

Research Article

The unsung success of injurious wildlife listing under the Lacey Act

Susan D. Jewell^{1,*} and Pam L. Fuller²¹U.S. Fish and Wildlife Service, 5275 Leesburg Pike, Falls Church, VA 22041, USA²U.S. Geological Survey, 7920 NW 71st Street, Gainesville, FL 32653, USAAuthor e-mails: susan_jewell@fws.gov (SDJ), pfuller@usgs.gov (PLF)

*Corresponding author

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Abstract

Previous papers discussing the effectiveness of injurious wildlife listings under 18 U.S.C. 42(a) of the Lacey Act have emphasized failures while ignoring the many successes. We looked at the 120-year history of injurious listing and then determined the effectiveness of the listings since the U.S. Fish and Wildlife Service (USFWS) gained the listing authority in 1940. We measured success by the effectiveness of listing relative to the stage of the invasion process – that is, whether or not a species was established at the time of listing, if it since established, and if it subsequently spread to other States. The USFWS started listing preemptively with its first rule in 1952 and has added the majority of species preemptively since then. We analyzed the 307 species that were listed for invasiveness (excluding species listed for other injurious reasons). Of those species, 288 (94%) were listed preemptively (before they became established). Although we acknowledge that other factors may play a role, we consider species that were listed before establishment and remained not established as “very effective” listings. All 288 remained not established – a 100% prevention rate when listed preemptively. Only 19 of the 307 species (6%) were listed after establishment, and they remain established. The listings are considered “effective” for the 4% that remained within the State(s) they were established in at listing and “ineffective” or “not applicable” for the 2% that spread to other States. The rationale for listing established species is explained herein. We conclude that injurious species listings can be effective at any stage, but prohibiting the importation into the United States of high-risk species prior to their introduction and establishment into U.S. environments is very effective in preventing invasions, and this success has heretofore been overlooked.

Key words: injurious wildlife species, invasive species, nonnative, prevention, regulation, wildlife importation, 18 U.S.C. 42

Introduction

Countries around the world are striving to prevent invasions of animals or plants that may impair their economies or cause extinctions of native species. The United States has a national law specifically legislated to prohibit the importation of harmful or invasive wildlife species. Under 18 U.S.C. 42(a) of the Lacey Act, the Secretary of the Interior may prescribe by regulation (that is, add to the injurious list) wild mammals, wild birds, fishes, mollusks, crustaceans, amphibians, reptiles, and the offspring or

eggs of any of the foregoing that are injurious to human beings, to the interests of agriculture, horticulture, or forestry, or to the wildlife or wildlife resources of the United States. The only agency authorized by Congress to add species to the Federal list of injurious wildlife is the U.S. Fish and Wildlife Service (USFWS), as designated by the Secretary of the U.S. Department of the Interior. The following analysis provides a quantitative measure of the effectiveness of injurious species listing.

Brief History of Injurious Wildlife Listing

To determine how we could measure the effectiveness of injurious listing covering more than a century, we first had to understand the original statute, what the subsequent amendments were, and how they determined when and what species were listed. Injurious wildlife became a Federal designation in 1900, when U.S. Representative John F. Lacey authored the first major Federal wildlife statute in the United States, commonly known as the Lacey Act (U.S. Congress 1900). One of the purposes stated for the Lacey Act was to “regulate the introduction of American or foreign birds or [mammals] in localities where they have not heretofore existed.” Another law, also recognized as part of the Lacey Act and enacted simultaneously with the injurious provisions, includes broad conservation protections of native species against animal and plant trafficking (now called 16 U.S.C. 3371–3378). However, this paper deals exclusively with the statute that describes the injurious wildlife listing provisions, which we refer to herein as the Lacey Act, and which is now properly called “18 U.S.C. section 42. Importation or shipment of injurious mammals, birds, fish (including mollusks and crustacea), amphibia, and reptiles; permits, specimens for museums; regulations”.

The authority for enforcing the statute was given to the U.S. Department of Agriculture (USDA) in 1900. The statute was limited to wild mammals and birds to protect the interests of agriculture and horticulture. In 1940, Congress transferred certain functions of the USDA to the U.S. Department of the Interior, including injurious wildlife responsibilities. The Secretary of the Interior delegated the injurious wildlife listing responsibility to the newly formed Fish and Wildlife Service (White House 1940). Congress expanded the listing authority in 1960 to include fishes, mollusks, crustaceans, reptiles, and amphibians, and Congress also added “injurious to human beings, forestry, or to wildlife or wildlife resources of the United States” as purposes for designating species (U.S. Congress 1960; Jewell 2020).

