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Usefulness of volunteer data to measure the large scale decline of "common" toad populations

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ABSTRACT

Measuring a species decline is pivotal to evaluate their conservation status, but an accurate assessment of demographic trends requires observations collected across broad spatial and temporal scales. Volunteers can help to collect information over large scales, but their data may be affected by heterogeneity for sampling efforts and protocols, which may influence detection probability. Ignoring this issue may conduct to misleading conclusions. Here we show that data collected by different volunteer groups can be integrated with measures of sampling efforts, to obtain information on large scale demographic trends. We collected data on 33 common toad (*Bufo bufo*) populations across Italy for the period 1993–2010. We used two approaches (meta-analysis; analysis of average change in population size) to evaluate the overall demographic trend. We incorporated measures of volunteer sampling efforts into analyses, to take into account changes in detection probability. Toad abundance significantly declined in the last decade. From 2000 to 2010, 70% of populations showed a strong decline, and only 10% increased. Trends were heterogeneous among populations, but taking into account sampling effort reduced heterogeneity by 40%. We detected a 76% cumulative average decline of toad populations, despite an increasing mean sampling effort. The widespread toad decline rises concern for its future, also because the causes remain unclear. Volunteer data can be extremely useful to identify large scale population trends, if information on sampling effort are recorded and used to adjust counts.

1. Introduction

In the last two decades, a growing body of evidence has shown that amphibians are declining at the global scale (e.g., Houlahan et al., 2000): many populations and species have shrunk or even disappeared at the local or regional scale (Meyer et al., 1998; Lips et al., 2004; Griffiths et al., 2010). Knowledge of the amount and rate of species decline, and in which populations it occurs, is paramount to evaluate their conservation status. For instance, observing a reduction in population size, or strong demographic oscillations associated with small population size, are key criteria used by the IUCN to assess whether species are threatened by extinction (IUCN, 2001). However, documenting a decline can be challenging. First, populations may undergo natural demographic fluctuations. For instance, many amphibian populations are known to exhibit natural demographic cycles, with strong year-to-year variation even in absence of a true decline (Pechmann and Wilbur, 1994; Meyer et al., 1998; Green, 2003). Only observations collected across a long time span may allow an accurate assessment of demographic trends (Schmidt et al., 2005; Salvidio, 2009). Moreover, observations covering multiple populations across broad spatial scales are needed for an exhaustive assessment of species status (Storfer, 2003). Unfortunately, the collection of data over large spatial and temporal scales is complex and requires time, money, personnel, and the resources for their training (e.g., Reading et al., 2010; Selonen et al., 2010; Cameron et al., 2011).

The use of volunteers can help to overcome the difficulties of broad scale monitoring. Volunteers can be extremely useful to conduct biodiversity monitoring, as well as increasing public percep-

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tion and involvement toward conservation issues (Carrier and Beebee, 2003; Bell et al., 2008; Schmeller et al., 2009; Sewell et al., 2010). For instance, in Europe, at least 40,000 volunteers participated to nearly 400 independent schemes of biodiversity monitoring from 2005 to 2007, 15% of which focused on the herpetofauna (Schmeller et al., 2009). The availability of so many volunteers allowed the collection of a large amount of data that could not be obtained with the use of professionals only (Schmeller et al., 2009). Nevertheless, some concern exists about the actual usefulness of volunteer data (e.g., Genet and Sargent, 2003; Brashares and Sam, 2005). If volunteer groups follow different monitoring protocols, their data may be extremely heterogeneous. When indexes of population abundance are collected, special care is needed to identify and control the factors influencing species detectability (e.g., Williams et al., 2002). Detectability can be variable across time and space because of multiple factors, including environmental conditions, monitoring protocols, and even because observers with different expertise record data on different populations or during different years (Link and Sauer, 2002; Sauer et al., 2010). It might therefore be difficult integrating such volunteer counts to obtain reliable information for the analyses of population trends (Link and Sauer, 1998).

