Alien reptiles and amphibians in South Africa: Towards a pragmatic management strategy

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Biological invasions are a growing problem in South Africa. Many alien species have been introduced for various reasons and through multiple pathways over the past few centuries. Invasive alien reptiles and amphibians (herpetofauna) are not yet a major problem in the country. However, escalating difficulties with invasive species in these groups worldwide, and changing circumstances in South Africa, suggest a high risk of increased problems in the future. This paper reviews key issues pertaining to invasive alien herpetofauna worldwide and discusses how risk assessment can be used as part of an effective biosecurity strategy for South Africa. Nearly 300 species of alien herpetofauna have already been imported into the country via the pet trade and are being kept in captivity. There is a need to consider the potential threat of these species, and others still to be introduced, in line with practices in other countries where formal risk assessment policies are in place to separate potentially invasive species from those that are unlikely to be problematical. New legislation in South Africa seeks to regulate activities involving alien species, but exactly how this will be done has yet to be finalized. Each province in South Africa currently has its own legislation with different requirements; this causes many problems. Records of permit applications are also poor, complicating attempts to compile accurate inventories and to discern trends in imports and permit allocations. We define a pragmatic framework for dealing with alien reptiles and amphibians in South Africa. The framework identifies key issues facing the country and considers how the situation and advances elsewhere in the world can be used to set priorities. We propose that a risk assessment protocol be implemented for categorizing species as permissible or prohibited for import and trade. Accurate data are needed on the alien species already in South Africa.

Introduction

People started translocating organisms around the world long before modern civilizations.[1] South Africa has received thousands of alien plant and animal species over the past four centuries. These have included many useful species, such as food crops and livestock, as well as others that have been detrimental to the environment and the economy. For example, the Australian black wattle (*Acacia mearnsii*) has been estimated to have cost US$1450 million (R8550 million) in stream-flow reduction alone in South Africa prior to 1998.[2] The first exotic species to arrive were livestock and associated plant species brought in by native Africans from areas further north in the continent. These species do not appear to have had markedly detrimental effects on the environment.[3] When European settlers arrived in the 1600s, however, the rate of introduction and utilization of exotic species increased dramatically, changing the face of South Africa.[3] Species were introduced because the South African environment lacked species (or equivalents) deemed essential by the settlers for their agriculture, forestry, and many other uses. With no control over what species were introduced, and no awareness of the potential environmental effects of these species, indiscriminate importation of many species took place, with consequent problems. The reasons behind the introduction of alien species, and the pathways of introduction to and spread within South Africa, have changed markedly over time. More alien species are now arriving, in larger numbers, from more parts of the world, by more routes, and to serve more diverse human needs than ever before.[1] Understanding the forces driving these introductions is crucial for devising ways of slowing the influx.

Invasive alien plants are one of the biggest threats to South Africa's biodiversity, and much more attention has been given to the study and management of invading plants than to other groups. Vertebrates are also a problem. Most of the birds and mammals introduced to South Africa were brought in by settlers as pets or 'novelties' to compensate for the lack of familiar species in the region,[3,4] though some pests, such as the house rat (*Rattus rattus*), were introduced accidentally by trading vessels on their way from the Middle East. Alien freshwater fish have probably had a more dramatic effect than birds or mammals. Their introduction has detrimentally affected the functioning of freshwater ecosystems in many areas.[5,6] Fish have been introduced mainly for angling and aquaria,[3] but aquaculture has also played a role.

With the recognition that biological invasions pose a considerable threat to biodiversity, society has begun to address the problem in various ways—by managing those species that have already become invasive, and by attempting to reduce the influx of additional species that could invade in the future. In South Africa, most attention has been focused on the groups mentioned above, as the most pressing environmental problems have emerged from invasions by these groups. However, in several parts of the world invasive reptiles and amphibians (hereafter herpetofauna) are emerging as a major problem.[7] Although these groups are not a serious problem in South Africa, several invasive alien herpetofaunal species have had dramatic social and economic consequences in other parts of the world. Prominent examples are the cane toad (*Bufo marinus*) in Australia (and many other parts of the world),[8,9] the brown tree snake (*Boiga irregularis*) in Guam,[10] the Caribbean tree frog (*Eleutherodactylus coqui*) in Hawaii,[11] and the number of invasive herpetofaunal species worldwide is increasing.[12,13]

