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Will climate change reduce the efficacy of protected areas for amphibian conservation in Italy?

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ABSTRACT

Amphibians are an important and imperiled component of biodiversity. In this study we analyze the efficacy of Italian reserve network for protecting multiple amphibian species in a climate change scenario, considering both nationally designated areas and Natura 2000 sites. Our approach is based on ensemble niche modeling estimate of potential range shift under two carbon emission scenarios (A1FI and B1) and two dispersal assumptions. The predicted distributions were used to perform gap and irreplaceability analyses. Our findings show that the current Italian reserve network incompletely represents current amphibian diversity and its geographic pattern. The combination of the nationally designated protected areas and the Natura 2000 sites improves current representation of amphibians, but conservation targets based on geographic range extent are achieved for only 40% of species. Under the future scenarios, Natura 2000 sites become a crucial component of the protected areas system. Nonetheless, we predict that climate change decreases for many species the amount of suitable range falling into reserves, regardless of our assumptions about dispersal. We identify some currently unprotected areas that have high irreplaceability scores for species conservation and that maintain their importance under all the future scenarios we considered. We recommend designation of new reserves in these areas to help guarantee long-term amphibian conservation.

1. Introduction

Amphibians are an important component of biodiversity that has emerged as a global conservation concern because of recent worldwide declines (Stuart et al., 2004; Wake and Vredenburg, 2008; D'Amen and Bombi, 2009). The extrinsic causes of their decline owe to many environmental conditions acting synergistically, such as habitat loss and degradation, UV radiation, and disease (Alford et al., 2001; Daszak et al., 2003). In addition, recent changes in the global climate might impact adversely on amphibian populations. A causative relationship can exist between amphibian population reductions and climate anomalies (Daszak et al., 2005; Whitfield et al., 2007). For example, wetland desiccation due to climatic change is associated with amphibian declines in Yellowstone National Park (McMenamin et al., 2008). Similarly, climate change is associated with population disappearances in Italy (D'Amen and Bombi, 2009). The potential mechanisms underlying these local extinctions have become clearer in recently, with the demonstration of a relationship between increase in mean temperature, body condition decline, and decrease in fecundity (Reading, 2007). Extinctions of amphibians are projected to accumulate as climate warming increases in the decades to come, which suggests that new strategies are needed to maximize the effectiveness of conservation efforts for amphibians (IUCN, 2006).

Despite the imperilled status of amphibians, these vertebrates are not as well represented in conservation studies as are other, less threatened taxonomic groups (Brito, 2008) and are often neglected during conservation planning (Rodrigues et al., 2004; Pawar et al., 2007). However, the *in situ* conservation of viable populations in natural ecosystems is a fundamental requirement for the maintenance of amphibian biodiversity (Rodrigues et al., 2004). To this end the integration of the potential impacts of climate change with selection of protected areas has recently gained attention (Heller and Zavaleta, 2009). Some species will likely become locally extinct in existing reserves as their suitability declines. Amphibians will require for long-term conservation access to other areas that are currently climatically unsuitable but which will likely become suitable in the future (Hannah et al., 2002; Araújo et al., 2004; Heller and Zavaleta, 2009). In this

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light amphibian conservation strategies need to be re-examined in order to address lack of adequate species representation in existing reserves and to account for the anticipated risk of population decline due to climate change (Hannah et al., 2002).

In the European context, Italy harbours a relatively diverse amphibian fauna (Gasc et al., 1997; Bologna, 2004; Temple and Cox, 2009). In Italy, studies have separately addressed the effectiveness of protected areas for terrestrial vertebrates and the potential for detrimental climate change impacts on amphibians. Maiorano et al. (2006, 2007) evaluated the capacity of Italian national and Natura 2000 protected areas to conserve vertebrate biodiversity under current climatic conditions. These authors found that existing protected areas are often insufficient to conserve current patterns of biodiversity in Italy. Similar results exist for other European regions (Hopkinson et al., 2000; Dimitrakopoulos et al., 2004; Araújo et al., 2007). Finally, doubling current CO_2 levels will likely result in range contraction for those amphibian species that occur in mountainous and Mediterranean areas (Girardello et al., 2009). However, we know of no study that has focussed on Italy to investigate how extinction risk of amphibians is associated with the potential inadequacy of reserves systems under climate change.

The goal of this paper is to analyze the efficacy of the Italian reserve network for protecting amphibian diversity in a climate change scenario. We assessed how local amphibian biology and patterns of predicted climate change could act together to affect extinction risk and protected-area effectiveness over the next century. Moreover, we introduced a novel and flexible approach for conservation target definition to consider complex factors surrounding the effects of climate change. In particular, we incrementally adjusted targets for amphibian species conservation in response to the predicted change in species range size. We used these targets to determine under current and future climatic conditions the extent to which species are underrepresented in existing protected areas. We determined whether the current system of protected areas matches the most-valuable sites, taking into consideration the predicted effects of climate change on the distribution of suitable areas for amphibians. Additionally, we analyzed spatial options for filling gaps in the reserve system using an approach based on the principle of irreplaceability (Pressey et al., 1994; Coetzee et al., 2009). Such a framework could help to allocate limited conservation funds to priority areas, limiting investment in areas where conservation initiatives are likely inefficient in the long run.

