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Review: *An Ecological Risk Assessment of Nonnative Boas and Pythons as Potentially Invasive Species in the United States* by Robert N. Reed. 2005. Risk Analysis 25(3):753-766.

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We didn't pay much attention to this paper when it was published. But what seemed a speculative and hypothetical paper three years ago now has taken on new significance. A Notice of Inquiry was posted by the U.S. Fish & Wildlife Service on 31 January 2008 in the Federal Register, the purpose being to request biological and economic information on certain species of boas and pythons with a view toward assessing whether or not these species should be added to the Injurious Wildlife List of the Lacey Act. In light of this turn of events, we feel this paper now requires a careful evaluation.

The author, Robert N. Reed, was on the faculty of Southern Utah University when the paper was written. He currently is employed by the U.S. Geological Service in the Biological Services Division. Reed is identified on the internet as an "invasive species biologist." Among his current projects, he is one of several biologists from several government agencies that are monitoring and studying Burmese pythons, *Python molurus bivittatus*, in the Everglades.

The paper is divided into numbered sections and subsections, which we describe and review in order below.

Section 1. Introduction

The Introduction starts with a brief history of the most famous case of the establishment of a nonnative snake, that being the brown tree snake, *Boiga irregularis*, a colubrid species introduced in Guam. The purpose of the paper is then given as to model " . . . the risk associated with boas, pythons and relatives as potential invasive species in the continental United States."

A discussion follows that understandably argues that boas and pythons warrant this investigation. We offer the following summary.

There is a general review of the factors that might predispose boas and pythons to become invasive species. There is a brief overview of the classification and distribution of boas and pythons. Reed then details some aspects of the pet trade, emphasizing the numbers of boas and pythons that annually are imported.

Then follows a general discussion of factors of reproduction that could predispose snakes in general to become established and invasive. Some factors, such as high fecundity, are characteristic of some of the species in this paper; other boas and pythons have low fecundity. Another factor, sperm storage, is undoubtedly a beneficial trait for an invasive snake species, but nothing like the abilities of the brown tree snake is known in boas and pythons. Similarly, parthenogenesis could be a benefit, and has been reported in a Burmese python; we note that it is an extraordinarily rare event and is unknown in other boas or pythons. Fast growth – early maturation is another positive factor for several species, but is dependent on other environmental factors; not all boas and pythons have this potential.

Reed mentions climate as an important predictor of invasion. He stresses that not all boas and pythons are entirely tropical. For example, he identifies carpet pythons, *Morelia spilota*, as a species that exists in temperate climates. In nature the species ranges from near-equatorial tropics in New Guinea to temperate southern Australia to about 37°S latitude. There is the unstated implication that carpet pythons might be able to survive at 37°N latitude (about the latitude of Nashville or Las Vegas).

We point out that a problem with this example is that essentially all carpet pythons in the United States are descended from populations in the tropics from 7 to 20°S latitude. In the northern hemisphere, this latitude range would be from northern Colombia to Veracruz, Mexico.

There is a small captive U.S. population of diamond pythons, *Morelia spilota spilota*, probably the most temperate-adapted of all pythons. There are probably fewer than 100 animals (our estimate). Imports and exports are essentially nonexistent; these are valued and rare snakes and they have never been found in the wild in this country. In fact, this last sentence applies to the more common carpet pythons, as well.

Habitat preference is next identified as a predictor of invasive risk. Reed references the work of Madsen and Shine (1996, 1999) on water pythons (*Liasis fuscus*). He cautions that water pythons might be able to survive in the extensive swamps and marshes of the American south in a manner similar to what was described by Madsen and Shine at Fogg Dam, the study site for the above-referenced papers.

The population of water pythons at Fogg Dam is the densest known population of pythons in the world; in fact it is the densest known population of vertebrate predators ever studied. Interestingly, the Fogg Dam site was created by a man-made dam; it is not a naturally occurring habitat, but rather the consequence of extensive habitat and ecological disturbance.

