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LETTER

The Illegal Wildlife Trade Is a Likely Source of Alien Species

Pablo García-Díaz[1], Joshua V. Ross[2], Andrew P. Woolnough[3], & Phillip Cassey[1]

[1] School of Biological Sciences and Centre for Conservation Science and Technology (CCoST), The University of Adelaide, North Terrace SA 5005, Australia
[2] School of Mathematical Sciences, NHMRC Centre of Research Excellence in Policy Relevant Infectious Diseases Simulation and Mathematical Modelling (PRISM2), Centre for Conservation Science and Technology (CCoST), and ARC Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS), The University of Adelaide, North Terrace SA 5005, Australia
[3] Department of Economic Development, Jobs, Transport and Resources, 475–485 Mickleham Road, Attwood VIC 3049, Australia

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Correspondence
Pablo García-Díaz, School of Biological Sciences and Centre for Conservation Science and Technology (CCoST), The University of Adelaide, North Terrace SA 5005, Australia.
Tel: + 61-8-8313-36066; +61-8-8313-4042;
Fax: +61 8 8313 4362.
E-mail: pablo.garciadiaz@adelaide.edu.au

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Abstract

The illegal wildlife trade is driving biodiversity declines worldwide, yet its role in transporting alien species with a high likelihood of establishment is seldom considered. We demonstrate the threat posed by the illegal reptile trade in Australia. We modeled the establishment success of alien reptiles in Australia, revealing the importance of both minimum number of release events and the body length of the species. Using our model, we screened 28 alien reptiles illegally traded in Victoria, Australia. Establishment risk varied widely across species, and a whole-pathway analysis revealed that 5 out of the 28 species (17.9%) are likely to become established if released. The global dimension of the illegal wildlife trade calls for a tight transnational collaboration, via multilateral cooperation agreements arranging the share of resources. Complementary to this, we encourage conducting campaigns to raise public awareness about the risk and legal consequences of participating in the wildlife black market.

Introduction

The illegal wildlife trade is a threat to the persistence of animal populations worldwide, mainly due to overexploitation to meet the black market demand (Rosen & Smith 2010; Patel *et al.* 2015). An additional conservation concern is the potential for the illegal trade to be a source of alien invasive species and diseases in regions receiving illicitly traded animals (Smith *et al.* 2009). Alternately, regulating the wildlife trade as a pathway for invasive species might unintentionally foster the illegal trade in wildlife. Biosecurity policies aim to prevent the establishment of self-sustaining populations of new alien species, and commonly rely on conducting risk assessments to evaluate the likelihood of establishment of alien species; with species scored as high risk being banned from importation into the jurisdiction (Leung *et al.* 2012; Keller & Springborn 2013). Unfortunately, a risk-based system that prohibits species from importation might create the perverse outcome of making those species more desirable for wildlife enthusiasts, thus promoting the illegal wildlife trade (Rivalan *et al.* 2007). The interplay between alien species and the illegal wildlife trade has been largely neglected by researchers and decision makers when addressing either the conservation issues of the illegal wildlife trade or the management of alien species.

Here, we demonstrate the important role of the illegal wildlife trade as a source for alien species (biological invasion risk, hereafter), using the case example of the black market of alien reptiles in Australia. There is an existing legal trade in pet reptiles native to Australia (Swan 2008), but alien reptiles cannot be legally imported for private