The common toad (*Bufo bufo*) is a widespread species, inhabiting large areas of Europe and Western Asia. Although classified as 'least concern' by the IUCN (Agasyan et al., 2008), analyses suggested that the common toad may be declining in some European countries (Carrier and Beebee, 2003; Schmidt and Zumbach, 2005). Vehicular traffic causes high mortality to toads crossing roads during breeding migrations. For this reason, in several European countries mitigation measures are established, frequently managed by groups of volunteers (Langton, 1989; Schmidt and Zumbach, 2008). Volunteer groups sometimes rescue toads over many years, with important consequences on mortality, and can also collect a large amount of data on the crossing individuals. Obtaining quantitative estimates of toad decline is difficult (Schmidt and Zumbach, 2005), but the availability of a large amount of data collected by volunteers may help to achieve this task.

The aim of this study was obtaining quantitative measures of population changes of the common toad over broad temporal and spatial scales, through the use of volunteer data. We integrated yearly abundance data, collected by different groups of volunteers, on 33 Italian toad populations. For these populations, in night-time during the migration period, volunteers walk along the stretch of roads where the migration occurs, gathering the toads to transfer them to the other side, and recording the number of toads crossing the road toward the breeding site as a measure of toad abundance. A single time series may have bias or may only represent a local situation. However, observing a coherent trend among multiple series collected over the same period, and representing populations spread through a wide region, may provide useful information on the overall trend of a species (Houlahan et al., 2000). Variation in monitoring effort across years may affect detection probability, therefore we integrated measures of volunteers sampling efforts in our analyses (Schmidt, 2004). We used the meta-analysis approach to combine results from multiple, heterogeneous sources and obtain a reliable measure of the overall strength of the demographic trend (Arnqvist and Wooster, 1995). Furthermore, we combined data from multiple populations to obtain quantitative estimates of the overall population changes in time using the ΔN method, an approach allowing the analysis of average changes in population size (Houlahan et al., 2000). We also show that adjusting counts with the measures of the sampling efforts can greatly reduce data heterogeneity and improve the robustness of conclusions.

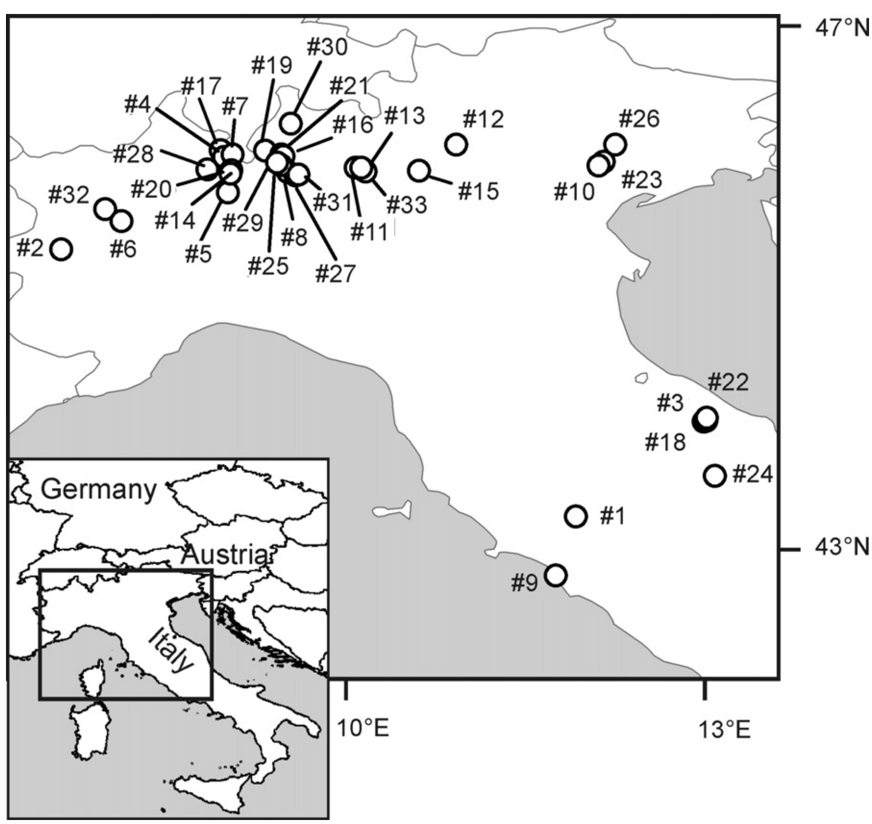

Fig. 1. Distribution of the 33 toad populations in Italy. See Table A1 in Supplementary material for further details on populations.