Fogg Dam is at 12°S latitude, and the huge shallow lake formed by the seasonal monsoon rains becomes a cracked mud flat for seven months of the year. There is no exactly similar habitat in this country; the only place even remotely comparable to Fogg Dam is the Everglades, but the climate and the water temperature are both significantly cooler. Interestingly, there is no further discussion of Madsen and Shine (1999), a study of how python nest sites even a few degrees cooler than optimum results in sharply increased mortality of breeding females and a significant reduction in hatching success. We question why this important and relevant result was not considered in Reed's study when apparently the author had the paper in hand.

Reed ends the introduction with vague statements on the dangers of imported parasites and pathogens, but as the primary example cites how human activity and the pet trade have spread chytrid fungi that affect toads and frogs—a story that has no bearing on the issues in this paper.

Section 2. Methods

Subsection 2.1 is a discussion on how the 23 taxa used in the risk analysis were chosen. Reed arbitrarily chose to concentrate on terrestrial or arboreal species. Only species for which more than 100 individuals had been imported during the 12-year period 1989–2000 were selected. Reed's Table I lists the 23 species selected, and the total numbers of each that were imported during that period.

Reed comments that there are little or no applicable data available from studies of any of the species in nature. He chose not to use data based on captive populations. He states "In the absence of adequate data for the majority of species, therefore I used body size and fecundity as factors in my analyses, as follows."

Reed uses maximum total length of each species for the value of body size in his analyses. He uses the highest known reproductive output as the value for fecundity for each species in the analyses.

To summarize the climatic profiles of the native ranges of each species, Reed uses data collected for each species based on the maximal known latitude and the maximal reported elevation for each species. It is stated that this is to calculate the coolest mean temperatures likely to be experienced by a species.

The highly biased filters placed on the data create a skewed profile based on the most extreme and aberrant values known for each species. Were Reed doing a similar analysis of primates, the value representing human body size would be 272 cm in height (107.1 inches). The values for fecundity would be 69 offspring for one female, in excess of 850 offspring for one male. We are not certain if the climatic profile for our species would be the South Pole or the top of Mount Everest. Do we need to comment further on the relevancy of the data in Reed's analyses?

Section 2.2 is a brief explanation of the source for the total numbers of individuals that were imported during the 12-year period of 1989 through 2000. The data were taken from the Law Enforcement Management Information System (LEMIS). Also, a factor in the risk analyses is the average economic value of an individual of each of the species. This datum was derived from the declared values of the imported animals in the LEMIS database, which has now been determined to have errors and be inappropriate for certain types of data analysis (Reaser and Waugh, 2007). In some cases—for example, ball pythons and boas—the values in the LEMIS database reflect wholesale prices for the purchases of large numbers of animals and are not in any way representative of the accepted values of those animals in the marketplace. Placing a contrived low value on these animals creates a strong bias against these species in the analyses that follow.

Section 2.3 lists the six predictions made by Reed on which his "quantitative model" is based. The "predictions" are actually assumptions, and there is no attempt to prove or disprove the validity of each. They seem, for the most part, to be logical or obvious statements, but they are not based on published information or experimentation, and are either untested or untestable hypotheses.

The assumptions are as follows, our comments are in brackets:

A. *Wild caught imports present a greater risk as an invasive species*. [We would agree that it seems likely that a wild-caught adult animal might have a better chance to survive if released than would a captive-raised adult animal, but we are not aware of any research with snakes that supports this supposition. In fact, a significant percentage of imports are animals that are captive-hatched and captive-born. We do not assume that these animals have any greater ability to survive outside of captivity than the already present captive populations. Neither do they have increased loads of internal or external parasites.]

B. *Species commanding high prices in the pet trade present a lower risk as invasive species*. [We observe that, based on the available data, they present zero risk. This is an important insight on the part of Reed. It follows that if a surcharge in the form of a tariff was placed on all imported reptiles, so that the minimum value of every imported reptile was equal or greater than $20, perhaps $30, then all imported animals would present minimal or no risk for invasion. It is the importation of large numbers of "cheap" reptiles that creates the greatest risk that they will be released or escaped into the wild.]

C. *Species that are imported in high numbers present a greater risk as invasive species*. [Maybe, but based on the fact that none of the total number of animals that were imported during 1989–2000, as reported in subsection 3.1 of this paper, became invasive during that period or since to the present, then the value for actual observed risk is zero. It is our opinion that any greater risk posed by species imported in high numbers comes from that fact that these are the "cheap" species; they have less value to importers, distributors, and eventually to owners. Again, we propose that the solution is to regulate through tariffs the minimum value for imported reptiles.]

