Will climate change affect terrapin (*Pelusios subniger paritalis* and *P. castanoides intergularis*) conservation in Seychelles?

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Abstract: We report a modeling study on habitat suitability and predicted distribution shifts of two species of Seychelles's freshwater turtles (*Pelusios castanoides* and *Pelusios subniger*) under a climate change scenario. We utilized data from the entire species distribution for modeling habitat suitability of the two species under current and future climate conditions, by using the MAXENT algorithm. At the continental scale, it appeared that *P castanoides* will shift its range towards more coastal areas, whereas *P. subniger* will move towards more southern sites. In the Seychelles archipelago scale, habitat suitability for *P. castanoides* will decrease significantly, mainly in the interior areas of Mahé Island. On the contrary, the climatic conditions are predicted to remain suitable for *P. subniger*, which will enjoy a significantly increased habitat suitability in Seychelles.

Key Words: Chelonia; Pelomedusidae; range shifts; climate change; habitat suitability; ecological modeling

Introduction

Despite their isolated location, in the middle of Indian Ocean, the Seychelles islands hold a species-rich fauna and are home of many endemic taxa. Together with other Indian Ocean archipelagos and Madagascar, Seychelles belong to one of the biodiversity hotspots, being both one of the richest and most threatened reservoirs of plant and animal life on Earth (Myers et al. 2000; Conservation International 2007).

The Seychelles islands hold three freshwater turtle species, all of which represent endemic and Critically Endangered taxa. These species belong to the African genus *Pelusios* and they probably colonized the archipelago during the Wisconsin glacial period (15,000 years ago) through a land chain from Africa and Madagascar (Gerlach & Canning 2001).

The Seychelles black mud turtle (*P. subniger parietalis* Bour, 1983) occurs only in marshes and temporary pools with standing water feeding on aquatic invertebrates, fish, amphibians, and aquatic plants (Gerlach 2008a). Only eight populations survive, at low elevation, on the islands of Mahé, Cerf, Silhouette, Praslin, La Digue, and Fregate. It was extirpated from St. Anne and Cousin Islands (Gerlach 2008b). The eight remaining populations are restricted to very small areas, with total surface ≈ 6 hectares, and a total number of individuals < 700. In addition, only five out of the eight populations show evidence of recent breeding activity. Apart from Seychelles, *P. subniger* is distributed, with the nominal subspecies, in Madagascar and continental Africa from Tanzania to Mozambique. The Seychelles yellow-bellied mud turtle (*P. castanoides intergularis* Bour, 1983) occurs in lowland rivers and some marshes feeding on aquatic invertebrates (mainly snails), fish, amphibians, and aquatic plants (Gerlach 2008c). It is restricted to nine very small populations, with total surface < 3 hectares and a total number of individuals < 150, on the islands of Mahé, Cerf, Silhouette, Praslin, La Digue, and Fregate (Gerlach 2008c). Moreover, only four out of the nine populations currently show evidence of reproduction (Gerlach 2008b). Apart from Seychelles, *P. castanoides* is distributed, with the nominal subspecies, in Madagascar and in coastal and sub-coastal areas of continental Africa from Tanzania to Mozambique. The Seychelles mud turtle (*P. seychellensis* [Siebenrock, 1906]) is known from three specimens only, collected at the end of 19th century (Bour & Gerlach 2008). A report in 1994 (Gerlach & Canning 1996) may have been in error. No further specimens have been observed and the species is probably extinct. Nevertheless, it is possible that very few individuals still survive in upland marshes within humid tropical forest on Mahé. As highlighted by Luiselli (2008), all of these taxa are extremely threatened, restricted to very small geographic ranges, and represented by exceptionally low numbers of individuals. Therefore, any measure aimed at protecting terrapin species or marshy habitat in Seychelles may be crucial for their short- and long-term survivorship.

