Human–Wildlife Interactions 6(2):204–211, Fall 2012

Examining a potential brown treesnake transport pathway: shipments from Guam

Samantha S. Kahl, 274 Ellington Plant Sciences Building, Department of Forestry, Wildlife and Fisheries, Southern Appalachian Research Branch, The University of Tennessee, Knoxville, TN 37996, USA *samantha.kahl@hotmail.com*
Scott E. Henke, 700 University Boulevard, MSC 218, Caesar Kleberg Wildlife Research Institute, Texas A&M University, Kingsville, TX 78363-8202, USA
Marc A. Hall, 233 Pangelinan Way, USDA/APHIS/Wildlife Services, Barrigada, Guam 96913, USA
Andrea R. Litt, P.O. Box 173460, Department of Ecology, Montana State University, Bozeman, MT, 59717-3460, USA
Gad Perry, Box 42125, Department of Natural Resource Management, Texas Tech University, Lubbock, TX, 79409-2125, USA
David K. Britton, UTA Box 19498, University of Texas at Arlington, U.S. Fish and Wildlife Service, Arlington, TX, 76019, USA

Abstract: Shipments of cargo and household goods have been identified as pathways for brown treesnake (*Boiga irregularis*) transport from Guam to other locations. We analyzed data regarding shipments of military household goods leaving Guam during 2006 to 2009 to identify the potential for human transport of brown treesnakes to the United States by determining when shipments most commonly occur and identifying primary receiving areas. We found that the number of shipments was highest during the months of May and June and that California receives more shipments (23% of total shipments) than any other location. Approximately 98% of shipments originated from the U.S. Navy and U.S. Air Force, with naval shipments increasing over time. Guam is currently undergoing a military buildup during which shipments are expected to increase, suggesting the need for increased vigilance and prioritization of inspection efforts.

Key words: *Boiga irregularis*, brown treesnake, Guam, human–wildlife conflicts, inspection, invasive species, pathway, shipment

Brown treesnakes (*Boiga irregularis*) arrived on the Pacific island of Guam when a snake originating from the Admiralty Islands, north of Papua New Guinea, was unloaded from a cargo ship berthed in Apra Harbor following World War II (Rodda et al. 1992). Since that time, the Brown treesnake has had numerous detrimental ecological and economic effects and has become one of the most damaging invasive species in the world (Rodda and Fritts 1992, Bradshaw et al. 2009).

Guam is a small island of approximately 544 km^2 and is the largest, southernmost island in the Mariana Islands archipelago (Central Intelligence Agency 2010). It is a major hub for both civilian and military transport, allowing snakes to hitchhike unnoticed to a wide diversity of destinations (Fritts et al. 1999). Perry and Vice (2009) assessed the potential for survival of Brown treesnake in the transportation network and predicted elevated risk of establishment on some other islands. The generalist diet and reproductive capabilities of Brown treesnake increase the possibility of successful establishment in other locations (Savidge 1988, Perry and Vice 2009, Aldridge et al. 2010, Mathies et al. 2010).

A large-scale military buildup on Guam, known as the Guam and Commonwealth of the Northern Mariana Islands (CNMI) Military Relocation, is currently underway. It will involve movement of troops from Japan and elsewhere to Guam and creation of a new berth in Guam's Apra Harbor (Department of Defense 2010). This relocation is expected to include a population increase of almost 80,000 on Guam at some points, with an increase of approximately 33,000 people over the long term (Department of Defense 2010, Government Accountability Office 2011). This represents a population increase of up to 18.5% compared to the current population estimates (Central Intelligence Agency 2010) and doubtlessly will result in a greatly increased volume of cargo shipments to and from Guam. The greater rate of transport will increase the risk of brown treesnake stowaways, with commensurate risk of the snakes' establishment elsewhere (G. Perry, Texas Tech University, unpublished data).

