HHS Public Access

Author manuscript

Transbound Emerg Dis. Author manuscript; available in PMC 2018 April 01.

Published in final edited form as:

Transbound Emerg Dis. 2017 April ; 64(2): 528–537. doi:10.1111/tbed.12396.

Public health implications of changing rodent importation patterns— United States, 1999–2013

Emily W. Lankau[1,2], **Julie R. Sinclair**[3,*], **Betsy A. Schroeder**[4], **G. Gale Galland**[3], and **Nina Marano**[3]

[1]LandCow Consulting, Madison, Wisconsin, USA

[2]Department of Infectious Diseases, University of Georgia, Athens, Georgia, USA

[3]Division of Global Migration and Quarantine, Centers for Disease Control and Prevention, Atlanta, Georgia, USA

[4]Department of Biomedical Sciences and Pathobiology, Virginia-Maryland Regional College of Veterinary Medicine, Blacksburg, Virginia, USA

Summary

The United States imports a large volume of live wild and domestic animal species; these animals pose a demonstrated risk for introduction of zoonotic diseases. Rodents are imported for multiple purposes, including scientific research, zoo exhibits, and the pet trade. Current U.S. public health regulatory restrictions specific to rodent importation pertain only to those of African origin. To understand the impacts of these regulations and the potential public health risks of international rodent trade to the United States, we evaluated live rodent import records during 1999 –2013 by shipment volume and geographic origin, source (e.g., wild -caught versus captive-or commercially bred), intended purpose, and rodent taxonomy. Live rodent imports increased from 2,737 animals during 1999 to 173,761 animals during 2013. Increases in both the number and size of shipments contributed to this trend. The proportion of wild-captured imports declined from 75% during 1999 to <1% during 2013. Nearly all shipments during these years were imported for commercial purposes. Imports from Europe and other countries in North America experienced notable increases in volume. Gerbils and hamsters arriving from Europe and chinchillas, guinea pigs, and hamsters arriving from other countries in North America were predominant taxa underlying this trend . After 2003, African-origin imports became sporadic events under the federal permit process. These patterns suggest development of large -scale captive rodent breeding markets abroad for commercial sale in the United States. While the shift from wild-captured imports alleviates many conservation concerns and risks for novel disease emergence, such consolidated sourcing might elevate exposure risks for zoonotic diseases associated with high-density rodent breeding(e.g. , lymphocytic choriomeningitis or salmonellosis). A responsive border health system must periodically re-evaluate importation regulations in conjunction with key stakeholders to ensure a balance between the economic benefits of rodent trade against the potential public health risks.

*Correspondence: Julie R. Sinclair, CDC Quarantine Station – Philadelphia, Terminal A-West, 3rd floor, Philadelphia International Airport, Philadelphia, PA 19153, tel. 215 365-6405, bwg5@cdc.gov.

Keywords

animal importation; pets; public health; rodents; trade; wildlife; zoonotic diseases

Introduction

Most emerging infectious diseases are zoonotic with link s to novel and more frequent interaction/contact between humans and wildlife species (Taylor, Latham, and Woolhouse 2001, Wolfe, Dunavan, and Diamond 2007, Jones *et al.* 2008, Saez et al. 2015). The United States imports a large volume of live wild and domestic species annually, and these animals pose a demonstrated risk of zoonotic disease introduction (CDC 2003, Pavlin, Schloegel, and Daszak 2009, Smith *et al.* 2012). The U.S. Centers for Disease Control and Prevention (CDC) regulates the importation of a subset of wildlife species known to carry zoonotic diseases of highest concern for human illness, including nonhuman primates, bats, African rodents, family Viverridae (linsangs, genets, binturongs, and most civets), and small fresh water turtles , tortoises, and terrapins. Understanding these and broader patterns in wildlife importation, including species overseen by other government agencies, is critical to assess zoonotic disease risks from wildlife importation and to inform future regulations and disease surveillance strategies.

Rodents have become increasingly popular as pets (11% increase in the number of households with rodent pets between 2007 and 2012; AVMA 2014). However, these animals can be infected with a number of established zoonotic agents, including *Salmonella*, lymphocytic choriomeningitis virus, Machupo virus, *Rickettsiatyphi* (causative agent of murinetyphus), *Francisella tularensis* (causative agent of tularemia), monkeypox virus , and *Yersinia pestis* (causative agent of plague)(Merrburg, Sinleton, and Kijlestra 2009) and are considered a particularly important potential reservoir of emerging zoonotic infections due to the high taxonomic and ecological diversity of the order Rodentia and their associated viruses (Luis et al 2013). During 2003, 71 people in the United States were infected with monkeypox that originated from a shipment o f wild-caught African rodents (CDC 2003). This event resulted in a joint CDC-U.S. Food and Drug Administration (FDA)ban on importation and interstate movement of live or dead rodents of African origin except for scientific, exhibition, or educational purposes with a valid permit issued by the CDC or (for dead rodents) if rendered noninfectious by a CDC-approved method. “African rodent” is defined in these regulations as inclusive of 1) rodents caught or bred in Africa and shipped to the United States or 2) rodents shipped from any origin whose native habitat is in the African continent(42 Code of Federal Regulations [CFR] Part 71.56; U.S . Code of Federal Regulations 2015b; CDC 2015a; 21 CFR Parts 16 and 1240). In 2008, FDA repealed their portion of the ban, which restricted interstate movement, having found that CDC’s importation prohibition was sufficient to protect public health. Shipments of live African-origin rodents and products without a valid CDC permit continue to be denied entry.

What long -term impacts the importation aspect of this ban has had on rodent trade to the United States are unclear , in particular for potentially driving any shifts in shipment origins, animal acquisition sources, or species being imported. The U.S. Fish and Wildlife Service

(USFWS)maintains electronic records of wildlife species importation events. A preliminary analysis of USFWS rodent importation records from 1999–2006 suggested that rodent importation volume continued to rise after the 2003 implementation of African rodent regulations(Schroeder *et al.* 2008). This analysis indicated a shift from wild -caught species , including those of African origin, to rodent species with native ranges in Asia and South America that continued to be shipped from multiple countries outside of the African continent (Schroeder *et al.* 2008). In this manuscript, we performed a finer-scale analysis of rodent import records extending from 1999 through 2013 to more fully explore historical and recent rodent importation trends, to document the effects of the African rodent regulations on trade patterns, and to consider contemporary zoonotic disease risks associated with rodent importation to the United States.