The present major threats to the fauna of the archipelago derive from habitat destruction and introduction of invasive alien species. Habitat destruction is due to the expansion of the human population, especially in the granitic islands with increased development pressures. Habitat loss threatens all species, especially species that are range restricted. Introduced species such as rats, cats and dogs are demonstrated to have had substantial impacts on some species through predation. While invasive plants such as water lettuce (*Pistia stratiotes*) substantially modified aquatic ecosystems, shading out submerged vegetation and causing deoxygenation and stagnation of marshes (Gerlach 1997). Certainly, habitat destruction, as well as predation by introduced species, and habitat alteration by water lettuce represent important factors affecting the conservation status of freshwater turtles in Seychelles and, probably, have already driven *P. seychellensis* to extinction (Gerlach & Canning 2001). In addition, it should be noted that the Seychelles terrapins are particularly sensitive to several of the risk variables analyzed by Luiselli (2008), on the basis of which they should be considered among the most sensitive freshwater turtles of the entire Sub-Saharan Africa.

Moreover, new pressures have arisen. Global climate change has recently been recognized as one of humankind's most profound and far-reaching threats to biodiversity (Thomas et al. 2004). The changing climate could affect species survival and provoke deep changes in the structures of all ecosystems. From several important reviews undertaken for the study of potential effects of global warming on biodiversity, Africa emerges as the most vulnerable of all continents (Hulme 1996; IPCC 2001). Some climate change studies predict an increase of temperature throughout the year with an annual average of +2.8° C over tropical Africa and an associated precipitation increase of 4.2 mm/month (IPCC 2007). In Seychelles, maximum and minimum temperatures are expected to increase by between 0.63° C and 3.67° C, the dry season is becoming drier and wet season is becoming wetter, and increased frequency of occurrence and severity of extreme events are predicted (Payet & Agricole 2006).

Given that previous climatic changes have led to wide-scale shifts in paleo-species distributions, and to many mass extinctions (e.g. Barnosky 1986; Woodward 1987), extant species are also expected to move rapidly in response to moving climatic envelopes. Some of these alterations have already been reported (e.g. Pounds et al. 1999; Grabbherr et al. 1994; Parmesan et al. 1999). The geographical shift of the species following their climate envelopes could be impractical for island endemic species, also small intra-island movements may be complicated by the human-altered fragmented and disturbed habitats. In areas such as Seychelles in particular, climate change is likely to be devastating for many species confined to small islands. Endemic species could suffer the worst impact of climate change because of their restricted range and narrow ecological requirements. For these reasons the biota of Seychelles represents a global priority for conservation owing to the islands' exceptional endemic diversity and ongoing loss of natural habitats.

Many reptiles are especially vulnerable to rapid habitat changes and may suffer many more extinctions than more vagile animals because of their limited dispersal abilities (Gibbons et al. 2000). Consequently, climate changes could result in conditions that eliminate or severely restrict species with limited distributions. Moreover, global warming may have the greatest impact on those reptiles (crocodilians and some turtles) that have temperature-dependent sex determination (Janzen 1994), whereby the sex ratio of the hatchlings is determined by nest temperatures during incubation.

In the light of such changing scenarios, the first challenge for conservationists is to re-think the planning of protected areas and other natural landscapes to accommodate the future effects of climate change to effectively protect vulnerable taxa (Araújo et al. 2004; Williams et al. 2005). Population shifts due to ecophysiological responses to climate warming may be impeded or at least hampered by landscape fragmentation, so that existing nature reserves could be inadequate to preserve current biodiversity. The Seychelles's National Parks, that cover a high proportion of the land area (43%) but were designated mostly in the 1960s and 1970s, so not taking into account the likely impacts of climate change (Gerlach 2008d). In small island systems the potential for re-designing reserves may be limited and there is little dispersal between islands for most terrestrial taxa (Gerlach 2008d). Thus, certain species are believed to face such grave threats from climate change that the only way to save them from extinction may be "assisted migration" (Hoegh-Guldberg et al. 2008).

In such scenarios, the prediction of climate change effects on distribution of threatened species (such as indigenous terrapins) is a critical issue in focusing conservation efforts towards those areas that may act as long term refuges. Here we provide a preliminary analysis of the climate change effects on the distribution of *Pelusios* species and habitat suitability on Seychelles.