The complex history of when, how, and what taxonomic groups were regulated during the first half of the 20th century precludes the ability to quantify the success of injurious listings consistently from 1900 to the present. Jewell (2020) explains the chronology in a summary of the injurious wildlife provisions and provides the background and the major amendments of the Lacey Act. We focus herein on outcomes of the

injurious listings while under the authority of the USFWS, technically starting with its first listings in 1952 and with the caveats noted below.

Current Injurious Wildlife Listing Authority

Since 1948, all wildlife species could be legally imported unless specifically regulated under the Lacey Act or other law. Under the current provisions from 1960 (U.S. Congress 1960), the Secretary of the Interior may prescribe by regulation (that is, amend to the list) those “wild mammals, wild birds, fish (including mollusks and crustacea), amphibians, and reptiles, . . . or the offspring or eggs of any of the foregoing that are injurious to human beings, to the interests of agriculture, horticulture, or forestry, or to the wildlife or wildlife resources of the United States” (18 U.S.C. 42 (a)). The injurious species list is maintained in the U.S. Code of Federal Regulations (CFR; 50 CFR sections 16.11–15). The USFWS may approve permits for exceptions to the prohibitions for zoological, educational, medical, or scientific purposes (50 CFR 16.22), and Federal agencies may import injurious species without a permit solely for their own use (50 CFR 16.32). The injurious provisions do not restrict designations to only nonnative species or only live specimens.

Once a species is added to the injurious list, importation is prohibited into the United States, any territory of the United States, the District of Columbia, the Commonwealth of Puerto Rico, or any possession of the United States, as is any shipment between the continental United States, the District of Columbia, Hawaii, the Commonwealth of Puerto Rico, or any possession of the United States (the “shipment clause”). However, the authority to prohibit interstate transport within the continental United States has changed from 1900, when interstate transport was explicitly prohibited (U.S. Congress 1900). In 1960, language was added to prohibit “any shipment between the continental United States,” which then was sometimes interpreted in USFWS and Congressional listings to prohibit and sometimes to not prohibit interstate transport between the States within the continent. In 2017, a court sided with the latter interpretation, so that existing and future listings do not prohibit crossing State lines on the continent (DCC 2017). Thus, any analysis regarding the effectiveness of interstate prohibitions would have to consider these complications. The analysis presented herein does not include the effect of interstate prohibition on established species but does use *prima facie* evidence if an established species has spread to another State.

The injurious wildlife provisions do not include any other prohibitions for injurious wildlife, such as sale, possession, or intra-state transport. Furthermore, listing a species is discretionary because the statute is worded “which the Secretary . . . may prescribe by regulation . . .” (U.S. Congress 1960), so listing may not necessarily occur for high-risk species. No funding is specifically appropriated for injurious listing. The lack of authority to

prohibit interstate transport precludes injurious listing from being effective at controlling or diminishing the spread of populations of injurious species once they are established.

The Listing Process

Species can be listed by Congress, such as the original 1900 injurious list (English sparrow, European starling, the mongoose, and genus *Pteropus* fruit bats; no other scientific names given) and the subsequent amendments for zebra mussel (*Dreissena polymorpha* (Pallas, 1771)) (U.S. Congress 1990), brown tree snake (*Boiga irregularis* (Bechstein, 1802)) (U.S. Congress 1991), bighead carp (*Hypophthalmichthys nobilis* (Richardson, 1845)) (U.S. Congress 2010), and quagga mussel (*Dreissena rostriformis* or *D. bugensis* Andrusov, 1897) (U.S. Congress 2018). Species are more commonly listed by the USFWS, which follows the rulemaking process under the Administrative Procedure Act (U.S. Congress 1946). The USFWS may propose a species for listing as injurious either by a petition from an outside entity or by recommendation from its own experts. However, there is no requirement to address petitions, only to consider them. The agency has been petitioned to list species relatively rarely. The USFWS was petitioned to list the mitten crab genus *Eriocheir* in 1987 (USFWS 1989); the brushtail possum (*Trichosurus vulpecula* (Kerr, 1792)) in 1996 (USFWS 2002a); the silver carp (*Hypophthalmichthys molitrix* (Valenciennes in Cuvier and Valenciennes, 1844)) and bighead carp in 2002 (USFWS 2007a); the black carp (*Mylopharyngodon piceus* (Richardson, 1846)) in 2002 (USFWS 2007b); the Burmese python (*Python bivittatus* Kuhl, 1820) in 2006 (USFWS 2012); and 43 species in 2016 (CISP 2016; none listed). The majority of species from the latter petition were already widely established, with prevention from establishment not possible.

