Optimizing protection efforts for amphibian conservation in Mediterranean landscapes

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A B S T R A C T

Amphibians epitomize the modern biodiversity crisis, and attract great attention from the scientific community since a complex puzzle of factors has influence on their disappearance. However, these factors are multiple and spatially variable, and declining in each locality is due to a particular combination of causes. This study shows a suitable statistical procedure to determine threats to amphibian species in medium size administrative areas. For our study case, ten biological and ecological variables feasible to affect the survival of 15 amphibian species were categorized and reduced through Principal Component Analysis. The principal components extracted were related to ecological plasticity, reproductive potential, and specificity of breeding habitats. Finally, the factor scores of species were joined in a presence-absence matrix that gives us information to identify where and why conservation management is required. In summary, this methodology provides the necessary information to maximize benefits of conservation measures in small areas by identifying which ecological factors need management efforts and where should we focus them on.

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1. Introduction

Amphibian populations are suffering significant decline worldwide. Several causes, such as habitat disturbance (Dunson et al., 1992; Blaustein et al., 1994), UV radiation (Bancroft et al., 2007), pathogens (Carey, 2000) and pollution (Carey and Bryant, 1995), have been proposed to explain the reduction in amphibian populations. If amphibian populations are in decline, it is also likely that ecosystems in which they live are suffering a decrease in quality (D’Amen and Bombi, 2009). However, factors responsible are multiple and spatially variable and, thus, declining in each locality is likely to have its own particular combination of causes (Carey and Bryant, 1995). At least in most European landscapes, habitat alteration, fragmentation and destruction are probably the main causes of current and future amphibian populations declines and species extinctions (Dodd and Smith, 2003; Stuart et al., 2004; Becker et al., 2007; Temple and Cox, 2009).

The main threat for amphibians in the study area is the intensive olive tree monoculture, which occupies about 50% of the province (about 600,000 ha) and is the main cause of wetlands alteration (Ortega et al., 2003; Guerrero et al., 2006; García-Muñoz et al., 2009, 2010a, 2010b, 2011a, 2011b). Among the species present in the study area are four urodels (Salamandra salamandra, Pleurodeles waltl, Triturus pigmeus and Lisotriton boscai) four members of the family Alytidae (Subfamily Alytidae with two members: Alytes cisternasi and Alytes dickii); Subfamily Discoglossinae with two members: Discoglossus jeanneae and Discoglossus galganoi), two bufonids species (Bufo bufo and Bufo calamita), one members of the family Pelobatidae (Pelobates cultripes), two species of the family Pelodytidae (Pelodytes punctatus and Pelodytes ibericus), two species of the Family Hylidae (Hyla meridionalis and Hyla arborea) and one species from the family Ranidae (Phelophylax perezi).

Resources for conservation are limited and their allocation must be carefully decided. Here, a case study in the south-eastern Iberian Peninsula is used to implement a different approach for local conservation needs. In this sense, it is intended to tackle the problem of amphibian decline, to determine key ecological and life history traits requirements of the analyzed species, in order to prioritize allocation of the limited funds for conservation. Specifically,
the objective is developing a replicable methodology to categorize the study area according to low scale needs for management strategies based on the biological and ecological variables feasible to affect the survival of amphibian species.

2. Methods

2.1. Study area

The study area includes the administrative area of the Jaén province, Southern Spain (Fig. 1), which is divided into 169 UTM 10 × 10 km squares. The importance of this area for amphibians is evident since it harbours 60% of the autochthonous species in the Iberian Peninsula, and 100% of species in Andalusia region (Montori et al., 2005). The network of protected areas in this region is constituted by a total of eleven areas, mostly mountainous and lowland wetlands. The whole study area covers 13,500 km², with an altitude range between 230 and 2167 m a.s.l.. Geographically, it is characterized by two main fluvial depressions (Guadalquivir and Guadiana Menor), with strongly anthropic alterations, and surrounded by major mountain ranges (Sierras Béticas and Sierra Morena) with different characteristics and geological history. From the herpetological point of view, this situation promotes the presence of Iberian and North African species, but also Baetic and Atlantic endemisms (Ceacero et al., 2007; Pleguezuelos et al., 2002).