Few, if any, areas of the world are completely protected from the introduction of non-native species (Mack et al. 2000). Transoceanic shipping is a classic vector for invasive species introduction to the continental United States. However, every potential vector of invasive species introduction requires expert evaluation, as there is no single strategy for stopping an introduced species once it has arrived (Simberloff et al. 2005). Although Perry and Vice (2009) examined the number, frequency, and destination countries of large vessels leaving Guam, they did not look at the final destinations of those shipments. Brown treesnakes have an affinity for small, dark spaces (Pendleton 1947) and may not exit a container at its initial point of arrival. It is, therefore, important for risk assessment to determine where every package is opened, rather than just the location of where it enters a country (Figure 1).

We fear that the establishment of brown treesnakes on other islands will increase the risk of future invasion to the U.S. mainland (Perry and Vice 2009; G. Perry, Texas Tech University, unpublished data). Our goal was to define locations with high potential for brown treesnake arrival and introduction. We obtained data on inspections of outgoing military and commercial shipments from Guam, focusing on cargo and household goods which are of especially high concern (Perry and Vice 2009) and which are expected to see a particularly large increase as a result of the ongoing troop buildup on Guam. We chose to use inspections because the inspection forms provided us with the most comprehensive data collection system available for information on all shipments leaving the island, including date, destination, weight, military organization, and available information on cargo type.

Many household goods shipments from Guam enter continental United States through 1 military port in Long Beach, California. We, therefore, hypothesized that areas in the southern coastal United States receive more shipments from Guam than from other locations. However, many vessels leaving Guam carry sealed containers going to multiple final destinations. The shipments are not completely broken down until they reach their final destination. Therefore, it was necessary to examine the final destinations of those shipments, rather than just ports of entry, to examine propagule pressure (i.e., the distribution of propagule size and patterns of arrival). Analyzing the shipment dates allowed us to determine whether or not shipments increase during a certain time of year and whether the number or weight of shipments has changed over several years. Knowledge of the timing of shipments and who is responsible for those shipments (i.e., what military branch they are coming from) potentially would provide cause for supplementing inspection personnel at a certain time or military base or making general changes in inspection protocol.

Figure 1. Brown treesnake exiting a cardboard box. (*Photo courtesy C. M. Watson*)

Methods

We collected inspection data from USDA/APHIS/Wildlife Services (WS) on Guam for military shipments from January 2006 through September 2009. Data included shipment inspection date, final destination, total shipment weight, and military organization associated with the shipment. We also obtained data on the number of inspections of all military and commercial aircraft, vehicles, warehouses, and pallets that were inspected during October 2005 to September 2010 and data on all military and commercial aircraft, cargo, and household goods that left Guam without inspection during October 2005 to September 2008. To assist in identifying risk factors, we acquired data about snake captures by WS employees during spotlighting and trapping procedures (fiscal years 2007–2010), and for inspections (fiscal years 2009–2010).

Statistical analyses

We used a generalized mixed model approach (PROC MIXED; Littell et al. 2006) to examine variation in the number and weight of shipments inspected over time (by month, year, and a month × year interaction) and by military branch. We excluded shipments where the military branch was unknown; additionally, data for shipments by the U.S. Air Force in May 2007 were missing. To account for non-independence of multiple shipments to each destination over time, we treated destinations as subjects, examined 5 covariance structures (compound symmetric, first-order autoregressive, first-order autoregressive moving average, toeplitz, and variance components), and selected one based on values of Akaike's information criterion adjusted for small sample bias (AICc; Littell et al. 2006). We log-transformed the number of shipments and weight of shipments to better meet model assumptions. We presented raw means and confidence intervals for shipments and weight of shipments by month and year. We calculated raw means of shipment numbers using all potential destinations that received shipments at any time during the study period though not necessarily having received a shipment every month. We used descriptive statistics to rank final destinations, based on cumulative number of shipments and total shipment weight per destination per year, to compute sums total number of shipments by military branch and types of inspections performed and to describe missed inspections by WS employees.