With sufficient information, the USFWS evaluates the species considered for listing under a set of criteria the agency developed (see USFWS 2016a, p. 1538). Normally, the USFWS prepares a proposed rule and publishes it in the *Federal Register*, seeks public and peer review comments, considers those comments, then prepares and publishes a final rule. Required determinations, such as an economic analysis and a National Environmental Protection Act (NEPA) assessment are also made. The length of time needed for the listing process depends on such factors as the number of species being considered simultaneously, if the species is in U.S. trade, and staffing resources. There are no statutory deadlines, and listings have taken as short as 14 months and as long as 7 years (USFWS 2016a and USFWS 2007a, b, respectively).

In general, species are listed as injurious because they possess traits that may allow them to establish nonnative populations, spread into new U.S. ecosystems, and cause harm (Lodge et al. 2006). However, a species may be listed solely because of the direct harm it can cause without establishing

Table 1. Summary by taxonomic group of currently listed injurious wildlife used in this analysis. Some listed fishes and amphibians were excluded because they were not listed for invasiveness as noted in the text. (See USFWS 2020 for more detailed table of listed species under 50 CFR 16).

Taxa	Number of Species Listed	Number of Listed Species Analyzed	Number of Species Established
Mammals	96	96	2
Birds	4	4	2
Fishes	431*	189	9
Mollusks	2	2	2
Crustaceans	6	6	1
Reptiles	10	10	3
Amphibians	236	0	0
TOTAL all listed species	785		19
TOTAL used in this analysis		307	19

* Includes 242 salmonids.

a population and spreading its range. For example, a species may be listed because it is highly venomous or because it is a host to a pathogen or parasite that affects wildlife or humans. Entire genera or families may be listed, but each species within the taxa must possess the trait or traits that make it injurious. The analysis presented here is based on a subset of 736 species listed as of August 2020 (Table 1 and Supplementary material Table S1).

Except for two large taxa, all species were listed for invasive traits (although some also possessed directly harmful traits) and only for live specimens. The two taxa that are not invasive were listed because they are carriers of contagious pathogens that affect fishes and salamanders, and the listings include dead specimens. The family Salmonidae was listed in 1968 (now totaling 242 species; USFWS 1968) and can be hosts of pathogens causing viral hemorrhagic septicemia, spring viraemia of carp, and other fish diseases. The 20 genera of salamanders (USFWS 2016a; now revised to 236 species) can be hosts of *Batrachochytrium salamandrivorans*, a recently discovered fatal fungus of salamanders in Europe that is not yet known to be found in U.S. ecosystems.

Several papers have emphasized the failure of Lacey Act listings (Bean and Rowland 1997; Bean 2001; Fowler et al. 2007; Alexander 2013; Keller and Springborn 2013; Norvell 2016; Hill et al. 2018), primarily because of the time required to complete a rule and because the listing came too late in the invasion process. Some of these papers (such as Fowler et al. 2007; Hill et al. 2018; Norvell 2016) ignored the substantial number of species listed before they were introduced and that remained absent from the United States.

This paper does not dispute that the time to list a species has often been too long and that listing came too late to keep some species from establishing. The objective of this paper is to quantify the effectiveness of injurious wildlife listings at different stages in the invasion process for each individual species listed, regardless of whether the species was listed as part of a genus or family listing. This method of quantifying the effectiveness of the listings under the Lacey Act improves on previous papers because it

considers the history of the listing authorities since 1900, treats the taxa more consistently, and considers the stages of the invasion process (not just after establishment).

Materials and methods

We obtained all information from publicly available sources. We obtained the names of the injurious families, genera, and species in 50 CFR 16.11, 16.12, 16.13, 16.14, and 16.15 as of 2020 and itemized each taxon into its component species. The number of species in a genus or family may have changed after the listing as new species are discovered or taxonomists synonymize or split species, and the language in the regulations accounted for these changes (meaning if a new species was discovered or renamed in a listed genus or family, it is covered by the regulation). These numbers may even change after this publication, conceivably because many of the taxa are native to remote regions of the world where new species are still being discovered, or because taxonomy of some groups is being revised.

We analyzed species numbers based on current taxonomy as verified by the Integrated Taxonomic Information System (<https://itlis.gov>), Fricke et al. (2020a, b), and the most current literature. We also consulted national checklists for mammals (Bradley et al. 2014), birds (Lever 1987; Pyle and Pyle 2017; Chesser et al. 2018), reptiles and amphibians (SSAR 2017; CNAH 2019), mollusks and crustaceans (U.S. Geological Survey 2020a; Fofonoff et al. 2019), fishes (Fricke et al. 2020a, b; U.S. Geological Survey 2020a), and vertebrates (Witmer and Fuller 2011).