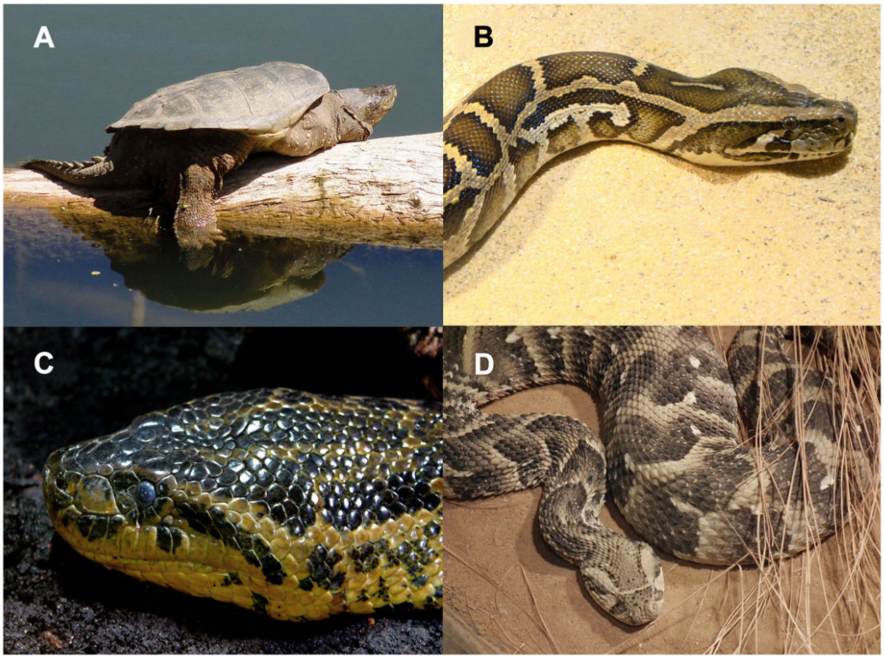

Figure 1 The four top-ranked alien reptiles illegally traded in Australia based on the risk of establishment if released at moderate propagule number ($n = 3$ releases; see Figure 3 and Table S3). (A) Common snapping turtle (*Chelydra serpentina*), mean posterior probability of establishment success in mainland Australia: 0.70 (photo source: Wikipedia user Leejcooper, licensed under Creative Commons); (B) Burmese python (*Python bivittatus*), mean posterior probability of establishment success: 0.59 (photo source: Wikipedia user Vassil, work released to the public domain); (C) Yellow anaconda (*Eunectes notaeus*), mean posterior probability of establishment success: 0.57 (photo source: Wikipedia user H. Zell, licensed under Creative Commons); (D) Puff adder (*Bitis arietans*), mean posterior probability of establishment success: 0.56 (photo source: Wikipedia user 4028mdk09, licensed under Creative Commons).

trade (Department of Environment, Government of Australia: https://www.environment.gov.au/biodiversity/wildlife-trade/exotics). Nevertheless, since 1999 alien reptiles are the group of vertebrates most commonly intercepted at the border, and by onshore Australian biosecurity agencies (Henderson *et al.* 2011). An exceptional record of illegal alien reptiles has been maintained by one mainland Australian State, Victoria. This record was generated during a confiscation campaign, deployed as an amnesty for people to surrender alien species to authorities, and a concerted policing effort to seize alien species; over the period 1999-2012 (Figure 1). The intensiveness of the campaign, and its long-term deployment (13 years) offers a rare snapshot of the wildlife black market and provides us with the unique opportunity to assess the biological invasion risk posed by the illegal trade in alien reptiles.

We conducted a two-stage process to evaluate the biological invasion risk of illegal alien reptiles. First, we developed and tested a predictive model for the establishment success of introduced reptile species in Australia. Second, we used our predictive model to screen 28 species that have been detected by the Victorian Government as being traded illegally within the jurisdiction. We evaluated the biological invasion risk posed by the black market pathway as a whole (i.e., how many species being illegally traded would likely become established if released?), and for each of the species traded (i.e., what is the likelihood of establishment success of a traded species if released?).

Methods

Data

We gathered information on: (1) the identity of introduced reptile species into mainland Australia (the main continental landmass and Tasmania) and Australian island territories (Christmas Island, Cocos [Keeling] Islands, Lord Howe Island, and Norfolk Island) and (2) whether these species are established or not, from sources including compilations on introduced reptiles globally and regionally (Kraus 2009; Henderson *et al.* 2011) and detection data provided by the Australian Government Department of Agriculture and Water Resources. We complemented these data sources with information obtained from a comprehensive literature review and from web pages reporting missing pets (see Database S1 for

Table 1 Definitions and summary statistics for the six covariates used for modeling establishment success of introduced reptiles in Australia and external Territories

Covariate	Definition and transformation	Summary statistics Mean ± SD (Range)
Propagule number	Minimum number of independent release events ($\log_{10}$)	Turtles ($n = 13$): 0.21 ± 0.30 (0.00-0.95) Squamates ($n = 58$): 0.18 ± 0.23 (0.00-0.70) Total ($n = 72$): 0.18 ± 0.24 (0.00-0.95)
Body length	Average adult body length, cm ($\log_{10}$) Turtles: carapace length Squamates: snout-vent length	Turtles ($n = 13$): 1.43 ± 0.22 (1.00-1.82) Squamates ($n = 50$): 1.39 ± 0.62 (0.60- 2.48) Total ($n = 63$): 1.40 ± 0.56 (0.60-2.48)
Fecundity per breeding season	Number of eggs per clutch (oviparous species) Number of juveniles born per season (viviparous) (Squared root)	Turtles ($n = 13$): 3.32 ± 0.81 (2.45-5.48) Squamates ($n = 50$): 2.51 ± 1.19 (1.00-4.90) Total ($n = 63$): 2.67 ± 1.6 (1.00-5.48)
Number of congeneric species	Total number of species of the same genus present in Australia ($\log_{10} + 1$)	Turtles ($n = 13$): 0.38 ± 0.40 (0.00-0.85) Squamates ($n = 58$): 0.62 ± 0.63 (0.00-2.06) Total ($n = 72$): 0.57 ± 0.60 (0.00-2.06)
Preferred body temperature	Average body temperature during activity bouts (ºC)	Turtles ($n = 7$): 26.19 ± 5.11 (21.80-37.00) Squamates ($n = 41$): 31.73 ± 3.05 (22.50-38.10) Total ($n = 48$): 31.01 ± 3.82 (21.80-31.80)
Area	Area of the region, km^2/10,000 ($\log_{10}$)	Mainland Australia: 2.89 Christmas Island: -1.87 Cocos (Keeling) Islands: -2.85 Lord Howe Island: -2.84 Norfolk Island: -2.46

