Endemism in Sardinia: Evolution, ecology, and conservation in the butterfly Maniola nurag
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Citation for published version (APA):
Amsterdam: IBED, Universiteit van Amsterdam

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V.

Conservation in Mediterranean nature reserves:
Conservation parameters of the endemic Sardinian butterfly
*Maniola nurag* (Lepidoptera, Satyridae)

Naturschutz und Landschaftsplanung 33, 227-232 (2001)
Zusammenfassung

Summary
Endemic species are a major focus in conservation biology in Europe. The Mediterranean is the richest area in Europe in terms of endemism, but also the least well studied. This paper summarises the results of a six-month field study on the endemic Sardinian butterfly *Maniola nurag*. It presents a method to define population structure and dynamics of the species at the regional scale. Metapopulation structure is inferred from mark-release-recapture experiments and the minimum size and structure of a protected area for effective butterfly conservation is determined. Habitat characteristics and information on ecology are reported. Landscape management parameters that will enhance conservation of this endemic species are suggested, as well as practical ways to increase public awareness for conservation measurements in Southern Europe.

Introduction
Past efforts to conserve threatened species by maintaining local nature reserves have not always succeeded (e.g., J.A. Thomas, 1989; C.D. Thomas, 1995). Nevertheless, national parks and nature reserves can also protect butterflies (Grill & Kati, 2000). In Sardinia all endemic and rare butterfly species occur in areas intended to become nature reserves but that are not yet officially declared such. This is a great advantage with respect to other areas in Mediterranean Europe like, for example Spain, where only two of the nine national parks have endangered butterflies in their boundaries. In Greece the most important areas for endemic or endangered butterflies are not represented in the ten national parks (65 000 ha) and in continental Italy, where most of the relevant sites are not included among the five existing national parks (271 400 ha), the situation is similar (Munguira, 1995). The Mediterranean is the richest area of Europe in terms of endemism. Only a
few endemic European butterfly species are restricted to countries outside the Mediterranean (Munguira, 1995). The importance of endemic species for nature conservation in Europe is evident: their disappearance from the restricted area where they occur would imply their total extinction. Besides, being generally products of very particular (a)biotic conditions, they are indicators of extremely rare communities whose conservation is a main focus in conservation biology.

How often and how far organisms move imposes a scale on the environment. Highly mobile individuals integrate habitat changes over broader scales than do more sedentary ones. A species' potential mobility thus determines the scale at which populations respond to habitat changes (Hanski & Gilpin, 1997). If a conservation strategy is to be efficient, a detailed knowledge of population structure on different spatial scales is necessary (May, 1994). The dispersal

![Figure 1. A typical habitat of Maniola nurag - Monte Fumai in central Sardinia.](image)

ability of a species is of crucial importance for the long-term persistence of its populations and has to be considered when establishing a nature reserve (Hanski, 1991; Warren, 1992; Stacey et al., 1997; Mousson et al., 1999). As a predictive tool of population survival in a fragmented landscape (Gilpin & Hanski, 1991; Hanski & Gilpin, 1997) the metapopulation concept as a 'population of populations' (Hanski, 1999) has been developed. In such a system, each local population has its own probability of extinction and (re)colonization. Within the landscape occupied patches are connected by migration. The question whether several populations are to be considered as a single metapopulation is decisive when proposing a conservation strategy: should management emphasize a habitat network, or the
conservation of each individual population? A nature reserve is only useful when it covers a bigger area than what is used by the organisms to be protected for local and regional movements during their lifetime (May, 1994).

In this paper (I) the population structure of *Maniola nurag* is assessed at the landscape scale, (II) population structure and dynamics of the species at the regional scale are inferred, (III) habitat characteristics reported, and (IV) a background for landscape management favourable for the conservation of this endemic species is suggested.

**Methods**

**The species**

The Sardinian Meadow Brown (*Maniola nurag*) is endemic to Sardinia; it is a univoltine species, with adults flying from May to mid September depending on altitude and local weather conditions (Figure 1). At lower altitudes females aestivate during the hottest part of the summer (Tolman & Lewington 1997; Kleinekuhle, 1999). According to Kleinekuhle, 1999 and Jutze et al., 1997 larval host plants are grasses including *Festuca morisiana*. Adults were observed using different nectar sources including *Cistus monspeliensis* and thistles. The species is quite widespread over the island and usually observed in altitudes above 500 m. It occurs on grassy, flowery places amongst bushes and rocks. Figure 2 shows a typical habitat of the butterfly. *Maniola nurag* resembles *M. jurtina*, the widespread Meadow Brown to which it is supposed to be closely related.