D. *Species of larger body sizes present a greater risk as invasive species*. [We would dispute this statement as conjecture not borne out in observation or reason. Even Reed states "Of all the predictions listed here, this statement is perhaps the most debatable… " While this might be true for ornamental fish, it is generally true that as pythons and boas attain larger sizes and sexual maturity they have greater value. We propose that there are ecological and climatic reasons why large species do not naturally occur in the continental United States. It is our observation that across the United States, the average sizes of large native species such as bullsnakes, indigos, eastern diamondback rattlesnakes and western diamondback rattlesnakes are decreasing.]

E. *Species of higher fecundities present a greater risk as invasive species*. [Reed states "all things being equal . . . " but in fact all things are not equal. In the absence of data on the rate of reproduction or the reproductive life span of any of these species, and the survival rate of offspring, this assumption is baseless. In most cases, species with high fecundity are known to have offspring with low rates of survival. We realize that Reed here may be basing this assumption on propagule pressure theory—that for each species there is a minimum number of individuals necessary to establish a population, and that high fecundity increases the odds that that number will be equaled. However, so far as we can find, there simply is nothing published or proven with regard to the establishment of reptiles in a novel environment. For the purposes of these analyses, it is our opinion that the use of the maximum reproductive output as the value for fecundity rather than average annual output completely invalidates this assumption.]

F. *Species with a greater range of climatic tolerances present a greater risk as invasive species*. [This assumption contradicts one of the most basic tenets of ecology, that individuals of a population are adapted to particular selective pressures in their environment. For example, the species *Boa constrictor* occurs from northern Argentina to the Amazon Basin and on to the Sonoran desert of northwestern Mexico and Tamaulipan thorn scrub of northeastern Mexico. Reed's assumption would predict that because *Boa constrictor* can be found in a wide range of habitats, elevations and climates, it presents a greater risk as an invasive species because it is so adaptable. In fact, this is false. Were such an assumption true, then it would follow that a boa from the Sonoran desert would thrive in the Amazon Basin or in Patagonia. This seems unlikely, and it is without any basis in experiment or in the literature. In our opinion, there is no boa that will thrive throughout the range of boas, just as there is no species of boa or python that is such a generalist as to be able to colonize any more than a small area that happens to match its particular genetic and behavioral adaptations.]

Reed's Table II lists for each species the values of the variables that were used in his risk-assessment analyses. In the following subsections, Reed defines the equations he used to perform three different risk analyses.

In subsection 2.3.1, the following formula is used to estimate T, the relative risk associated with international trade in live snakes:

$T = \%WC \times (\text{Imports}/\text{Value})$

where:

%WC = percent of imported snakes declared as wild-caught in the LEMIS database;
Imports = mean number of animals imported annually; and
Value = the average declared value (in US$) per imported animal.

In subsection 2.3.2 the following formula is used to model E, the risk from ecological variables:

$E = \text{Fecund} + \text{TL} - \text{Temp}$

where:

Fecund = maximum known number of offspring in a single reproductive bout;
TL = total length (m) of the largest reported individual; and
Temp = minimum temperature (°C) for persistence, as calculated by Reed based on the maximum elevation and maximum latitude at which the species is known to occur.

In subsection 2.3.3 the following formula is used to model risk using what Reed terms a "synthetic index." By combining values from the first two analyses, Reed derived the following equation: $R = T + E$, where "R" equals the overall relative risk of establishment.

In subsection 2.3.4, Reed describes the data treatment. All variables were standardized on a scale of 0 to 1. After this transformation, the value of 1 was added to each variable, so that no variable in the analyses would have a value of 0.

We make the following observations on the risk analyses:

1. As discussed, the data set is skewed to the point of being nonsensical.

2. The six assumptions on which the risk assessment is based are untested or untestable hypotheses. We feel that there are significant problems performing any analyses based on variables created from these assumptions. We do not feel that Reed adequately explained or defended the bases for each of the assumptions.