Materials and methods

In this paper, we evaluate the probability of persistence of freshwater turtles in the Seychelles islands under future climatic conditions and, in such scenarios, we identify general areas climatically suitable for terrapins. Potential effects of projected climate change on Seychelles's terrapins distribution were assessed using single-species bioclimatic inductive models based on species-environment interactions derived from point data (Guisan & Zimmermann 2000). We utilized geostatistical modeling techniques for defining the climate envelope that best describes the spatial range of the species. We utilized as presence data the sites (with geographic references included) given in 'World Turtles Database', available at: http://emys.geo.orst.edu/main_pages/database.html. Because the climatic conditions experienced in Seychelles represent only a small subsample of the species' potential climatic envelope, we utilized data from the entire distribution of *P. subniger* and *P. castanoides* to define their climatic exigencies. *P. seychellensis* was not analyzed because its point distribution would have required much more detailed environmental data than those used preliminary in this paper. These data has a spatial resolution of 1' of geographic degree, corresponding to approximately 2 km. These data were correlated with climate variables (e.g. Pearson & Dawson 2003; Huntley et al. 2004) derived from WorldClim databank (Hijmans et al. 2004). The future climatic conditions were obtained from Govindasamy et al. (2003) according the CCM3 emission scenarios outcomes of IPCC (2007). All of the environmental predictors have a spatial resolution of 2.5' of geographic degree. The modeling procedure was performed by adopting the MAXENT algorithm. The reliability of the potential distribution models was assessed by AUC criterion through a Jackknife procedure. The main positive feature of AUC consists of being a single threshold-independent measure for model performance (Fielding & Bell 1997; Manel et al. 2001; Lehmann et al. 2002; Thuiller 2003; Brotons et al. 2004; McPherson et al. 2004; Thuiller et al. 2005; Allouche et al. 2006; Peterson et al. 2007). An AUC value can be interpreted as the probability that a presence site, randomly chosen from the dataset, has a higher predicted value than an absence site (Elith et al. 2006, Phillips et al. 2006). In order to increase the spatial resolution of our predictions for the Seychelles islands, we inter-poled the values of habitat suitability deriving from the models with the Spatial Analyst function of ArcView3.2. The obtained outcomes have a spatial resolution of 30" of geographic degree.

Results and discussion

The habitat suitability maps under present and future climatic conditions for *P. castanoides* are presented in Figure 1, whereas the maps for *P. subniger* are given in Figure 2. For *P. castanoides*, AUC value was 0.957 (Figure 3A), whereas AUC value was 0.908 for *P. subniger* (Figure 3B). In both cases, these were very good values for this type of analyses. Comparing the habitat suitability maps for current vs. future distribution, *P. castanoides* showed a relatively clear shift towards more coastal areas, whereas *P. subniger* showed a very clear shift towards more southern sites. If we focus our attention on the Seychelles archipelago, some very intriguing scenarios would appear (Figures 4 and 5). In fact, the habitat suitability for *P. castanoides* in the Seychelles is predicted to decrease significantly (Wilcoxon test: $z = 5.442$, $p < 0.0001$), mainly in the interior areas of Mahé Island. On the contrary, the climatic conditions are predicted to remain suitable for *P. subniger*, which will enjoy a significantly increased habitat suitability (Wilcoxon test: $z = 5.443$, $p < 0.0001$) in Seychelles.