**Study areas**

The study was carried out in Sardinia, Italy. Six sites ranging in elevation from 500 to 1100 m were surveyed from May to September 2000 (Figure 3). The locations were chosen at different altitudes according to the occurrence of the target species in stable populations and in such a way that levels of altitude differed among sites. Localities can be divided into two sets of sites: Monte Novo, Monte Fumai and Pira è Onni are situated in the centre of the island in the Gennargentu region (9°25'/40°5''), surrounded by Sardinia’s highest elevations; Femmina morta, Monte Eccas, Nuraghe Sa Fraigada in the south-west in the Sette Fratelli forest (9°25'/39°15''). The sites were at least 1 km apart; the greatest distance between two sites (north – south) was 100 km. Air-line distance to the coast was ca. 20 km for the northern sites and 10 km for the southern sites.
Mark-release-recapture analysis
To investigate dispersal between habitat patches and estimate population sizes, mark-release-recapture (MRR) analyses were conducted in one population at “Femmina morta”. This site (250 x 250 m) is situated on a plateau ca. 600 m above sea level (Figure 4) and was studied in May/June 2000 on the following capture days: May 25, 29, and 30; June 1, 3, 4, 8, 11, 14, 16, 18, and 19. Butterflies were caught with a hand held net and marked individually with a consecutive number on the ventral surface of the hind-wing using a thin point permanent marker pen (Figure 5). Each individual was released at the point capture immediately after marking that handling took less than one minute. The patch where butterflies were marked and the location of all subsequent recaptures were recorded as well as wing wear (estimated on an arbitrary scale from 0 = perfect condition, fresh individual to 3 = severe wing damage, old individual), sex, time, weather, and behaviour (fly, rest, mate, court, or feed). That way the ‘encounter history’ of each individual and its movements was established. Each sampling day was divided into three sub-sample periods of one hour each, to permit a later analysis of the data using the Robust-Design method (Nichols, 1992). The robust design method uses a combination of open and closed population models within the same study (Nichols, 1992). It includes secondary sampling periods within each of primary periods. The time interval between successive secondary periods within a primary period is short. Consecutive primary periods are separated by relatively long intervals. In this study it is used to estimate the number of individuals active at a given sampling occasion.

Vegetation surveys and habitat description
At all sites, general surveys of vegetation characteristics were undertaken to
provide a background against which to view and interpret the butterfly data (Sutherland & Hill, 1995). Predominant species of ground, shrub, and tree layer were noted as well as the categories bare ground, rocks, and grass. On the Femmina Morta site, transect counts of flower heads (Cistus monspeliensis) (Figure 4) were carried out to estimate the abundance of potential nectar sources. On six days (June 8, 11, 13, 14, 16, and 19) corresponding to peak-flowering period of Cistus the abundance of flower heads was counted within fifteen 1-m²-frames in a patch occupied by M. nurag and an unoccupied patch. Percent cover of predominant vegetation species and vertical vegetation structure were measured using a thin stick (= point-square) of two-meter length, that was lowered vertically into the vegetation until it touched the ground (Sutherland & Hill, 1995). The stick was marked in 10 cm intervals. The number of touches per plant-species along the length of the square pin, e.g., Arbutus unedo 1 touch at 0-10 cm, 4 touches at 50-60, 3 at 110-120 etc, were recorded. That way 150 point-quadrates were sampled all over the MRR site, using a random-stratified distribution for sample selection.

Data analysis

Estimates of population size in the 2000 season and daily population sizes at different sampling occasions were made from MRR data using Jolly-Seber models for open populations (Schwarz & Arnason, 1996) with the POPAN 5 program (Arnason & Schwarz, 1995; Arnason et al., 1998) which proved to provide reliable results in similar studies with Maniola jurtina (Munguira & Thomas, 1992), Parnassius appollo (Meglez et al., 1998), and Boloria aquilionaris (Mousson et al., 1999). Survival was allowed to vary with time, probabilities of capture were set equal for all capture sessions. The number of individuals active at a sampling occasion were estimated using the Robust Design procedure provided by the software MARK (White & Burnham, 1999). Percent-cover of plant species at the MRR study area was calculated as
where \( t_{sp} \) is the presence of a species at a point-square and \( T_{nt} \) the total of point-squares sampled.