Materials and Methods

Data Sources

We submitted a Freedom of Information Act request to the USFWS for Law Enforcement Management Information System (LEMIS) database records of all live rodent importation events occurring during 1999–2013. The LEMIS database consists of information (e.g., codes for purpose, transportation, and source) obtained from USFWS Form Number 3-177 “Declaration for Importation or Exportation of Fish or Wildlife” which is presented by importers or their agents with shipments at ports of entry to the United States(USFWS , 2013). USFWS also restricts wildlife imports to USFWS -designated ports of entry as detailed in the USFWS Form Number 3-177 filing instructions.

From the LEMIS database, we acquired information on shipment dates and number of shipment fractions. A shipment fraction is a single species portion of a shipment containing two or more rodent species listed under the same USFWS shipment identification number. Shipment fractions primarily represent different species included in the same shipment from a single exporting supplier that are listed separately in the LEMIS dataset to allow for tracking of animal entry by species. For example, if a shipment contained two hamster species and one gerbil species, it would appear in the data set under a single shipment identification number and as three separate shipment fractions (i.e., three separate rows of data) separated by species. The data included information on rodent species, quantity, source (e.g., wild-caught, captive-bred, or commercially bred), country of shipment origin, U.S. port of entry, declared purpose, and disposition of the shipment.

Individual rodent species were identified in the LEMIS data by both common name and scientific genus and species. However, for some shipment fractions only genus -or family -level identification was provided. We used the common and taxonomic names as provided in the LEMIS data to further categorize rodent imports to taxonomic family and geographic native range using taxonomy and natural history information on each species from online taxonomy resources (Wilson and Reeder (editors) 2008, Myers *et al.* 2014 , Wikipedia 2014).This was done to facilitate aggregation of the data at a higher taxonomic level to simplify presentation of taxonomic trends through time.

Countries of shipment origin (derived from a LEMIS data field titled Country Importing/Exporting)were assigned to geographic regions for categorical and spatial analysis according to World Health Organization continent categorizations provided in 1:110-m scale base maps obtained from Natural Earth (free vector and raster map data @ naturalearthdata.com), except for assigning Russia to Asia rather than Europe in order to better visually capture the physical geography of country clusters in maps. Maps were made using the Natural Earth base maps merged with LEMIS data by country of origin and continent .

The LEMIS data also included a field labeled Country Origin which upon review seemed indicative of any of the following options: 1) the actual country from which the animals were being shipped to the United States (in agreement with the Country Importing/Exporting field); 2) the animals' native habitats(in disagreement with the Country Importing/Exporting field and a situation that included a number of entries listing the Country Origin as the United States); or 3) the original source of the animals that were then shipped to and raised in another country (in disagreement with the Country Importing/Exporting field and a situation that included a number of entries listing the Country Origin as the United States). Instances of conflict between the two fields (Country Importing/Exporting and Country Origin) were identified by cross-tabulation and the entries with conflict were identified for manual visual assessment. Review of the identified entries demonstrated that both of the latter situations were relatively rare and often occurred for species native to North America and/or stated as originating in the United States and imported into the United States by zoological institutions in other countries (i.e. , Country Origin field listed United States, while Country Importing/Exporting field listed another country that matched the location of the listed exporting institution).

Data analysis

Descriptive analyses were performed to explore changes in shipment characteristics and volume and types of live rodents being imported by year and geography. Descriptive analyses, statistical tests, and graphics were performed in Microsoft Excel® 2007 (Version 12.6715.5000; Microsoft, Redmond, WA, USA)and R version 2.13.0 (R Core Development Team 2011). Data were mapped using Quantum GIS version 1.8.0 Lisboa (Quantum GIS Development Team 2013) and Natural Earth maps (Free vector and raster map data @ naturalearthdata.com).

Ethical considerations

These analyses were based on pre -existing data collected as part of the USFWS and CDC's regulatory enforcement activities without the authors having any direct contact with either importers or animals. Analyses did not include any personal identifying information for private individuals, which were excluded from the Freedom of Information Act records received from USFWS. All data are presented in aggregate to further prevent identification of specific importers or exporters.

Results

During 1999–2013, LEMIS recorded 4,435 live rodent shipment fractions imported under 2,230 unique shipment identification numbers(hereafter referred to simply as “shipments”).The total number of shipments and shipment fractions increased significantly during 1999–2013, while the number of receiving importers within the United States remained relatively constant (Figure 1a). Average shipment size (i.e., average number of rodents/shipment, Figure 1b) and the number of single exporter shipments containing a diversity of rodent species (i.e., average number of shipment fractions/shipment, Figure 1c) both increased significantly during the study period.

Live rodent imports arrived at 36 U.S. ports of entry, with over 75% of total imports for the entire study period arriving at one of three ports of entry: Dallas-Fort Worth, Texas; Chicago, Illinois; or Atlanta, Georgia(Table S1). A small portion of the shipment fractions were denied entry into the United States up on arrival. Of the 4,435 shipment fractions, 34 (0.8%)were denied entry: 4 were abandoned (54 rodents), 12 were re-exported (2,220 rodents),and 18 were seized by the federal government(70 rodents) . Shipments denied entry were distributed across years without any notable pattern related to implementation of the 2003 African-origin rodent regulation; reasons for denial of entry were not provided in the LEMIS dataset. For simplicity, this minority of shipments denied entry were included in all analyses. Thus, numbers provided throughout represent attempted rodent imports arriving at points of entry, because inclusion of this minority of shipments denied entry had negligible impact on overlying trends and interpretations for rodent imports successfully entering the United States.