The general increase in global trade and travel has led to a substantial increase in the rate of biological invasions around the world. Invasive species are considered one of the main threats to biodiversity.[14] South Africa has introduced legislation to regulate the import of alien species and to monitor international entry points to prevent the introduction of unwanted species. The National Environmental Management: Biodiversity Act (No. 10 of 2004), and the imminent regulations for dealing with invasive species under this act, focus on preventing the influx of unwanted invasive species (pre-border intervention) and on managing invasive species already inside the country (post-border intervention). Management is needed at every stage—to stop high-risk species from being introduced; to detect and eradicate incipient invasions; and to contain, manage, and mitigate the impacts of established invaders. Preventative measures are clearly the most cost-effective, because the cost of managing invasive species increases exponentially following

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Table 1. Examples of negative effects of alien herpetofauna on the environment and various sectors of society.

Impact of alien herpetofauna	Sector affected	Examples
Competition with local species (for food, water, breeding and nesting sites, and territories)	Biodiversity	The cane toad (*Bufo marinus*), which occurs naturally in Central and South America,[17] is invasive in over 50 countries,[9] e.g. Australia, where it was introduced in 1935 as a biological control agent for sugarcane pests.[9] *B. marinus* feeds on nearly any metazoan and is thus able to out-compete many native amphibians. The toad also competes for breeding habitat.[12,18,19] Another example is the American bullfrog, which competes with native tadpoles (*Rana aurora*) in the northwestern U.S.A.[20,21]
Predation (including localized species extinctions)	Ecosystem, biodiversity, humans reliant on ecosystem services	'Island tameness' is a phenomenon often seen on islands that previously lacked predators, where the native species have not co-evolved under predatory pressure and are thus not adapted to escape when predators are introduced.[22] The brown tree snake (*Boiga irregularis*) (native to Australia, Papua New Guinea and the Solomon Islands)[23] is invasive on the island of Guam[22] where it has been responsible for the loss of all that island's native mammal species (3 bats), most of its lizards and 9 of the 12 native forest birds.[10] The snake may also have unpredictable secondary effects: by preying upon many seed dispersers, seed banks of many woody trees may be depleted.[12] The cane toad not only affects the native fauna on which it feeds, but also those species that prey on it which are poisoned by the toad's toxic skin.[8]
Disruption of ecosystem processes and functioning	Ecosystem, biodiversity	The Caribbean tree frog (*Eleutherodactylus coqui*) that was introduced to Hawaii via horticultural trade in the 1980s,[11] affects ecosystem processes and invertebrate communities on the island.[24] The frog increases the rate of nutrient cycling and new leaf production, which in turn may favour alien over indigenous plant species which are adapted to nutrient-poor soils.[24] The frog also significantly reduced invertebrate numbers at one of two sites studied.
Initiation of amphibian declines through the spread of disease	Biodiversity	There is currently a troubling worldwide decline in amphibian populations. Amphibian presence may be used as an indication of the overall health of an environmental system.[25] Therefore, if there is a decline in amphibians, other species may be at risk too. Alien species (along with elements of global change) are thought to be one of the key contributors to these declines.[25] South Africa's own *Xenopus laevis* is thought to be one of the contributors to the spread of the disease chytridiomycosis (caused by the *Batrachochytrium* fungus) to native frogs in Australia and North and Central America.[26] This is thought to be one of the main causes of amphibian declines in these areas.[26]
Attacks on people, livestock, or wild animals	Human health, agriculture, biodiversity	Large, powerful or venomous species, such as pythons, boas, cobras or rattlesnakes, are a specific concern, especially where no anti-venom is available. *B. irregularis*, a relatively small back-fanged and mildly venomous snake, is known to attack people (primarily infants) while they are sleeping in their beds.[27] Introducing such species as pets could lead to an increase in such incidents.
Spread of disease to humans	Human health	*Salmonella* is transmitted by the red-eared slider (*Trachemys scripta elegans*) amongst others and can be transferred to humans.[28] The cane toad (*Bufo marinus*) feeds on human faeces and is speculatively linked to the spread of hookworms (*Trichuris trichuria* and *Schistosoma mansoni*).[29]
Hybridization with local species	Biodiversity	*Ambystoma tigrinum*, a salamander introduced to California, has hybridized with the local species *A. californiense*.[30] Riley *et al.*[30] found hybrid salamanders in six out of six pools that were sampled. Hybridization is a concern where alien species have native relatives. If progeny are viable, inbreeding with the native population will contaminate the gene pool and may potentially lead to the extinction of rare adaptations or even species.[31,32]
Damage to agriculture, human habitation and the economy	Human society	*B. irregularis* has also had significant social and economic impacts on Guam,[33–35] including the loss of poultry, and power failures when snakes get caught in power lines. The annual cost of power failures related to brown tree snakes on Guam was estimated at over US$1 million.[34] Another, often under-estimated, financial burden is the costs associated with the control and eradication of alien pests. Once an alien species has established a population and become invasive, it is very difficult, if not impossible to eradicate or control.[12,36]
Effects on property prices and the disruption of trade	Human society	The Caribbean tree frog has a call which reaches nearly 100 dB at 0.5 m,[37] and the noise caused, particularly at night, adversely affects property prices.[38] *E. coqui* also threatens floriculture and nursery industries in Hawaii and perhaps Florida, because of bans imposed on import and export of nursery products for fear of transporting this disruptive frog.[11,38,39]