2. Materials and methods

2.1. Species data set

We utilized presence data of Italian amphibians from CKmap 5.3.8 (Stoch, 2000–2005). This database reports species occurrence within the Universal Transverse Mercator (UTM, 10 × 10 km) grid that intersects the Italian territory (see D'Amen and Bombi, 2009). We updated distribution information for newly recognized species using maps from IUCN Red List (see Frost, 2008 for a discussion; IUCN, 2009). To avoid biases caused by small sample sizes, we excluded from the analysis species with less than 20 records. At the same time, we also discarded those ubiquitous species for which we could not select a sufficient number of pseudo-absence points for model construction. Alien species, cave species, and species only marginally present in Italy with respect to their entire range were also excluded. As a result, we analyzed a total of 22 species, of which 20 are ranked by European Red List of Amphibians in the Low Concern category, while *Bombina pachypus* is considered Endangered, and *Rana latastei* Vulnerable (Temple and Cox, 2009). We adopted nomenclature following Frost (2008).

2.2. Environmental data sets

Niche-based models were calibrated using climatic, land use, and topographical predictors. Of 20 variables initially, we retained only those correlated at 0.70 or lower. Since the primary interest of this exercise is forecasting and not estimating model parameters, this level of correlation is not of concern (Legendre and Legendre, 1998). We used seven bioclimatic predictors: (1) annual mean temperature, (2) mean diurnal temperature range, (3) isothermality, (4) temperature annual range, (5) mean temperature of wettest quarter, (6) precipitation of warmest quarter, and (7) precipitation of coldest quarter. Current values for these variables were derived from the WorldClim database (Hijmans et al., 2005), which are climate grids for 1950–2000 with a resolution of 30 arc-seconds ($\sim$1 km). Potential future values for the time interval 2041–2070 were derived from the 10 arc-minute resolution climate grids of Mitchell et al. (2004) for the IPCC scenarios A1FI and B1 and the HadCM3 circulation model, which is widely used for predicting climate change effects on fauna distribution in Europe (e.g. Araújo et al., 2004, 2006). We chose A1FI and B1 to capture some of the uncertainty surrounding future projections, since they are based on contrasting story lines covering the range of possible demographic, socio-economic and technological changes thought to influence greenhouse gas emissions. To produce high-resolution climate scenarios, the 10 arc-minute grids were expressed as anomalies to the 1950–2000 period of WorldClim, interpolated to 30 arc-seconds resolution and then recombined with the corresponding grids from the WorldClim data set.

The effects of existing land use on habitat availability were accounted for by including two land cover variables, the percentage of forested surface and herbaceous vegetation (Corine Land Cover IV, SINAnet, 2008). Finally, topographic information was included in the models as the prevalent exposition direction in a continuous north–south gradient ranging between 1 and -1, derived from digital elevation model (75 m resolution). All variables were prepared in a geographical information system (ArcMap 9.2) and rescaled to the UTM resolution (10 × 10 km) to the extent of Italy.

2.3. Reserves data set

Data on the location of existing protected areas in Italy are available from the national Ministry for the Environment (ftp://ftp.scn.minambiente.it/Cartografie). These data comprise boundaries of Nationally Designed Protected areas (NPAs) and sites included in the European Natura 2000 network. NPAs consist of 774 parks that were founded by national or local administrations before 2004, with a total surface of approximately 29,400 km^2 (slightly less than 10% of the country's surface). The Natura 2000 network consists of 2885 sites, which are largely overlapping with NPAs and increase the protected surface by 34,700 km^2 (Natura 2000 areas not overlapping NPAs are hereafter defined as EPAs). Thus, the Overall Protected Areas (OPAs) cover a total surface of 64,100 km^2 (21% of Italy) (Gambino and Negrini, 2002).

The problem of matching reserve boundaries with species distribution is common when dealing with national atlases datasets at coarse resolution (Araújo, 1999, 2004). In these cases, a threshold is needed to determine whether reserves should be considered present or absent in a grid cell. For solving this issue we tested different thresholds (from zero to 100% with intervals of 10) and chose the value that resulted in selection of a number of cells with a total surface equal to the total surface of Italian protected areas (considering independently NPAs and OPAs). We considered as protected any cell with a proportion of park coverage larger than 40%. This is consistent with Araújo (2004), who observed a plateau in species accumulation curves with the use of a 40% coverage threshold to assign reserves to grid cells.

2.4. Niche modeling

We modelled species distributions using eight different techniques available in the R-based BIOMOD package (Thuiller, 2003; R Development Core Team 2008): Generalized Linear Models (GLM; McCullagh and Nelder, 1989), Generalized Additive Models (GAM; Hastie and Tibshirani, 1990), Classification Tree Algorithms (CTA; Breiman et al., 1984), Artificial Neural Networks (ANN; Ripley, 1996), Mixture Discriminant Analysis (MDA; Hastie and Tibshirani, 1996), Multivariate Adaptive Regression Splines (MARS; Friedman, 1991), Generalized Boosted Regression Models (GBM; Friedman, 2001), and Random Forest (RF; Breiman, 2001). Pseudo-absence points for each species were generated by a random selection among the grid cells where the species was not reported, maintaining a prevalence of 50% (Liu et al., 2005). The performance of each model was determined with 10-fold cross-validation of *AUC* (Fielding and Bell, 1997). Subsequently, we derived projections for the future climatic scenarios A1FI and B1.