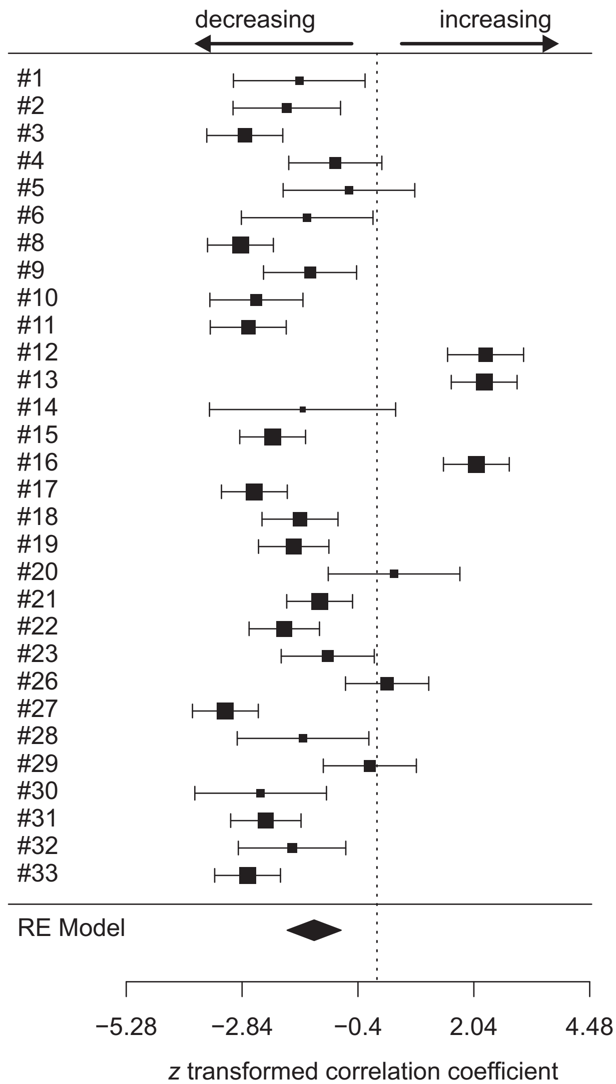

Fig. 2. Forest plot showing the effect sizes and corresponding 95% confidence intervals for the 30 populations analysed with meta-analysis, using Kendall's correlation and taking into account the sampling effort. The symbol size is proportional to the precision of the estimates. RE model: summary estimate based on the random-effects model, the confidence interval limits are shown by the outer edges of the polygon. Forest plots of analyses using different approaches are reported in Supplementary material, Figs. A1–A3.

2. Methods

2.1. Data gathering

We considered common toad breeding sites for which abundance data on at least three consecutive years were available; we assumed that each site corresponds to one population. The authors are responsible of several toad rescue projects involving volunteers for several years (see Table A1 in the Supplementary online materials). Furthermore, we contacted herpetologists and volunteer groups operating in Italy, performing toad rescue activity and collecting quantitative data on toad abundance. We also examined the available literature, including the grey literature, to obtain further time series of toad abundance, for the period 1993–2010. None of the populations considered was in urban or suburban areas.

For each population, in each year, we collected the following information: number of toad rescues during their migration to breeding sites, and sampling effort data: presence and length of drift fences, pit-falls, and underpasses; how and when the volunteers operate (see Table A1). Toad rescues is the number of toads that are transferred by volunteers toward the breeding wetlands. The number of animals that are counted twice is probably negligible: in population #2, toads were marked individually using pit tags, and only 1.5% of individuals crossed the road twice during the same season (AB unpublished data). In most populations, fences are posed along the road, to prevent unassisted toad crossing. At two sites (#11 and #28) underpasses were built during the data collection period (in 2002 and 2006, respectively). The presence of underpasses can strongly affect toad count, thus data collected before and after the underpass building are not comparable. Therefore, for the meta-analysis we considered data collected after the underpass construction only; for the ΔN method we considered data collected before and after underpass building as two distinct time series. Results remain unchanged if these populations are removed from the analyses.