During 1999–2013, 1,490,383 individual live rodents were imported, with import volume peaking at 246,04 0 rodents during 2007 (Figure 2). Live rodents were exported to the United States by 68 countries , representing all continents but Antarctica. Imports from Europe, North American countries (excluding the United States), and South Americain crease d during the study period (Figure 2, Figure S1), with the Netherlands and Czech Republic making the largest contributions to this increase (99.5% of all European imports and 90.5% of all global imports during 1999–2013; Table S2). Imports from Europe peaked during 2007 at over 240,000 live rodents; those from North America (primarily Canada and Mexico)peaked during 2011 at nearly 17,000 live rodents, and those from South America peaked during 2013 at more than 17,000 live rodents(Table S2, Figure S1). This near exponential increase in live rodent imports from Europe, North America (primarily Canada and Mexico), and South America began around 2001, two years before implementation of CDC’s African -origin rodent regulations in June of 2003 (Figure 2, Figure S1). In contrast, imports from Oceania (primarily Australia and New Zealand) were few and sporadic throughout the study period , and imports from African and Asian countries declined substantially (Table S2, Figure S1). Imports from Asian countries experienced a smooth decline during 1999–2013, but those from Africa show ed a marked decrease in 2004 (Table 1, Table S2, Figure S1). After 2001, an increasing majority of imported live rodents were obtained through captive or commercial breeding (97% of total; Figure 3a). Minority sources making up the final 3% of rodent sources include captive-bred endangered species protected under the Convention on International Trade in Endangered Species(i.e., animals

bred in captivity under CITES Resolution Conf. 10.16, CITES 2000), ranching operations, and unknown. In all years the vast majority of imported live rodents were designated for commercial purposes (99% of total; Figure 3b). Minority purposes excluded from Figure 3b included captive breeding and for personal use.

Live rodent imports during 1999–2013 were identified to 23 families, 81 genera, and 80 named species. However, 75,097 individuals (5.0% of total imports) were identified only to the genus level and 782 (0.05% of total imports)only to family . Including counts of unique genera in which species names(i.e. , specific epithets) were not provided, it is possible that more than 100 unique rodent species were imported during this period (Table S4). At the beginning of the study period (i.e., 1999), a wide diversity of species were imported in small numbers; as the study period progressed, members of the hamster, chinchilla, guinea pig, and gerbil groups constituted an increasing majority of live rodent imports(Figure 4). Hamster species (family: Cricetidae, genera: *Cricetulus* , *Cricetus*, *Mesocricetus*, and *Phodopus*), in particular, constituted nearly 85% of all imported live rodents during 1999 – 2013. These species primarily arrived from Europe and North America (primarily Canada and Mexico, Figure 5).Overall, between 1999 and 2013, there was a dramatic shift in live rodent import patterns and volume, with large increases in importation of hamsters from Europe, primarily the Netherlands and Czech Republic ;hamsters, chinchillas and guinea pigs primarily from North America (primarily Canada);and guinea pigs from South America, primarily Peru and Guyana (Figure 5).

Discussion

These live rodent importation patterns suggest a shift from low -volume niche markets for various purposes including exotic pet trade to large-scale, captive rodent breeding abroad for commercial sales in the United States, most likely to supply the pet industry . During the study period, larger and more species-diverse shipments arrived from a few countries: primarily gerbils and hamsters from Europe and guinea pigs, chinchillas, and hamsters from Canada and Mexico. The rodent species identified in these shipments overlap considerably with those listed as available for sale online by the top two pet stores by volume of market share(together constituting>50% of total pet retail market share, Brennan 2014). Rodents listed online as available for sale included chinchillas (*Chinchilla brevicaudata, Chinchilla lanigera,* or mixtures of these two species), hamsters (*Mesocricetus auratus, Crecetus grideus, Phodopus campbelli, Phodopus roborovskii*), gerbils (*Meriones unguiculatus*), guinea pigs (*Cavia porcellus*), mice (*Mus musculus, Mus musculus domesticus*),and rats (*Rattus norvegicus*). Rodents for sale were listed under a variety of common or breed names, and only one of the two retail chains provided partial or complete scientific nomenclature associated with these common names at the time these websites were reviewed. This list of species available for sale at high-volume pet stores indicates the dominant consumer interest in small mammal pets , including species identified in this study as being imported to the United States in large numbers .

A primary motivation for these analyses was to ascertain the potential economic impacts of the current rodent import restrictions on live rodent trade. These data support a conclusion that the restrictions have had minimal impact on the overall market. Even several years

before implementation of the 2003 U.S. restriction of African -origin rodent imports, live rodent imports predominantly originated from Europe and were being captive or commercially bred rather than wild caught. Despite the implementation of import restrictions in 2003, a near exponential increase in live rodent imports was observed during 2003 -2007. This increase in live rodent import volume was evident before 2003 and continued to rise smoothly until 2008, when live rodent imports experienced a declining trend lasting until 2010, with a rebound in volume during 2011–2013. These shifts in import volume may reflect both the impacts of global economic conditions and changing consumer pet rodent preferences.

In particular, the increasing rodent import trend observed over this early portion of the study period likely reflects increasing consumer demand or marketing in the United States for commercially bred rodent pets (particularly, gerbils, hamsters, guinea pigs, chinchillas, and hamsters).

The 2003 African-origin rodent import restrictions potentially eliminate d a niche market for certain live exotic species as pets (e.g., Gambian rats , porcupines). Potentially this market could have expanded with consumer demand to become a commercial captive-breeding operation rather than relying on wild-caught animals, but implementation of the African-rodent import restrictions might have precluded this potential. However, non-African continent species imports(e.g., New World squirrels and Asian ground squirrels), which might also represent a niche exotic pet market , did not demonstrate an increasing trend during the study period. Thus, while it is difficult to document any likely economic suppression resulting from restrictions on importation of African-origin rodents, these data suggest that consumer demand for, or marketing of, more traditional pet rodent species influenced rodent import trends more so than CDC’s regulatory restrictions .

Intentional illegal importation or smuggling of live African rodents is assumed to be an uncommon event because of the difficulty maintaining clandestine live animals over the long transit from Africa, limited number of direct flights from Africa to the United States, and the animals’ expected relatively low commercial value. Accordingly, studies of disease risks related to rodent smuggling focus more on the importation of bushmeat originating from African rodents or nonhuman primates rather than the importation of live animals from Africa . Attempted import, and denial of entry, of rodent bushmeat from Africa occurs with some regularity (Wyler and Shekh 2013, Bair-Brake *et al* . 2014). CDC has received reports of illegal commercial imports(i.e., items not rendered noninfectious) of intact dead African rodents or rodent materials (e.g., quills, skins, limbs) for religious or souvenir shops , whereas the only live African rodents reported recently are mice accidentally stow ed away in passenger luggage or cargo (CDC unpublished data).