We computed a consensus of single-model projections for each scenario using the weighted average approach, which increases significantly the accuracy of species distribution forecasts (Araújo and New, 2007; Marmion et al., 2008). We utilized the *AUC* scores to weight the corresponding models and included in the consensus estimation only those models with an *AUC* score higher than 0.70 (Swets, 1988). In particular, the habitat suitability of the *i*th grid cell (WA_i) was calculated as:

$$WA_i = \frac{\Sigma_j (AUC_j \times p_{ji})}{\Sigma_j AUC_j}$$

where AUC_j is the validation score of the model elaborated with the jth technique and p_{ji} is the probability of presence for the considered species as predicted by jth model. We transformed these probability values into presence/absence maps by using an optimal ROC threshold (Cantor et al., 1999), which optimizes the percentage of correctly predicted presences and absences (Liu et al., 2005).

Individual dispersal capability might severely restrict the ability of populations, and consequently of whole species, to track suitable climatic conditions geographically (Guisan and Thuiller, 2005; Massot et al., 2008). Consequently, we accounted for specific ability of range shift by considering species-specific dispersal limitations derived from the literature of the species, or a closely related species (Hannah et al., 2007; Appendix A). This value represents a realistic measure of the intrinsic ability of a species to shift its distribution in response to climate change. In deriving future projections, the application of the dispersal constraint allowed us to distinguish between a potentially suitable area, and a potentially colonizable area (*sensu* Engler and Guisan, 2009). In particular, each species could occupy suitable cells within a dispersal radius from current observations according to the vagility of the species. As species range shifts are also influenced by extrinsic factors, i.e. the highly fragmented landscape, we considered a second, more-restrictive scenario of no-dispersal in order to estimate the proportion of current habitat that remains suitable under future conditions. Potential distributional shifts were measured as the difference in the total number of grid cells occupied currently and under each of the future climate change scenarios.

2.5. Criteria for species conservation targets

We established the conservation target for species conservation for use in both gap and irreplaceability analyses on the basis of species-specific extent of occurrence, following Rodrigues et al. (2004). We defined 10 cells (1000 km^2) as the minimum area needed for species viability. For those species with an initial range of less than 10 cells, we set the conservation target to 100% of the current range size. On the other hand, we set a 10% conservation target for very widespread species (>1000 cells [>10^6 km^2]), as this percentage represents approximately the total Italian surface covered by NPAs. Targets for all species with intermediate range sizes were calculated by interpolating the extreme range size targets using a linear regression on the log-transformed number of initially occupied cells (Appendix B).

Because our criterion for setting species conservation targets relied on range extents, we adjusted conservation targets on the basis of range size alteration that is predicted to take place with climate change. This flexible approach permits future modification of species conservation requirements to account for climate change. For instance, a species might be currently distributed to few cells and, therefore, have a very high conservation target. If this species will have more suitable habitat in the future, and will enlarge its distribution accordingly, the relative target should be proportionally reduced in order to use efficiently limited funds for conservation (Appendix B).

2.6. Gap and irreplaceability analyses

In gap analysis species distributions are compared to the distribution of conservation areas and the degree of species representation in the reserve network is determined (Jennings, 2000). We considered those species not represented in any protected area to be gap species, while species that met only a portion of their conservation target were considered partial gap species (Rodrigues et al., 2004).

To measure relative conservation importance of different map cells, we estimated the irreplaceability value of each grid cell using the C-Plan Systematic Conservation Planning System, Version 4 (Pressey et al., 2009). Simply defined, the irreplaceability of a map cell is the degree to which the cell is required in a reserve network in order to achieve established conservation targets (Pressey et al., 1994). To avoid an intractable exact calculation, irreplaceability was estimated as the number of combinations of sites that include the focal site and meet conservation targets, but which would not meet the targets if the focal site were removed. This estimation was done using a predictive approach based on the central limit theorem (Ferrier et al., 2000). Finally, irreplaceability values were rescaled between 0 and 1: values close to 1 indicate difficult to replace sites, potentially containing species endemic to those sites, while values close to 0 indicate easily replaceable sites, ones containing only widely distributed species. We predicted the irreplaceability of each cell using current species occurrences and using future potential distributions under different climate and dispersal scenarios. In addition, we considered three alternative conservation systems (i.e. no reserves, NPAs, and OPAs) for assessing the relative contribution of existing reserve networks.

2.7. Test of park efficacy

In order to evaluate the effectiveness of the existing Italian national park system (OPAs) and its components (NPAs and EPAs), we compared the mean irreplaceability value of cells in conservation networks to the mean value expected in cells randomly selected regardless of their conservation status (Araújo et al., 2007). We calculated the probability that the observed mean value for protected cells differed from a random mean value by comparing the observed mean value to the distribution formed by 5000 random selections of a number of grid cells equal to the number of protected cells (Gotelli, 2000). For present and future scenarios, we tested whether OPAs and NPAs have higher irreplaceability than the remaining map cells, i.e. with all protected areas excluded. Additionally, we estimated in an irreplaceability analysis the contribution of the new Natura 2000 sites designation to the representativeness of the existing reserve system. Because the existence of reserves alters the estimate of the irreplaceability of map cells and, therefore, the potential contribution of all the "unreserved" sites, we recalculated the irreplaceability values considering the existence of NPAs for testing EPAs selection for present and long-term conservation.

