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Alien invaders and reptile traders: what drives the live animal trade in South Africa?

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Abstract

The global trade in reptiles for pets has grown rapidly in recent decades. Some species introduced by the pet trade have established and become invasive, for example the Burmese python in Florida. Although there are currently no invasive alien reptiles in South Africa, the last 30 years has seen an exponential increase in the number of introductions of an increasing number of species from an increasing number of countries. We determine and analyse the presence and abundance of species in the South African reptile trade. This serves as a background to efforts to overhaul the management and regulation of this trade, particularly given the need for increasingly objective risk-assessment protocols. We show that introduced species tend to come from specific families including Boidae, Chameleonidae, Elapidae, Pythonidae, Testudinidae and Viperidae. Moreover, within specific families (e.g. chameleons), species of larger body size are more likely to be introduced. As the risk of a species becoming invasive may be increased by higher propagule pressure, it is also important to characterize the volume of trade. Here we analyse data on the abundance of reptiles in South Africa using generalized, additive models and show that venomous and expensive species are traded in low numbers, whereas species that are easy to breed and handle or are large, colourful or patterned are preferred. These human imposed preferences have the potential to cause significant taxonomic changes to the reptile fauna of South Africa, which still largely reflects natural biogeographic and evolutionary processes. Elucidation of import and trade patterns enables us to estimate the probable propagule pressure of any particular species. Because the dispersal pathway defined by trade influences the likelihood of invasion, this information is important for informing policy development and directing management efforts.

Introduction

Species traded for ornamentation, novelty value and as pets form an important pathway for the introduction of invasive alien species (Hulme *et al*., 2008). As with all introductions they pose a risk to native biodiversity and ecosystem functioning. There are numerous examples of invasive populations resulting from such trade, for example ornamental plants (Reichard & White 2001; Groves, Boden & Lonsdale, 2005) and fish (Duggan, Rixon & MacIsaac, 2006; Copp, Templeton & Gozlan, 2007). Recently, there has been a surge in the trade of reptiles for pets (Auliya, 2003; Kraus, 2003, 2009). The number of live reptiles imported to Europe under permits issued by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) almost quadrupled during the 1990s, largely due to an increase in demand from the pet trade (Auliya, 2003). There is increasing concern about the implications of this trade for biosecurity, especially as a number of introduced reptiles have already become invasive, for example, the Burmese python in the Florida Everglades, USA (Snow *et al*., 2007), and the red-eared slider in numerous countries worldwide (Lever, 2003).

In this paper, we use 'introduction' and 'introduced' to refer to non-native species whose presence in an area is attributable to human activities (see Pyšek *et al*., 2004). In this context, introduced species need not be established, naturalized or invasive, or indeed have been given the opportunity to escape from captivity. The crossing of biogeographical barriers is, however, a necessary first step for any species to become invasive outside its natural range (Richardson *et al*., 2000).

Regional, national and global initiatives are required to regulate general introduction pathways; identify which species are potentially invasive; and to prevent the introduction, or escape and spread of high-risk species (Kaiser, 1999). Where introduced species will clearly have a significant impact on the economy (e.g. food sources), cost– benefit analyses (e.g. De Wit, Crookes & van Wilgen, 2001) can inform decisions on whether or not to permit introductions. However, cost–benefit analyses will not be reliable if the potential impacts are poorly circumscribed. Understanding trade dynamics may improve evaluation of the driving forces and associated risks. Only species which are introduced can establish, and those that are widely disseminated post-introduction have an increased likelihood of establishing and becoming invasive. Descriptions of the subset of species that are introduced are necessary to enable systematic analyses of the factors determining invasion success; see Blackburn & Cassey (2007) and Blackburn & Duncan (2001) for analyses of bird introductions.

In this paper, we analyse the popularity of alien reptile species in the live animal trade in South Africa. First, we determine which species from the worldwide pool have been introduced to South Africa, and in particular which families are over-represented. Second, we establish which factors are linked to the abundance of alien species that are kept in South Africa. Our initial hypotheses were that venomous or rare species would be imported as these are likely to be a curiosity (Auliya, 2003; Brook & Sodhi, 2006; Courchamp *et al*., 2006), but that these species would not attain high abundance; and we expected that large, brightly coloured, attractive species, which are easily bred, would be best represented in the trade in number of individuals.