Differences in sample sizes are because propagule number and the number of congeneric species vary across regions and alien species, whereas length and fecundity are species-specific covariates. Preferred body temperature was not a covariate in the model, but rather it was used to calculate the absolute thermal safety margin. However, as there were missing data for body temperatures (15 species with missing data), we illustrate here the distribution for the species for which we had data, and which we used for the Bayesian imputation procedures. Information sources are provided in Table S1.

full details). An introduced species was defined as one that has been released, or has escaped into the wild, in an area outside its native range (Blackburn *et al.* 2011). Our definition of introduced species encompasses both species whose native range does not include any part of jurisdictional Australia (alien species) and species whose native range includes part of jurisdictional Australia, but that have been introduced to other parts of the country not included within the limits of their native range (i.e., domestic exotic species; Guo & Ricklefs 2010). We considered a species as established if it has been present for over 10 years in the wild and has been reported as breeding (Blackburn *et al.* 2011). The final data set contained 71 species-by-region (mainland/islands) records of 63 reptile species introduced anywhere in Australia, and their invasive status in the region (Database S1); between 1840 and 2005. Sixty species have been introduced to mainland Australia, five to Christmas Island, four to Cocos (Keeling) Islands, one to Lord Howe Island, and one to Norfolk Island (11 reptile species introduced to islands). Species introduced to mainland Australia belong to two extant reptile Orders: Testudines (turtles and tortoises; 13 species) and Squamata (lizards and snakes; 47 species), whereas all species introduced to islands are squamates. There was no information available on the establishment success of 3 of the 63 (5%) introduced species on the mainland, all of them domestic exotic species (namely, *Elseya dentata* [Gray 1863], *Elusor macrurus* [Cann & Legger 1994], and *Gehyra dubia* [Mackleay 1877]). We treated the establishment success of these species as missing data.

For the 71 species-by-region records, we recorded six covariates for modeling the establishment success of introduced reptiles in Australia. Our choice of covariates was informed by existing knowledge of the factors related to the establishment success of introduced reptiles (Bomford *et al.* 2009; Fujisaki *et al.* 2010; Van Wilgen & Richardson 2012; Mahoney *et al.* 2014; García-Díaz *et al.* 2015; Tingley *et al.* 2016). The definition of the covariates, units, and transformations are provided in Table 1, and the data sources can be found in Table S1. We defined propagule number following Lockwood *et al.* (2005) as the minimum number of independent release events that have occurred regardless of the number of individuals released, for which there is no information available. The absolute thermal safety margin (aTSM) was defined following Clusella-Trullas *et al.* (2011) as the absolute difference between the species' preferred body temperature and the median average temperature of the warmest quarter in an area within 50 km of towns and cities in the region of introduction (see Text S1 for a description of methods and caveats of using aTSM values).

The Victorian Government has conducted an intensive campaign for recording, seizing, and intercepting illegal alien wildlife during the period 1999-2012 (Database S2). Thirty-three alien reptile species were identified during the campaign, but we discarded those that have already been introduced into the country, and were used for fitting our own establishment model. In total, 28 alien reptiles new to Australia were evaluated (84.9% of the 33). For these species, we also compiled information on the same covariates potentially influencing establishment success as for the introduced species (see Table S1, Text S1, and Database S2 for data and data sources).

Modeling establishment success

We modeled the probability of establishment success of introduced reptiles in Australia and the external Territories (pe_i for species i) as a function of the covariates through a regularized Bayesian logistic regression. We controlled for the potential effects of autocorrelation among taxonomic orders (Testudines vs. Squamata), the origin of the introduced reptiles (alien vs. domestic exotics), and the location of introduction (mainland vs. island) on the establishment by including an Order-specific, an origin-specific, and a location-specific intercept. The final model was defined as follows:

$$\text{logit}\,(pe_i) = \alpha_{or(i)} + \alpha_{g(i)} + \alpha_{og(i)} + \sum_{j=1}^{6} \beta_j X_{i,j} \qquad (1)$$

$$E_i \sim \text{Bernoulli}\,(pe_i) \qquad (2)$$

where $E_i \in \{0, 1\}$ is the establishment success of species i in Australia, $\alpha_{or(i)}$ represents the Order-specific intercept, $\alpha_{g(i)}$ is the location of introduction-specific intercept (mainland and island), $\alpha_{og(i)}$ is the origin-specific intercept (alien and domestic exotics), β_j are the covariate coefficients (slopes), and $X_{i,j}$, $j = 1, \ldots 6$, are the six putative covariates (Table 1). In order to obtain a Bayesian regularized model, we constructed a full model (i.e., including all the covariates in the logistic regression), and used a Laplace prior for the slopes $\sim Laplace(0,\, b)$ $b \sim Uniform(0.1,\, 2)$ (Gelman *et al.* 2013).

For the taxonomic Order-, origin-, and location-specific intercepts, we used a multivariate Normal prior, $\sim MVN(0,\, \Sigma)$, where Σ is the Order-, origin- or location-level variance-covariance matrix. We used an uninformative Wishart prior for Σ, where the variances (diagonal values) were $\sigma^2 = 100$, and the covariances (off-diagonal values) were set to zero (i.e., no autocorrelation between the levels of the intercepts). The degrees of freedom for the Wishart prior were set to two.