3. Results

3.1. Predicted changes in species distributions

All modeling techniques provide good performance, with median *AUC* values between 0.83 and 0.9 (lower quartile: $0.79 < AUC < 0.85$; upper quartile: $0.88 < AUC < 0.93$). We find that Generalized Boosted Regression Models, Multivariate Adaptive Regression Splines, and Random Forest are the best performing models, with $AUC > 0.9$ for 10 species out 22 (Appendix C). Consensus models show diverse responses of species range to alternative climatic scenarios and dispersal assumptions (Table 1). Under a no-dispersal assumption (NO-DISP), all but two species are projected to lose suitable habitat in the future (median loss of 51%). Losses are generally higher under the A1FI than under the B1 climate scenario although this difference is not statistically significant ($U = 220.00$; $p = 0.6055$. Mann–Whitney *U* Test; Table 1). Under a dispersal assumption (DISP), the consensus models forecast a reduction of the range size of 60% and 50% of the species under A1FI and B1 scenarios respectively (Table 1). We predict that eight species (36.36%) suffer range reduction irrespective of climate change and dispersal scenario. One species, *Pelobates fuscus* is predicted to lose all suitable habitat under the A1FI scenario and absence of dispersal (Table 1). On the other hand, under the dispersal assumption, the consensus forecasts for four species (18.18%) show an increase in the number of cells with suitable climate (Table 1).

Table 1
Current range extent (number of occupied cells), and percentage of predicted change in the future climatic conditions (according to A1 and B1 socio-economic scenarios), under different dispersal assumptions.

Species	Current range extent	Percentage of predicted range change			
		NO-DISP		DISP	
		A1	B1	A1	B1
Bombina pachypus	339	−40.24	−33.14	30.47	46.75
Bombina variegata	166	−75.32	−60.76	−40.51	−13.29
Discoglossus pictus	127	−1.64	−4.10	79.51	73.77
Discoglossus sardus	41	−73.17	−46.34	−29.27	39.02
Hyla intermedia	1110	−3.33	−6.94	128.11	99.10
Hyla sarda	58	−21.82	0.00	256.36	392.73
Lissotriton italicus	255	−14.12	−10.20	47.06	54.90
Lissotriton vulgaris	738	−50.27	−56.64	−20.19	−30.49
Mesotriton alpestris	351	−46.15	−46.72	−4.27	−1.99
Pelobates fuscus	64	−100.00	−92.19	−68.75	−29.69
Pseudepidalea balearica	638	−5.96	−10.19	257.84	203.13
Pseudepidalea sicula	99	0.00	0.00	167.35	162.24
Pseudepidalea viridis	109	−52.29	−51.38	−1.83	−0.92
Rana dalmatina	810	−50.74	−57.04	−20.12	−31.11
Rana italica	577	−44.89	−44.71	2.95	2.25
Rana latastei	235	−55.74	−55.32	−33.19	−31.06
Rana temporaria	514	−51.58	−42.53	−34.11	−20.21
Salamandra atra	82	−95.00	−63.75	−91.25	−36.25
Salamandra salamandra	680	−63.07	−54.25	−41.67	−29.58
Salamandrina perspicillata	242	−51.65	−57.02	33.47	20.66
Salamandrina terdigitata	53	−96.15	−73.08	−90.38	0.00
Triturus carnifex	958	−77.24	−71.82	−56.16	−49.90

3.2. Gap analysis

Using a 40% coverage threshold for matching reserves to grid cells, Nationally Designed Protected Areas (NPAs) and Overall Protected Areas (OPAs) occupy 282 and 617 cells respectively (Appendix D). All of the species we considered are currently represented in both NPA and OPA protected areas. Nine species met their targets in OPAs, but none do when we restrict the analysis to NPAs (Table 2). In addition, more than half of the partial gap species (59% and 62% with NPAs and OPAs respectively) meet less than 50% of their respective targets (Fig. 1 and Table 2). The predicted number of species for which conservation targets are met decreases in the future independent of dispersal or climate change scenario. Considering NPAs, some amphibians are predicted to become totally gap species, disappearing from all of the currently protected map cells. At the same time, the number of species that meet their target with OPAs will decrease and, if no-dispersal is assumed, one species will be completely absent in OPAs. In particular, *P. fuscus*, *Pseudepidalea viridis*, and *R. latastei* are only marginally represented in reserves (Table 2), each being protected in less than four cells by NPAs (Appendix E). Their representation is expected to decline in the future, when they will be completely unrepresented in NPAs, independent from the considered scenario. Moreover, if no-dispersal is assumed, no map cells with suitable climate for *P. fuscus* will be protected by OPAs, while *P. viridis* and *R. latastei* will be protected by OPAs in 5 cells or fewer (Appendix E).