We reviewed literature and online databases for each species to determine if it was established (defined by the U.S. Geological Survey's Nonindigenous Aquatic Nuisance Species database (U.S. Geological Survey 2020a) as "population shows evidence of successful reproduction (i.e., presence of multiple life stages or year classes and overwinter survival") or absent in the United States at the time of listing and its current presence or absence as of August 2020 (see Table S1, which includes the date listed). For a species that was established at the time of listing, we ascertained the original and current range to determine if it has spread to, and become established in, at least one other State or territory. We used the date the prohibitions took effect, which varied up to 5 months after the date of final rule publication. We also used the date of the first known established population and location of those occurrences in the United States. "Introduction" herein means, as a result of human activity, the intentional or unintentional escape, release, dissemination, or placement of an organism into an ecosystem to which it is not native (White House 2016).

We divided the species into five categories primarily by the effectiveness of the listing in relation to the stage in the invasion process (whether established or not) and secondarily by if it spread to other States. This applies

only to the species still listed as of 2020. Therefore, we categorized effectiveness of listing for the 307 species as follows:

- A. For a species that was not established in the wild in the United States at the time of its listing and:
 1. is not established: the listing is considered “very effective” (we assumed the listing was very successful at preventing a new species from becoming established);
 2. is established: the listing is considered “ineffective” (the listing failed to prevent the establishment of a new species).
- B. For a species that was established in the wild in the United States at the time of its listing and:
 1. has not spread its range to another State or has reduced its range (remained within the States or territories where present when listed): the listing is “effective” (the listing was effective at stopping the spread);
 2. has spread its range to at least one other State by human mediation: the listing is considered “ineffective” (the listing was ineffective at stopping the spread);
 3. has spread its range to at least one other State naturally: the listing is considered “not applicable” (the statute’s prohibitions could not have stopped this type of spread).

The two categories for species not established should require no additional explanation as to how species were assigned. A species that was not established in U.S. ecosystems at the time of listing and remained not established demonstrates the most significant strength and purpose of the statute, which is to prevent species from becoming introduced into U.S. environments and resulting in harm to the enumerated interests.

The three categories for species that were established when listed may benefit from more explanation. We recognize the limitations of the statute in curtailing the spread of a species once it has established. Because of these limitations and the variables in the biology of the taxa, these results should be considered of lesser significance than the results for the species not established when listed. Even if the statute prohibited interstate shipment, a species that was established on the continental United States at the time of listing could spread naturally, because the statute has no mechanism to block the natural spread (especially by, but not limited to, organisms flying or swimming). Examples include the English sparrow (*Passer domesticus* (Linnaeus, 1758)) and the European starling (*Sturnus vulgaris* (Linnaeus, 1758)) listed in 1900. Therefore, we cannot apply effectiveness or success standards to the statute to prevent this type of spread, hence “not applicable.” Some species spread both by human mediation (assistance) and naturally on their own, but the species that spread primarily naturally

were counted only in that category, because they could spread regardless of human mediation. Species that spread primarily by human mediation were placed only in the human-mediated category (“ineffective”). Conversely, the statute could have been “effective” during its history, albeit in a limited way, to contain species by minimizing human-caused spread to other States by the shipment clause and the intermittently applied interstate prohibition, by people voluntarily not transporting the species because they learned of the potential harm from the listing, and by States utilizing the USFWS’s scientific documentation provided in the listing rule to support State regulations.

Caveats and Assumptions

In our analysis, we did not distinguish between Congressional or USFWS listings, or whether by petition or USFWS initiation. We assume that the timing of listing a species relative to its invasion stage is more relevant than who listed it or how long it took. We included the most recent listings but recognize that, for species listed within the last few years, judging long-term success may be premature.

We excluded the 242 species of salmonids and 236 species of salamanders from this analysis because they cause harm as vectors for pathogens (which cannot be listed) and were not evaluated for invasiveness. Although we did not include the salmonids (listed in 1968) and salamanders (listed in 2016) in our analysis, it is worth noting that, to date, the respective pathogens they carry have not been found to have entered the United States by salmonid importation (salmonids: J. Bader, USFWS, written communication 2020) and not found in the U.S. environment (salamanders: Waddle et al. 2020). If we did include the salmonid and salamander listings, perhaps as two respective collective taxa, we would categorize them both as “very effective”.

We also excluded the English sparrow and European starling because they are not currently listed. Both species were on the original injurious list in 1900 after they had been introduced and become widespread in the United States. In 1960, Congress removed both species from the injurious list (U.S. Congress 1960; Jewell 2020). Considering a 60-year absence on the injurious list, judging effectiveness would be unwarranted.

Other species that were excluded in this analysis include: Mynas (*Acridotheres* spp.) and the European hare (*Lepus europaeus* Pallas, 1778), which were listed by USFWS’s regulation in 1952 (USFWS 1952) but not currently mentioned in the Code of Federal Regulations, so they are not considered listed. Seven bird species, six mammal species, and two mammal families that were declared injurious by regulation in 1935 (USDA 1936) are excluded because they also do not appear in the Code of Federal Regulations or the statute, so they are not being prohibited from import.