We ran the model using three chains, with 810,000 iterations each and with a thinning of five, discarding the first 400,000 iterations after checking for mixing and convergence of the chains. This procedure produced 246,000 draws from the posterior marginal distribution of the parameters. We conducted the Bayesian analyses using the R statistical software (R Development Core Team 2015) interface to the JAGS software (Plummer 2003; annotated script is provided in Code S1). We report the mean and 95% credible interval (CI) values from the marginal posterior distribution for each parameter.

We assessed the performance of our model in matching the recorded patterns of establishment success by calculating the area under the curve of the receiver operative characteristic curve (AUC) and the Bayesian realized residuals. In both cases, we excluded the four species with missing data for establishment success. Bayesian realizd residuals were calculated as (E_i - pe_i), and vary from -1 (predicted to establish but not recorded as established) to 1 (recorded as established but not predicted to establish), with zero indicating a perfect fit of the model (Gelman *et al.* 2013). We calculated the Bayesian realized residuals and AUC values for each iteration of the chains, and we report the means and 95% CIs.

Biological invasion risk of the illegal trade

We assessed the biological invasion risk posed by the illegal reptile trade using the full regularized model to estimate the establishment success (E_i, for species i) and the probability of establishment success (pe_i) for the illegally traded alien reptiles. We obtained posterior estimates of E_i, and pe_i for illegally traded reptiles for mainland Australia by inputting values for the covariates for each species in our model.

We evaluated the pathway-level risk by estimating the total number of the 28 alien reptiles being illegally traded that would likely become established if released (Te), by summing across all the species' establishment success values

$$Te = \sum_{i=1}^{28} E_i \qquad (3)$$

We had no information on the propagule number for the illegally traded species, given that they have never been introduced, so we performed analyses across a range of propagule number values (minimum number of release events regardless of the number of individuals), ranging from 1 to 20 releases, to represent a broad range of situations. In order to aid in the interpretation of our analyses, and to put our estimates for the probability of establishment success in context, we focused on estimates of propagule numbers of one, three, and seven

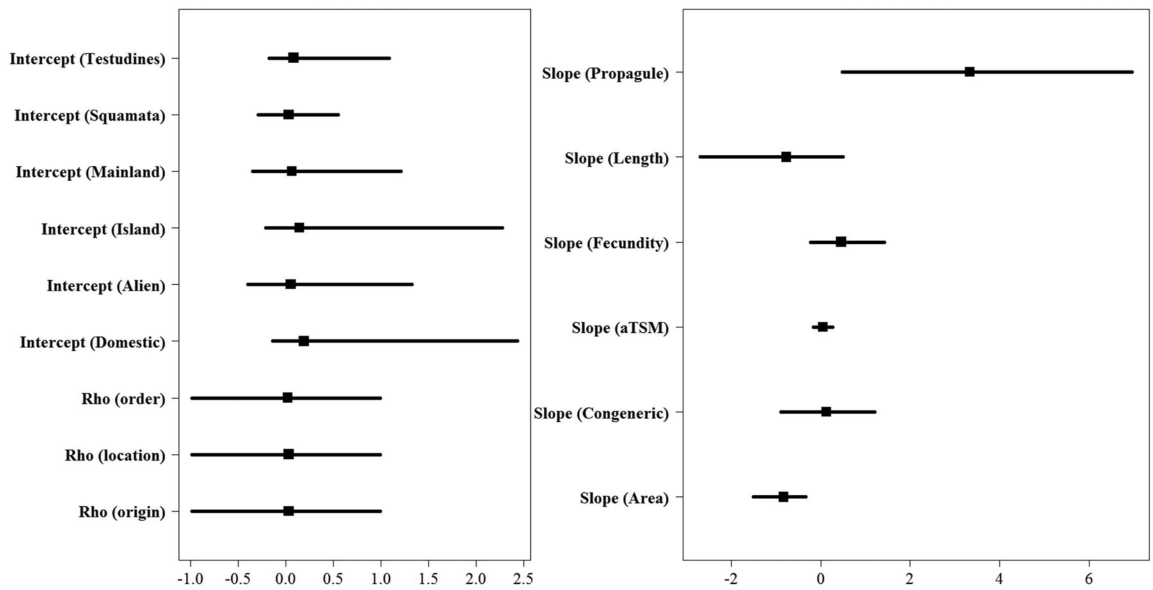

Figure 2 Posterior estimates (mean and 95% CI) of the effect sizes of the Order- origin- and location-specific intercepts and of the covariates on the establishment success of introduced reptiles in Australia. Note that the values of the covariates were transformed (see Table 1). Rho are the intercept correlation coefficients between the groups.

(low, moderate, and high propagule numbers, respectively). These corresponded to the lower 95% CI, mean, and upper 95% CI values for propagule numbers for introduced reptile species already established in mainland Australia (19 species; obtained from our database on the introduced reptiles introduced into the country).