3.3. Irreplaceability analysis

Considering no cells as protected, the areas of highest values of irreplaceability for amphibian conservation are found on the island of Sardinia and the lowlands of North-Eastern continental Italy (most irreplaceable 1% of cells; Appendix Fa, see Appendix G for place name locations). Secondary regions of high irreplaceability are present on Sicily and on the Tyrrhenian side of Southern Italy. The inclusion of Nationally Designed Protected areas (NPAs) in GAP analysis reduces irreplaceability scores for cells along the Italian peninsula and on the Tyrrhenian side of Southern Italy. Other peak areas of irreplaceability remain almost unmodified (Appendix Fb). The addition of Natura 2000 areas (EPAs) had a strong positive effect, but the pattern of change is still similar to when no protected cells are included (Appendix Fc), with the most irreplaceable 1% of cells still being unprotected in Sardinia and in North-Eastern continental Italy.

Under future conditions, under both climate scenarios, and with no cells considered as protected, Sardinia and Sicily remain in the future as important as they are currently, (Appendix H). The map cells on the Tyrrhenian side of Southern Italy increase in irreplaceability, as do cells in the mountainous areas of central and eastern Alps and, secondarily, in the central Apennine (Appendix H). If the presence of all protected areas (OPAs) is considered, the irreplaceability maps calculated for future conditions represent the focal areas where new reserves should be designed for the long-term conservation of amphibians. The geographic pattern of these areas is similar among predictions based on the four socio-economic and dispersal assumptions: Sardinia, the lowlands of North-Eastern continental Italy and the central Alpine foothills are primary important areas and hold the most irreplaceable 1% of cells

Table 2
Percentages of target met by each species in NPAs and OPAs under present conditions and alternative dispersal and climate change scenarios. Values larger than 100% are represented by a dash. Values lower than 50% are presented in italics and percentages equal to 0 are highlighted in bold italic (ext = species that are projected to became extinct under the future conditions).

Species	Present		NO-DISP A1		NO-DISP B1		DISP A1		DISP B1	
	NPAs	OPAs	NPAs	OPAs	NPAs	OPAs	NPAs	OPAs	NPAs	OPAs
Bombina pachypus	71.99	–	62.39	97.19	67.96	–	77.62	–	84.21	–
Bombina variegata	*9.35*	*38.74*	*13.97*	*38.43*	*15.04*	*42.61*	*18.93*	52.99	*17.93*	55.29
Discoglossus pictus	*20.34*	*29.73*	*21.06*	*29.16*	*18.1*	*26.33*	*24.17*	*34.52*	*19.89*	*30.42*
Discoglossus sardus	*13.47*	*43.78*	*37.05*	64.84	*21.49*	64.48	*30.48*	65.31	*21.27*	63.81
Hyla intermedia	77.48	–	64.31	–	62.92	–	64.62	–	64.88	–
Hyla sarda	*10.51*	*39.4*	*3.25*	*29.28*	*10.91*	*40.9*	*1.76*	*21.11*	*7.56*	*36.1*
Lissotriton italicus	61.97	–	54.09	88.61	57.39	91.15	68.57	–	72.84	–
Lissotriton vulgaris	*39.96*	–	*21.18*	*48.81*	*21.31*	*47.45*	*28.37*	70.1	*27.07*	62.6
Mesotriton alpestris	*25.25*	83.24	*24.86*	74.59	*22.51*	77.52	*46.57*	–	*42.4*	–
Pelobates fuscus	*2.45*	*7.36*	ext	ext	***0***	***0***	***0***	*23.13*	***0***	*12.59*
Pseudepidalea balearica	*35.88*	76.77	*27.52*	63.39	*24.24*	55.16	61.32	–	51.19	–
Pseudepidalea sicula	*18.3*	*36.6*	*18.42*	*36.84*	*18.42*	*36.84*	*23.21*	*39.04*	*23.42*	*39.39*
Pseudepidalea viridis	*1.72*	*25.81*	***0***	*14.19*	***0***	*11.2*	***0***	*17.41*	***0***	*13.85*
Rana dalmatina	63.84	–	*25.1*	59.17	*24.39*	60.04	*36.74*	90.18	*33.5*	84.58
Rana italica	81.03	–	*42.72*	81.55	*47.51*	85.33	60.9	–	61.75	–
Rana latastei	*3.33*	*14.44*	***0***	*7.09*	***0***	*5.29*	***0***	*13.79*	***0***	*13.55*
Rana temporaria	53.28	–	*49.4*	–	*49.71*	–	53.74	–	54.66	–
Salamandra atra	*26.93*	97.35	75	75	*26.13*	87.09	*42.86*	*42.86*	*23.01*	69.04
Salamandra salamandra	67.92	–	*16.99*	63.43	*18.43*	64.51	*31.61*	96.69	*34.21*	–
Salamandrina perspicillata	*33.95*	82.14	*27.98*	64.19	*30.14*	70.92	*34.74*	75.26	*35.19*	76.42
Salamandrina terdigitata	72.78	92.37	–	–	*45.87*	61.16	60	60	*42.56*	51.07
Triturus carnifex	86.68	–	*6.92*	*31.14*	*6.24*	*30.18*	*23.85*	63.6	*13.69*	*48.78*