However, lack of accuracy or truthfulness of reporting by importers might result in uncertainty as to the country of origin and taxonomic group of live rodents. This uncertainty poses challenges to enforcing regulations that apply not only to shipment origin but also to rodent taxa with a native range in or inclusive of portions of Africa. This issue might present in a number of ways and could allow for both unintentional and illicit regulatory breaches. Review of CDC permit records showed sporadic shipments of rodents whose taxonomy

suggested that allowing entry without a permit might not have been appropriate, notably species of gerbils, jirds, and porcupines originating from non-African countries that were imported for commercial purposes (CDC unpublished data). Many of these shipments were of unclear regulatory status because of incomplete taxonomic information or contained species that are technically covered by import restrictions because of the species' native range but are broadly considered to be domesticated because of a long history of captive breeding. Given the sporadic nature of these events and the species involved (in particular species of gerbils which are commonly sold as domestic pets), many of these breaches were most likely inadvertent events rather than intentional efforts to smuggle animals. Such inadvertent breaches likely arose from a combination of importer's lack of awareness of the species native range and the challenges faced by border inspection authorities in recognizing the wide diversity of rodent species that are covered by these restrictions, particularly when shipments arrive from a non-African country. Since species identification information is required to be provided by importers, there may also be opportunity for importers to intentionally misidentify African -origin species as a closely-related allowable species. Visual differentiation of rodent species can be challenging even for expert mammologists without close inspection of morphologyor genetic analysis.

Another limitation of these analyses rests in reliance on importers to accurately and honestly record of animal origins. For these analyses, we focused on the reported shipment origin, but it cannot be guaranteed that the reported origin was the ultimate origin (i.e., breeding site, place of capture, or most recent long-term residence) and not just the most proximate flight origin. We observed this as a potential issue in a recent analysis of dog importation patterns (Sinclair *et al.* 2014).For example, live rodents could be shipped from Africa to Europe and then to the United States as part of a multi-flight itinerary and might be reported in the LEMIS data as originating from the most recent flight origin in Europe . This misreporting by the importer could be unintentional or done with intent to illegally import (i.e., smuggle)rodents and would be difficult to detect at border entry points. Similarly, species taxonomy could be misreported for smuggling purposes as well if a similar non-African-origin species were listed in place of the true species identity. However, we did not observe any notable higher taxonomic -level replacement patterns of the most common African-origin imports before the implementations of restrictions during 2003, suggesting that the latter strategy has not been widely used for the purposes of intentional smuggling. As previously discussed, incomplete taxonomic information might be allowing sporadic imports of species with historical ranges in Africa. These results reveal the challenges of enforcing a regulation that relies not only on species identification but also on an understanding of foreign markets and trade routes before arrival in the United States as well as accurate reporting of ultimate origins of these shipments.

Conclusions

The observed limited importation of wild-captured rodents in recent years alleviates many concerns about risks of importing novel or non -endemic zoonotic diseases. However, consolidated sourcing of captive-bred rodent imports is not without potential health risks for human exposures to zoonotic disease agents associated with high-density rodent breeding, such as lymphocytic choriomeningitis or salmonellosis, during or after transit(Edison et al.

2014) . It is unclear if importation of commercially bred rodents poses any differing or unique risks to human health compared to domestic breeding of these same species, because many of the diseases of notable human health concern for rodents bred in captivity are either ubiquitous or widespread.

U.S . importation regulations must balance potential economic benefits of unrestricted rodent trade against potential public health risks. Although African rodent importation restrictions are justified by a demonstrable risk of importing monkeypox, a serious zoonotic disease not currently present in the United States (CDC 2003), further research is required to fully understand the relative public health risks from rodents procured internationally versus from animals sourced through domestic markets. Specifically of interest are source -country regulations for rodent breeding facility health and hygiene to mitigate health risks associated with high-density breeding before shipment . We are also unaware of any testing or disease monitoring that might be performed before shipment because this information is not recorded in current import records. Such information might inform considerations of limited restrictions, such as enacting enhanced health requirements for rodent importation similar to those currently in use for importation of nonhuman primates, which include importer registration and facility inspections, mandatory arrival quarantine periods, and screening requirements for arriving nonhuman primates to target specific diseases of greatest human health concerns(42 CFR Part 71.53; U.S. Code of Federal Regulations 2015a; CDC 2015b). A responsive border health system must periodically re-evaluate importation regulations in conjunction with key stakeholders to ensure that regulations balance potential economic benefits of animal trade against any potential public health risks.

Regardless of whether rodents purchased as pets are imported or domestically bred, consumers should be educated about the potential health risks associated with keeping rodents as pets and be informed about proper handling and hygiene to prevent infections. Standard disease prevention measures include thorough hand washing after cleaning up after rodents or handling rodents, supervising childrens' hand washing after any contact with rodents, and limiting contact with rodents for people who are immunocompromised or more susceptible to diseases(e.g., young children, older individuals, and pregnant women)known to be carried by domestic rodents, such as salmonellosis or lymphocytic choriomeningitis (CDC 2015c).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank Robert Mullan and Adam Langer for their contributions to this work as well as CDC quarantine station and headquarters staff for assistance with data collection. We also thank two anonymous reviewers for their comments and recommendations. The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

References

American Veterinary Medical Association (AVMA). [accessed 4 May 2015] US Pet Ownership Statistics. 2014. Available online: https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx

Bair-Brake H, Bell T, Higgins A, Bailey N, Duda M, Shapiro S, Eves HE, Marano N, Galland G. Is that a rodent in your luggage? A mixed method approach to describe bushmeat importation into the United States. Zoonoses Public Health. 2014; 61(2):97–104. Epub 2013 May 16. DOI: 10.1111/zph.12050 [PubMed: 23678947]

Brennan, A. [accessed 4 May 2015] Lucky dog: Pet owners will invest in premium products as disposable income rises. IBIS World Industry report 45391, Pet stores in the US. 2015. Available online: http://www.ibisworld.com/gosample.aspx?cid=1&rtid=101

Centers for Disease Control and Prevention (CDC). Update: Multistate outbreak of monkeypox—Illinois, Indiana, Kansas, Missouri, Ohio, and Wisconsin, 2003. Morb Mort Wkly Rep. 2003; 52:642–646.

