserving Italian species and divergent genetic lineages) helps to preserve the evolutionary potential of the whole species.

Table 6 – Species of conservation concern currently not protected by Italian law (DD, Data Deficient; NT, Near Threatened).

Species	Endemic	Limited distribution range	Threatened (Italian IUCN category)
Talpa romana	✓		
Talpa caeca		✓	DD
Arvicola amphibius			NT
Chionomys nivalis			NT
Microtus brachycercus	✓		
Apodemus alpicola		✓	DD

Although Rodents and Soricomorpha include most of the Italian endemic mammal species, their protection is in most cases inadequate. Species which would need conservation attention, such as *A. amphibius* or *C. nivalis*, are not protected at all and can be controlled without any permission. This is a great difference with respect to bats, which are "particularly protected" according to the national law and European Directive. The Habitats Directive, in particular, requires a monitoring scheme for protected species and the evaluation of possible effects of activities that could affect habitat and species in or close to the Nature 2000 network or in breeding sites. Only four small mammal species, one of which, *H. cristata*, is now considered as introduced, benefit of such a high level of protection. Furthermore, not including small mammals in European Directives has important implications also on the allocation of funds devoted to conservation projects. For instance, almost 70% of the funds allocated until 2010 to LIFE projects on mammals in Italy involved only three species (brown bear, wolf, Apennine chamois), while no project on small mammals has been funded (Silva et al., 2011).

The protection of Italian small mammals is far from being adequate. The National Law 157/1992 on Wildlife protects all free-living species of mammals and birds, with the only exceptions of moles, rats, mice and voles. Therefore, according to this law, while introduced mammal species are protected, despite their impacts, and their control is strictly regulated, many native small mammals are not protected at all. This implies that no conservation strategy is currently applied to these species, notwithstanding some of them are endemic or considered nearly threatened by the Italian IUCN red list (Tab. 6). We agree that there should be the possibility to better control the two rat species and the house mouse, or some vole species, such as *Microtus savii*, where they produce damage or pose at risk public health and human activities. However, it is time to amend the present law, including moles, mice and voles in the protection and allowing in derogation the numerical control only of those species actually impacting on human activities.

Invasive alien species may affect ecosystems and human well being in different ways (Vilà et al., 2010). In Italy, introduced rodents may produce a variety of impacts that, however, are rarely quantified. If we consider *M. coypus*, a species which is widely distributed and controlled in the country (Panzacchi et al., 2007), quantitative information on its damage to natural vegetation are reported only in two studies based on comparison before and after the colonization of some wetlands by the aquatic rodent and after its control (Bertolino et al., 2005) and comparing plots where the species was excluded with control areas (D'Antoni et al., 2002). Management activities of introduced species including long-term control plans offer good opportunities for applied research, which are seldom exploited. For instance, different authors have hypothesized that *M. coypus* could affect waterbirds preying on eggs and nestling (Scaravelli, 2002; Tinarelli, 2002). However, only recently with the use of photo-cameras it has been shown that coypu did not eat eggs, but rather use the nests as resting platforms, thus destroying or sinking the eggs (Bertolino et al., 2011; Angelici et al., 2012). Even when data are collected the authors are in most cases likely to present the results in national conferences, without subsequently producing a full paper. For instance, very few data are available on the damage produced by *H. cristata* despite some studies were presented in conferences.

In conclusion, Italian small mammals are largely neglected and even not protected in the case of many rodents. Efforts are mostly directed toward the management of those species whose impact on human activity and wellbeing is documented, while conservation activity is very limited. There is an urgent need to reconsider the status of these species by increasing our knowledge on their ecology, distribution and populations trends. Monitoring projects for single species or groups of them should start with an effective coordination between different areas. National laws should be amended providing protection for native rodents. At the end, there is the need to involve the general public to get more support in the conservation effort. This should be achieved primarily by raising the image of these specie through the production of impacting publications and starting projects of citizen science, as done for decades by The Mammal Society in Great Britain.

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