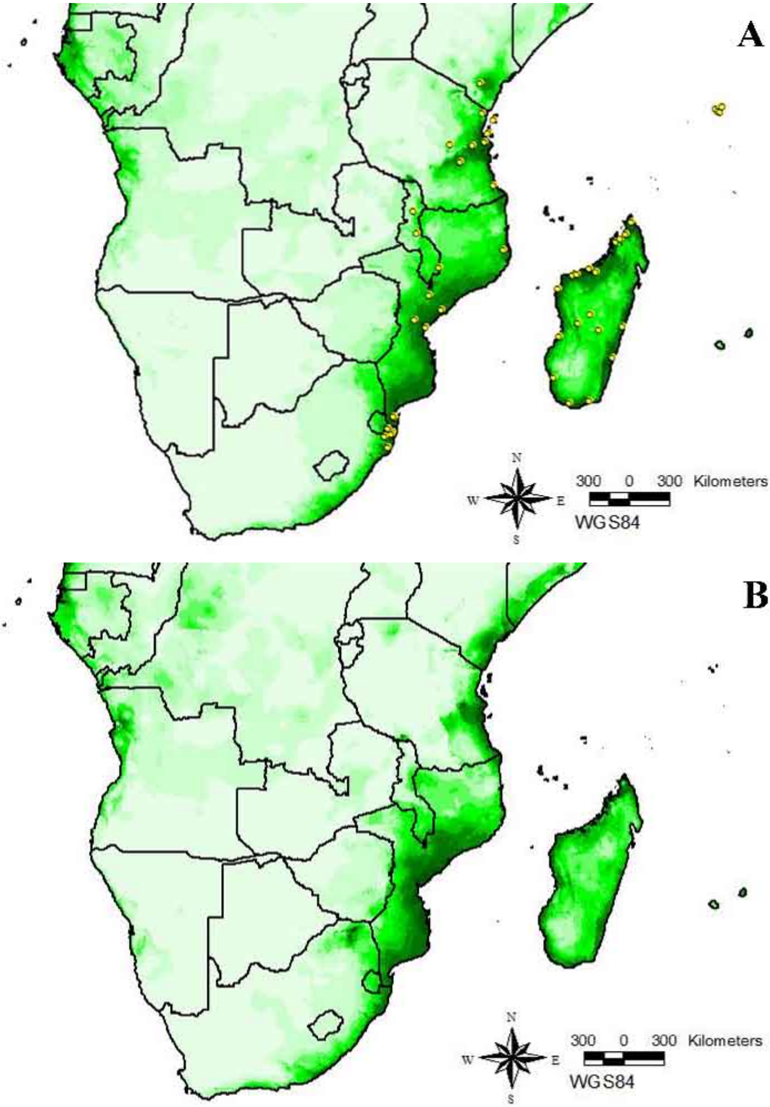

Figure 1. Habitat suitability maps, under current (A) and future (B) climatic conditions, for *Pelusios castanoides*. Note that the records from all subspecies known are included in the map A. The green scale is proportional to habitat suitability, with pale green = not suitable, and dark-green = highly suitable.