South Africa serves as a useful test region for these analyses for several reasons. Because it is illegal to keep/collect indigenous reptile species in some provinces of South Africa, trade is largely restricted to imported, alien species. While this simplifies our data analysis, this does mean that breeders/traders cannot replace an alien species with a native, as can be done in the case of plants with the promotion of 'native-only' garden centres. Although no reptile species have yet become established in South Africa the pet trade is relatively young, and there are some reports of feral individuals (van Wilgen, Richardson & Baard, 2008). Furthermore, the country contains a range of climates suitable for many reptile species, as can be seen by the diverse native reptile fauna (*c*. 500 species across the southern African region Branch, 2001). New legislation [the National Environmental Management: Biodiversity Act (no. 10 of 2004)], and an overhaul of associated regulations, means there is a requirement for increasingly objective means to manage and regulate the importation of alien species. As propagule pressure plays a pivotal role in species establishment (Reaser, Meyerson & von Holle, 2008), it is important to understand what determines species abundance in the trade and to identify species that are likely to become highly abundant. Moreover, it is prudent to determine such factors while the volume of trade is still small. By identifying attributes characterizing sought-after species, we seek to explain the taxonomic biases in species introductions and to pinpoint potentially useful characteristics for risk assessments that can inform decision making under the new legislation. We also propose a model to describe the abundance of species traded in South Africa.

Methods

Data collection

We assembled a database of alien reptile species present in South Africa up to and including 2007. Permit records for alien reptiles were requested from conservation authorities in each of South Africa's nine provinces. In addition, we obtained lists from the main zoos of the species in their collections and those reptiles commonly dumped at or sent to the zoo (as unwanted exotic pets). We also asked pet stores to supply inventories of their species, reviewed lists of species offered for sale on the internet in South Africa, and collated CITES trade data for live reptile specimens for the 30-year period between 1976 (first available year) and 2005 (last complete year at the time of survey) [see van Wilgen, *et al.* (2008) and the Appendix S1 for details and data limitations].

Estimates of the number of individuals (i.e. abundance) of each species in South Africa were made by experts involved in the pet trade and at national zoos (see 'Acknowledgements'). As the reptile trade in South Africa is relatively small compared with that in other countries (e.g. the USA), it was relatively simple for people involved in the day-to-day business of the trade to make such abundance estimates. The abundance data include both imports and domestic production.

For taxonomic comparisons we used a revised checklist of native reptile species complied by W. R. Branch in 2007 for the South African Reptile Conservation Assessment (http://sarca.adu.org.za/about.php). The TIGR Reptile Database (Uetz, Hallermann & Baker, 2008) was used to standardize species names and tabulate the number of genera and species per family (http://www.reptile-database.org/db-info/SpeciesStat.html). Names and numbers presented here are those as listed on 29 January 2008.

To determine the factors promoting species popularity, we compiled a list of eight traits possibly associated with preference. This list of traits was developed in consultation with pet store or park owners and hobbyists in three provinces in South Africa. The traits were: (1) size (measured as the logarithm of average head to tail length in cm); (2) dangerous or innocuous (dangerous species are those than can inject a venom into humans or inflict serious harm through constriction or a powerful bite); (3) presence or absence of colours other than brown, black or grey; (4) presence or absence of patterning; (5) presence or absence of interesting features (e.g. frills, dewlaps or horns); (6) whether the species can be bred in captivity; (7) whether the species is easy to handle and care for; (8) trading price (measured as the logarithm of price in South African rand). We simplified all the traits to a logical (yes or no) except size and price where we could obtain quantitative estimates. Our predictor set thus comprised two continuous variables and six binary factors. Both size and price data were log-transformed before analysis to normalize errors. The traits can be broadly grouped into fear factor (1–2); attractiveness (3–5); and trader/keeper-related factors (6–8).

Trait data were collated from published literature and online sites, as well as pet store inventories and internet pet store databases. All data were checked by an experienced South African reptile breeder.