To estimate the degree of similarity between sites in terms of their dominant plant species, Sorensen Similarity Index (\( S \)) was calculated as

\[
S = \frac{2a}{b+c}
\]

where \( a \) is the number of species common to both samples, \( b \) the number of species in sample 1, and \( c \) the number of species in sample 2 (Krebs, 1989; Southwood, 1996).

**Results**

**Demographic parameters**

A total of 221 individuals (190 males and 31 females) were marked at the FM site. The total of capture events carried out is 345 for males and 42 for females. From the 75 males recaptured after marking, 36 were recaptured once, 23 twice and 16 at least three times. As females provided only nine recapture events demographic parameters could be estimated only for males. For males a total population size of 488 individuals was calculated. Estimates of daily population size (Jolly Seber Model) and individuals active per sampling occasion (Robust Design) at the MRR site are shown in Figure 6. No estimates could be made for the first and the last sampling occasion. The decrease in population size and activity in the middle of the sampling period is most likely due to rainy weather conditions on the days before
creating unfavourable conditions for butterflies. The longest interval between two capture events was 20 days for males, for female imagoes that aestivate potential life-time is supposed to be longer.

**Flight period and aestivation**

As frequently observed in butterflies (Wiklund & Fagerström, 1977; Mousson et al., 1999), protandry was evident. Adult males were observed at all sites by May 20th. Single females could be observed by May 25th at altitudes below 700 m. In the beginning of June females appeared scattered at all sites. Adult butterflies'
age structure derived from wing-wear is shown in Figure 7. By June 16th all individuals observed already had used wings and males had disappeared from the lower sites. By June 25th no butterflies were observed at the lower sites, whereas at the Monte Novo, Monte Fumai, and Pira è Onni sites sporadic females were observed continuously until the beginning of September. They did not fly as much as males but tended to rest in the shade under bushes for the major part of the day. Aestivation behaviour seems to be dependent on altitude. At lower altitudes females aestivate and reappear towards the end of August to deposit eggs. At higher altitudes the flight period continues uninterruptedly from June to August.

![Figure 7](image)

**Figure 7.** Proportions of individuals flying indicated distances at the MRR site.

<table>
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<tr>
<th></th>
<th>PO</th>
<th>FM</th>
<th>MN</th>
<th>MF</th>
<th>ME</th>
<th>NSF</th>
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<td>0.68</td>
<td>0.81</td>
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<td>0.77</td>
<td>0.96</td>
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**Table 1.** Sorenson Similarity Indices of the vegetation recorded at the different study sites. PO = Pirra e Onni; FM = Femmina Morta; MN = Monte Novo; MF = Monte Fumai; ME = Monte Eccas; NSF = Nuraghe sa Fraigada.
Table 2. Predominant plant species at different study sites in comparison; FM = Femmina Morta, MN = Monte Novo, MF = Monte Fumai, PO = Pira e Onni, ME = Monte Eccas, NSF = Nuraghe Su Fraigada.

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<tr>
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<tr>
<td>Genista corsica</td>
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<td>Gramineaeae</td>
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<td>X</td>
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<tr>
<td>Inula viscosa</td>
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<tr>
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<tr>
<td>Ononis natrix</td>
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<tr>
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<tr>
<td>Quercus cocifera</td>
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<td>X</td>
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<tr>
<td>Rosmarinus officinalis</td>
<td>X</td>
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<tr>
<td>Rubus spp.</td>
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<tr>
<td>Teucrium capitatum</td>
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<tr>
<td>Thymus herba-barona</td>
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<tr>
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Adult nectar resources
Adult butterflies of both sexes were observed nectaring on plant species that were flowering during their flight period. At the southern site this was Cistus monspeliensis in May/June (Figure 4) and Atractylis gummifera in August, whereas at the northern sites besides those two species, Carlina corymbosa was visited. No significant differences in abundance of nectar sources were found between habitat patches occupied by M. nurag and unoccupied patches.
Hypocheris glabra
Cistus creticus
Inula viscosa
Anthemis cotula
Rubus spp.
Plantago spp.
Ferula communis
Cistus salvijblius
Carlina comnubosa
Bar ee ground
Moss
Erica arboris
Rocks
Other
Arbutus unedo
Asphodelus spp.
Cistus monspeliensis
Grass

Figure 8. Percent-cover of predominant plant species, bare ground and rocks at the MRR site in comparison.