2.2. Selected variables

We assumed that the reproductive and ecological strategies of the species analyzed here have evolved in natural undisturbed systems. However, since many environments are now highly degraded, some of these strategies may have greater risks (“low number of clutches” or “long larval period”) under a wide range of common practices or even unpredictable alterations of human origin. In consequence, current presence/absence (P) together with nine biological and ecological variables feasible to affect the survival of amphibian species under highly disturbed environments, were selected, categorized and analyzed. These were: distribution range (DR); altitudinal valence (AV); reproductive strategy (RS); eggs (offspring) number (EN); breeding habitats (BH); maximum age (MA); larval period length (LP); adult habitat (AH); and anthropic impacts (AI) (Table 1). These variables were considered to cover main aspects related to the distribution, demography, reproduction, ecology, habitat requirements, and anthropic impacts previously reported for every species in the study area. Species values for these variables were obtained from the literature (Pleguezuelos and Moreno, 1990; Pleguezuelos, 1997, 2002;
Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories and comments</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence/absence data</td>
<td>Percentage of UTM 10 × 10 squares occupied by every species. 169 squares were considered.</td>
<td>We assume that species with greater distribution area showed a lower risk of local extinction.</td>
</tr>
<tr>
<td>(P):</td>
<td>3: &lt; 25%; 2: 25–50%; 1: 50–75%; 0: &gt; 75%.</td>
<td></td>
</tr>
<tr>
<td>Distribution range</td>
<td>Index of the distribution area of species respect to its whole distribution area.</td>
<td></td>
</tr>
<tr>
<td>(DR):</td>
<td>3: Endemism; main distribution area; 2: Isolated area; 1: Peripheral area; 0: Area in the middle of the distribution of the species.</td>
<td></td>
</tr>
<tr>
<td>Alitudinal valence</td>
<td>Altitude ranges where every species may occur.</td>
<td>We assume that species restricted to a particular altitude are subject to a higher probability of local extinction than those with a wide range of altitudinal occupation.</td>
</tr>
<tr>
<td>Reprorductive strategy</td>
<td>Capability of every species to enjoy one or two breeding seasons per year, and how many clutches can they lay in each one. This variable may be quite different when applying this method to other climatic regions.</td>
<td>We assume that species with a single clutch per year are more likely to miss the single clutch that species that perform multiple clutch per year.</td>
</tr>
<tr>
<td>(RS):</td>
<td>3: One reproductive period with only one clutch; 2: One reproductive period with several clutches; 1: Two reproductive periods (spring and autumn) with lonely clutches; 0: Two reproductive periods with several clutches.</td>
<td></td>
</tr>
<tr>
<td>Eggs (offspring) number</td>
<td>Average number of eggs in every clutch.</td>
<td>We assume that a lower investment in the number of eggs will result in less adaptive capacity, in an ecosystem subject a significant volume of changes in a very short period of time.</td>
</tr>
<tr>
<td>Breeding habitats</td>
<td>Summatory of habitats where every species may breed, and categorized ranging from 0 to 3: reservoirs, rivers, brooks or streams, lakes, semi-permanent ponds, temporary ponds, great human facilities (pools, irrigation ditches, channels . . .), small human facilities (basins . . .).</td>
<td>Whether the species is capable of reproduction in a single type of habitat, this will mean a higher probability of extinction, if the specific breeding habitat changes or is destroyed.</td>
</tr>
<tr>
<td>(BH):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum age</td>
<td>Maximum age in the wild for every species.</td>
<td>Whether the species is capable of living more years, there is a greater probability that a successful breeding season occurs.</td>
</tr>
<tr>
<td>Larval period length</td>
<td>Average duration of the larval period.</td>
<td>If the larval period, usually aquatic, is long, the species is more prone to suffer unavoidable exposure, such as pollutants, where the larvae cannot avoid contamination until they complete metamorphosis and move to the land environment.</td>
</tr>
<tr>
<td>(LP):</td>
<td>3: &gt;6 months; 2: 3 to 6; 1: 2 to 3; 0: &lt;2.</td>
<td></td>
</tr>
<tr>
<td>Adult habitat</td>
<td>Conservation degree bear by every species to survive in an area.</td>
<td>If a species is a generalist in terms of habitat selection, this species is supposed to be more adaptable to changes in the ecosystem and therefore less vulnerable to extinction.</td>
</tr>
<tr>
<td>Antropic impacts</td>
<td>Number of anthropic impacts which affect every species, further ranged from 0 to 3: aversion killing, road killing, emergent diseases, sensitivity to pesticides, sensitivity to exotic species, detectability degree.</td>
<td>We assume that not all species are affected similarly by human activities.</td>
</tr>
</tbody>
</table>