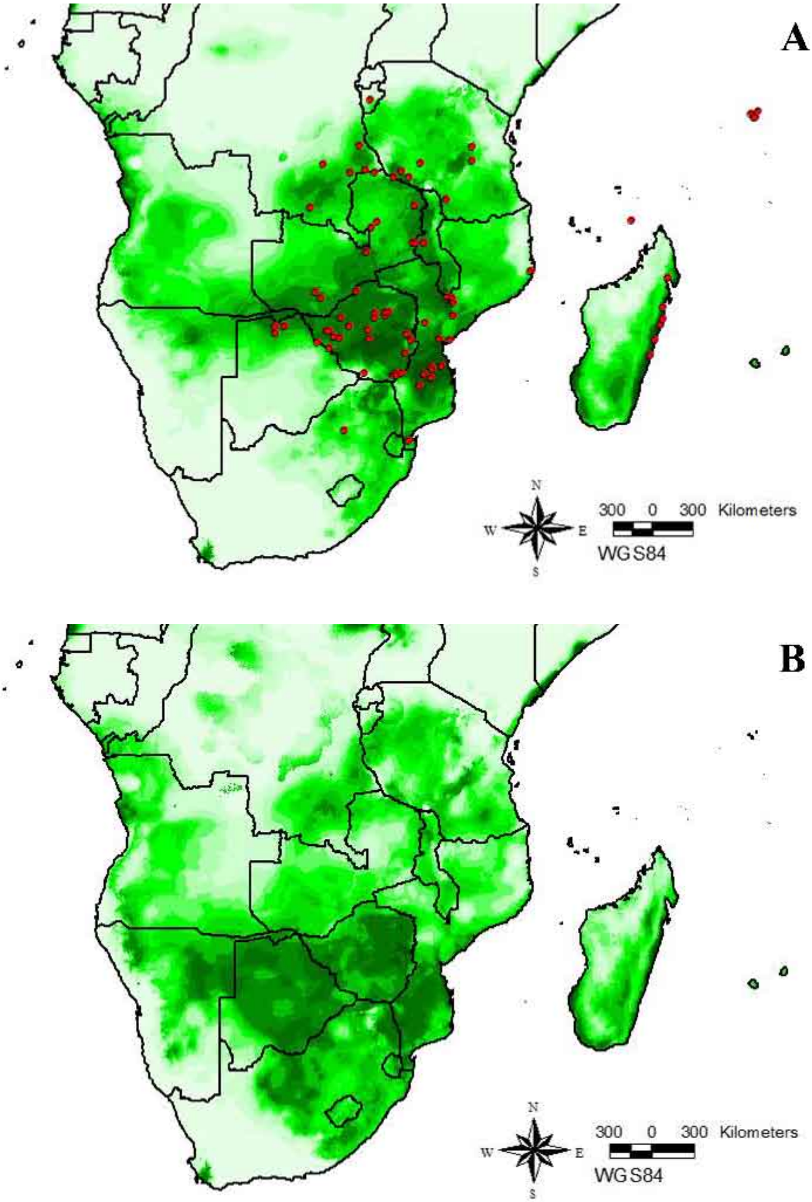

Figure 2. Habitat suitability maps, under current (A) and future (B) climatic conditions, for *Pelusios subniger*. Note that the records from all subspecies known are included in the map A. The green scale is proportional to habitat suitability, with pale green = not suitable, and dark-green = highly suitable.

Overall, our results are particularly noteworthy in that we highlight two opposite patterns of terrapins in response to predicted climate change at the scale of the Seychelles islands: indeed, whilst one species was clearly damaged by future climatic changes (*P. castanoides*), the other may even benefit from the changes (*P. subniger*). These opposite changes are clearly independent because our modeling techniques did not take into account the interspecific relationships between these species. However, the occurrence of interspecific interactions between these species could not be ruled out, because it is well established that *Pelusios* species may be competitors for space and food when in sympatry, and especially when their natural habitat is altered (for instance, see the case of *Pelusios niger* and *Pelusios castaneus* in southern Nigeria; see Luiselli & Akani 2003; Luiselli et al. 2004, 2006; Luiselli 2008b). Currently, our data on the ecology of the two Seychelles species of *Pelusios* are too scanty to allow understanding of the deeper aspects of the coexistence ecology of these turtles. More detailed predictions should be based on more detailed environmental data and a deeper knowledge of the population sizes of turtles and on their microhabitat exigencies at the local scale (Bombi et al. 2009). Thus, in situ specific reasearch devoted to highlight such obscure aspects of the field biology of the two *Pelusios* species are strongly advocated in order to refine the modeling analysis presented here. These field studies should also investigate the possible occurrence of the apparently extinct *P. seychellensis*. In any case, it should be taken into account that the CCM3 emission scenario utilized in our analyses is the most optimistic, hence more severe and more unpredictable modifications of the distribution range of the two species are to be expected if less optimistic emission scenarios occur.

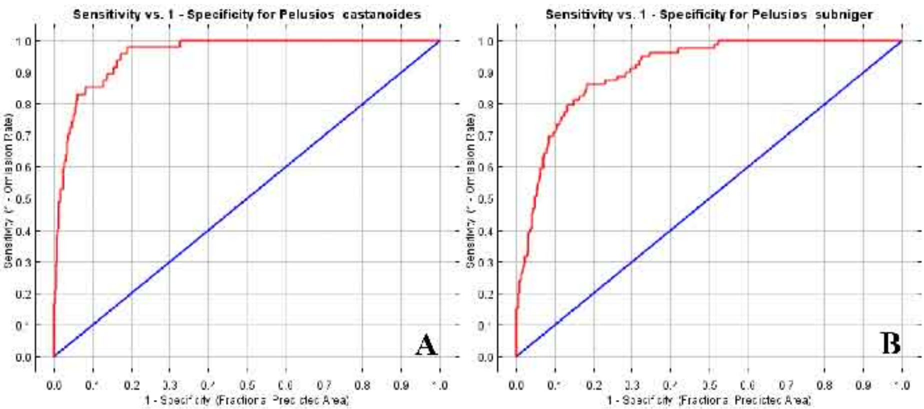

Figure 3. Receiver Operating Characteristic (ROC) plots for the potential distribution model of *Pelusios castanoides* (A) and *Pelusios subniger* (B). The “Area Under ROC Curve” is the AUC value.