CDC. [accessed 4 May 2015] Bringing an African Rodent into the United States. 2015a. Available at: http://www.cdc.gov/animalimportation/africanrodents.html

CDC. [accessed 4 May 2015] Bringing a monkey into the United States. 2015b. Available at: http://www.cdc.gov/animalimportation/monkeys.html

CDC. [accessed 4 May 2015] Healthy Pets, Healthy People: Pocket Pets. 2015c. Available at: http://www.cdc.gov/healthypets/pets/pocket-pets.html

Convention on International Trade in Endangered Species (CITES). [accessed 4 May 2015] CITES Resolution Conf. 10.16 (Rev.). Tenth meeting of the Conference of the Parties. 2000. Available at: http://www.cites.org/eng/res/10/10-16C15.php

Edison L, Knust B, Petersen B, Gabel J, Manning C, Drenzek C, et al. Trace -forward investigation of mice in response to lymphocytic choriomeningitis virus outbreak. Emerg Infect Dis. 2014; 20(2): 291–295. DOI: 10.3201/eid2002.130861 [PubMed: 24447898]

Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. Nature. 2008; 451:990–993. DOI: 10.1038/nature06536 [PubMed: 18288193]

Luis AD, Hayman DTS, O'Shea TJ, Cryan PM, Gilbert AT, Pulliam JRC, et al. A comparison of bats and rodents as reservoirs of zoonotic viruses: are bats special? Proc R Soc Lond [Biol]. 2013; 280:20122753. http://dx.doi.org/10.1098/rspb.2012.2753.

Merrburg BG, Singleton GR, Kijlestra A. Rodent-borne diseases and their risks for public health. Crit Rev Microbiol. 2009; 35:221–270. [PubMed: 19548807]

Myers, P., Espinosa, R., Parr, CS., Jones, T., Hammond, GS., Dewey, TA. [accessed 4 May 2015] The Animal Diversity Web. Available at http://animaldiversity.org

Pavlin BI, Schloegel LM, Daszak P. Risk of importing zoonotic diseases through wildlife trade, United States. Emerg Infect Dis. 2009; 15:1721–1725. DOI: 10.3201/eid1511.090467 [PubMed: 19891857]

Quantum GIS Development Team. [accessed 4 May 2015] Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project. 2013. Available at: http://qgis.osgeo.org

R Development Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing; Vienna, Austria: 2011. Available at: http://www.R-project.org/ [accessed 4 May 2015]

Saez AM, Weiss S, Nowak K, Lapeyre V, Zimmermann F, Düx A, et al. Investigating the zoonotic origin of the West African Ebola epidemic. EMBO Mol Med. 2015; 7:17–23.

Schroeder, B., McQuiston, J., Marquis, R., Galland, G., Marano, N. Anticipating the next monkeypox: Trends in rodent importation, 1999–2006. International Conference on Emerging Infectious Diseases; Atlanta GA. 2008. abstract

Sinclair JR, Washburn F, Fox S, Lankau EW. Dogs entering the United States from rabies endemic countries, 2011–2012. Zoonoses Public Health. 2014; Epub 22 Sept 2014. doi: 10.1111/zph.12160

Smith KM, Anthony SJ, Switzer WM, Epstein JH, Seimon T, Jai H, et al. Zoonotic viruses associated with illegally imported wildlife products. PLoS One. 2012; 7(1):e29505.doi: 10.1371/journal.pone.0029505 [PubMed: 22253731]

Taylor LH, Latham SM, Woolhouse ME. Risk factors for human disease emergence. Philos Trans R Soc Lond B Biol Sci. 2001; 356:983–989. DOI: 10.1098/rstb.2001.0888 [PubMed: 11516376]

U. S. Code of Federal Regulations (CFR). [accessed 4 May 2015] Title 21: Food and Drugs Parts 16 and 1240—Regulatory hearing before the food and drug administration and control of communicable diseases. 2003. Available at: http://www.fda.gov/OHRMS/DOCKETS/98fr/03-27557.htm

U. S. Code of Federal Regulations (CFR). [accessed 4 May 2015] Title 42: Public Health PART 71—Foreign Quarantine Subpart F—Importations §71.53 Requirements for importers of nonhuman primates. 2015. Available at: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=a9858ffc8029c02da1d3b46d4eb9dfea&n=42y1.0.1.6.59.6&r=SUBPART&ty=HTML#42:1.0.1.6.59.6.19.7

U.S. Code of Federal Regulations (CFR). [accessed 4 May 2015] Title 42: Public Health PART 71—Foreign Quarantine Subpart F—Importations §71.56 African rodents and other animals that may carry the monkeypox virus. 2015. Available at: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=a9858ffc8029c02da1d3b46d4eb9dfea&n=42y1.0.1.6.59.6&r=SUBPART&ty=HTML#42:1.0.1.6.59.6.19.7

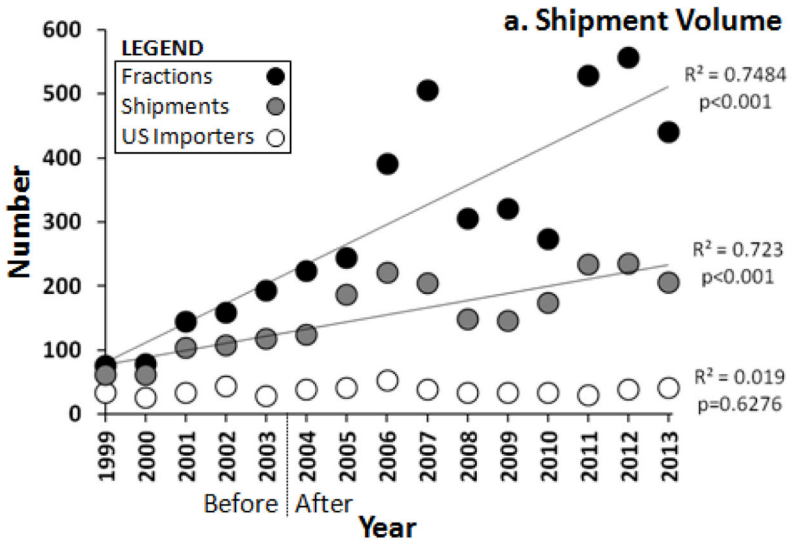
U.S. Fish and Wildlife Service. [accessed 4 May 2015] Office of Law Enforcement – Declaration for Importation or Exportation of Fish or Wildlife (Form 3-177). 2013. Available at: http://www.fws.gov/le/declaration-form-3-177.html