We received late word (relative to preparation of this manuscript) that two individuals of a species of walking catfish (*Clarias gariepinus* (Burchell,

1822)), listed in 1970 prior to known U.S. presence, had been found in the wild in Puerto Rico (Rodríguez-Barreras and Zapata-Arroyo 2019). However, we do not have confirmation that this species is established. There are also multiple reports of reticulated pythons (*Malayopython reticulatus* (Schneider, 1801)) in Puerto Rico that require verification of establishment (Robert Reed, U.S. Geological Survey (USGS), written communication 2020). Reticulated pythons were already present in U.S. trade and captivity on the U.S. mainland when they were listed in 2015, but we are not including the species in our results as established because we lack confirmation of establishment.

We included the bats of the genus *Pteropus* (USFWS 1952) according to their current taxonomic status of 65 species. All species of mongooses were prohibited from 1900 to 1948; from 1948 to 1965, one species was considered injurious, and from 1965 to present, all species of mongoose or meerkat of the genera *Atilax*, *Cynictis*, *Helogale*, *Herpestes*, *Ichneumia*, *Mungos*, or *Suricata* (and synonyms) are injurious. We included these 19 species in our analysis. We included the walking catfish family (Clariidae) with 118 species, the snakehead family (Channidae) with 57 species, and the mitten crab genus (*Eriocheir* spp. and synonyms) with 5 species according to their current taxonomic status. These numbers may differ from other reports because the number of species identified within taxonomic groups (genus or family) can change with time.

In 2012, the USFWS listed *Python molurus* (Linnaeus, 1758) as one species with two subspecies: Indian python *P. m. molurus* and Burmese python *P. m. bivittatus*, while explaining the uncertainty of the taxonomy and that both organisms and their hybrid offspring were covered by the rule (USFWS 2012). Since then, some genetic studies have split the species into two species (Reynolds et al. 2014; Hunter et al. 2018). Therefore, we use the two species in this analysis. However, in addition to being listed as injurious wildlife, we recognize that the Indian python has been prohibited from importation because it has been federally listed under the Endangered Species Act as endangered since 1976. As far as we can determine, *P. m. molurus* was not established when listed as endangered or as injurious.

Results

Enumerating all listed species under each listed taxon resulted in 307 species assessed for invasiveness (excluding the salmonids and salamanders) (Table 1 and Table S1). We categorized each species as either established or not in the United States at the time of listing. Of the 307 species, 285 were from 11 genera and 2 families or multiple listing of related species, and they included only 11 species that were established at the time of listing (Table 2), indicating the USFWS's preemptive intentions at listing.

We evaluated effectiveness of the listing for each of the 307 species (Table 3). No species that was not already established in the United States

Table 2. Listings by entire genus (11 genera) and family (2 families), or related species*. “Number of species” is the number of species currently included in the genus or family when the whole genus or family is listed. “Number of species established at listing” is 0 if no members of that taxon were established in the United States when listed.

Taxa	Number of Species		Number of species established at listing
	Total in taxon	Listed	
Fruit bats (<i>Pteropus</i> genus)	65	65	0
Mongoose (7 genera)	19	19	1
Multimammate rats (or mice) (<i>Mastomys</i> genus)	8	8	0
Walking catfishes (Clariidae family)	118	118	2
Snakeheads (Channidae family)	57	57	3
Asian carps*	NA	4	3
Mitten crabs (<i>Eriocheir</i> genus)	5	5	1
Anacondas (<i>Eunectes</i> spp.)	4	4	0
Pythons*	NA	5	1
TOTAL		285	11

Table 3. Results of the categories of effectiveness for all currently listed species as of 2015 and as of 2020.

Category	All species as of 2015 Number of species (%)	All species as of 2020 Number of species (%)
Not established at listing, not established since (“very effective”)	278 (94.2)	288 (93.8)
Not established at listing, established since (“ineffective”)	0 (0)	0 (0)
Established at listing, remained within States or Territories (“effective”)	10 (3.3)	12 (3.9)
Established at listing, spread to other States or Territories by human mediation (“ineffective”)	3 (1.0)	3 (0.9)
Established at listing, spread to other States or Territories naturally (“not applicable”)	4 (1.3)	4 (1.3)
TOTAL	295 (99.8)	307 (99.9)