2.2. Statistical analyses

2.2.1. Meta-analysis

We analyzed data using two different approaches. First, we used a meta-analysis to combine data from individual populations and assess the strength of their overall demographic trend. Meta-analysis allows to integrate the results of multiple studies, obtained through different data sources and with different methods, to obtain a quantitative measure of the overall strength of the trend. As each toad population was monitored by different people, we considered data from each population as a single "study". Meta-analysis was focused on the period 2000–2010. We included in meta-analysis only populations for which at least four consecutive years after 2000 were available, because sampling variance (see below) can not be calculated if sample size is <4 (Hartung et al., 2008). Following Houlahan et al. (2000), for each population we calculated the Kendall's correlation coefficient between year of monitoring and number of counted toads. We used the partial correlation between year and toad count, while controlling for sampling efforts in order to take into account potential effects of its variation; for a few populations (Table A1) sampling effort was constant, therefore we used Kendall's correlation instead of partial correlation. We converted values of Kendall's correlation coefficient to z scores (Sokal and Rohlf, 1995; Kim and Yi, 2006) as a measure of effect size (Viechtbauer, 2010). We then fitted a random-effect meta-analytical model in two steps: (1) we used maximum-likelihood to estimate the amount of heterogeneity among populations, τ^2 (Viechtbauer, 2010); (2) we estimated the average true effect by weighted least squares. For each population i, we calculated the weight w as

$$w_i = 1/(v_i + \hat{\tau}^2)$$

where v_i is the sampling variance of the population (Hartung et al., 2008, p. 22), and $\hat{\tau}^2$ is the estimate of τ^2; (3) we used a two-sided permutation test (10,000 permutations) to assess whether the average true effect is significantly different from zero (Viechtbauer, 2010). τ^2 (i.e., heterogeneity) is a measure of variability among studies analogous to the standard deviation, but which takes into account the sample size of each study (Viechtbauer, 2010), in this case the number of years. We used the Cochran's Q-test to assess significance of τ^2 (Hedges and Olkin, 1985). In order to evaluate whether taking effort into account can improve the results of analyses and reduce heterogeneity among studies, we repeated the meta-analysis both including and non-including sampling effort information (see Table A1 for details on the used effort measures).

Advantages of Kendall's correlation include robustness to outliers and to non-linearity (Sokal and Rohlf, 1995). Nevertheless, to

Table 1
Results of meta-analysis evaluating the overall trend of populations for the period 2000–2010. Comparison of results obtained taking and non-taking into account the sampling effort.

Model	Effect size			Heterogeneity				
	Mean weighted value	SE	P	$\hat{\tau}^2$	SE	Q	df	P
Without sampling effort	−1.30	0.34	0.0008	3.26	0.91	662.4	29	<0.0001
With sampling effort	−1.32	0.28	<0.0001	2.06	0.60	427.8	29	<0.0001

$\hat{\tau}^2$: Heterogeneity estimate.
Q: Cochran's Q-test value.

assess whether our conclusions are affected by the choice of the correlation coefficient, we also repeated analyses using Pearson's correlation. Standard correlations assume independence of residuals; this assumption is not always met in time series analyses. We therefore used Durbin Watson statistic to evaluate autocorrelation of residuals (Fox, 2002). Only 6% of Durbin Watson tests was significant at $\alpha = 0.05$, and none was significant after sequential Bonferroni correction, suggesting that autocorrelation did not bias our results. Furthermore, we calculated Moran's I to test whether effect sizes are affected by significant spatial autocorrelation. This test allows to evaluate if the decline is idiosyncratic of some particular region, or general within the study area (Rangel et al., 2010).