Results

The 5 states that received the most shipments from Guam during 2006 to 2009 were California, Virginia, Florida, Texas, and Washington (Table 1). Of the total 1,259 destinations for shipments leaving Guam, San Diego, California, had a higher cumulative number of shipments than any other destination (Table 1).

The number ($F_{30,\ 38000}$ = 3.01, P < 0.0001) and weight ($F_{30,\ 38000}$ = 2.53, P < 0.0001) of shipments differed by month and year (year × month). The average number of shipments per month across all destinations peaked in May and June in 2006 ($\bar{x}$ = 0.23, 95% CI = 0.18–0.28 and $\bar{x}$ = 0.25, 95% CI = 0.19–0.3 shipments, respectively) and then again in May and June in 2008 (0.22, 0.17–0.27 and 0.24, 0.19–0.29, respectively). The low means for number of shipments per month were driven by the likelihood that any 1 destination having received a shipment in any particular month was fairly low. The weight of shipments also peaked in May and June in 2006 ($\bar{x}$ = 382, 95% CI = 295–465 and $\bar{x}$ = 431, 95% CI = 328–535 kg, respectively) and in 2008 (372, 276–469 and 391, 294–487 kg, respectively). There was a peak in January of 2009 in the number of shipments ($\bar{x}$ = 0.18, 95% CI = 0.13–0.23) followed by a drop in shipment number ($\bar{x}$ = 0.03, 95% CI = 0.02–0.04) and weight ($\bar{x}$ = 58, 95% CI = 33–83 kg) of shipments in September 2009.

The number and weight of shipments received at each destination differed by military branch ($F_{3,\ 263}$ = 44.00, P < 0.0001 and $F_{3,\ 263}$ = 43.41, P < 0.0001 respectively). Of the 9,339 inspections performed by WS between January 2006 and September 2009, 97% were for U.S. Navy and U.S. Air Force shipments, which tended to peak during mid-summer (Figure 2).

Between October 2005 to September 2008, 5,635 aircraft, cargo, and household goods items were scheduled for inspection, but were not inspected. Of those, 18% occurred in May (95% CI 16.9–18.9) and 10% occurred in June (95% CI: 9.6–11.2), when cargo volumes were highest (Figure 2). The largest number of missed inspections (2,167) occurred in 2007, but dropped to the lowest value the following year, with only 716 in 2008. Military and commercial items accounted for 59% and 41% of missed inspections, respectively. Most missed inspection items had stateside destinations (56%), with 27% of those going to California. A total of 33% of unintentionally missed inspections had destinations in Micronesia, 3% in Europe, and ≤1% in other countries. Although Hawaii was not ranked among the top 10 locations receiving shipments from Guam, 143 household goods shipments destined for Hawaii were inspected between January 2006 and September 2009, and a total of 233 flights, vehicles, pallets, or household goods shipments destined for Hawaii left Guam uninspected between October 2005 and September 2008 (4% of the all missed inspections). No single trend was apparent in inspections over time from 2006 to 2010 (Table 2). Household goods inspections peaked in 2010, aircraft inspections were highest in 2006, vehicle inspections peaked

Table 1. Top 15 ranked final destinations for outgoing shipment inspections performed by USDA/APHIS/Wildlife Services on Guam for January 2006 to September 2009 by total weight and cumulative number of shipments. Potential for human assisted translocation of brown treesnakes is highest in these locations.