Although we would have liked to assess the role which rarity plays in species popularity, the only measure of rarity we could find was the International Union for Conservation of Nature's conservation rating and these data were not available for sufficient taxa to make any inferences. Alligators and crocodiles were excluded from the analysis of abundance data, as these species are more commonly kept in zoos and parks, not as pets, and are thus not selected according to the same criteria as applied by pet owners.

Factors influencing the likelihood of species being introduced into South Africa

To look for geographical patterns in trade routes, we compared the native range of all introduced species (as documented on the TIGR Reptile Database), with the export country listed on CITES.

To look for taxonomic biases in introduced species at family level, we compared the number of species introduced per family with a random expectation generated using the hypergeometric distribution (R v. 2.7.2 R Development Core Team, 2008). We considered families outside the 95% confidence intervals to be either over- or under-represented in the trade. To visualize these results, we plotted the number of species per family against the proportion of species introduced per family (in both cases excluding South African natives). We then performed the same analyses for native species, comparing the number of native species to the percentage of the family which they comprise.

To determine whether there is a body-size bias in the species introduced from a given family, we examined how size affects the likelihood of species introduction within two families: the Chameleonidae and the Boidae (in the classification used here Boidae includes Pythonidae, but see Slowinski & Lawson, 2002). We chose these families as both had a large number of introduced species and body size data were easily obtainable (http://www.auburn.edu/cosam/collections/reptiles_amphibians/projects/body_size.htm; Nečas, 1999). Moreover, as South Africa has similar numbers of native (22) (Tolley & Burger, 2007) and introduced chameleon species (17), a comparison could be made between the body size of native and introduced species. Analyses were performed in R. Body size data were log-transformed to normalize errors and *t*-tests were used to test whether introduced species were significantly different in size from non-introduced species in the same family or from species native to South Africa.

Factors determining the abundance of alien reptiles kept in South Africa

Having looked at taxonomic and size bias in imported species, we were interested in determining which factors make some species become abundant in the trade, while other species are imported or traded in very small numbers. To quantify the effect of different species traits on the number of individuals (abundance) per species in South Africa, we used generalized additive models with negative binomial errors (package mgcv, v. 1.4.1, Wood, 2008).

First, we screened pairwise correlations between the independent predictor variables to avoid offering substantially collinear variables to the model selection (Belsley, Kuh & Welsch, 1980). No pair of independent predictor variables was correlated at $R^2 > 0.5$, and so all predictors were included in the analysis. We then fitted models using Poisson and quasi-Poisson error distributions, but found the models to be substantially over-dispersed, and so used a negative binomial error distribution instead. We varied the number of smoothing parameters for the continuous variables (i.e. size and price) and, by looking at the resulting changes in curvature, determined the largest number of degrees of freedom required (*sensu* Wintle, Elith & Potts, 2005). Model selection uncertainty was analysed by comparing the similarity in fit between the highly competitive models ($\Delta\text{AIC} < 2$; Burnham & Anderson, 2002). The robustness of inference derived from the best model was explored on the basis of how consistently the same inference (coefficient and level of significance of each predictor) arises from those models that have similar (but slightly larger) AICs, using 1000 bootstrap replicates.

For many species we could not obtain data on trader/keeper-related factors (i.e. breeding success, price or temperament in captivity). Moreover, we were concerned that there was some circularity in attempting to explain abundance using price data (species may become cheaper because they are more popular). Therefore, we performed three sets of analyses – first, we included species for which data on all the predictors were available ($n = 77$); second, using the same dataset ($n = 77$), we excluded price from the predictor set; and third, we used all species in our sample and excluded the predictors breedability, handling ease and price ($n = 234$). In each case, we fitted all possible combinations of explanatory variables, and ranked the competing models according to AIC values.

Results

Species introduced

We found records for 275 alien reptile species from 30 families in South Africa (Appendix S2). The CITES data suggest that the number of individuals imported has doubled roughly every 4 years between 1976 and 2005, while the number of different species introduced and the number of different donor countries have increased steadily over the same period (Fig. 1). One hundred and eighteen alien CITES listed species were imported from 45 countries between 1976 and 2005 (Fig. 1). We also documented one accidentally introduced species (the flowerpot snake *Ramphotyphlops braminus*) (Brooke, Lloyd & de Villiers, 1986).