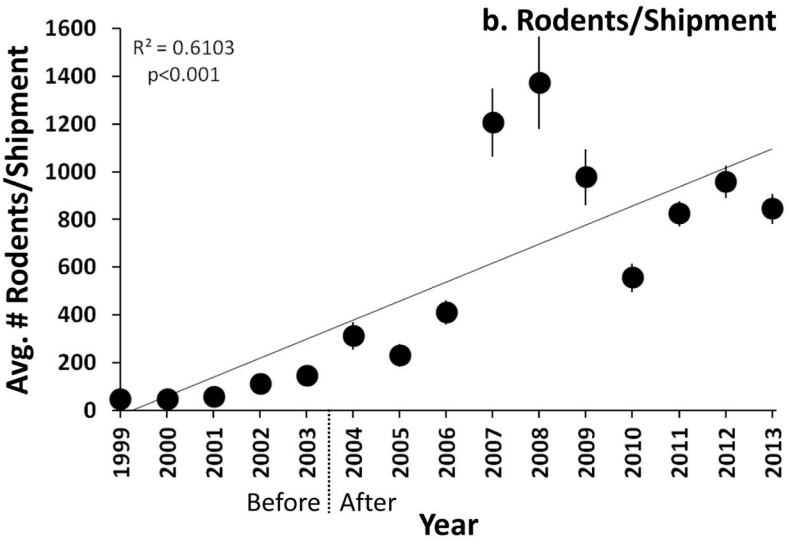
Wikipedia contributors. Rodent. Wikipedia, The Free Encyclopedia; 2014. Available at: http://en.wikipedia.org/wiki/Rodent [accessed 4 May 2015]

Wilson, DE., Reeder, DM., editors. Wilson and Reeder's Mammals of the World. 3. Smithsonian National Museum of Natural History; 2008. onlineAvailable at: http://www.vertebrates.si.edu/msw/mswcfapp/msw/index.cfm [accessed 30 April 2014]

Wolfe ND, Dunavan CP, Diamond JJ. Origins of major human infectious diseases. Nature. 2007; 447:279–283. DOI: 10.1038/nature05775 [PubMed: 17507975]

Wyler, LS., Sheihk, PA. International Illegal Trade in Wildlife: Threats and U.S. Policy. Congressional Research Service Report for Congress, RL 34395; 2013. Available at: https://www.fas.org/sgp/crs/misc/RL34395.pdf





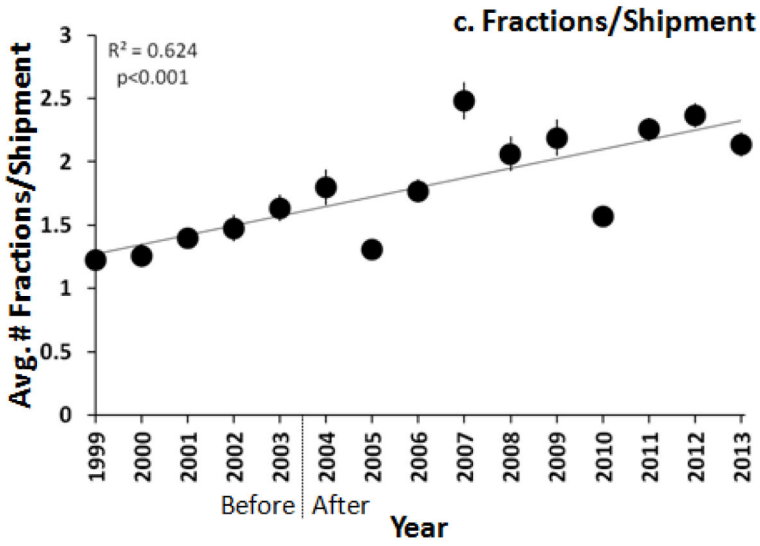


Figure 1. Shipment characteristics of annual rodent imports before and after the 2003 CDC African rodent ban — United States, 1999–2013

Figure 1 shows temporal trends in shipment volume, shipment size, and shipment species diversity (i.e., number of shipment fractions/shipments).A significant change in both the number of shipments and shipment fractions was observed, compared to a relatively constant number of receiving importers during 1999–2013 (Panel a). During this same period, shipment size increased significantly over time (a vg. number of rodents/shipment ± standard error of the mean (SEM); Pearson's correlation, Panel b) and shipment species diversity, measured by the correlation of the avg. number of shipment fractions/shipment (± SEM) to year, also increased significantly (Panel c). The dotted line included in this and subsequent figures indicates passage of restrictions on African-origin rodent importation during 2003 (marks imports received before and after this regulation change).