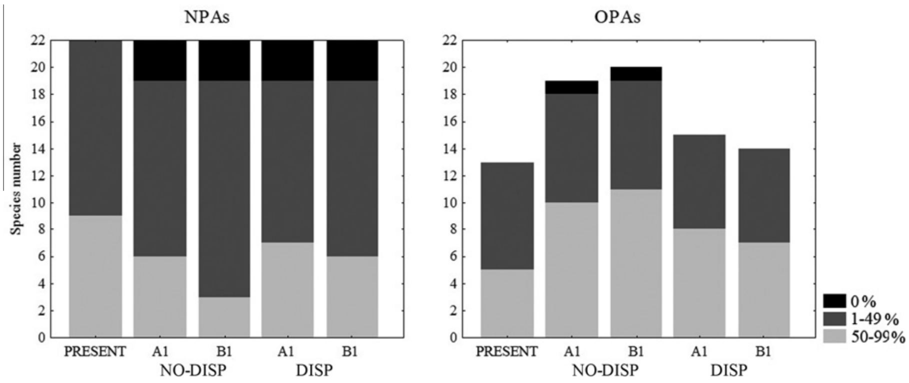

Fig. 1. Species representation. Number of gap and partially gap species in the current conditions and in the future scenarios, considering only NPAs and the OPAs. Different blocks colors represent amounts of target met.

(Fig. 2). Sicily and the Tyrrhenian side of Southern Italy represent further peaks of irreplaceability, and the central and northern Apennine become important in projections that assume no disperse occurs (Fig. 2a and c).

3.4. Representativeness in protected areas

The comparison of mean irreplaceability values of protected map cells with values calculated from 5000 sets of randomly selected map cells reveals that presently the entire network of Italian reserves (OPAs) and its components separately (Nationally Designed Protected areas [NPAs] and the Natura 2000 sites not overlapping with the former [EPAs]) protect sites with greater irreplaceability than that expected by chance (Table 3). This is also true under projections of future climate (both A1FI and B1) assuming no-dispersal occurs. To the contrary, assuming dispersal occurs and under both A1F1 and B1 scenarios, cells with NPAs are not more irreplaceable in the future than cells selected at random, and cells with EPAs are only marginally more irreplaceable than randomly chosen, unprotected cells. Nevertheless, Italian reserves have non-random differences in terms of mean irreplaceability respect to unprotected cells under future scenarios (both A1FI and B1) if they are considered as a whole (OPAs) (Table 3).

4. Discussion

Range modifications are predicted for all amphibian species under future climatic conditions and these changes will affect the degree to which species are represented in the Italian protected area network. Our results showed that under current conditions the existing network does not represent neither the entirety of amphibian diversity nor its geographic pattern. This inadequacy will aggravate on the long-term, when range shifts and reductions due to climate change will lead at decreasing species representation over the entire protected area system. We identified some areas currently highly irreplaceable and that will maintain their importance under all future climate scenarios. The inclusion of such areas in the network can produce an improvement of the network ability in protecting amphibians on the long-term.