The introduced species originate from countries all around the world, with most from Oceania (85, of which 30 are native to Australia); followed by Africa (82, 25 native to Madagascar); Asia (76); North America (59); South America (32); Central America (26); and Europe (13). (Note some species have distribution ranges spanning more than one continent or region.) However, only 45 countries were documented in the export of CITES species [African and European countries made the majority of exports (58%)]

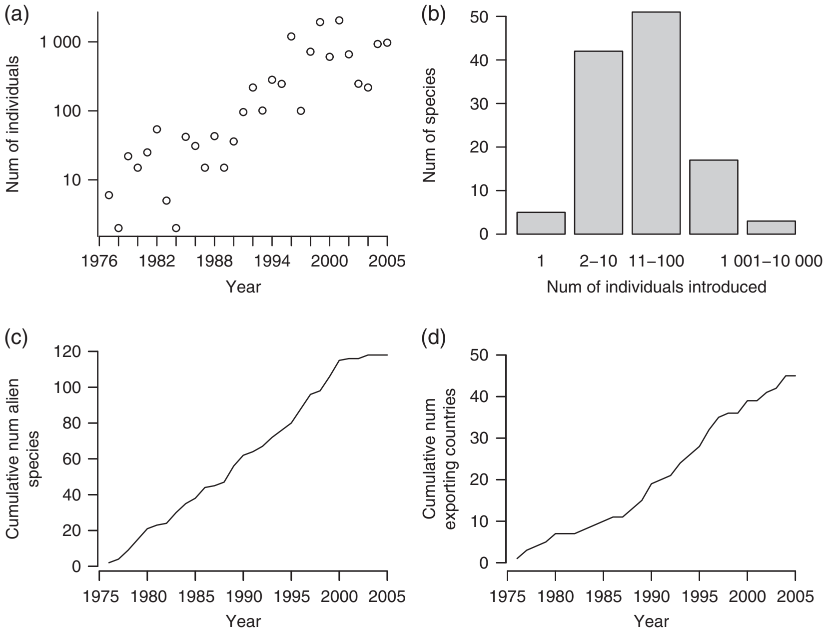

Figure 1 Changes in the number of CITES-listed alien reptile species and individuals imported into South Africa between 1976 and 2005. (a) The number of individuals imported per year (doubling time = 3.83 years); (b) number of species imported in different abundance classes; (c) cumulative number of species imported per year; and (d) the cumulative number of countries from which exports into South Africa originated.

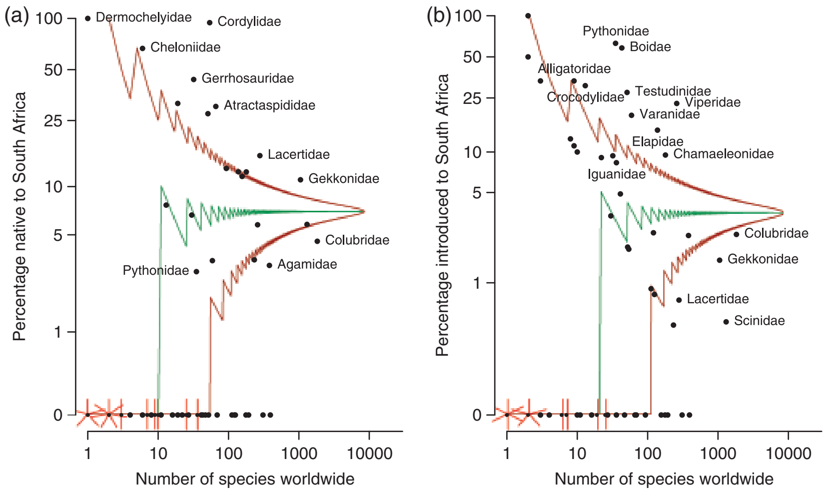

Figure 2 Taxonomic patterns in (a) native and (b) introduced reptile families. Each point represents a reptile family. Families represented by points falling between the lines are not significantly over or under-represented (relative to reptiles as a whole). The median (middle line) and confidence intervals were estimated from the hypergeometric distribution, with the confidence intervals being 95% values adjusted for multiple comparisons. Multiple points are indicated by lines.

and 71% of species were exported from a country outside of their native range.