their establishment.[15,16] Here, we discuss crucial considerations from many sources that have a bearing on alien herpetofauna in a South African context and that relate to requirements for an effective and practical protocol for risk analysis. Our departure point is that such a protocol should merge the best science and information available worldwide with common sense, considering the needs and concerns of all affected parties, and effectively separate potentially problematic species from those with minimal risk of becoming invasive.

Why should we worry about alien herpetofauna?

Invasive alien herpetofauna have the potential to cause a number of negative effects, ranging from impacts on native biota to affecting the day-to-day course of society (Table 1). Understanding the combination of these effects is important but can be very difficult.[12]

These species are inadequately studied, and detailed assessments have been made for only a handful of herpetofauna worldwide. Although some species have had dramatic effects, the consequences of invasion of others go relatively unnoticed as they are not as conspicuous to the public as those of large mammals, plants, or diseases. Although South Africa has

Fig. 1. Exotic reptiles are extremely popular in the pet trade. This has led to an increase in illegal importations. Pictures **a** and **b** show boxes of snakes [kingsnakes (*Lampropeltis pyromelana, L. alterna*) (**a**) and green tree pythons (*Morelia viridis*) (**b**)] intercepted at O.R. Tambo International Airport, Johannesburg, in 2005. Many of the exotic species in South Africa are captive-bred locally [for example, (**e**) baby leopard geckos (*Eublepharis macularius*)] and then sold in pet stores (**d**, **f**, **g**), which are especially popular in Gauteng and KwaZulu-Natal (see Table 2). Examples of the species sold are red-tailed boas (*Boa constrictor*) (**c**), green iguanas (*Iguana iguana*) (**h**) and Meller's chameleons (*Chamaeleo melleri*) (**i**). (Photographs: J. du Toit, R. Potts, R. Boshoff, N. van Wilgen and D. Richardson).

not suffered impacts due to invasive herpetofauna to date, the increase in invasions in other parts of the world with similar environments and/or socio-economic drivers (such as the pet trade), has led to increased demand and volumes of importation of alien herpetofauna.[13,40] This suggests that South Africa could well face more problems in the future. There is certainly a marked increase in the promotion of alien herpetofauna as pets, and local awareness needs to be raised concerning the potential consequences of invasions. There are currently nearly 300 species of alien reptiles and amphibians being kept in captivity in the country, and it is likely that there are many more undocumented species (N.v.W., unpubl. data; Fig. 1).

South African herpetologists have made several *ad hoc* observations of non-captive (escaped or released) alien reptiles, both in rural and urban areas during the past five years. These anecdotal observations include records of a kingsnake (*Lampropeltis alterna*) in a suburban garden in the Strand and an alligator snapper turtle (*Macroclemys temmincki*) in a pond at a George commercial crocodile facility (E. Baard, pers. obs.), a Burmese python (*Python molurus bivittatus*) in a Cape Town wetland (M. Burger, pers. comm.), a yellow ratsnake (*Elaphe obsoleta quadrivittata*) in a Cape Town suburb (M. Witberg, pers. obs.), western diamond-backed rattlesnakes (*Crotalus atrox*) seen by and removed from properties in Johannesburg by J. Marais (pers. comm.), several corn snakes (*Elaphe guttata*), a grey rat snake (*Elaphe obsoleta spiloides*), a northern pine snake (*Pituophis melanoleucus melanoleucus*) removed from a Durban urban area (J. Marais, pers. comm.) and a green iguana (*Iguana iguana*) in Gauteng province (G. Alexander, pers. comm.). These could be warning signs of potential future problems.