García-París et al., 2004; Ceacero et al., 2007; García-Muñoz et al., 2010a,b), as well as field data and observations by the authors. Data for Iberian Painted Frog (D. galganoi) were merged with those from the Spanish Painted Frog (D. jeanneae) because of the difficulty to differentiate both species without genetic analysis (García-París et al., 2004) and because there is even disagreement about their specific status (Zangari et al., 2006; Velo-Antón et al., 2008). Nonetheless, no differences between the ecological and biological traits of both Dis coglossus have been described.

2.3. Statistical analysis

Principal Components Analysis (PCA) was performed with the ten studied ecological and biological variables to reduce...
dimensionality among them. We considerer include also the Presence (P) in the study area in the PCA analysis, to take into account the implicit risk of presenting a marginal distribution in the study area. Factor with an eigenvalues greater or equal to 1.0 were selected. In addition, factor coordinates of cases (species; value of each factor for the), the sum of the species factorial scores when only considering the species present in the cell: which means that the final score of a given cell, for each factorial axe, is both influenced by the number of species present and the species scores on the considered factorial axe (Scores for each UTM square correspond to: \( \sum F_i \cdot S_p \); where \( F_i \) is the value of factor score for the specie i; and \( S_p \) denote the presence, 1, or absence, 0, of the specie i).

Linear regression of each extinction risk component (F1, F2, and F3), were performed regarding the percentage of protected UTM 10 \( \times \) 10 squares where every species occurs. This analysis provides information about which species are infra- or overprotected in the study area respect to every extinction risk component.

Statistica 7 software for Windows (StatSoft Inc., 2005) was used for all statistical analysis.

### 3. Results

The scores for the independent variables considered to affect survival of amphibian species in the study area are shown in Table 2. The first three principal components (PC1, PC2, and PC3) in the PCA analysis had eigenvalues higher than 1 and accounted for 72.30% of the total variance among the studied biological and ecological variables (Table 3). The first principal component (PC1: 39.73%) was positively correlated with the species presence in the study area, altitudinal valence, eggs number, larval period length and adult habitat. The second principal component (PC2: 20.16%) was positively correlated with the reproductive strategy. Finally, the third principal component (PC3: 12.42%) was negatively correlated with breeding habitats used. Thus, these Principal Components (PC1, PC2 and PC3) were interpreted as a gradient of impacts (AI), and factors coordinates of cases (F1, F2, F3).

Table 2: The scores of the ten ecological and biological variables used in the factor analysis. The significant structuring variables (<0.7, following Budaev, 2010 for small sample size) relative to each axis are indicated in bold characters. See Table 1 for further explanation about values and abbreviations.