Taxonomic patterns

Of a total of 111 reptile families recognized in the study, 22 contained species native to South Africa. Of these, nine families are over-represented in South Africa (e.g. the Cordylidae), while three are under-represented (e.g. Colubridae) (Fig. 2a). Introduced alien species originate from 30 families. Of these families, nine had more species introduced than expected by chance (i.e. over-represented in the trade) (Fig. 2b). While several families were over-represented by both native and alien species (Chameleonidae, Elapidae and Testudinidae), other common alien families, the Alligatoridae, Boidae and Pythonidae are absent or poorly represented in South Africa (Fig. 2). Only five families had fewer introduced alien species than would be expected [including the Gekkonidae and Lacertidae, which are over-represented by native species (Fig. 2)], suggesting clear shifts between the taxonomy of native and introduced species.

Within those families studied in depth (chameleons, boas and pythons), species with larger body sizes are more likely to be introduced. For example, introduced chameleons were significantly larger (mean = 32.99 ± 15.09 cm SD) than native species (mean = 16.76 ± 5.4 cm SD, $P<0.001$) and non-native chameleons which were not introduced (mean = 19.67 ± 10 cm SD, $P<0.001$) (Fig. 3). Boas and pythons showed similar trends.

Species abundance model

To quantify the effect of species traits on the abundance of species in the trade, we compared a large number of

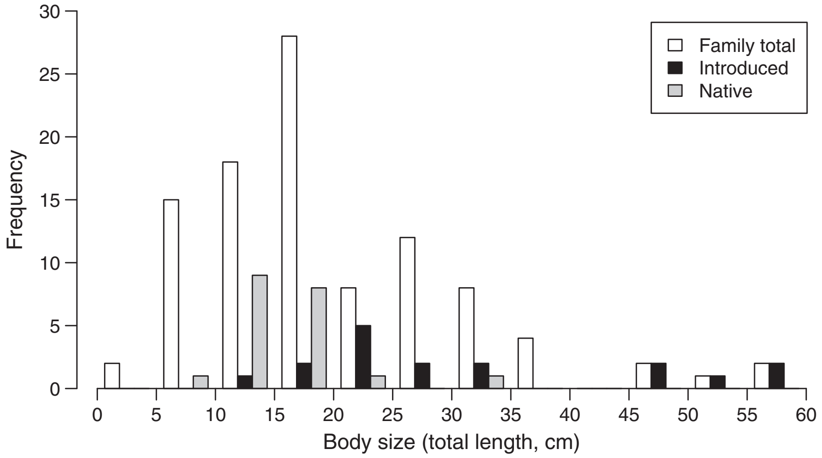

Figure 3 Distribution of body size in the family Chameleonidae for all species (unshaded), introduced species (black) and species native to South Africa (grey). Data were log-transformed before analyses. Mean log body size of introduced species is significantly larger than mean log size of all chameleon species and native species. Size data were unavailable for 25 (out of 179) species.

Table 1 Generalized additive models of the determinants of the abundance of reptiles kept as pets in South Africa