Furthermore, there are increasing reports in South Africa and around the world of

illegal imports and other activities involving alien herpetofaunal species (Box 1; Fig. 1). Austria and the Czech Republic are two countries where this trade is extremely popular. Over 1000 tortoises, as well as consignments containing over 1000 spiders and reptiles, were intercepted by Austrian customs officials between 1999 and 2001.[41] Illegal imports may not be the only concern. Experience with invasives from other taxa, especially plants, shows that routine trade between countries could lead to species introductions.[42] For example, the growing and diversifying trade between Africa and Australia could be problematic as Australia has a rich reptile fauna (836 species),[43] many species of which occur in ecosystems which have close analogues in South Africa. Australia and South Africa have already exchanged many species that have become invasive, and diversifying and increasing trade is likely to drive further introductions and invasions over the next few decades. South African regulations and strategies need to account for the fact that growing trade links are very likely to lead to further introductions/invasions and these issues need to be built into integrated management strategies.

Box 1. Some illegal activities involving reptiles making the news around the world in the past two years.

August 2005 – Australia: A man was arrested at a Brisbane airport when officials discovered six snakes in his hand luggage. Another 33 reptiles were found in his other luggage. They were being transported in plastic containers, shampoo bottles and loud-speakers.[44]

September 2006 – Thailand: A Madagascan man was apprehended by customs officials in Thailand when his luggage was found to contain 200 chameleons and tortoises.[45]

May 2007 – China: Over 5000 animals – including several reptile species – were found on an abandoned fishing boat in the South China Sea. It is thought that the owners abandoned the illegal consignment when the boat broke down. The animals were in very poor condition and were presumably being transported for use in exotic food dishes and traditional medicines.[46]

May 2007 – South Africa: A newspaper report states that the trade in alien reptile species is increasing and that there have already been several reports of alien species such as diamond-backed rattlesnakes (*Crotalus atrox*) outside captivity on the Highveld and in Mpumalanga.[47]

June 2007 – South Africa: A parcel containing 10 venomous alien snake species [including monocled cobras (*Naja kaouthia*), Arabian saw-scaled vipers (*Echis* sp.), and Australian taipans (*Oxyuranus* sp.)] was intercepted at a Johannesburg post office. No anti-venom for these snakes was available in South Africa at the time.[48]

June 2007 – Egypt: A man was apprehended at an airport in Cairo attempting to carry a bag containing 700 live snakes onto a plane bound for Saudi Arabia, where he planned to sell them.[49]

What forces drive the introduction of alien herpetofauna?

Kraus[13] reviewed the published literature on introductions of herpetofauna to regions outside their natural range (approximately 577 recorded introductions). Most publications concerned species introduced to the United States, Caribbean and Pacific islands. He found that there has been an exponential increase in the rate at which species are being moved around the world. Since 1860, the number of introductions has doubled every 40 years or so.[13] Of the species documented, frogs had the highest success rate of establishment, with 134 of 177 (76%) introduced species generating viable populations. Where the reasons for introduction were recorded, six main pathways were found to be prevalent. By far the two most important sources of introductions (63%) were intentional import (followed by escape or intentional release) via the pet trade and accidental import where species had found their way into the cargo of ships or aircraft.[13] The four other pathways included species that were introduced for biological control, as food for humans, for aesthetic purposes, and accidentally with nursery-trade products.[13] Currently, the growing demand for reptiles as pets in the European Union drives increasing imports each year,[40] while the increase in world trade continues to add to the number of unintentional introductions.[13]

What does the South African law require with regard to alien species?