Results

Establishment success

From 60 reptile species introduced into mainland Australia and territorial islands, and for which we had reliable information on their establishment success (out of a total of 63 species introduced), 23 have succeeded in establishing self-sustaining populations (38.3%), comprising 17 squamates (73.9% out of 23 established species) and 6 turtles (26.1%). Our regularized logistic model demonstrated good predictive performance (AUC, mean = 0.84; 95% CI: [0.74, 0.90]; Bayesian realized residual, mean = 0.003; 95%CI: [-0.07, 0.11]), and revealed, after controlling for the effects of the taxonomic Order, origin, and location, that the establishment success of introduced reptiles in Australia was driven by propagule number, body length, and the area of the region where the species has been introduced.

Propagule number positively and strongly influenced establishment success (slope coefficient mean: 3.33; 95% CI: [0.48, 6.96]), whereas both body length and the area of the region of introduction had negative effects on the establishment success of introduced reptiles (Figure 2 and Table S2). The species' fecundity had a marginally positive effect on establishment success (Figure 2)

Biological invasion risk of the illegal trade

Species-specific estimates of the probability of establishment success varied across the pool of the 28 illegal species screened (Figure 3 and Table S3). The only turtle species found in the illegal market, *Chelydra serpentina* (Linnaeus, 1758), always had the highest probabilities of establishment success of the 28 species. Alternately, two species of snakes always had the lowest probabilities of establishment success (*Micruroides euryxanthus* [Kennicott, 1860] and *Crotalus durissus* [Linnaeus 1758]).

The illegal reptile trade represents a biological invasion risk regardless of the simulated propagule number (Figure 4 and Table S4). Our findings indicate that if illegal alien reptiles were released a moderate number of times (number of releases = 3), and in the absence of further onshore management, approximately 12 of the 28 illegal species would be likely to become established (mean: 12.42; 95%CI: [4, 22]).

Discussion

The illegal trade in alien reptiles can pose genuine biological invasion risks. It is likely that the next alien reptile invader may already be present within an Australian