Figure 9. Total of touches of plants at the MRR site per height class.

Dispersal
At the MRR site males moved actively between all habitat patches but preferred certain patches more than others (Figure 8). Those were mainly shaded bush edges where vegetation remains green longer than in open areas. Maximum distance moved by marked individuals was at least 210 m. Mean flight distance (N=221) between two capture events was 60 m. The proportions of individuals flying certain distances are shown in Figure 9. Small farm roads did not appear to be barriers to the dispersal of individuals. Of the individuals recaptured 15.7% had stayed in the patch of original capture, 66.3% were captured in at least two different patches, 18.1% of the individuals were recaptured in at least three different patches. There was no relationship between distance and the time between two consecutive recaptures (data not shown).

Habitat characteristics
All six study sites showed high similarities in vegetation composition (Table 1). Asphodelus spp., Helichrysum stoechas, Carthamus lanatus, Cephalantera rubra, and Cistus spp. were common to all sites. Predominant plant species at the various study sites are shown in Table 2. At the MRR site grass, Cistus spp., Asphodelus spp. and Arbutus unedo were the dominant features. Other species, bare ground or rocks covered less than five percent of the surface (Figure 10). Vegetation thickness diminished with distance from the ground (Figure 11).
Discussion

Like many other butterfly species (Thomas & Hanski, 1997) M. nurag population structures show a hierarchy of scales and satisfy the requirements for a metapopulation sensu Hanski et al. (1995): (1) habitat patches support local breeding populations, (2) no single population is large enough to ensure long-term survival, (3) patches are not too isolated to prevent recolonization, (4) local dynamics are sufficiently asynchronous to make simultaneous extinction of all populations unlikely. The three southern populations in the Sette Fratelli area are to be considered as one metapopulation with occasional migration between the sites. Also the Monte Novo and Monte Fumai sites are thought to be part of one metapopulation network. Subpopulations might be separated by patches of unsuitable habitat but remain connected by migrants.

**Long term persistence of local populations**

With estimated daily population sizes at peak flight period not exceeding 150 pairs the long-term persistence of local populations clearly depends on extinction-recolonisation processes in a metapopulation network (Harrison & Talor, 1997). A single population would have no chance of long term survival. Many studies have confirmed the prediction that the expected lifetime of a population increases with its current size (e.g., Hanski, 1999) genetic variation. The minimum viable population size is an estimate of the minimum number of individuals in a population which is required to assure a good chance of surviving for some relatively long period of time, for instance 95% chance of survival for at least 100 years (Soulé, 1980, 1987; Lande, 1988). For metapopulations consisting of small and hence extinction-prone (Harrison & Talor, 1997; Mousson et al. 1999) local populations like those of M. nurag, an analogous concept of minimum viable metapopulation size may be defined as the minimum number of interacting local populations necessary for a long-term persistence (Harrison & Talor, 1997). I expect that for M. nurag this would be a network of three populations. To exactly predict the minimum number of local populations required for the persistence of the metapopulation, genetic population structure analysis combined with the collection of further empirical field data is being conducted.

**Risk of local extinction**

The garrigue-type landscape used by M. nurag is a very dynamic system and undergoes severe seasonal changes. In winter, temperatures in mountainous areas of Sardinia can reach levels below 0°C whereas in summer they rise up to 60°C ground temperature. After spring precipitations the grassland dries
out entirely until autumn rains bring back some humidity. Overgrazing by free roaming herds of sheep, goats, and horses can cause severe damage to vegetation. All Mediterranean landscapes are prone to fires. This environmental instability might easily eliminate local butterfly populations which are extremely sensitive to weather, and other disturbances.

**Dispersal ability**

The MRR survey at the Femmina Morta site showed that local mobility is high and covers distances of more than 200 m. Considering that mark-recapture experiments underestimate movement distances (Shreeve, 1995; Dennis & Shreeve, 1996), *M. nurag* is supposedly capable of moving away from its locality in excess of 500 m. Evidence from its sister species *M. jurtina* which has similar population structures shows that those butterflies are able to move in access of 330 m across unsuitable habitat (Munguira & Thomas, 1992). This indicates that also species which are thought to be rather sedentary will move considerable distances in search for new habitat (Shreeve, 1995). Records of butterflies in places clearly not suitable for breeding, such as inner cities, further support the view that individuals of even the most sedentary species occasionally move relatively long distances (Dennis & Shreeve, 1996). To have clear evidence for the butterfly's dispersal ability, female movement, in particular, will have to be studied in detail.