3. The equations with which the risk analyses were performed are imaginary constructs—there is no argument or proof offered to explain any basis for a second level of assumption that there is a quantifiable relationship, mathematical or otherwise, between any values used in the analyses. This is personal opinion disguised as science by mathematical equations.

4. The treatment of the data is incorrect. As described in subsection 2.3.4, by adding the value of 1 to each variable after being "standardized," the mathematical relationships between some variables are arbitrarily changed. For example, in the formula in subsection 2.3.1, the standardized variable for "imports/value" might be $.4/.6 = .67$, which is a significantly different value after 1 is added to the numerator and denominator, creating $1.4/1.6 = .875$.

5. The analyses do not indicate any actual potential for the overall risk of a species to become invasive. Rather the methodology rates the relative risk of a species in comparison to the other species in the analyses. For example, in the analysis based on ecological variables, a carpet python, *Morelia spilota*, generates a considerably greater risk value than a vine boa, *Epicrates gracilis*; that being interpreted as a prediction that the carpet python has a greater relative risk of becoming an invasive species compared to the vine boa—however, the values generated are not predictive of the actual potential or fitness of either species to be able to establish outside their natural range, rather the results of the analyses only compare the relative differences between the species in the analyses. The species may vary greatly in their comparisons to each other, but the species with the very highest risk values may actually have no ability whatsoever to establish outside their ranges or inside the continental boundaries of the United States.

Section 3. Results and Discussion

The entire section is conversational in tone. The section includes Tables III and IV. Table III lists for each species the three values generated by the risk assessment analyses. Table IV comprises three columns, each containing the list of species; each column represents one of the analyses, and the names of the species are sorted in the column according to their ranking in that particular analysis, with the species with the lowest values at the tops of the lists and the greatest values at the bottoms of the lists.

Subsection 3.1 is a general discussion of commercial trade in boas and pythons. The most important species in commerce are identified, and the numbers imported and the declared values of these species are detailed.

Reed states that during the period from which he selected his data, 1989–2000, a total of 404,177 boas, pythons and relatives were imported. This was 40 species in 17 genera. He refers to "and relatives" throughout the text, but specifically mentions only boas and pythons—we are not certain to what "relatives" he refers.

He then goes on to state that during this period, "the most important species in the import trade include *Python regius* (366,808 individuals), *Boa constrictor* (115,131 individuals), *Python reticulatus* (27,992 individuals), *Python molurus* (12,466 individuals), *Python curtus* (11,135 individuals), and *Python sebae* (8,245 individuals)." Reed notes that more than 1,000 individuals of each of six additional species were imported. These numbers for only 12 of the 40 species add to a minimum of 547,777 individuals, contradicting his stated total for all boas, pythons and relatives for the period.

Subsection 3.2 is a discussion of the risk assessment results. Subsection 3.2.1 is a discussion of the trade variables used in the data set; subsection 3.2.2 is a discussion of the ecological variables; and 3.2.3 is a discussion of the synthetic model.

Subsection 3.2 reads rather like a general text on the acquisition, maintenance and problems associated with each of the species, with some emphasis on the problems.

Subsection 3.3 is titled "The Consequences of Establishment." Subsection 3.3.1 is a discussion titled "Implications for Conservation of Species Listed under the Endangered Species Act." Here Reed emphasizes that introduced snakes might further endanger species that already are threatened or endangered. He states, "I therefore compared geographic distributions of species listed as threatened or endangered in the United States with the areas most likely to be colonized by invasive boas and pythons." Hawaii is identified as the place with the highest risk, but is dismissed as having strong laws forbidding the importation or possession of snakes. He then spends the remainder of the section discussing the possible results of boas and pythons becoming established in south Florida. He prefaces the south Florida scenario with the statement "Discussions of which species are most likely to be impacted by establishment of invasive snakes are, of course, speculative." Reed does not identify the criteria used in selecting south Florida.

Table V is a list of the vertebrate animals that are listed as threatened or endangered that are "likely" to be impacted by feral populations of boas and pythons. All but one species are restricted to south Florida and Florida Keys. At the bottom of the list the eastern indigo is identified in a separate section titled "Listed Species Likely to Experience Competition or Exposure to Pathogens from Boas, Pythons, and Relatives." According to Snow et al. (2007), one species from this list is reported to have been consumed by an introduced Burmese python (two Key Largo woodrats, *Neotoma floridana smalli*, were found in the stomach of one python.)