	AIC	AIC 2.5% bootstrap	AIC 50% bootstrap	AIC 97.5% bootstrap	Intercept	s [log(Size)] $k=4$	Venomous	Colour	Patterns	Features	Breeding	Handling	Log (Price)
(a) $n=77$													
1	977.245	887.08	962.50	1031.16	12.22^{***}	**	-0.83^{**}	–	–	0.95^{**}	0.99^{**}	–	-1.06^{***}
2	977.805	887.35	963.87	1029.30	11.8^{***}	**	-0.72^{*}	–	–	0.97^{**}	1.02^{**}	0.35	-1.04^{***}
3	979.158	882.42	963.85	1031.65	12.19^{***}	**	-0.80^{**}	–	0.2	0.94^{**}	0.92^{*}	–	-1.08^{***}
4	979.24	878.82	963.85	1032.54	12.16^{***}	**	-0.82^{**}	0.021	–	0.95^{**}	1.0^{*}	–	-1.06^{***}
5	979.613	883.39	964.97	1205.54	11.71^{***}	**	$-0.68^{(.)}$	–	0.3	0.97^{**}	0.94^{*}	0.36	-1.07^{***}
(b) $n=77$ (price excluded)													
1	1002.574	894.43	985.35	1048.00	3.03^{***}	*	-1.26^{*}	$0.72^{(.)}$	–	1.13^{*}	2.47^{***}	0.64	
2	1003.796	895.38	982.01	1055.43	3.71^{***}	$^{(.)}$	-1.60^{***}	0.59	–	1.08^{*}	2.44^{***}	–	
3	1004.455	903.89	981.47	1051.50	3.28^{***}	**	-1.30^{**}	0.69^{**}	−0.26	1.14^{**}	2.52^{***}	0.60	
4	1004.51	911.26	988.23	1056.88	4.27^{***}	$^{(.)}$	-1.72^{***}	–	–	$0.73^{(.)}$	2.38^{***}	–	
5	1004.544	890.17	988.63	1054.78	3.71^{***}	$^{(.)}$	-1.41^{**}	–	–	$0.79^{(.)}$	2.42^{***}	0.59	
(c) $n=234$ (breeding, handling and price excluded)													
1	2627.345	2409.280	2584.372	2719.280	3.36^{***}	***	-1.36^{***}	0.77^{***}	1.39^{***}	0.97^{***}			
2	2637.085	2368.88	2593.45	2726.98	4.41^{***}	***	-1.39^{***}	–	1.14^{***}	0.74^{***}			
3	2637.608	2378.91	2597.64	2742.47	3.96^{***}	***	-1.44^{***}	0.62^{**}	1.27^{***}	–			
4	2639.006	2392.97	2591.06	2734.12	4.80^{***}	***	-1.46^{***}	0.64^{**}	–	0.87^{***}			
5	2642.793	2403.91	2608.09	2739.42	4.50^{***}	***	-1.47^{***}	–	1.08^{***}	–			

Three scenarios are shown (a) all eight predictors were included; (b) price was excluded; (c) all trader/keeper predictors were excluded (but note the increase in number of species). For each scenario, models were fitted with all combinations of predictors. The top five models, as determined by AIC, are shown, along with the median and 95% confidence intervals for AIC based on 1000 bootstraps. Predictors that were absent in a given model are indicated by '–'. The effect size and significance of predictors in each model are shown. The following significance levels are used: $^{***}P<0.001$; $^{**}P=0.001$; $^{*}P=0.01$; $^{(.)}P=0.05$.

candidate models. While the analyses did not produce a single model that had a significantly better fit than any other model, the top competing models all showed similar trends. When price was included in the analysis, it was by far the strongest predictor of abundance: more expensive reptiles are less commonly traded. Similarly, dangerous species are less common, whereas species that are larger, easier to breed and have interesting features tend to be more common (Table 1). These variables explained the largest portion of the variation in abundance when price was excluded (see Table 1 for effect sizes). While the relationship with price was clearly positive, there was some evidence that there is not a straight linear relationship between size and abundance (size was more accurately modelled with a smoothing spline with four degrees of freedom) (Appendix S3). Presence of colour and patterns were poorly correlated with abundance if trader/keeper variables were included. However, in the analysis on the full dataset (where trader/keeper variables were excluded), there was a clear preference for more colourful or patterned species (Table 1).

Discussion

General and taxonomic patterns

Patterns of diversity for native species are determined through biogeographical and evolutionary processes, and over-represented native families tend to be those which evolved or radiated in Africa, for example Cordylids

(Fig. 2a, Frost *et al.*, 2001). However, we found that the patterns of introduced species richness were notably different to those of native species, and result from totally different selection criteria. A number of human-related traits dictate whether species are introduced and determine their subsequent supply and demand, thus defining an interesting and important dimension of the 'dispersal pathway' (*sensu* Wilson *et al.*, 2009). Firstly, people want attractive pets. Therefore, we see an over-representation of families with colourful and patterned species, for example chameleons, boas and iguanas (Fig. 2b). If these species are easy to breed, handle and keep, we also see an increase in their abundance (Table 1). For example, easy-to-breed colubrid snakes are abundant, whereas chameleons, which often require special care and can be difficult to breed in captivity, are not as abundant as would be predicted by their attractiveness. Species that do not make good pets often do not become abundant. For example, species that are popular in zoos and parks, but which are difficult to handle or have dangerously venomous bites, are less common. However, while venomous Elapidae and Viperidae are under-represented in terms of abundance, a large number of species have been introduced from these families. The large diversity of sizeable and dangerous introduced animals could be because experienced keepers may enjoy the challenge of keeping and breeding less abundant and easily manageable species. Furthermore, people like to boast with their possessions (McIntosh & Schmeichel, 2004), and large/dangerous animals are most impressive. Some species are even advertized as burglar deterrents in South Africa, with larger, more powerful species serving as a more effective deterrent.