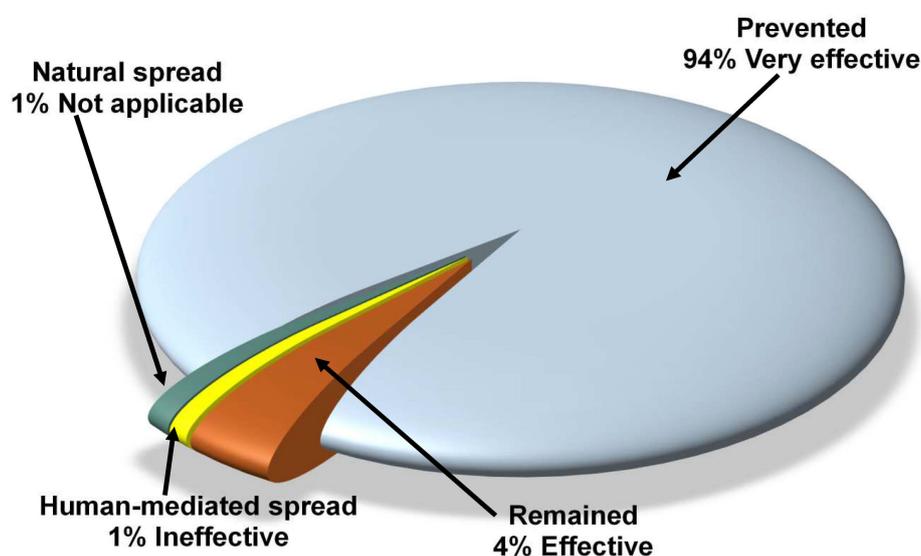


Figure 1. Current status of the 307 injurious species analyzed. Ninety-four percent were not established in the United States at the time of their listing, and they all remain unestablished (“very effective”). Four percent of species were already established but remained within those States (“effective”), while less than 2% spread naturally to other States (“not applicable”), and less than 1% spread by human-mediated spread (“ineffective”).

at the time of its listing has since established in the country, which is a 100% prevention (of establishment) rate, the category of “very effective” (Figure 1). If the walking catfish *Clarias gariepinus* and the reticulated python are found to be established in Puerto Rico, they would be the first known

Table 4. Current status of species with established populations in the United States at the time of their listing as injurious (N = 19), with the year each listing took effect, placed under the category of listing effectiveness. Species that spread by both human-mediated and natural means were counted only once, categorized by the more prominent pathway in establishing populations in new disconnected areas. Further details for spread can be found in the Table S1.

Species remaining within original State(s) where established when listed “Effective”	Species that spread after listing	
	To new States by human-mediated transport “Ineffective”	To new States naturally “Not applicable”
Mongoose, small Indian 1952	Rabbit, European 1952	Crab, Chinese mitten 1989
Bulbul, red-whiskered 1968	Mussel, zebra 1990	Carp, black 2007
Sparrow, Java 1968	Snakehead, northern 2002	Carp, silver 2007
Catfish, walking (<i>Clarias batrachus</i>) 1970		Carp, bighead 2010
Catfish, walking (<i>C. fuscus</i>) 1970		
Snake, brown tree 1990		
Snakehead, blotched 2002		
Snakehead, bullseye 2002		
Python, Burmese 2012		
Python, Northern African 2012		
Zander 2016		
Mussel, quagga 2018		

species to establish after being listed. The reticulated python was already present in trade in the United States when listed but not known to be established. The walking catfish has been listed for 50 years, so it appears that they entered Puerto Rico illegally. The snakehead (*Channa micropeltes* (Cuvier, 1831)) and two anacondas (*Eunectes notaeus* Cope, 1862 and *E. murinus* (Linnaeus, 1758)) have been reported in the United States before and after listing but have not established (Table S1), and the presence of these species is likely due to captivity (and possible breeding) from pre-listing importation.

Nineteen species (6.2%) already had established populations in the country when they were listed (Table 4, Table S1). Twelve of those remained within the State or territory where they occurred at listing, with the Java sparrow (*Lonchura oryzivora* (Linnaeus, 1758)) having the only reduced range. The sparrow was extirpated from the continent (Florida) but is still established in Hawaii and Puerto Rico. We consider these listings “effective.” We attribute the lack of cross-border spread to either the reduction in propagule pressure or the interstate transport prohibition as interpreted by the USFWS for many years, or both. Propagule pressure is a measure of the number of individuals of a species arriving to a region to which they are not native (Duncan 2011). This has been identified as a key factor in the ability of the species to establish populations in new regions, because the more individuals that arrive, the greater the chances of establishment in that region. Some species that had not spread were found only on islands that were part of the shipment clause prohibition and some were ground-dwellers (less mobile).