**Small-scale habitat requirements and local dynamics**

*Maniola nurag* has a restricted distribution, but is abundant where it occurs. The butterfly fits thus well into the type of rare species described in the classification of Rabinowitz et al. (1986) and Gaston (1994). Considering that in Sardinia the type of habitat required by this butterfly is largely available, the species occupies only a small fraction of the potential habitat. This is thought to be due to particular requirements with respect to microclimatic conditions and vegetation structure. Stable metapopulations can only persist at sites providing a certain level of small-scale habitat heterogeneity. Though basically a grassland species with larvae feeding on different species of *Festuca* spp., all sites where *M. nurag* was observed contained bushes or shrubs. These structures in the vegetation provide shade during the hottest part of the day as well as shelter from predators. Heat, wind, draught, and humidity act differently on caterpillars, pupae, and adults in sheltered patches than in open areas (Hanski et al., 1995; Mousson et al. 1999). Shelter provided by bushes and trees, for example, can prevent local extinctions in case of extreme climatic conditions. Towards the end of the flight period, when vegetation had already become very dry the number of occupied patches at the
Femmina Morta site decreased and butterflies withdrew to those patches that provided more shade and comparatively fresher vegetation.

**Towards an effective butterfly conservation**

The main conclusion of this study is that *Maniola nurag* populations in Sardinia form metapopulation networks whose long-term persistence requires ‘connectivity’ between local populations. An efficient conservation strategy for such species should rather emphasize the management of a habitat network than the conservation of local populations. Stepping-stones must be provided to support long-distance (re)colonization processes. Additionally, the minimum amount of suitable habitat necessary for metapopulation persistence has to be considered. Areas to protect *nurag*-type species would have to cover at least 500 ha for each population in order to be bigger than what is required by the organisms for interpopulation movements. Given the metapopulation structure, it would thus mean areas of about 2000 ha. The maintenance of habitats containing the vegetation characteristics necessary for *M. nurag* (see Table 2, Figures 10 and 11) is crucial.

Management strategies favourable towards conservation of butterflies in the nature reserves to be constructed in Sardinia should include the maintenance of low density livestock grazing with controlled numbers of herds as well as extensive agriculture. Traditional land use techniques generally proved favourable for butterfly conservation in a similar study. Reforestation with non-native tree species should be stopped immediately as it destroys habitats valuable not only for butterflies but also for many other native species. Small and quiet farm roads did not appear to be barriers against dispersal. The problem of roads is more relevant for nature reserves and protected areas in North and Central Europe. A big advantage of Sardinia is that in the areas designated to become nature reserves, roads are much smaller, less well maintained, and except in summer time, much less frequented.

Wide busy roads can form barriers to dispersal (Mader, 1984; Munguira & Thomas, 1992) and many individuals are killed on windscreens (Munguira & Thomas, 1992). In a study on 23 British butterfly species Munguira & Thomas (1992) found that the mortalities of butterflies caused by vehicles were insignificant compared to those caused by natural factors: 0.6 percent of adults of species from closed populations, and 7% of those from open populations were killed by cars. This is at least an order of magnitude lower than the proportion of young butterflies killed by predators or parasitoids (Dempster, 1984). For already endangered species, however, the effects could be more devastating. Mobile and migratory species are generally more
vulnerable to traffic (Munguira & Thomas, 1992).

It has to be pointed out, that nature conservation management in South Mediterranean areas has to be quite different from the situations we know from North-Central Europe, where public awareness for conservation measurements is much higher. As already stated by other authors (Munguira, 1995), it is evident that poorer countries are less interested in conservation. On the other hand, these are the areas in Europe where natural habitats are usually still in good condition, so the need for protected areas is less evident. Here, good information would be necessary, hand in hand with proper national and international funding (e.g. from the European Community), as subsidies are the only way to encourage traditional land uses where they are no longer profitable, and the best way to prevent a shift to activities that might pose problems for rare species.

**Acknowledgements**
This work was supported by a doctorate grant of the Austrian Academy of Science. Gabriel Nève and Steph Menken constantly supported this study. Roberto Crijnar and Paolo Casula provided help in selection of the field sites. Kees Nagelkerke gave valuable advice. Sally Capper, David Harrington, John Sherba, Hank Dutt and Joan Jeanrenaud linguistically improved earlier versions of this manuscript. Raoul Schrott shall be thanked for technical assistance.