<table>
<thead>
<tr>
<th>Species</th>
<th>P</th>
<th>DR</th>
<th>AV</th>
<th>RS</th>
<th>EN</th>
<th>BH</th>
<th>MA</th>
<th>LP</th>
<th>AH</th>
<th>Al</th>
<th>FI</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelobates cultripes</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2.0</td>
<td>2.372</td>
</tr>
<tr>
<td>Triturus pygmaeus</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2.0</td>
<td>2.023</td>
</tr>
<tr>
<td>Lissotriton boscai</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2.0</td>
<td>1.916</td>
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<tr>
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<td>3</td>
<td>1</td>
<td>2</td>
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<td>3</td>
<td>0</td>
<td>0</td>
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<td>2</td>
<td>3</td>
<td>2</td>
<td>2.0</td>
<td>2.395</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2.0</td>
<td>1.661</td>
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<tr>
<td>Discoglossus sp.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
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<td>2</td>
<td>3</td>
<td>2</td>
<td>2.0</td>
<td>1.661</td>
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<tr>
<td>Pelobates cultripes</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
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<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2.0</td>
<td>0.203</td>
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<tr>
<td>Pelobates puntatus</td>
<td>3</td>
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<td>0</td>
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<td>1</td>
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<td>1</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
<tr>
<td>Pelobates ibicens</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
<tr>
<td>Hyla arborea</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
<tr>
<td>Hyla meridionalis</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
<tr>
<td>Bubalus rufus</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
<tr>
<td>Bubalus ibicens</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
<tr>
<td>Pelophylax pereri</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>0.500</td>
</tr>
</tbody>
</table>

For all statistical analysis.

#### 4. Discussion

Using an amphibian community in Southern Iberian Peninsula as study case, a methodological procedure has been developed to identify those areas where conservation actions should be focused. Specifically, this method indicates which factors constitute the greatest extinction risk for each species and for each 10 \( \times \) 10 UTM...
Fig. 2. Factorial maps F1–F2 and F2–F3 for both species and traits. Species coding: S. salamandra (1), P. waltl (2), T. pymaeus (3), L. boscai (4), A. dickhilleni (5), A. cisternasii (6), Discoglossus sp. (7), P. punctatus (8), P. ibericus (9), P. cultripes (10), B. calamita (11), B. bufo (12), H. meridionalis (13), H. arborea (14), P. perezi (15). Traits coding: Presence/absence data (P); distribution range (DR); altitudinal valence (AV); reproductive strategy (RS); eggs (offspring) number (EN); breeding habitats (BH); maximum age (MA); larval period length (LP); adult habitat (AH); Antropic impacts (AI).

Fig. 3. Priority areas (in darker squares) are those where more species with greater needs for specific management measures are present. Thus, Fig. 3A shows those areas needing habitat conservation and permanent aquatic ecosystems. Fig. 3B shows those areas where disturbances in breeding habitats should be avoided during the breeding periods. Fig. 3C shows those areas with a high number of species with high breeding habitat specificity, and thus, individual management measures are needed for every involved species.
The protected areas network certainly maintains important territories for amphibians’ conservation. However, according to the
results, there are still substantial parts of our study area which require protection. As previously shown, there are species with high risk of extinction (P. walli, T. pygmaeus, L. boscai, A. cistermani, A. dichilheni, B. bufo, B. calamita, H. meridianalis, and P. cultipes) which are not adequately covered by the protected areas (see similar data in the same study area in García-Muñoz et al., 2010a, b).

Preventing the local extinction of these species goes through expanding protected areas or by performing specific conservation plans to minimize their threats. Developing a replicable methodology (especially based on standardized local data) is, hence, relevant, especially because it can be applied at different spatial and temporal scale to determine conservation priorities.

Our method provides an alternative way to estimate conservation risks based on a statistical approach, easily interpretable. In addition, the factors responsible for amphibian decline (see among others, Schuytema and Nebeker, 1999; Houllahan et al., 2000; Tejedo, 2003) do not affect to different populations of the same species in the same way, since these factors vary locally (Carey and Bryant, 1995). Thus, the results calculated for different areas may be used to link conservation plans at large scale. On the other hand, this methodology produces similar outputs than habitat suitability models (e.g. Sillero, 2010) without needing so many detailed records, whereas uses ecological and biological variables of species to produce mechanistic models instead of usual correlative ones. Nevertheless, further research may combine both approaches to develop conservation models in response to novel ecosystem situations.

5. Conclusions

In conclusion, developing a replicable methodology (based on local data) is hence relevant, especially because it can be applied at different spatial scale to determine conservation priorities. In summary, understanding amphibian decline, as a sum of factors that vary locally, could be used in developing indices applicable to medium size areas. In last term, this provides tools for protecting amphibians more successfully and at reasonable costs for conservation authorities.

Acknowledgments