South Africa's National Environmental Management: Biodiversity Act (No. 10 of 2004) (NEMBA) requires that a risk assessment be undertaken before a permit may be issued for activities involving an alien species (including importing, selling, keeping in captivity, or releasing the species). This Act has not yet been put into practice, however, as regulations to guide its implementation are still in preparation. Also, there is currently no set protocol whereby risk assessment may proceed, and provincial conservation agencies largely rely on either their own expertise or information provided to them by applicants or gleaned from the Internet. This does not promote an objective or well-informed (or even accurate) approach in considering permission to import alien species. Furthermore, the majority of provincial agencies have no herpetologists on their staff to advise them. The Department of Environmental Affairs and Tourism is currently working with scientists to draw up regulations in accordance with the Act.

We conducted a telephone survey in March 2007 with provincial nature conservation agencies and governmental permitting departments, which revealed that most of South Africa's provincial nature conservation agencies do not know how many or even which alien (and native) herpetofaunal species are being kept in captivity in their provinces. Furthermore, each of the nine provinces has its own legislation, and policies differ considerably between provinces with regard to stringency, application, and scientific basis (Table 2). An additional problem is that in most cases risk assessment relies on 'expert' opinion, where the expert is a South African scientist with limited herpetological experience. In practice, these experts often have little knowledge of foreign species or invasive-species training/knowledge. Local herpetologists are sent lists of species that are desired for import, to which they then provide their opinion as to whether or not the animal should be permitted (E. Baard, pers. obs.; V. Egan, pers. comm.). Different experts use different criteria, and have different thresholds for what to them constitutes a high risk, or factors regarded as relevant for suitable habitat for a foreign species. Once a species has been introduced to one province, it can easily be moved to other provinces around the country, even ending up in areas where the legislation differs and would not permit it. This is obviously far from ideal and it is clearly desirable for one standard, defendable protocol to be developed for use throughout the country.

What do international agreements require?

The World Trade Organisation (WTO) governs international trade. Agreements

Table 2. The legal requirements for the import, transport and/or captive keeping of herpetofauna in the nine provinces of South Africa and the implications of these for biosecurity.

Province	Legal requirements	Implications for biosecurity
Eastern Cape	Only alien species imported prior to 2002 may be imported again. All other species are prohibited (N. Bam, pers. comm.).	RAs* were not required for historic introductions, thus species brought in prior to current legislation are not necessarily low risk, nor are currently prohibited species high risk. Potentially invasive species may thus still be introduced and benign species banned.
Free State	Import permits required, but permits not required for captivity or for keeping in captivity.	Alien species may legally be bred and traded within the province without notification of officials. No information exists on the number of species and individuals.
Gauteng	Import permits (and accompanying RA* with the onus on the applicant) required, but permits are not required for captivity or for keeping in captivity (L. Lötter, pers. comm.).	Because the animals may be traded freely, no one has applied for import permits to date (L. Lötter, pers. comm.). Records of species in the province are absent and therefore no means of proving the provenance of a species or individual (that is, from within the province or outside South Africa). Risks of transporting high-risk species to other provinces are high, in the absence of border control between provinces.
KwaZulu-Natal	Import permits (with RA and onus on applicant) are required for herps. No captivity permits required.	Same as Gauteng, but application has been more stringent, and RA has been applied. Records exist of species imported into the province, but not of those being kept or bred.
Limpopo	RA required, but current legislation is unclear about which species require assessment and which may be freely imported, therefore enforcement is difficult.	No control over alien species in the province and no documentation of species present.
Mpumalanga	RA required for import and captivity or for keeping in captivity of alien species.	New legislation introduced in 1998, but enforcement is problematical. Very few permit applications, though it is suspected that trade exists (L. Swart, C. Hobkirk, pers. comm.).
Northern Cape	RA required for import and captivity or for keeping in captivity of alien species.	Control appears to be adequate.
North West	RA required for import and captive keeping of alien species.	Stringency of implementation questionable as permit data have not been obtainable after seven months of written and telephonic requests.
Western Cape	Import (with RA), transport and captivity permits are required for reptiles and no alien amphibians are permitted (due to concerns relating to the spread of disease rather than invasive potential) (D. Hignett, pers. comm).	Control appears to be adequate and permit system ensures good record-keeping. However, as with other provinces, law enforcement remains a problem, as a search warrant is required to implicate illegal traders.