2.2.2. Analysis of average change in population size: ΔN method

Second, we used the ΔN method to combine measurements of population change across multiple populations, to estimate the "average" change in population size over time, and test for an overall trend in population size (Houlahan et al., 2000). In this analysis, we considered all populations with data for at least three consecutive years. For each population with abundance N in year t, we calculated $\Delta N = \log(N+1)_{t+1} - \log(N+1)_t$ for successive yearly intervals. We then calculated

$$\overline{\Delta}N \equiv \left(\sum_{i=1}^{n} \Delta N\right) \Big/ n$$

based on all populations (n) for which data for the time interval (t, $t+1$) are available. This procedure was repeated for each year from 1993 to 2010; the annual averages were used to compute the cumulative average change (Houlahan et al., 2000). Sampling effort was not constant over time, therefore for each population we calculated $\Delta Effort$ as the difference in effort between consecutive years. Measures of effort were highly variable among studies, including rank scales, number of volunteer/hours and length of drift fences (Table A1). For each population, effort was scaled to mean = 0 and variance = 1. We then visually compared the plots of $\overline{\Delta}N$, $\overline{\Delta}Effort$, and sample size, to assess whether average population trend may be related to changes in sampling effort/sample size. Other methods proposed to estimate $\overline{\Delta}N$, such as least squares (Alford et al., 2001), can not be applied reliably to our dataset because some populations went extinct during the period (determining negative estimates of N) and not all populations were monitored during all years (determining a large number of missing values) (Houlahan et al., 2001). We performed analyses in R (www.r-project.org) using the package *metafor* (Viechtbauer, 2010), and the function *pcor* to perform partial correlation and transform correlation coefficients to z (Kim and Yi, 2006). We analyzed spatial autocorrelation in SAM 4.0 (Rangel et al., 2010).

3. Results

We collected data on 33 toad populations (Table A1), spread across Central and Northern Italy (Fig. 1); time series covered periods ranging from three to 18 years (average 8.5). Data correspond to a total of 1,042,966 toad rescues.

3.1. Meta-analysis

The majority of populations declined during the period 2000–2010. After taking into account sampling effort, 21 out of 30 populations showed a strong decline, while only three showed an increase during this period (Fig. 2). Results obtained not taking into account sampling effort were similar (22 declining and four increasing populations) (Fig. A1). The toad rescue protocols and the volunteer groups were different among the few increasing populations, therefore it is unlikely that results are affected by the data collection method.

The mean weighted effect size was significantly below zero, indicating an overall decline of populations (Table 1). The results obtained taking and non-taking into account sampling effort were similar (Table 1, Fig. A1). The Cochran test showed a significant heterogeneity of trends among populations (Table 1). Among-population heterogeneity was particularly high if sampling effort was not taken into account; heterogeneity was 40% lower when sampling effort was included into the model. Using Pearson's correlation instead than Kendall's correlation provided similar results (Table A2, Fig. A2–A3). Effect sizes were not spatially autocorrelated (Moran's $I = -0.16$, $P = 0.18$) indicating that the decline was not idiosyncratic to one particular region.

3.2. Overall demographic trend

By pooling the data from all 33 populations together using the ΔN method, we quantitatively evaluated the overall trend of populations for the period 1993–2010. Apparent increases, i.e. average annual trend ± SE > 0, occurred several times during the 1990's (e.g., in 1995 and in 1999, Fig. 3a), and corresponded to years in which sampling efforts substantially increased (Fig. 3b). A strong overall decline, i.e. average annual trend ± SE < 0, was evident in 2004 and for the period 2007–2010, despite sampling effort remained high during these years (Fig. 3). For the period 2000–2010, there was a 76% cumulative average decline of populations, despite an increasing mean sampling effort (+0.89).

4. Discussion

Long term and broad scale demographic data are needed for a correct assessment of species' conservation status. Despite multiple global reports of amphibian declines, quantitative long term data remain limited (Schmidt et al., 2005; Bell and Pledger, 2010). We combined volunteer data to show a widespread, dramatic decline of the common toad in Italy, particularly during recent years.