Weight rank	Number of shipments rank	Destination	Weight (kg)					Number of shipments				
			2006	2007	2008	2009	Total	2006	2007	2008	2009	Total
1	1	San Diego, Calif.	351,046	353,048	315,479	206,566	1,226,139	262	229	208	117	816
2	2	Benicia, Calif.	203,595	102,285	192,754	102,489	601,123	115	64	106	58	343
3	3	Norfolk, Va.	118,916	140,478	139,711	43,182	442,287	73	77	71	29	250
4	4	Jacksonville, Fla.	100,017	72,153	124,004	34,456	330,630	62	47	71	18	198
5	5	San Antonio, Tex.	111,547	86,024	52,655	60,001	310,227	64	50	35	28	177
6	8	Arlington, Va.	62,392	97,817	807,785	22,271	990,265	33	44	40	9	126
7	6	Virginia Beach, Va.	70,125	93,848	49,501	38,601	252,075	53	53	40	23	169
8	7	Oak Harbor, Wash.	40,007	73,592	78,562	34,836	226,997	29	48	37	16	130
9	11	Groton, Conn.	59,965	42,751	49,056	25,174	176,946	34	21	33	12	100
10	9	Pensacola, Fla.	45,722	31,951	77,573	15,694	170,940	34	19	41	12	106
11	10	Coronado, Calif.	63,684	82,645	15,808	8,559	170,696	38	42	16	7	103
12	12	Bremerton, Wash.	44,157	69,377	43,681	10,886	168,101	34	37	28	8	97
13	15	Great Lakes, Ill.	42,524	39,168	46,925	8,664	137,281	28	25	29	5	87
14	13	Hampton, Va.	41,277	30,243	19,998	45,200	136,718	32	15	28	16	91
15	14	N. Las Vegas, Nev.	39,179	43,500	34,927	15,275	132,881	32	19	25	13	89

Table 2. Total number of inspections performed by USDA/APHIS/Wildlife Service employees on Guam for Fiscal years 2006–2010. HHG = household goods.

	Inspection type				
Fiscal year	Aircraft	HHG	Vehicles	Warehouses	Pallets
2006	6304	2294	3176	6079	127,435
2007	5746	1900	2695	5672	157,831
2008	5149	1826	3604	6189	167,379
2009	5429	1928	5064	7332	169,232
2010	5535	2620	3977	7960	164,467

Table 3. Number of brown tree snakes captured by USDA/APHIS/Wildlife Services employees during spotlighting and trapping procedures in military housing areas on Guam for Fiscal years 2007-2010.

	Year			
Procedure	2007	2008	2009	2010
Spotlighting	104	41	481	562
Trapping	2604	2639	2624	2697

in 2009, and warehouse inspections generally appeared to increase over time, but this was not part of our analysis.

Snake spotlighting in military housing on Guam by WS employees resulted in a peak of 562 brown treesnake captures; trapping in military housing resulted in a peak of 2,697 captures in 2010 (Table 3). Wildlife Services employees reported finding 7 snakes during inspections of military and commercial items in fiscal year 2009 and 2 snakes in fiscal year 2010.

Discussion

International and transoceanic shipping and trade have increased across time, and this has pushed risk assessment for invasive species to the forefront of the prevention efforts (Hulme 2009). Because successful eradication of an invasive species is rare (Mack et al. 2000), it is important to employ prevention efforts, rather than rely on post-facto responses (Bax et al. 2001). Better knowledge of where Guam's cargo goes and how it is inspected is crucial for improving biosecurity. Our study helps identify not only the ports through which material from Guam enters the United States, but also the final destinations where it is unpacked and the times of year that it is most likely to be in transit. Alarmingly, we also found that thousands of uninspected items leave Guam for the continental United States and Hawaii. Because Hawaii is already considered an at-risk location for brown treesnake introduction (Kraus and Cravalbo 2001, Rödder and Lötters 2010), we found that during our study period most shipments with Hawaiian destinations left Guam without inspection.

All items leaving Guam during the summer season (late May through mid-August) should be considered high-priority for inspection. Although many of the reasons for items leaving Guam uninspected are uncontrollable by WS, increases in the number of inspections performed, especially during the peak months of May and June and to the locations we have identified as receiving the most shipments, will likely be needed to decrease the likelihood of brown treesnake transport. Over time, spikes in shipment numbers may occur due to increases in military personnel movement between bases, but with continuous collection and analysis of shipping data, these changes can become more manageable.