*RA, Risk assessment; all RAs differ in structure, composition and stringency.

made by this body aim to optimize fair trade and reduce the number of restrictions imposed on trade. Those restrictions that are in place relating to commerce in organisms serve primarily to stop trade in species that may harm humans, animals, and plants, as a result of spreading economically important pests and diseases.[50] The WTO's Sanitary and Phytosanitary Agreement (SPS Agreement) recognizes the World Organisation for Animal Health (Office International des Epizooties) and the International Plant Protection Convention (IPPC) as the international bodies that set the standards for plant and animal health and phytosanitary measures worldwide.[50] The focus of these organizations is, however, such that future restrictions on trade due to undocumented risks associated with the transport of alien species are unlikely. World trade is economically and socially extremely important, and hampering it can have negative consequences. As a result, the application of the precautionary principle (that is, the use of extreme caution in decision-making in the absence of precise data) is often not an option. The WTO allows this principle to be invoked to control the entry of species only when sound, scientific reasons (defendable in court) to substantiate any proposed restrictions are available.[51] This necessitates the formulation of a scientific process whereby risk assessment can proceed.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) impacts directly on trade in some reptiles and amphibians. Trade in species whose populations are potentially threatened by such trade are monitored in three appendices (depending on the severity of the threat). Data from CITES are an important source of information for detecting overall trends, since there is a substantial trade in herpetofauna that could affect species and/or populations. The appendices include 96 amphibian (16 Appendix I, 90 Appendix II) and 606 reptile (70 Appendix I, 511 Appendix II) species and subspecies.[52] The stringency of trade conditions depends on how threatened a species or population is by international trade. Though this serves to protect species threatened by trade and documents the movement of such species around the globe, it covers less than 10% of the herpetofaunal species worldwide, leaving a substantial gap in documentation. Available data aid in understanding the forces driving trade in these species and help to quantify the volume of trade and trends in imports and exports. This kind of information is vital when drawing up risk assessment procedures, as these need to be implemented in the correct places; that is, if species come in mainly via air freight for the pet trade, it is better to concentrate legislation and effort in these areas rather than investigating food entering via sea freight (which could be more important in some countries, e.g. China; Box 1).

What is risk assessment?

The field of risk assessment has arisen largely from work on the threat of chemicals (with their precisely-known proper-

ties and behaviour) to human health, and definitions of risk assessment often reflect this focus.[53] Risk is a measure of both the likelihood that an event will take place (in our case the establishment of a population of an alien species) and the consequences of such an event, should it occur (effects of the invasion).[54] Risk assessment takes both these components into account, including the degree of surety and/or error associated with these estimates.

Risk assessment for invasive species needs to discriminate effectively and objectively between potential pests and non-pests, and there should be only a small number of taxa which cannot be placed with confidence into either category.[55] The system should be cost-effective and should be able to identify geographical regions where a given species is most likely to invade.[55] In the past, the use of risk assessment to prevent the import of potentially invasive species has been met with scepticism.[56] This is because many people believe that risk assessment will lead to economic losses should a large number of species be rejected, even though the species might not prove to be problematic (that is, they are false positives). This has led to many countries avoiding risk assessment for alien species even though it is used to evaluate other environmental risks,[56] such as chemical hazards. However, recent evidence shows that the rate of successful invasion in vertebrates is much higher than previously predicted.[13,57] Nevertheless, a number of risk assessment protocols that have been applied to a variety of taxa have accurately predicted (80–95%) the outcome of species invasiveness in many parts of the world.[55,56,58–60]

Application of risk assessment to alien species

One needs to know where to act to formulate effective prevention measures. Ecological risk assessment for alien species needs to address two key issues: defining the likelihood that a species will become invasive, and determining the potential impact that the species could have, should it become invasive. Many studies have focused on investigating the risks associated with the introduction of alien species (e.g. Phelong *et al.*[55] and Daehler and Carino[58]); most of these consider various barriers which a species needs to overcome before it can become invasive.[61] These include geographic barriers (that restrict entry into the country), environmental and habitat barriers upon arrival, and biotic barriers created by, for example, predation or competition for space or other resources.[61] A problem is that many species are prevented from becoming invasive by barriers that are temporary (e.g. the absence of an essential mutualist, or marginal climatic conditions)—hence the well-documented lag phase in many plant invasions.[62] Determining the barriers restricting herpetofaunal invasions will be an important step. Once it is clear that a species is able to establish a population, the possible effects of the population(s) need to be considered—will there be adverse consequences and how severe will these be?