A simultaneous decrease over such a large area is unlikely to be caused just by natural fluctuations. The combination of multiple time series through the ΔN method indicates a 76% decline during the last decade; this decline was not biased by the effect of one or a few populations, but was consistent across the whole study area (Fig. 2). According to the IUCN criteria, species experiencing population size declines >50% per decade or in three generations should be categorized as "endangered" (IUCN, 2001); therefore our data

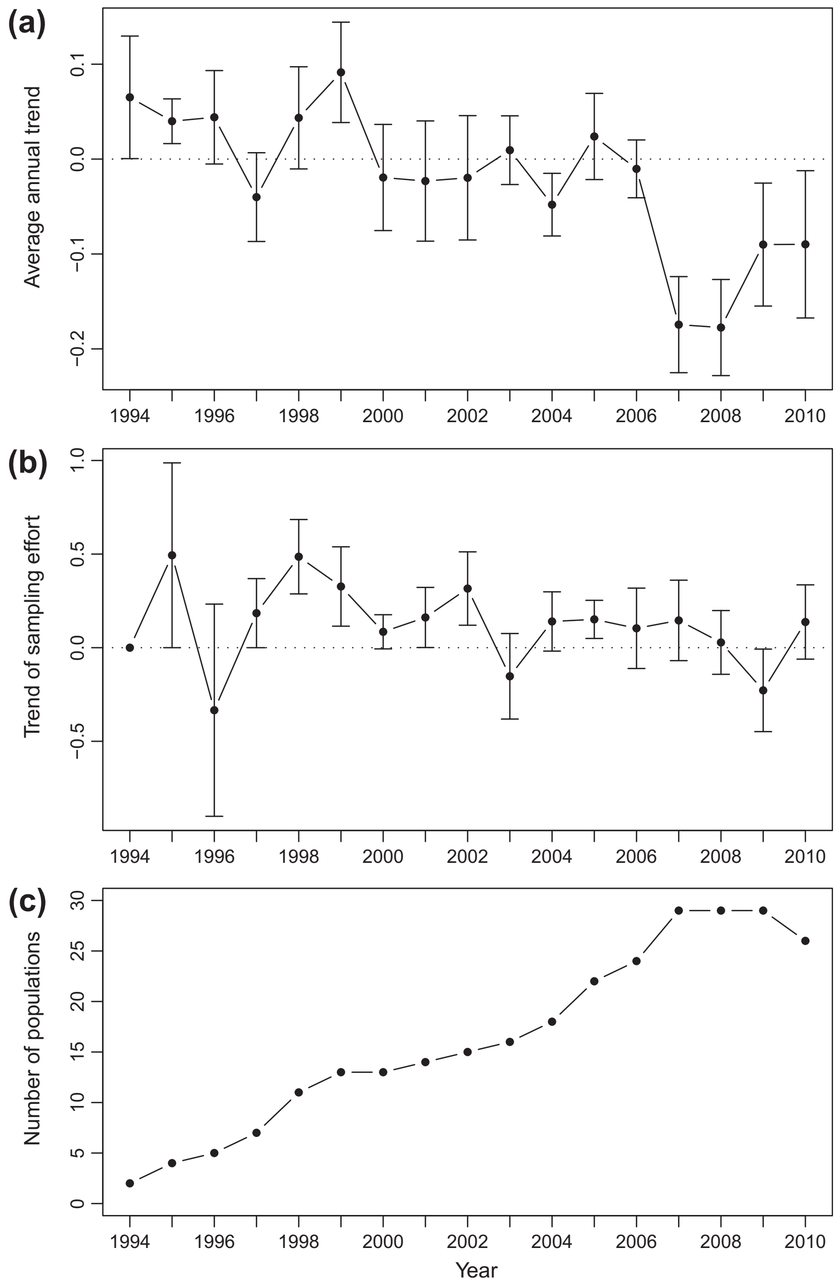

Fig. 3. (a) Average trend of all common toad populations monitored ($\overline{\Delta}N$); (b) average trend in sampling effort; (c) number of populations included in the analysis. Error bars represent SE. In (a) and (b), values below zero indicate declines, values above zero indicate increases.

would suggest to reclassify the status of this species, at least at the national level. Nevertheless, the species remains abundant at local scale, with several populations counting thousands mature individuals. It has been proposed that the rigid application of IUCN criteria to widespread species might be misleading, as declining species with large ranges and abundant populations may be classified as threatened despite it is unlikely that species will disappear in the near future (Mrosovsky, 2003). On the other hand, such a dramatic decline over a few generations (see Cvetković et al., 2009) rises strong concern for the future of the species, as many populations have declined or went extinct in less than one decade. For example, population #10 counted nearly 6000 individuals in 2004, while it is currently extinct; similarly, population #17 declined from >3000 toads during 2000–2005, to less than 700 in 2009–2010 (see Table A1 and Fig. 1 for details).