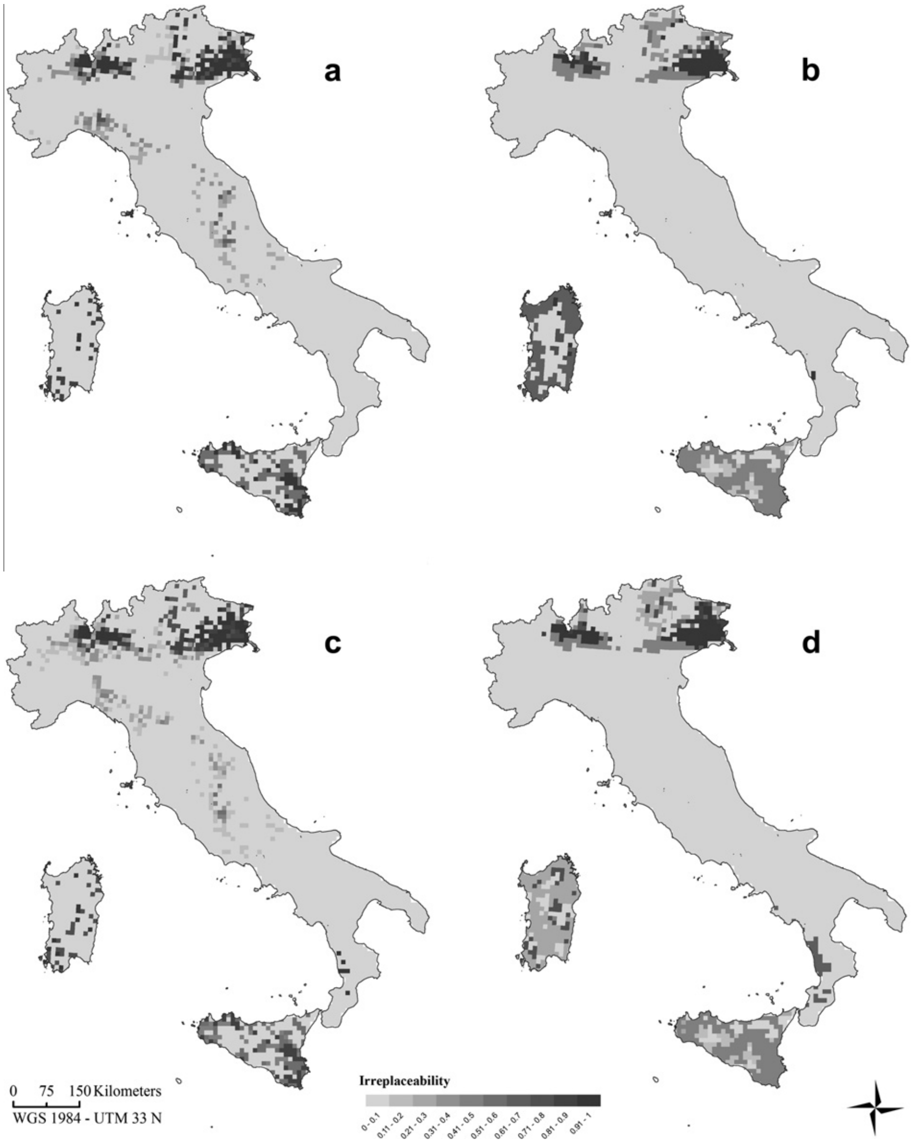

Fig. 2. Future irreplaceability patterns. Future irreplaceability patterns calculated by considering the existing OPAs, based on a consensus forecast in different climatic scenarios (A1: a and b and B1: c and d) and dispersal assumptions (no-dispersal: a and c, and dispersal: b and d).

Table 3

Non-randomness test of differences between the mean irreplaceability value in protected cells (M_{obs}) and in 5000 random cell selections in the whole grid (M_{sim}). Irreplaceability was calculated by considering all cells as unprotected for NPAs and OPAs, and taking into account the existence of NPAs for EPAs. Non-random differences were assumed when $P_{Mobs \geqslant Msim} \leqslant 0.05$. In italic we presented significant values after Bonferroni correction.

Present				NO DISP						DISP					
				A1			B1			A1			B1		
	M_{obs}	M_{sim}	$P_{Mobs \geqslant Msim}$	M_{obs}	M_{sim}	$P_{Mobs \geqslant Msim}$	M_{obs}	M_{sim}	$P_{Mobs \geqslant Msim}$	M_{obs}	M_{sim}	$P_{Mobs \geqslant Msim}$	M_{obs}	M_{sim}	$P_{Mobs \geqslant Msim}$
NPAs	0.249	0.180	*>0.001*	0.254	0.184	*>0.001*	0.256	0.186	*>0.001*	0.202	0.180	0.045	0.202	0.181	0.063
EPAs	0.206	0.155	*0.001*	0.200	0.158	*0.001*	0.225	0.160	*>0.001*	0.164	0.156	0.277	0.189	0.159	*0.012*
OPAs	0.251	0.180	*>0.001*	0.248	0.184	*>0.001*	0.261	0.186	*>0.001*	0.209	0.180	*0.001*	0.217	0.181	*>0.001*

4.1. Extinction risk driven by climate change

Predictions of range modification for amphibian species in Italy are clearly dependent on assumptions of dispersal. Under both alternative emission scenarios, if species are allowed to disperse, consensus models show potential eastward and upward range shifts for many species both in the peninsula and in northern Italy. Similar directions of species range shifts have already been documented in Europe and elsewhere for other groups (e.g. Parmesan et al., 1999; Erasmus et al., 2002). However, as there is high uncertainty about the ability of amphibians to successfully navigate highly fragmented landscapes, which leaves the assumption of no-dispersal representing the most realistic scenario for all species (Smith and Green, 2005; Araújo et al., 2006). Under this assumption, the loss of predicted suitable habitat (70% or more) is forecasted for almost all species. The protection of the areas that remain suitable over the long-term is the most prudent approach for conservation planning (Bakkenes et al., 2002; Williams et al., 2005).

Predictions under different emission scenarios and dispersal assumptions agree in indicating that the species most sensitive to climate change are *P. fuscus*, *Salamandrina terdigitata*, *Salamandra atra*, and *Triturus carnifex*. Among those, Girardello et al. (2009) forecasted a large range reduction for the first two species only. This discrepancy with the present results is explained by the different modelling approach (a single technique) and climatic scenario ($2 \times CO_2$ climate scenario) used by Girardello et al. The four species we identified are either endemic or subendemic at various taxonomic levels in Italy, yet are classified as Least Concern in the most recent Red List of European Amphibians (Temple and Cox, 2009). As reduction of distributional area is consistently a good predictor of extinction risk (Koopowitz et al., 1994), our forecasts suggest increasing danger of extinction for these species by the middle of the current century. This supports the idea that the incorporation of vulnerability to climate change should be an important component of IUCN Red List assessments (Bomhard et al., 2005; Coetzee et al., 2009).

A specific comment is required for the Italian subspecies *P. fuscus insubricus*, which is endemic to the Po river plain of northern Italy and already recognized as a highly threatened taxon (Andreone and Luiselli, 2000; D'Amen and Bombi, 2009; Agasyan et al., 2008). We predict this subspecies to lose all suitable habitats in Italy by the mid 21st century under the assumption of no dispersal, in agreement with Girardello et al. (2009). Moreover, it is particularly difficult for this toad to move through the environmental matrix because of the substantial anthropogenic impact in the Po river plain. The ability of the species to disperse to follow the shifting location of suitable environmental conditions is of crucial importance for any management initiative for the species. The creation of specific corridors that could allow this toad to disperse to areas with appropriate climate would facilitate its conservation. However, "assisted colonization" (*sensu* Hoegh-Guldberg et al., 2008) could be necessary for preventing the extinction of this endemic taxon.