Finally, factors linked directly to trading and trade routes are also important in determining which species arrive in an area. For example, chameleons are native to Africa, Madagascar and some parts of Asia (Nečas, 1999), making their trade in South Africa simpler than that of species from the Americas. Indeed, most countries exporting CITES-listed species to South Africa were in Africa or Europe, the two regions closest to South Africa, even though these are not necessarily the regions with the highest reptile diversity. Yet, even if trade routes are in place, animals that cannot easily be bred will fail to become abundant. Such species will be more expensive because they are harder to come by. These species also pose a conservation problem as wild harvest is often used as an alternative to meet demands and many such species are endangered. For example, nearly 80% of chameleons and all pythons are CITES-listed and many of these are difficult to breed, yet are sought after in the pet trade due to their bright colour and forms, docile nature, and non-reliance on live prey (Reed, 2005). And while there have been some successful prosecutions, there is clearly an illegal trade from Madagascar to South Africa (South African Press Association, 2008). However, the fact that such a high percentage of CITES imports (71%) originated from regions outside of the species home range, indicates that species are probably being captive bred on a large scale and that introductions to South Africa may be a fairly good sample of species in the trade worldwide.

Price was clearly the best predictor of species abundance, with the most commonly traded species being the cheapest. This was despite difficulties in obtaining price estimates, and inherent price variability within a species [depending on the age, size, colour patterns and the source from which the specimen was bought (and bred), an individual of a given species can cost between US$1 and US$30 000]. Species that are easier to keep and breed are likely to become the most abundant, and, through market forces, their price will come down. Therefore, price is perhaps partly a function of abundance, and so price *per se* provides little insight in explaining which factors determine abundance. When price, breedability and handling are removed from the analysis, we see that presence of bright colours and patterns become significant predictors of the number of species in the trade. However, in countries where native reptiles can be kept legally, animals that are easy to collect and/or are abundant in the wild may be the most numerous in the trade.

Implications

By world standards, the reptile trade in South Africa is very small (Auliya, 2003). In 1999, there were 225 000 imports of live reptile specimens to Europe covered by CITES permits (Auliya, 2003), but only ~1000 individuals were imported to South Africa. The trade in South Africa is, however, growing rapidly (Fig. 1). Understanding the driving forces now will improve policy decisions, and could prevent potential future problems. Abundant species have a higher chance of becoming invasive due to high propagule pressure (Reaser *et al.*, 2008). Without understanding the biases inherent in the introduction and subsequent movement of species, traits associated with invasion cannot be determined. For example, relating a large body size to invasive success (Reed, 2005) for reptiles in South Africa, would need to consider the fact that humans preferentially introduce larger-bodied species. Similarly, other factors commonly used in risk assessment, such as fecundity, may also be biased. Species producing large broods may be selected for by breeders, as more profit could be made from a single pair. However, some selected traits may be linked to invasibility; that is, there may be some form of 'self selection' for invasive criteria. Species that are easily bred may also breed more easily outside of captivity if they are released or escape. Furthermore, export of the same species from many countries (CITES data), indicates that species which are tolerant of transport and perhaps even a broad range of environmental conditions may be selected for in the trade.

The source of species traded and existing trade routes also have implications for risk assessment. For example, exports from regions where species are not native are less likely to contain wild-caught individuals. Captive-bred individuals, in turn, are less likely to spread disease, while captive breeding also reduces impact on wild populations. Importing countries should also be wary of introducing species native to areas with similar climates (van Wilgen, Roura-Pascual and Richardson, 2009). Finally, a portion of the bias seen in species introductions can be attributed to a bias in trade links between countries.