The traditional model of invasive species interdiction relies solely on centralized inspection locations and organizations providing such inspections. Inspection programs on Guam and mainland ports of entry clearly have great value, as indicated by the repeated capture of brown treesnakes in military housing and cargo on Guam. Nonetheless, areas that receive

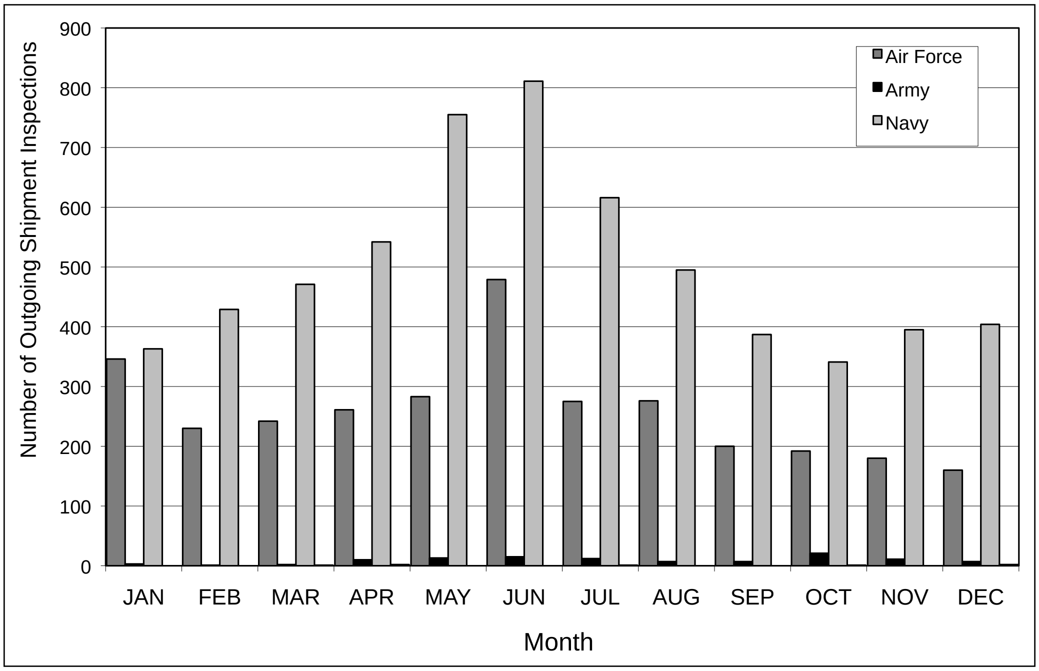

Figure 2. Number of outgoing household goods shipment inspections performed on Guam by USDA/APHIS/Wildlife Services per month from January 2006 to September 2009, broken down by military branch. Missing shipment data for the U.S. Air Force from May 2007 are not included.

substantial cargo from Guam and are at high risk of snake establishment might choose to make incoming shipments from Guam an inspection priority. We suggest that a modification of the local response model proposed by Perry and Farmer (2011) might offer a cost-effective choice. Our data highlight potential propagule pressure and points of entry for brown treesnakes, which are key components in mapping of risk in order to aid prevention (Hulme 2009). Identification of hotpots for brown treesnake arrival can be used to pinpoint locations where rapid-response members and public education are needed to increase the potential for early detection, as it is best to pursue exotics immediately following the first sighting (Bright 1999, Perry and Farmer 2011). According to our analysis, San Diego has received more than twice as many shipments as any other location, and it should, therefore, be considered a prime location for prevention efforts to take place.

We suggest that future studies examine the transportation network and include other possible origin points for brown treesnake incursion. Brown treesnakes are not the only species that may disperse through these transportation routes. For example, several exotic amphibian species have become established on Guam (Christy et al. 2007), and those, potentially, could also disperse. A broader focus would also be useful in preventing future species introductions due to the increasing human and cargo movements with the current military relocation (Wisniewski 2010).