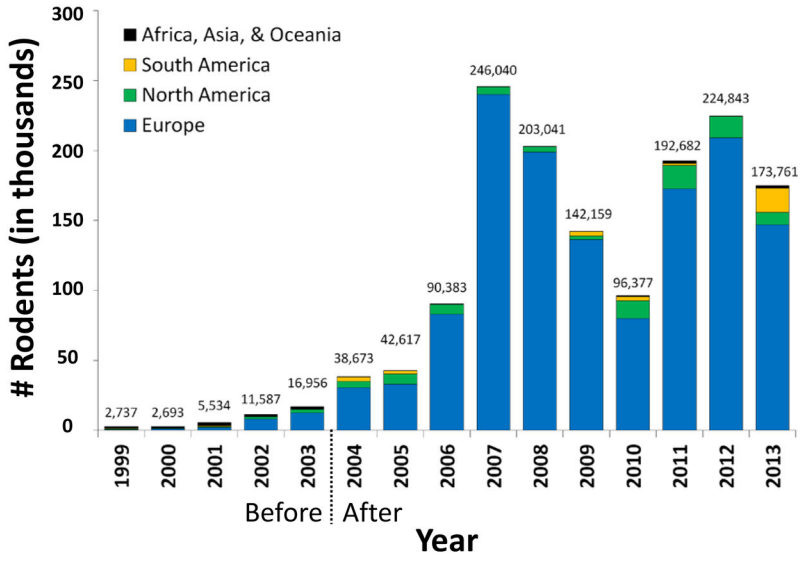


Figure 2. Annual rodent imports by geographic origin before and after the 2003 CDC African rodent ban — United States, 1999–2013

Figure 2 demonstrates an increase in total rodent import volume during 1999 –2013, primarily driven by an increased number of rodents arriving from European countries and to a lesser extent from North American countries. See also Figure S1 for demonstration of regional patterns.

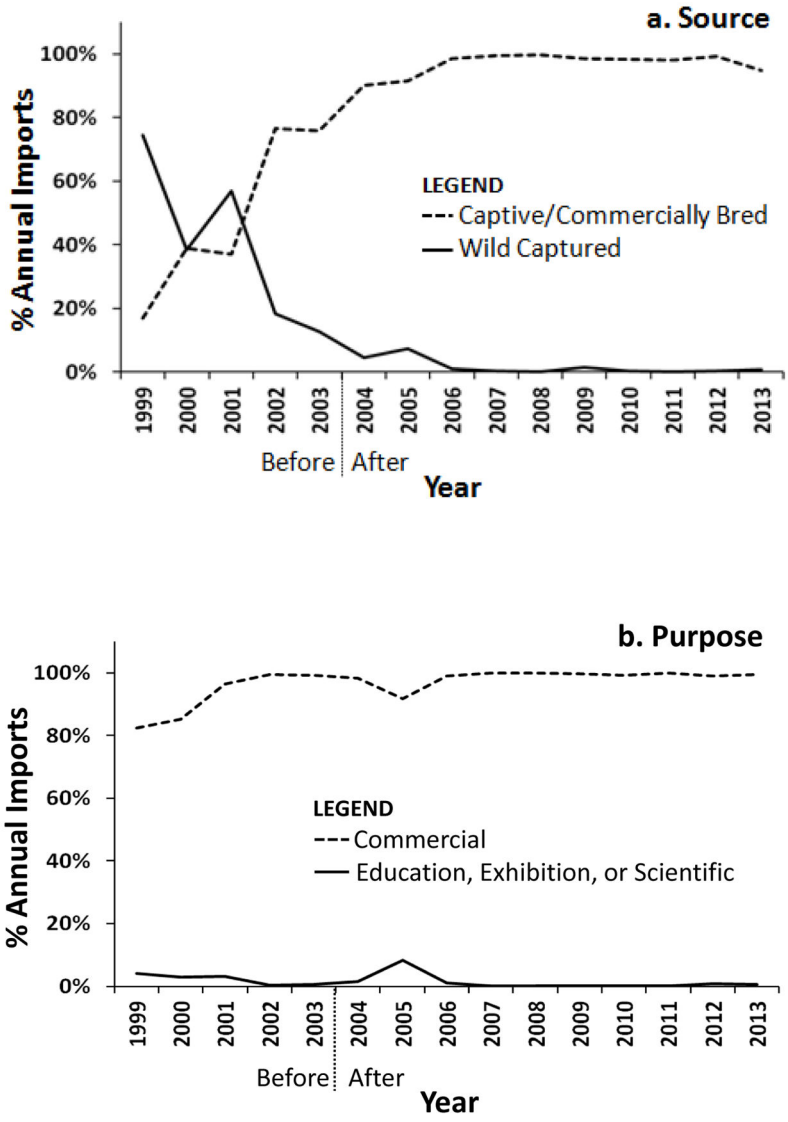


Figure 3. Annual rodent imports by source, and importation purpose before and after the 2003 CDC African rodent ban — United States, 1999–2013

Figure 3 demonstrates the increasing dominance of captive or commercial breeding as a source of rodent imports during 1999–2013 (Panel a) and of commercial purpose as the stated reason for importation (Panel b). In both panels, minority codes were excluded for simplicity of presentation. Minority sources excluded from this figure include protected under the Convention on International Trade in Endangered Species(i.e., animals bred in captivity under CITES Resolution Conf. 10.16, CITES 2000), ranching operations, and unknown. Minority purposes excluded from this figure include for captive breeding and personal use.