As traditional cost–benefit analysis is inappropriate as a means for justifying the regulation of importations of reptiles in the pet trade (due to the narrowly concentrated benefits), risk assessment must rely on parameterizing traits and introduction pathways to evaluate the invasive potential of species and related risks. A lack of biological data for many species outside of captivity means that risk assessment may be reliant on certain trade-related aspects, such as those used in this study (Reed, 2005). Where other data are unavailable, looking at popular traits will help to identify species which may be introduced or are likely to become abundant. Of particular importance in risk management is whether individuals are likely to be released into the wild. Experienced owners, with sophisticated facilities, can import highly specialized animals, which are likely to be introduced in small numbers and probably much less likely to escape or be released, due to the financial commitment of the pet and more advanced housing. On the other hand, people keeping cheaper, more abundant pets may spend less on housing and also be more likely to release their pet when it becomes an inconvenience. Owners are also more likely to dump their pet than kill it (large numbers of animals are dumped outside zoos in the hope that the animals will find a new home there). Some species are attractive when they are young and small, but the attractive features decline or disappear as the animal ages, resulting in the owner releasing the pet. For example, red-eared sliders (a type of terrapin) lose the patterns on their shells as they age, and many boas and pythons (e.g. the Burmese python) become unmanageably large (Snow *et al.*, 2007). This may be why these two species are among the most notorious reptile invaders (Lowe *et al.*, 2004). Other species may be problematic even if only a few escape. Large or venomous species have the capacity to harm native animals, livestock and even humans (Bomford, 2003). Indeed, South Africa produces anti-venom for only 14 reptiles (all snakes, eight of which are native) (South African Vaccine producers http://www.savp.co.za/index.htm, accessed March 2009), even though there are many other venomous species kept, sold and traded (see Appendix S1, S2). This poses a threat to the public should an individual escape.

Finally, we may not be able to detect certain current or likely future trends in South Africa due to the low trade rate. For example, low abundance of less attractive, easy to collect individuals may be a result of low trade volume – in other countries such as the US, exporters often export many cheap species to make sufficient profits. If the trade in South Africa increases with more imports coming from such facilities, we may see more of these species being imported.

Conclusions

The reptile trade in South Africa is expanding rapidly but is poorly regulated. As such, it presents some interesting challenges. We have shown that species selected for the trade differ from the native taxonomic pool. Currently, traded species are selected on the basis of physical and breeding attributes rather than any of the many other factors that shape biogeographical patterns of native taxa. This may have implications for endangered species as well as invasions. Encouraging trade in common species (to reduce the threat on endangered species) increases the risk of invasion through higher propagule pressure. Common species are also more likely to be abundant and thus cheaper, increasing the likelihood of their release when the owners tire of the pet. Furthermore, we are faced with the problem of keeping pet owners satisfied, while protecting our environment and public safety. On a positive note, the increase in popularity of reptiles as pets, though dangerous for threatened species, is increasing their stature and reducing the negative connotations which many of these species carry. This is important if we are to gain public support to save this class in the face of reptilian decline.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Lists of species as they appear on permits in each province in South Africa. This highlights the areas where record keeping is inadequate. Note that detail depends on information provided by the province and changes have not been made to mis-classified species. Sheet names are abbreviated as follows: EC = Eastern Cape, FS = Free State, G = Gauteng, KZN = Kwa-Zulu Natal, L = Limpopo Province, MP = Mpumalanga, NC = Northern Cape, NW = North West Province, WC = Western Cape.

Appendix S2. A list of all species recorded in South Africa as imported, in zoos, or appearing for sale in pet stores or online (sheet 1), their relative abundance in South Africa and traits for each species (sheet 2), and the references used to obtain trait data (sheet 3).

Appendix S3. A partial dependence plot of the relationship between Size and abundance (on the linear predictor scale) – i.e. the figure shows the response to Size having taken account of the effects of other variables. When $n = 77$ (i.e. the model where all variables are included), the basis dimension for the smoothing parameter for Size, **k**, that minimised the AIC of the best model was 4 (a). For $n = 234$, **k** was 6 (b). But in both cases, the largest species are favoured in the trade, and the smallest species are relatively less abundant.