Seven of the 19 species spread to new States (Table 4). The three that spread primarily by human-mediated transport after listing (zebra mussel, European rabbit, and northern snakehead; 0.9%) are considered “ineffective” (listings are more likely to succeed for less mobile species). The four species

that primarily spread naturally (bighead, black, and silver carps; Chinese mitten crab; 1.3%) were all aquatic species that could spread on their own using waterways. Effectiveness of listing was considered “not applicable” for these species because, once a species is well established in waterways, an injurious listing alone is not designed to stop the natural spread.

We included recent listings in our results but noted that judging long-term effectiveness may be premature. However, to see if they changed our conclusions, we looked at the results without the species that were listed within the last 5 years (Table 3). Twelve species were listed since 2015. Two were already established: the quagga mussel was widely established but has not spread from the States where it was present when listed, and the zander is found only in one lake and has not spread from there. The other 10 were not established when listed, and because they are all aquatic, we believe USGS’s Nonindigenous Aquatic Species database would have picked up a report. By removing the recent ones from our analysis, the total number analyzed decreases by 12 species (to 295), with the number established reduced by 2 (to 17), and the number not established at listing reduced by 10 (to 278). For “very effective,” both are close to 94%.

Discussion

The most notable result we found is that 100% (288/288) of the species that were not established in U.S. ecosystems at the time of listing remained not established. Thus, prohibiting importation at the pre-introduction stage of the invasion process is “very effective.” This measure of success was used in 1935 when the USDA added more species to the injurious list in 1935. Ira Gabrielson (Chief of the Bureau of Biological Survey) explained the advantage by noting the continued effectiveness of the Lacey Act, “It is gratifying to repeat that no forbidden species of bird or mammal has established a foothold in the United States since 1900” (USDA 1936).

Several factors may explain why listing high-risk species preemptively is effective. One is that it reduces the opportunity for the live animal industry to import for domestic breeding, which can increase captive populations even after prohibiting importation and possibly lead to escaped or released individuals. Another benefit of preemptive listing is to eliminate the opportunity for a species to enter different climate zones of the country, thus reducing the chance of establishment if released into the wild. Furthermore, listing preemptively can provide States with documentation for their own prohibitions on sale, possession, or other restriction. Even if a listed species is not intentionally imported, port inspectors may discover it and prevent its entry into the United States.

Proving failure is often easier than proving success, and this is true for injurious listings. A failure occurs when a species initially enters the United States after listing and becomes established. Our results show no failures. On the other hand, a success, which we define as prevention, occurs when

a species that was not present in U.S. ecosystems at the time of its listing has remained absent. The difficulty here is proving that listing was the cause and absence was the effect. Other factors may play a role. For example, a listed species may have been introduced and failed to survive, may have been introduced but not detected, may have been thwarted by State laws that prohibited the introduction (such as Ohio (Ohio DNR 2017) and Florida (FWC 2019)), or did not have a pathway to be introduced. It is also possible that merely the designation as injurious alerts the public of the harm those species could cause, which thus reduces the public's interest in acquiring injurious species.

By listing the Burmese python in 2012 after it became established in South Florida, the USFWS did not expect to cause its eradication or suppress its population numbers. Many reasons guided the decision, including reducing the risk of introduction to other parts of the country (USFWS 2012). Burmese pythons are disease and parasite vectors for livestock and native wildlife, have a large body size that enables them to prey on a wide variety of native wildlife, and can live for 20–30 years, thus causing harm without reproducing (Reed and Rodda 2009). Listing can also help reduce propagule pressure, which reduces the opportunity for all of these threats. Two studies published after the python listing show how imports can compound propagule pressure. Stringham and Lockwood (2018) found that reptile species with a relatively large adult mass that were imported in higher quantities and sold less expensively had a high probability of being released into the wild. Also, for such hardy species as the Burmese python, selection (survival) during transport can facilitate local adaptation, which may result in a greater likelihood of invasion success than predicted by propagule pressure alone (Briski et al. 2018). Thus, harsh transport conditions (such as overcrowding, multiple species per container, no food) may contribute to only the strongest individuals surviving to the destination, thus improving their chances of survival if released into the wild.

Success of injurious listing may be partially attributable to the USFWS approach of concurrently listing multiple species that have similar risk traits (Table 2). For example, although the USFWS was petitioned to list one constrictor snake (Burmese python), the agency simultaneously reviewed the risk of similar large nonnative constrictors and combined the risk assessment, injurious evaluation, and listing processes to preemptively list seven other species of large pythons and anacondas (counting *Python molurus* as one; USFWS 2012, 2015a). The USFWS used this same preemptive taxa concept with the fruit bat genus (USFWS 1952), seven genera of mongooses (USFWS 1965), the multimammate rodent genus (USFWS 1965), the walking catfish family (USFWS 1969), the mitten crab genus (USFWS 1989), and the snakehead family (USFWS 2002b). Listing species that are not in trade but that share risk traits with a species that is in trade may preclude importers from switching to the related species.