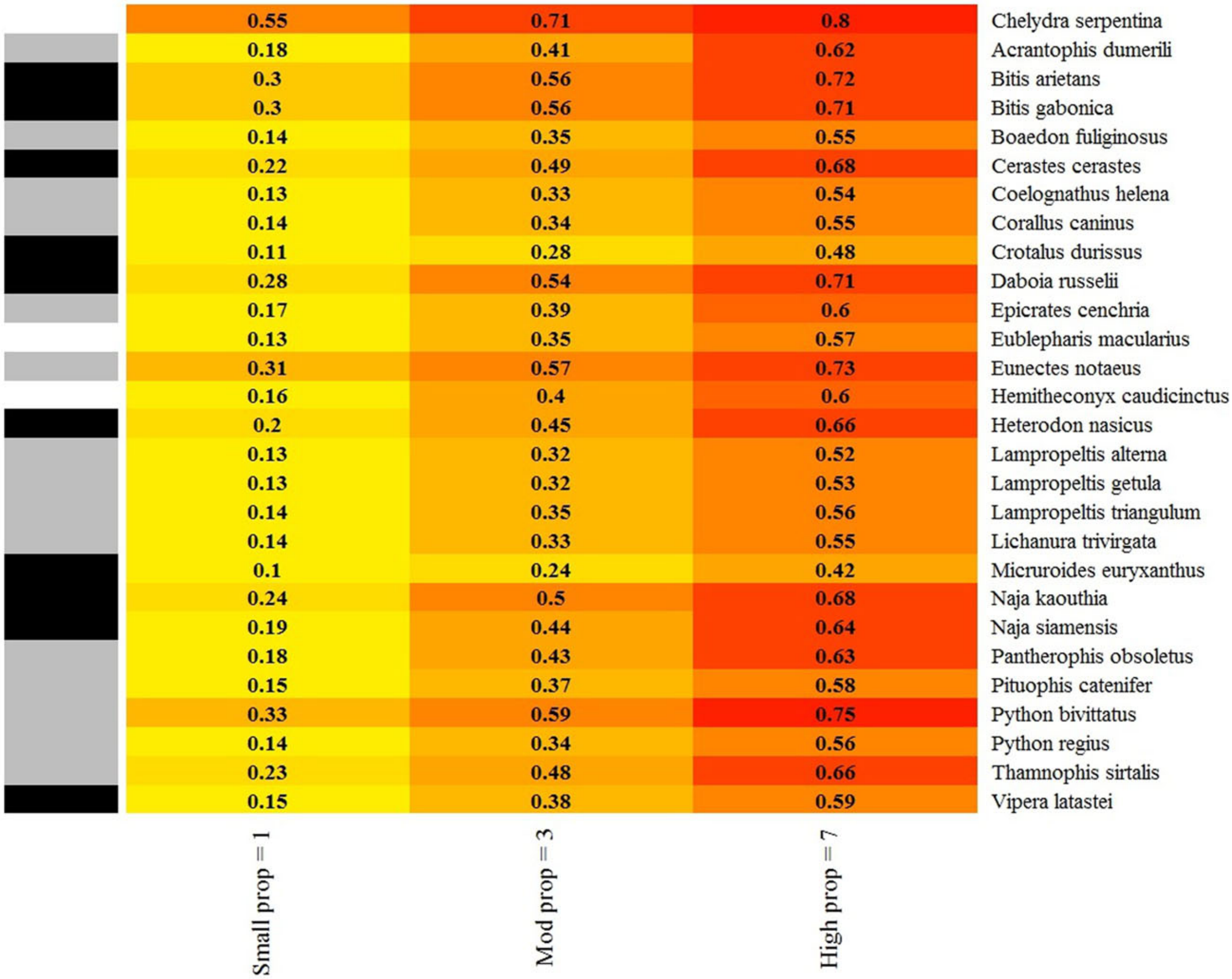

Figure 3 Mean posterior probability of establishment success in mainland Australia for 28 illegally traded alien reptile species. Values are plotted for three scenarios where the propagule number was varied (low, moderate, and high propagule number). Colors rank species by their mean probability of establishment, in a range from yellow (low risk) to red (high risk). The first species, the Common snapping turtle (*Chelydra serpentina*) is the only turtle species, and all other species belong to the order Squamata. Rows coloured to the left are snakes, and a black cell indicates venomous species. Note, to improve interpretability, propagule number values are not transformed here. Posterior estimates (mean and 95% CIs) can be found in Table S3.

jurisdiction. We found that introduced reptile species that had been released more frequently (higher propagule number) than other introduced reptiles were more likely to form a self-sustaining population in Australia. The importance of propagule number as a determinant of establishment success is a pervasive finding in invasion ecology and introduced reptiles are no exception (Bomford *et al.* 2009; Mahoney *et al.* 2014; García-Díaz *et al.* 2015). Larger reptiles were less likely to become established, an effect previously reported to influence the establishment success of introduced reptiles (Mahoney *et al.* 2014; Tingley *et al.* 2016). We suggest that the effect of body length, combined with the marginal positive effect of fecundity, upon establishment success of introduced reptiles in Australia indicates a positive relationship with fast-paced life histories (Vitt & Caldwell 2009; Herrando-Pérez *et al.* 2012).

Illegal alien reptiles, released at moderate or even low propagule numbers, could potentially become established in Australia (Figures 3 and 4). Once established, it is exceedingly difficult to control or eradicate alien reptiles, and any potential impact would likely be very difficult to manage (Engeman *et al.* 1998; Kraus 2009). It is particularly concerning that 10 out of the 28 species illegally traded are venomous snakes, which could be a serious hazard for the human and native wildlife populations if they were to become established in Australia (Figure 3 and Table S3). Thus, the illegal trade in alien

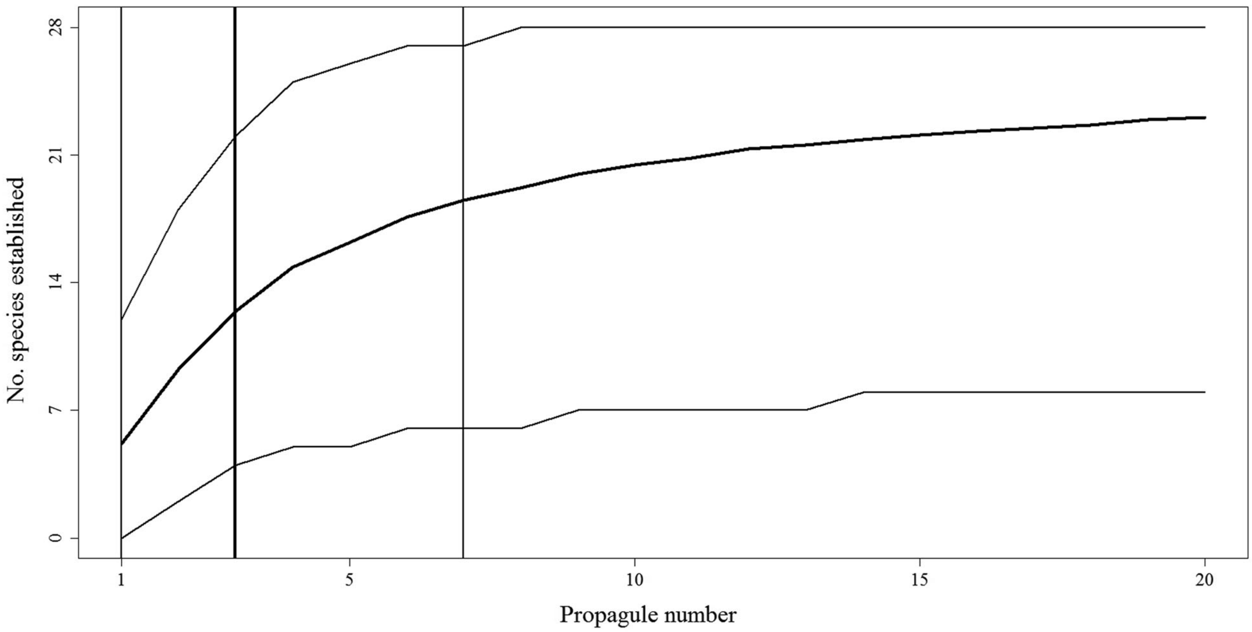

Figure 4 Posterior estimate of the total number of illegally traded alien reptiles in mainland Australia (mean and 95% CI) that would likely become established if introduced at various propagule numbers (maximum = 28 species established). Vertical lines indicate low, moderate, and high propagule numbers (one, three, and seven, respectively). Note, to improve interpretability, propagule number values are not transformed here. Posterior estimates (mean and 95% CIs) can be found in Table S4.

reptiles represents a risk in terms of both the likelihood of establishment and the high hazard for people and wildlife (Mazza *et al.* 2013).