Subsection 3.3.2 is titled "Pathogens Associated with Imported Snakes." Not surprisingly, the first point made by Reed is that nonnative snakes may harbor pathogens that are zoonotic. In our opinion, the statistical probability of a boa or python carrying a zoonotic pathogen that actually infects any humans approaches zero. We base this statement on the fact that for the past 40 years and longer, American snake keepers have lived in close contact with a captive U.S. population of boas and pythons that has grown to 600,000–800,000 animals (our estimate), and there are essentially zero reports of disease purportedly derived from contact with those snakes. This is not a prediction; this is a fact that Reed has overlooked or ignored.

Reed states that "the best-documented zoonosis related to reptiles is salmonellosis" and cites as the reference for this statement a controversial animal-rights manifesto (Franke and Telecky, 2001). In fact, salmonellosis credited to exposure to snakes is nearly unknown (Barker and Barker, 2006). Reed then lists several genera of bacteria that have been identified as possible zoonoses in reptile species other than boas and pythons (Johnson-Delaney, 1997). Referring to possible arachnid-born zoonoses, Reed mentions the single case of Q fever that possibly was from ticks on imported ball pythons, but which was never verified (Anonymous, 1978); and the presence of West Nile virus in blood samples from U.S. native colubrid snakes (Johnson-Delaney, 1997)—neither is relevant to this discussion.

Reed turns the discussion to ticks on tortoises, specifying the dangers posed to deer and livestock from heartwater fever, a disease carried by some tick species that have been found on imported tortoises. He refers to the ban placed by USDA on tick-infested tortoises, a requirement that imported tortoises must be tick free. The point of this digression was apparently to recommend that imported boas and pythons also be required to be tick-free when imported. We are unaware of any report of heartwater fever identified in ticks found on boas and pythons.

Then, in an unexpected digression, Reed cautions that there may be a problem because exotic boa and python species in extralimital populations may have a significantly reduced parasite load compared to ambient levels observed within the natural range of the species. Apparently they can be too healthy. This startling new reason to worry is based on the work of Torchin et al. (2003). The study examined 26 taxa of invasive invertebrates and vertebrates including the cane toad, *Bufo marinus* (= *Rhinella marina*), the mourning gecko, *Lepidodactylus lugubris*, and one other unidentified reptile/amphibian species.

Section 4. Conclusion and Recommendations

We're not sure what conclusion was reached beyond the statement that this type of risk analysis used models "that incorporate some amount of ambiguity and arbitrariness."

Reed makes six general recommendations regarding imported boas and pythons. We find that we generally agree with these common sense statements, some more than others. We commend Reed for the first recommendation, being that emphasis should be made to increase the attractiveness of captive-bred snakes to potential purchasers. However, several recommendations emphasize the need for identification, treatment, and quarantine of hypothetical parasites and pathogens that potentially might arrive on pythons and boas in the future; this we consider unnecessary in consideration of the absence of any such problems during the past four decades of importation of boas and pythons.

We see no link between the recommendations that can be correlated with such analyses as were unconvincingly attempted. In our opinion, the conclusion and recommendations of this paper should be the considered as the opinion of the author, rather than the result of scientific investigation.

In the last section, "Acknowledgments," one of us [DGB] is cited as having made contributions. In fact, no criticisms or recommendations that were made, many repeated here, were incorporated into the final form of this paper.

To summarize our criticisms of this paper, it is a rambling and disjointed attempt to validate general suspicions that imported boas and pythons may become established in feral populations in the United States. As stated by Reed, "A major problem with this type of risk analysis is that it is essentially an untestable hypothesis." We point out that scientific analysis must be testable, or there is no science. In our opinion this entire paper is essentially a narrative assertion, a subjectively chosen collection of confirming anecdotes. All statements regarding any invasive risk from the 23 taxa used in the analyses should be regarded as invalid. Such recommendations as are made in this paper are the outcome of the narrative and not the result of any statistical analysis or scientific investigation.

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