Likelihood of invasion. The first thing to examine is the likelihood of a species establishing a viable population.[12] Empirical evidence (from Britain, Florida and California, based on data gathered by Kraus from published records) shows that several key factors are correlated with the likelihood of a reptile or amphibian establishing in a new area.[12] These factors include the climatic match between the native range of the species and the area of its introduction; and evidence indicating that a species has been invasive elsewhere (which is often the most significant factor). Other factors regarded to be significant, which were not tested in the study, include those pertaining to the species biology, particularly feeding and habitat preferences, as well as reproductive output. It is important that all these factors are considered for a risk assessment protocol, though for many taxa insufficient data pertaining to these are available, limiting their usefulness for risk assessment.

Consequences of invasion. Having determined the likelihood of a species establishing a population, the next step is to assess the undesirable consequences that a species could have.[12] Impacts can be broadly grouped into three categories: environmental (e.g. loss of biodiversity, extinction of rare or threatened species, disruption of ecosystems); economic (e.g. reducing agricultural production); and social and political (e.g. affecting human health and well-being, impact on trade). Inadequate data on the impacts of alien herpetofauna makes it difficult to predict the effect that these species will have. Filling these and other gaps in knowledge remains a priority for herpetofaunal risk assessment.

It is important to realize that risk assessment protocols will never be completely accurate, and will probably overestimate the chance that a species has to invade.[12] However, they provide an objective way of screening many species by methods that are more useful than expensive, time-consuming and often impractical experimentation.[12] One also needs to bear in mind that overly strict policies regarding the importation of animals will probably increase the magnitude of illegal importations, which aggravates, rather than alleviates, the problem, and a healthy balance is called for (departmental and customs officials, pers. comm.). On the other hand, import prohibition will increase the market value of currently owned herpetofaunal pets, through rarity, and should decrease the likelihood of their owners releasing them (F. Kraus, pers. comm.). Paramount to all the above is that the necessary infrastructure to control policies must be in place to implement them (that is, alert customs officials, public awareness of regulations); otherwise, the policies become useless.

Herpetofauna are not often considered a priority for risk assessment; however, the fact remains that more than 30% of recorded introductions of alien reptile and amphibian species have resulted in the establishment of populations (though this figure may be biased, as established populations are more likely to be reported than those that are unsuccessful).[12] It is therefore prudent to consider prevention of further establishment of alien species, rather than waiting until it is too late.

Proposed action for South Africa

There are a number of issues regarding alien herpetofauna that are cause for concern in South Africa. Among these are the lack of cohesion in legislation between provincial and national legal instruments, the increasing trade in herpetofauna, and the large number of species that have already been imported. These issues can be addressed by means of a framework (Fig. 2) that takes due cognisance of the most important issues in the region. The first step is to assemble improved data on the alien species currently present in South Africa (such as which species are present, how many individuals, and where they are kept). Richardson *et al.*[3] discussed past, present, and likely future trends in introductions of birds and mammals into the country. Data required to compile a similar assessment for herpetofauna are lacking, and this information is needed to profile the current situation, and to determine changes to introduction pathways. These data can, however, be obtained by surveying captivity permits (where available), zoos and pet stores and reviewing the movement of CITES-listed species. Once the data are processed, work to determine which species may be potentially problematic