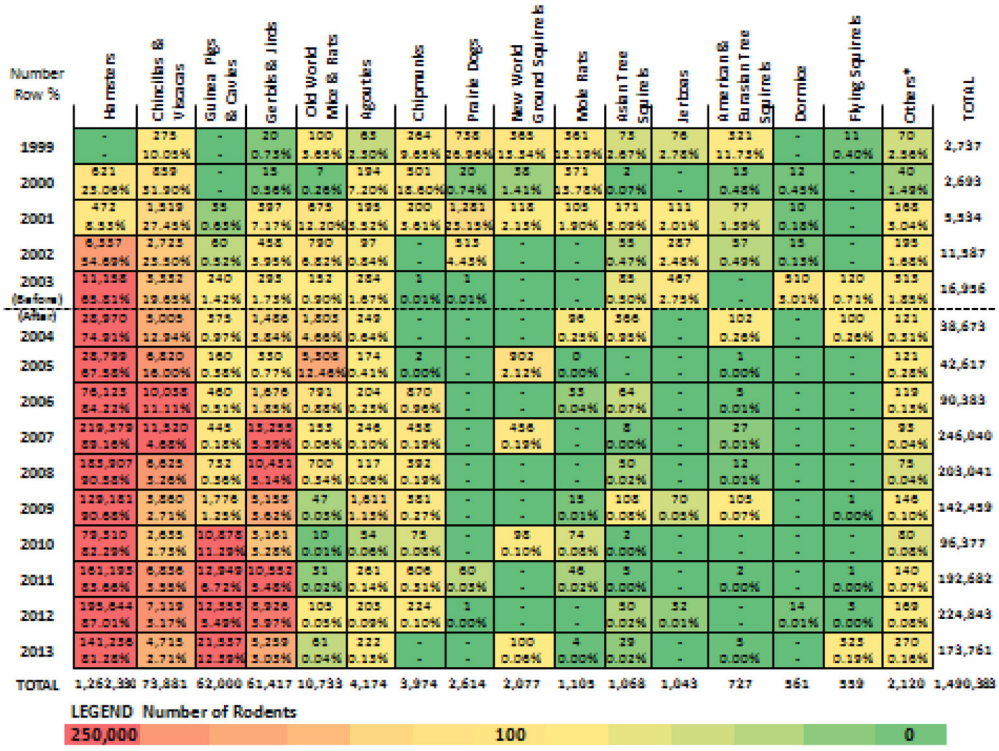


Figure 4. Annual imports by species group before and after the 2003 CDC African rodent ban — United States 1999–2013

Figure 4 summarizes changes in rodent import volume during 1999–2013 for the 15 top-ranking rodent groups (family or subfamily level). Hamster, chinchilla, gerbil, and guinea pig imports increased substantially during 1999–2013. Other rodents groups decreased or became sporadic. The “Other” category includes a variety of sporadically imported groups (see also Table S3 for a complete list of species and groups imported).

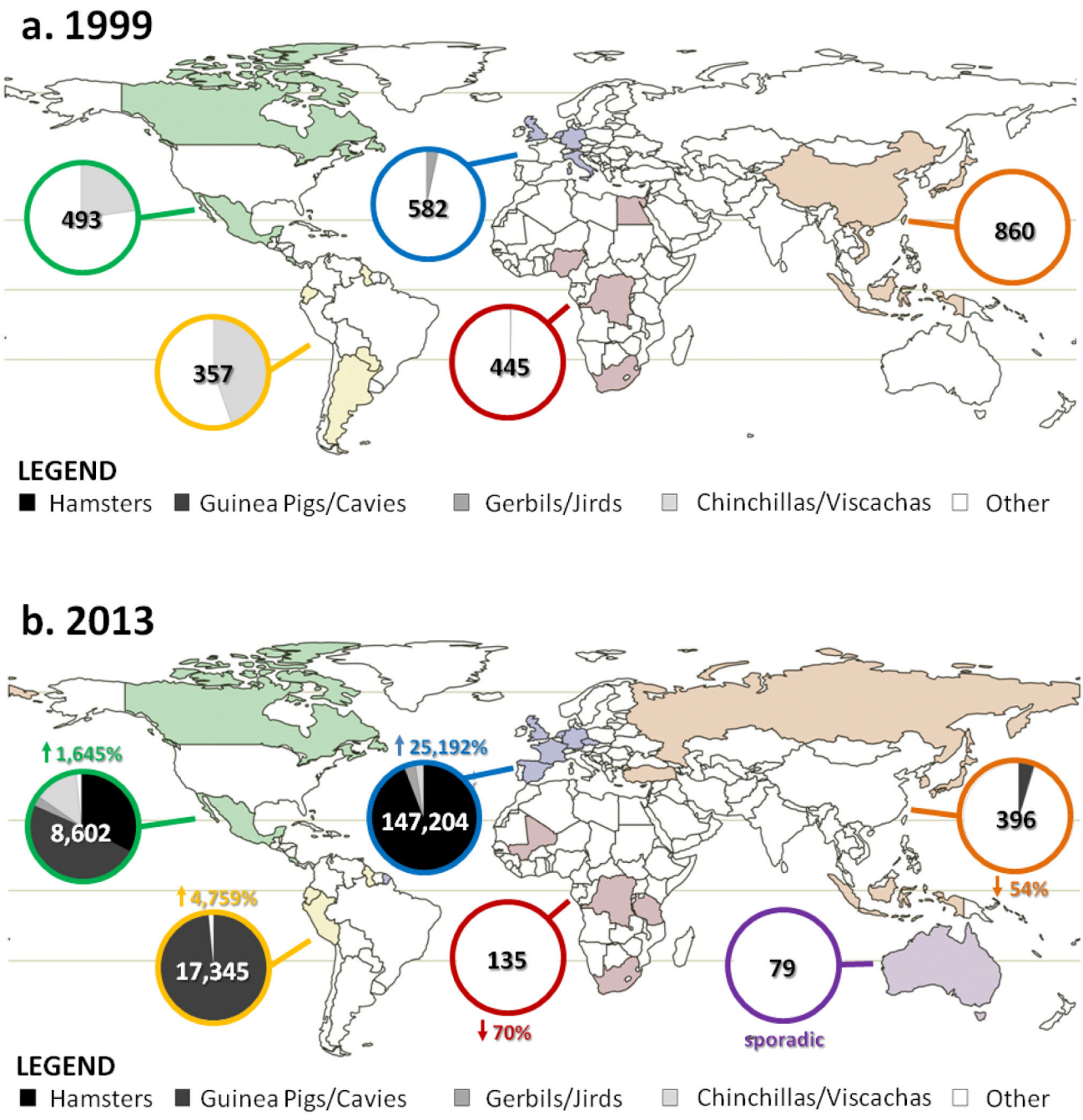


Figure 5. Comparison of U.S. rodent import volume during 1999 and 2013 by continent and rodent group

Figure 5. shows annual rodent imports by the top five species groups and continent. Total imports by continent and percent change in total imports compared to 1999 levels for each region are included with each pie chart showing relative imports by the five top-ranking species group s. Gerbils and hamsters arriving from Europe and chinchillas, guinea pigs, and hamsters arriving from North America were the predominant taxa driving large increases in rodent imports during 1999–2013 for both regions. In contrast, imports from South America were relatively sporadic during 1999 –2012 (see Figure 2 and Figure S1) but experienced a

single dramatic spike in guinea pig/cavy imports during 2013. Rodent imports from Asia and Africa experienced an overall decline during the study period.