We have focused on the biological determinants of the risk posed by the illegal wildlife trade, but human factors would clearly add to the overall risk (Perry & Farmer 2011). Particularly, we recommend more research into the dynamics of the black market and the motivations for keeping and releasing animals, which will determine the propagule number. Such research would serve to highlight potential policing targets (Perry & Farmer 2011; UNODC 2016). For the purposes of our work, we have assumed that reptile species detected in Victoria represent an adequate sample of illegal species available across Australia. Smugglers act across States indicating that our assumption is reasonable (see, e.g., this article: http://goo.gl/XiZjkl). Complementary information about the species traded in each State will produce a more nuanced image of the biological invasion risk posed by illegal reptiles in Australia. Nonetheless, we expect that such information would be difficult to obtain, and it is not clear whether it will lead to substantial changes in policies (Canessa *et al.* 2015).

Our work has important policy implications for the management of alien species and the illegal wildlife trade, closely aligned with the proposals recently made by the United Nations Office on Drugs and Crime in the *World Wildlife Crime Report* (UNODC 2016). The demand created by the illegal trade in wildlife must be tackled in concert with regulations and policy for the legal wildlife trade to ensure that both are adequately acknowledged and managed as important components of the overall biological invasion risk from the trade in wildlife. The illegal wildlife trade is an international issue and, therefore, the receiving jurisdictions should cooperate with potential exporting jurisdictions for addressing the biological invasion risks posed by the pathway (Wyatt 2013; Challender *et al.* 2015). Receiving jurisdictions could aim to identify potential source regions, and explicitly incorporate into their legislation the need for transnational cooperation including the allocation of appropriate resources for the task (Rosen & Smith 2010; Banks *et al.* 2015; Patel *et al.* 2015). It is possible that the trade in one species is legal in the exporting country but illegal in the receiving jurisdiction (UNODC 2016). In this situation, we suggest the development of multilateral agreements and frameworks to address globally the risks posed by the trade of wildlife. These agreements will provide policy and legislative certainty about the demanded roles and responsibilities of the signatory countries. In any case, all policies will also require appropriate public awareness campaigns, strongly emphasizing not only the risks posed by illegally traded animals but also the legal repercussions associated with their illegal possession (TRAFFIC 2008; Moorhouse *et al.* 2016).

Acknowledgments

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Database S1. Database of establishment success and propagule numbers (minimum number of independent releases) of introduced reptile species in Australia and external Territories.

Table S1. Definition and information sources for the six covariates included in the regularized Bayesian logistic regression for modeling the establishment success of introduced reptiles in Australia and external Territories.

Table S2. Posterior coefficient estimates obtained from the model for the establishment success of introduced reptiles in Australia and external Territories.

Table S3. Posterior predicted probability of establishment success in mainland Australia of 28 species of alien reptiles under three scenarios for propagule number (number of release events: low = 1, moderate = 3, and high = 7).

Table S4. Posterior estimates of the total number of illegally traded alien reptiles in mainland Australia that would likely become established if introduced at various propagule numbers (maximum = 28 species established).

Text S1. Procedures for calculating the absolute Temperature Safety Margin (aTSM) for models of establishment success of alien reptiles in Australia and external Territories, and for alien species illegally traded in the country.

References

Banks, N.C., Paini, D.R., Bayliss, K.L. & Hodda, M. (2015). The role of global trade and transport network topology in the human-mediated dispersal of alien species. *Ecol. Lett.*, **18**, 188-199.

Blackburn, T.M., Pyšek, P., Bacher, S. *et al.* (2011). A proposed unified framework for biological invasions. *Trends Ecol. Evol.*, **26**, 333-339.

Bomford, M., Kraus, F., Barry, S.C. & Lawrence, E. (2009). Predicting establishment success for alien reptiles and amphibians: a role for climate matching. *Biol. Invasions*, **11**, 713-724.

Canessa, S., Guillera-Arroita, G., Lahoz-Monfort, J.J. *et al.* (2015). When do we need more data? A primer on calculating the value of information for applied ecologists. *Methods Ecol. Evol.* **6**, 1219-1228.

Challender, D.W.S., Harrop, S.R. & MacMillan, D.C. (2015). Towards informed and multi-faceted wildlife trade interventions. *Glob. Ecol. Conserv.*, **3**, 129-148.