4.2. Current amphibian representation in Italian protected areas

The currently protected sites are on average more irreplaceable than remaining areas. Nevertheless, from gap and irreplaceability analyses it emerges that the existing network does not represent all amphibian species adequately under current conditions. This discrepancy can be explained by the site-specific strategy based on the direct and detailed knowledge of local diversity, which historically drove reserve selection in Italy (Maiorano et al., 2007). The combination of NPAs and Natura 2000 sites is essential for improving representation of amphibian, but targets based on geographic range extent are, nevertheless, achieved only for 40% of species. In fact, even if the Natura 2000 sites greatly increase the extent of protection geographically, the most irreplaceable areas for amphibian conservation (Sardinia, Sicily and the north-eastern Italy) are not integrated satisfactorily into the Italian reserve network. This lack of representation is of interest, considering that most of the species we did not considered are distributed in Sardinia (five species) and in north-eastern Italy (two species). The result is that the current reserve network is comprehensively inefficient and represents neither the entirety of amphibian diversity nor its geographic pattern.

Our results are in general accordance with earlier analyses of current park efficacy in Italy and that addressed all vertebrate classes (Maiorano et al., 2006, 2007). Maiorano et al. (2006) demonstrated that amphibians are one of the least protected taxonomic groups, with the highest absolute number of total-gap species. Interestingly, Maiorano et al. (2006) discovered high values of irreplaceability for some areas that we not particularly irreplaceable for amphibians. Particularly important is the case of Sardinia where, even considering Natura 2000 implementation, the number of protected areas is extremely low and none coincide with areas of the highest diversity of either vertebrates (Maiorano et al., 2006, 2007) or amphibians. To the contrary, by considering total vertebrate diversity, Sicily did not emerge in Maiorano et al. (2006, 2007) as an area of high irreplaceability, while this region is of great importance if one considers the conservation of amphibian diversity. Both previous analyses of Italian reserve efficacy (Maiorano et al., 2006, 2007) did not consider the likely impacts of climate change on biodiversity distribution patterns, thus the priority sites selected for reserve system implementation do not account for the protection of vertebrates long-term climatic refugia. Future research should address the effects of climate change on the projected species representation for each vertebrate class in the Italian reserve system.

4.3. Long-term efficacy of the Italian protected areas for amphibian conservation

Our study represents a first attempt to evaluate the long-term efficacy of the Italian protected areas for the conservation of amphibians. Our approach is based on niche modeling estimates of potential range shift leading changes in species representation in protected areas. Other studies used this approach to predict a decrease in species representation for different taxonomic groups and localities (e.g. Araújo et al., 2004; Hannah et al., 2007; Coetzee et al., 2009). Range shifts and reductions due to climate change will lead to a decrease in the efficacy of nationally designated protected areas in Italy. In particular, some species will be represented in the future in very few protected cells while three species are projected to lose all map cells with suitable climate if dispersal is assumed not to occur. Climate change is predicted to decrease the number of protected cells with suitable climate for many amphibian species over the entire protected area system. Under both future emission scenarios we examined, only when the OPAs are taken together as a whole are protected cells on average more irreplaceable than the remaining cells. This result underscores the importance of Natura 2000 sites in complementing the nationally designed protected areas for long-term conservation of amphibians. This is similar to what was found for the Iberian peninsula by Araújo et al. (2007), who determined that sites of community importance are priority areas for the implementation of national reserves networks.

We have located important areas that, if protected, could contribute to the conservation of amphibians in Italy. The areas we identified are not yet defined at a spatial resolution to permit the proposal of new park boundaries. New research at a finer spatial resolution is required for setting boundaries of new reserves that will complement existing ones. Interestingly, we identify some areas that are the most irreplaceable currently for conservation of amphibian species and which will maintain their importance under all future climate scenarios. In particular, the creation of new reserves in specific areas of Sardinia, north-eastern continental Italy, and Sicily would increase substantially the efficiency of the network of protected areas for ensuring the long-term conservation of amphibians. Such implementation assumes greater importance in view of the national responsibility that Italy carries for species protection (Schmeller et al., 2008). In fact both Italian main islands are focal region for the global survival of eight amphibian species (seven in Sardinia and one in Sicily), while the protection of north-eastern continental Italy is essential for the long-term persistence of the endemic frog *R. latastei*.

5. Conclusion

The great complexity of natural systems suggests that there are fundamental limits to the accurate prediction of future species distributions (Pearson and Dawson, 2003). Nevertheless, the identification of consensus among multiple modeling techniques, as applied in this study, is one of the most promising approaches to adequately represent the likely impacts of climate change (Araújo and New, 2007; Coetzee et al., 2009). A further improvement ensues from the inclusion of species dispersal ability, which reduces uncertainty in projections of species distribution shifts (Engler and Guisan, 2009). Moreover, adjusting conservation targets in response to variation in species range size, as proposed in this paper, makes prioritization methods sufficiently flexible for anticipating climate change impacts and accounting for them in systematic reserve design. This adaptive approach is important because time is a key factor in implementing conservation action. The early identification of areas that are to threatened by processes such as climate change is crucial for planning effective countermeasures. We find that in Italy, the most valuable areas for amphibian conservation have not yet been considered in any process of reserve selection. The same areas emerge as priorities for conservation of amphibian diversity, both currently and in the future. These areas are key for efficiently complementing the existing reserve system in Italy.

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Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.11.004.

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