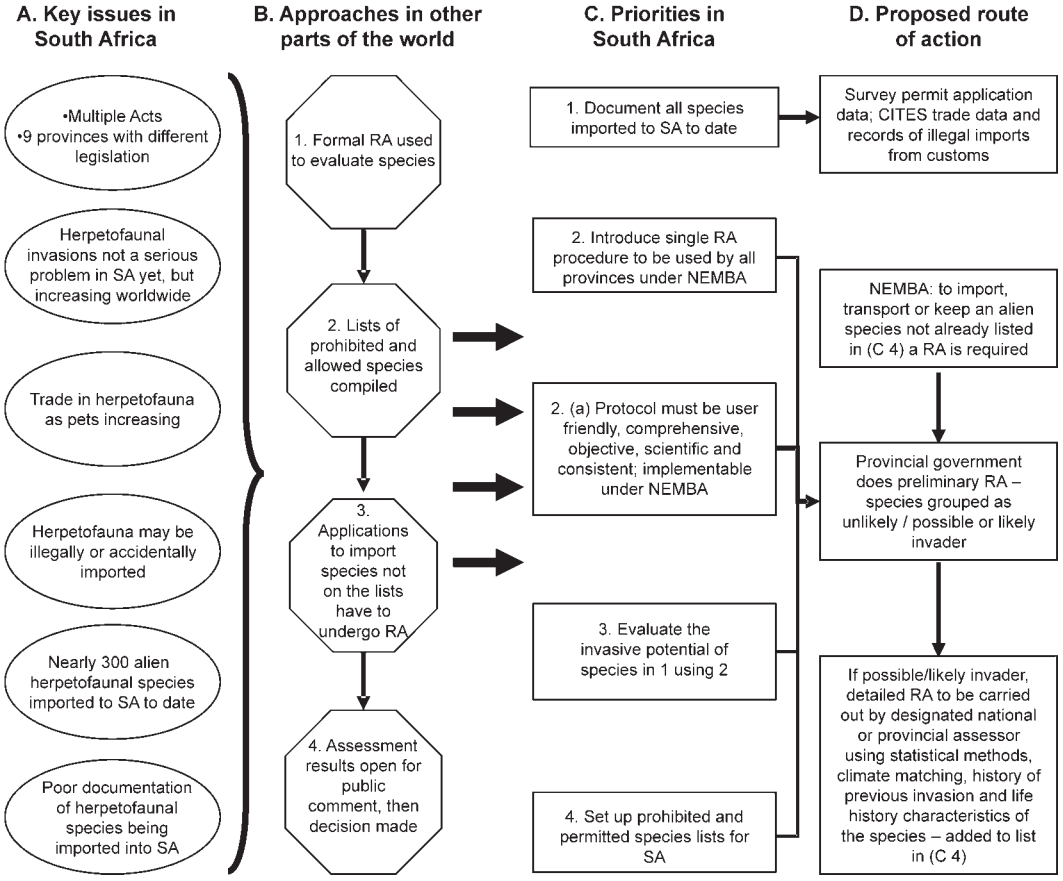

Fig. 2. A framework for defining priorities for dealing with alien reptiles and amphibians in South Africa. The figure shows how the identification of key issues facing the country (**A**) and consideration of the situation and advances elsewhere in the world (**B**) can be used to set priorities (**C**) and suggest a course of action (**D**). SA, South Africa; RA, risk assessment; NEMBA, National Environmental Management: Biodiversity Act.

can begin. This requires a risk assessment, aiming to place all species presently in South Africa on one of three lists: 1) species unlikely to become a problem and which may be traded without a permit (permitted species); 2) species with a high risk of establishing feral populations or causing harm to humans, livestock or the economy (prohibited species); 3) species for which inadequate information is available and for which further study is required. Species in category 3 would require a more detailed assessment. Should results remain inconclusive, the precautionary principle should be followed, that is, the species should be prohibited until conclusive evidence that it poses a minimum threat can be secured. Having such lists in place will ease the pressure on herpetologists, who are currently being forced to make decisions, without a standard scientific procedure. Importation of new species that do not appear on any of the three abovementioned lists requires a risk assessment as detailed in Fig. 2(D). We realize that predicting the impact of species can be problematic, especially where data are deficient, and it may be wise to restrict initial screening processes to examination of the likelihood of species establishment. We consider that this is achievable using the techniques and principles outlined in the sections above. Though no standardized scientific risk assessment protocol currently exists, work in this regard has begun.

It may also be wise to monitor the number of each species being traded, and perhaps to implement annual quotas. Because many of these species are being bred in South Africa, we recommend that no further importation of permitted species be allowed without a permit. This would take pressure off wild populations, and reduce the chance of introducing alien diseases. The fate of species that may be placed on a prohibited list, but which are already in the country, will require careful handling, to encourage owners to surrender stocks, and end breeding and trade in these species. If breeding and or trade in prohibited species is stopped for a specified period (such as an equivalent to two generations of such a species), the species should disappear from private collections. Special allowances could be made for zoos, research and educational facilities. Finally, improved awareness of the potential danger of alien species and of the need for risk assessment procedures among people in the pet industry, and members of the public, would go a long way in combating the problems that South Africa faces from invasive alien species.

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