Engeman, R.M., Linnell, M.A., Pochop, P.A. & Gamboa, J. (1998). Substantial reductions of brown tree snake (*Boiga irregularis*) populations in blocks of land on Guam through operational trapping. *Int. Biodeterior. Biodegradation*, **42**, 167-171.

Fujisaki, I., Hart, K.M., Mazzotti, F.J., Rice, K.G., Snow, S. & Rochford, M. (2010). Risk assessment of potential invasiveness of exotic reptiles imported to south Florida. *Biol. Invasions*, **12**, 2585-2596.

García-Díaz, P., Ross, J.V., Ayres, C. & Cassey, P. (2015). Understanding the biological invasion risk posed by the global wildlife trade: propagule pressure drives the introduction and establishment of Nearctic turtles. *Glob. Change Biol.*, **21**, 1078-1091.

Gelman, A., Carlin, J.B., Stern, H.S. & Rubin, D.B. (2013). *Bayesian data analysis*, 3rd ed. CRC Press, Boca Raton, FL.

Guo, Q. & Ricklefs, R.E. (2010). Domestic exotics and the perception of invasibility. *Divers. Distrib.*, **16**, 1034-1039.

Henderson, W., Bomford, M. & Cassey, P. (2011). Managing the risk of exotic vertebrate incursions in Australia. *Wildlife Res.*, **38**, 501-508.

Herrando-Pérez, S., Delean, S., Brook, B.W. & Bradshaw, C.J. (2012). Strength of density feedback in census data increases from slow to fast life histories. *Ecol. Evol.*, **2**, 1922-1934.

Keller, R.P. & Springborn, M.R. (2013). Closing the screen door to new invasions. *Conserv. Lett.*, **7**, 285-292.

Kraus, F. (2009). *Alien reptiles and amphibians: a scientific compendium and analysis*. Springer, Dordrecht, Netherlands.

Leung, B., Roura-Pascual, N., Bacher, S. *et al.* (2012). TEASIng apart alien species risk assessments: a framework for best practices. *Ecol. Lett.*, **15**, 1475-1493.

Mahoney, P.J., Beard, K.H., Durso, A.M. *et al.* (2014). Introduction effort, climate matching and species traits as predictors of global establishment success in non-native reptiles. *Divers. Distrib.*, **21**, 64-74.

Mazza, G., Tricarico, E., Genovesi, P. & Gherardi, F. (2013). Biological invaders are threats to human health: an overview. *Ethol. Ecol. Evol.*, **26**, 112-129.

Moorhouse, T.P., Balaskas, M., D'Cruze, N. & Macdonald, D.W. (2016). Information could reduce consumer demand for exotic pets. *Conserv. Lett.*, http://onlinelibrary.wiley.com/doi/10.1111/conl.12270/abstract.

Patel, N.G., Rorres, C., Joly, D.O. *et al*. (2015). Quantitative methods of identifying the key nodes in the illegal wildlife trade network. *PNAS*, **112**, 7948-7953.

Perry, G. & Farmer, M. (2011). Reducing the risk of biological invasion by creating incentives for pet sellers and owners to do the right thing. *J. Herpetol.*, **45**, 134-141.

Plummer, M. (2003). JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. pp. 20-22. *Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003)*. Vienna, Austria.

R Development Core Team. (2015). *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Rivalan, P., Delmas, V., Angulo, E. *et al*. (2007). Can bans stimulate wildlife trade? *Nature*, **447**, 529-530.

Rosen, G.E. & Smith, K.F. (2010). Summarizing the evidence on the international trade in illegal wildlife. *EcoHealth*, **7**, 24-32.

Smith, K.F., Behrens, M., Schloegel, L.M., Marano, N., Burgiel, S. & Daszak, P. (2009). Reducing the risks of the wildlife trade. *Science*, **324**, 594-595.

Swan, M. (2008). *Keeping and breeding Australian reptiles*. Mike Swan Herp Books, Lilydale, Australia.

Tingley, R., Mahoney, P.J., Durso, A.M., Tallian, A.G., Morán-Ordóñez, A. & Beard, K.H. (2016). Threatened and invasive reptiles are not two sides of the same coin. *Glob. Ecol. Biogeogr.*, **25**, 1050-1060.

TRAFFIC. (2008). *What's driving the wildlife trade*? East Asia and Pacific Region Sustainable Development Department, World Bank, Washington, DC.

UNODC. (2016*). World wildlife crime report: trafficking in protected species, 2016*. pp. 1-97. United Nations Office on Drugs and Crime, United Nations, New York.

Van Wilgen, N.J. & Richardson, D.M. (2012). The roles of climate, phylogenetic relatedness, introduction effort, and reproductive traits in the establishment of non-native reptiles and amphibians. *Conserv. Biol.*, **26**, 267-277.

Vitt, L.J. & Caldwell, J.P. (2009). *Herpetology. An introductory biology of amphibians and reptiles*, 3rd ed. Academic Press, Burlington.

Wyatt, T. (2013). *Wildlife trafficking: a deconstruction of the crime, the victims, and the offenders*. Palgrave Macmillan, Hampshire.