Management implications

Most of the top destinations for shipments are located in coastal areas that have been identified as high risk for the establishment of brown treesnakes if accidently introduced (Wisniewski 2010). Shipments, flights, and cargo going to these destinations should become priority for inspection purposes, both prior to leaving Guam and again at its final destination.

Our evaluation will be useful in a more finely tuned risk assessment for brown treesnakes and can be used to assist Guam-based WS in maximizing efficiency during times, both when most shipments leave the island and other inspections at locations that receive the most shipments. Shipments, flights, and cargo going to the destinations specified in this report should become priority for inspection purposes.

Acknowledgments

We thank USDA/APHIS/Wildlife Services on Guam for assistance with data collection and access. We thank L. Brennan and M. Tewes for comments on an earlier draft of this manuscript. Funding was provided by the North America Brown Treesnake Control Team through the U.S. Fish and Wildlife Service, Caesar Kleberg Wildlife Research Institute at Texas A&M University–Kingsville, and the Hispanic Leaders in Agriculture and the Environment fellowship. This is manuscript number 12-118 of the Caesar Kleberg Wildlife Research Institute.

Literature cited

Aldridge, R. D., D. S. Siegel, A. P. Bufalino, S. S. Wisniewski, and B. C. Jellen. 2010. A multiyear comparison of the male reproductive biology of the brown treesnake (*Boiga irregularis*) from Guam and the native range. Australian Journal of Zoology 58:24–32.

Bax, N., J. T. Carlton, A. Mathews-Amos, R. L. Haedrich, F. G. Howarth, J. E. Purcell, A. Rieser, and A. Gray. 2001. The control of biological invasions in the world's oceans. Conservation Biology 15:1234–1246.

Bradshaw, C. J. A., N. S. Sodhi, and B. W. Brook. 2009. Tropical turmoil: a biodiversity tragedy in progress. Frontiers in Ecology and the Environment 7:79–87.

Bright, C. 1999. Invasive species: pathogens of globalization. Foreign Policy 116:50–64.

Central Intelligence Agency, United States of America. 2010. CIA World Factbook 2010: Australia-Oceania: Guam, <www.cia.gov/library/publications/the-world-factbook/geos/gg.html>. Accessed on July 2, 2012.

Christy, M. T., C. S. Clark, D. E. Gee II, D. Vice, D. S. Vice, M. P. Warner, C. L. Tyrrell, G. H. Rodda, and J. A. Savidge. 2007. Recent records of alien anurans on the Pacific Island of Guam. Pacific Science 61:469–483.

Department of Defense. 2010. Record of decision for Guam and CNMI military relocation including relocating marines from Okinawa, transient nuclear aircraft carrier berth, and air and missile defense task force. Department of Defense, Washington, D.C., USA.

Fritts, T. H, M. J. McCoid, and D. M. Gomez. 1999. Dispersal of snakes to extralimital islands: incidents of the brown treesnake, *Boiga irregularis*, dispersing to islands in ships and aircraft. Pages 209–223 *in* G. H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors. Problem snake management: the habu and the brown treesnake. Cornell University Press, Ithaca, New York, USA.

Government Accountability Office. 2011. Military buildup on Guam: costs and challenges in meeting construction timelines. GAO-11-459R. Washington, D.C., USA.

Hulme, P. E. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. Journal of Applied Ecology 46:10–18.

Kraus, F., and D. Cravalbo. 2001. The risk to Hawai'i from snakes. Pacific Science 55:409–417.

Littell, R. C., G. A. Milliken, W. W. Stroup, R. D. Wolfinger, and O. Schabenberger. 2006. SAS for mixed models. SAS Institute Inc., Cary, North Carolina, USA.

Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689–710.

Mathies, T., J. A. Cruz, V. A. Lance, and J. A. Savidge. 2010. Reproductive biology of male brown treesnakes (*Boiga irregularis*) on Guam. Journal of Herpetology 44:209–221.