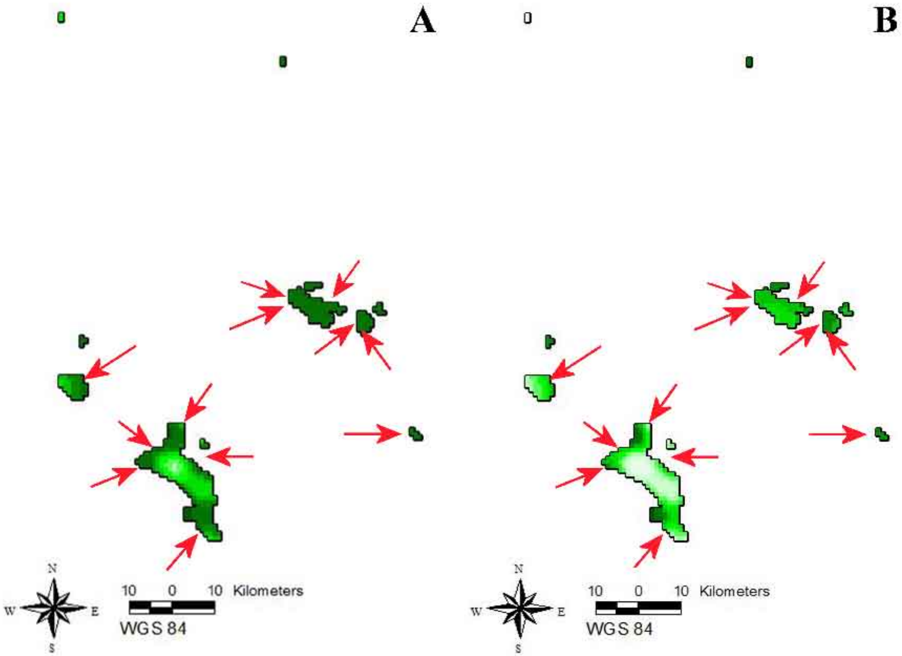

Figure 4. Habitat suitability maps, under current (A) and future (B) climatic conditions, for *Pelusios castanoides* in the Seychelles. The green scale is proportional to habitat suitability, with pale green = not suitable, and dark-green = highly suitable. Red arrows show current localities for the species.

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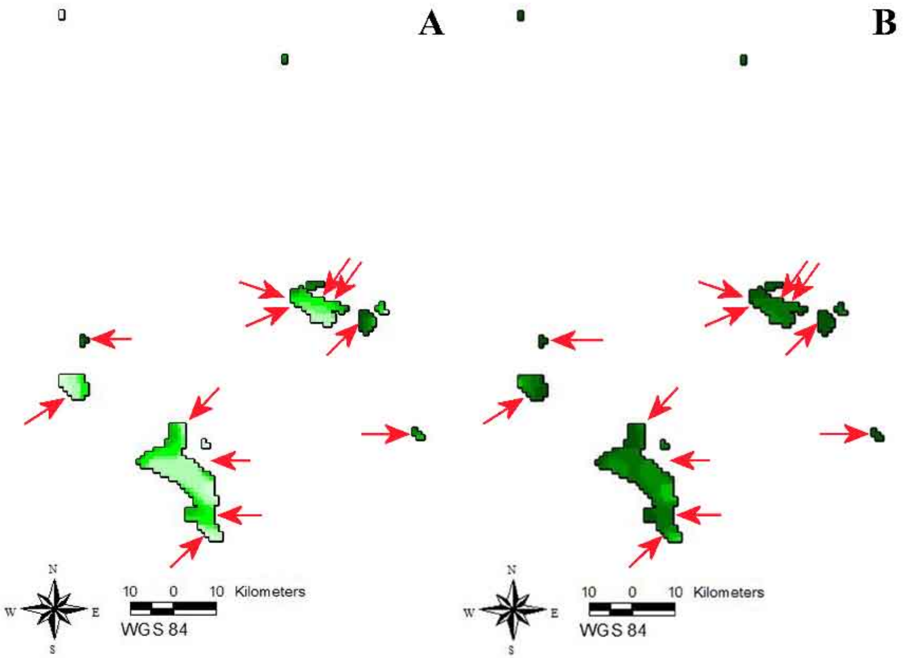

Figure 5. Habitat suitability maps, under current (A) and future (B) climatic conditions, for *Pelusios subniger* in the Seychelles. The green scale is proportional to habitat suitability, with pale green = not suitable, and dark-green = highly suitable. Red arrows show current localities for the species.

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