It is difficult to identify the causes of such a widespread decrease; we therefore expect that the decline will continue in the next future. The concern for this species is even higher, as analogous trends are ongoing also in other countries (Carrier and Beebee, 2003; Schmidt and Zumbach, 2005). The common toad occurs in many modified habitats, nevertheless several factors may negatively affect its populations, including habitat loss, fragmentation, chytridiomycosis, road mortality, pollution and climate change (Ficetola and De Bernardi, 2004; Reading, 2007; Agasyan et al., 2008); joint effects of multiple factors are also possible. Future studies are required to identify the drivers of toad decline.

Our data have some limitations. We analyzed a non-random sample of Italian toad populations: we selected them on the basis of availability of continuous time series, and we considered only rescued populations that live close to roads. On the one hand, the action of volunteers is expected to reduce road mortality. Actually, if road mortality negatively influences populations, an even sharper decline is possible in randomly selected, non-rescued populations, living in analogous habitats. On the other hand, even if none of our populations is located in suburban areas, they live nearby to human settlements and might therefore be not representative of populations in pristine environments. Nevertheless, it should be remarked that "pristine" areas are nearly absent in Italy. For instance, only 14% of the Italian territory is more than 5 km away from urban settlements, and the percentage is even smaller at low altitudes (Ferroni and Romano, 2009). Therefore, our populations are probably representative of a broad scale pattern, but the species might be particularly threatened in the most human dominated areas (Carrier and Beebee, 2003; Sutherland et al., 2010). Finally, we considered the total number of toads counted during breeding migrations, which is not the population size. Nevertheless, we employed indexes of abundance comparable across years within each population (Reading et al., 2010): adjusting counts for sampling effort allows to overcome the major drawbacks concerning the variations of detection probability (Schmidt, 2004).

The use of meta-analysis allowed us to combine data obtained from multiple sources, and detected strong heterogeneity of trends among populations. Heterogeneity can arise because populations actually have different trends (e.g., because of environmental differences), or because of variation in sampling protocols. For instance, in some cases apparent trends can be simply explained by variation in sampling efforts (e.g., overall increase in 1995 and 1999; Fig. 3). The incorporation of factors determining observation error into population models increases the accuracy of results (De Valpine and Hastings, 2002): the integration of sampling effort into analyses reduced among-populations heterogeneity (Table 1), improving the reliability of estimates. When volunteers are employed in biodiversity monitoring schemes, the use of well defined protocols is extremely important to obtain reliable data (Schmeller et al., 2009). On the other hand, volunteers sometime work using non-systematic approaches, and the coordination of protocols across multiple populations may be not feasible. Nevertheless, even if the mean detection probability of toads varies in time or among populations, multiple information (e.g., spatial and temporal extent of monitoring; numerical efforts) can be recorded, being useful to adjust counts in post hoc analyses that were not the primary aim of volunteer activities. Volunteers can also collect additional data (e.g., extent of road mortality, habitat transformation, or samples for disease analyses), helping to identify the causes of toad decline. Finally, volunteer data may be even more heterogeneous than in this study case, thereby posing new challenges to data analysis. If groups collect different indexes of abundance, more complex methods are required to estimate population trends, such as the Bayesian hierarchical framework proposed by Link and Sauer (2002) for North American bird monitoring.

Volunteers can be an invaluable resource for both conservation science and for practical conservation actions. First, volunteer activities can have positive effects on species and ecosystems. For instance, they can increase survival, and help to build structures for the mitigation of negative effects of human infrastructures. Volunteer direct involvement may also increase public awareness and interests toward conservation issues (Newman et al., 2003). Furthermore, volunteers can collect huge amount of valuable data on animal populations, that can be used to analyze the ongoing processes such as long term demographic trends, if collected using appropriate protocols. A tight collaboration among scientists, managers and volunteers can be extremely fruitful for conservation.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2011.06.011.

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