Pendleton, R. C. 1947. A snake "den" tree on Guadalcanal Island. Herpetologica 3:189–190.

Perry, G., and M. Farmer. 2011. Reducing the risk of biological invasion by creating incentives for pet sellers and owners to do the right thing. Journal of Herpetology 45:134–141.

Perry, G., and D. Vice. 2009. Forecasting the risk of brown treesnake dispersal from Guam: a mixed transport-establishment model. Conservation Biology 23:992–1000.

Rodda, G. H., and T. H. Fritts. 1992. The impact of the introduction of the colubrid snake *Boiga irregularis* on Guam's lizards. Journal of Herpetology 26:166–174.

Rodda, G. H., T. H. Fritts, and P. J. Conry. 1992. Origin and population growth of the brown treesnake *Boiga irregularis*, on Guam. Pacific Science 46:46–57.

Rödder, D., and S. Lötters. 2010. Potential distribution of the alien invasive brown treesnake, *Boiga irregularis* (Reptilia: Colubridae). Pacific Science 64:11–22.

Savidge, J. A. 1988. Food habits of *Boiga irregu-*

laris, an introduced predator on Guam. Journal of Herpetology 22:275–282.

Simberloff, D., I. M. Parker, and P. N. Windle. 2005. Introduced species policy, management, and future research needs. Frontiers in Ecology and the Environment 3:12–20.

Walters, L. J., K. R. Brown, W. T. Stam, and J. L. Olsen. 2006. E-commerce and *Caulerpa*: unregulated dispersal of invasive species. Frontiers in Ecology and the Environment 4:75–79.

Wisniewski, S. S. 2010. Preventing brown treesnake introduction to the continental United States through education, awareness, and risk assessment modeling. Dissertation, Texas A&M University, Kingsville, Texas, USA.

SAMANTHA S. KAHL currently is a postdoctoral research associate at the University of Tennessee in Knoxville. She earned her B.A. degree from Blackburn College in 2005, her M.S. degree from Saint Louis University in 2007, and her Ph.D. degree in wildlife science from Texas A&M University–Kingsville in 2010. Some of her interests include ecological risk assessment, amphibian and reptile conservation and ecology, invasive species management, and St. Louis Cardinal's baseball.

SCOTT E. HENKE (photo unavailable) is a regents professor and chair of the Animal, Rangeland and Wildlife Sciences Department at Texas A&M University–Kingsville and a research scientist with the Caesar Kleberg Wildlife Research Institute. His research interests include wildlife disease and human–wildlife conflicts.

MARC A. HALL (photo unavailable) is a supervisory wildlife biologist with USDA/APHIS/Wildlife Services on Andersen Air Force Base on Guam.

ANDREA R. LITT is an assistant professor in the Ecology Department at Montana State University. Her primary research interests include quantifying responses of animals to human activities and disturbance and exploring the mechanisms of those responses to develop tools for restoration. She has a B.S. degree in zoology from the University of Wisconsin, an M.S. degree in wildlife ecology and conservation from the University of Florida, and a Ph.D.degree in wildlife science with a minor in statistics from the

GAD PERRY is an associate professor of conservation biology at Texas Tech University. He received his Ph.D. degree from the University of Texas–Austin and has conducted research in Costa Rica, the British Virgin Islands, Pohnpei, and Israel, among other countries. His research focuses primarily on invasive and endangered species. He has co-edited the Journal of Herpetology since 2010.

DAVID K. BRITTON is the southwest regional aquatic nuisance species coordinator for the U.S. Fish and Wildlife Service. He helps protect our nation's fisheries and conserve aquatic resources by coordinating invasive-species prevention and control strategies across state and regional boundaries. He has been a participating member of the North America Brown Tree Snake Control Team since 2007. He earned his Ph.D. degree in quantitative biology from the University of Texas–Arlington in 2005.