Unlike the Endangered Species Act, the injurious statute (18 U.S.C. 42 (a)) does not allow listing for “similarity of appearance.”

Only 19 of the 307 species listed for invasiveness were already established when they were listed, with 12 of those remaining contained to the State they established in (Table 4). The Java sparrow was the only species that disappeared from where it originally established without known human intervention. The sparrow was never abundant in Florida and was last seen there in 1977 (Avery and Moulton 2007). The cause of the extirpation is unknown, but the lack of propagule pressure from the importation prohibition may have assisted the decline.

Previous analyses have fueled an inaccurate perception of the effectiveness of injurious listing. Bean (2001), Fowler et al. (2007), and Norvell (2016) undercount the number of species listed and hence the number of effective listings. Fowler et al. (2007) combined entire genera or families and counted them respectively as one entity each, stating that at least 9 of 16 taxa (56%) were already in the continental United States at the time of listing, and at least 7 of 16 taxa (44%) had established populations when listed. This calculation errs because the numerator is a single species and the denominator mixes single species with lumped genera and families. Alexander (2013) confuses the statute with the USFWS’s authority to add species by regulation and questions why 19 species of mongooses are listed instead of just the one in the statute and states that 18 U.S.C. 42 appears to ban only live creatures. Hill et al. (2018) states that the traditional process of listing is reactive and has failed to prevent the introduction and establishment of several species, providing examples of Asian carps and the northern snakehead, but ignoring the preemptive listing of the largescale silver carp and 54 species of snakeheads (Channidae).

Further inaccurate perceptions of the Lacey Act include failure to note that the first 48 years of the Lacey Act was a “white list” approach (Fowler et al. 2007; Keller and Springborn 2013; Norvell 2016), because wild mammal and bird imported shipments were banned except if allowed under permit (Jewell 2020). Bean and Rowland (1997) also do not recognize the agency and prohibition changes of the past 100-plus years. For example, they state that the original Lacey Act prohibited the “mongooses” (although it was only one species), fruit bats, and so on, but neglect to mention that all other wild mammals and birds were prohibited except by permit. They then explain that Congress greatly expanded the government’s authority to prohibit importing injurious wildlife in 1960, neglecting to mention the major decrease in authority in 1948 (Jewell 2020). They question why the Secretary failed to issue any regulations for 70 years, even though regulations were published regarding importing injurious birds and animals, regarding the issuance of permits for foreign wild animals, and regarding the allowance of certain cage birds and specimens for museums (U.S. Treasury 1933); the USFWS also issued regulations starting in 1952.

Failure is an inappropriate word to describe the outcome of an old law that was not designed for what it is now asked to do. Had the original law, which took a “white list” approach for wild mammals and birds, continued to this day, it is likely that it would have succeeded in its primary purpose for USDA (protecting agriculture and horticulture). However, the governmental reorganization in 1940 transferred the functions of injurious wildlife from USDA to the U.S. Department of the Interior (White House 1940), whose mission through the USFWS was focused more on conservation of fish and wildlife. The interests of agriculture or horticulture were not correspondingly changed in the statute, leaving the USFWS little motivation to prepare rules to protect agriculture and horticulture. With the “black list” approach starting in 1948, the injurious wildlife provisions of the Lacey Act lost further effectiveness. However, conservation became a greater priority and the Lacey Act gained broader authority with the 1960 amendment (U.S. Congress 1960) that included the other vertebrate classes, two taxa of invertebrates, and the expanded purpose to protect wildlife and wildlife resources. These additions are valuable, but they still do not make the statute adequate to prevent invasions across the entire animal kingdom, which increase in frequency every decade (Matlock 2014; Capinha et al. 2017; Seebens et al. 2017, 2018; U.S. Geological Survey 2020b).

Complicating the effectiveness of listing during the USFWS’s 80 years of responsibility is that the length of time needed for promulgating a rule has increased considerably due to the addition of Federal required determinations, such as economic analyses and NEPA assessments, hindering the ability to stay ahead of invasions. However, the USFWS has administratively streamlined some aspects, such as by risk screening and by obtaining the approval from the Council on Environmental Quality to utilize the minimal NEPA assessment required (USFWS 2015b). The USFWS is focusing its regulatory efforts to make prevention the goal of the program by using risk screening to prioritize species to evaluate, by selecting high-risk species that are not yet established in U.S. ecosystems (such as USFWS 2016b), and by further streamlining the listing process using globally available data to assess risk of establishment and harm.

Nevertheless, continuing to add species to the injurious list after they have established and caused harm can be justified. If a species shares the traits of injuriousness with other species, particularly in the same genus or family, then including the already-invasive species provides a clear example to demonstrate why the related species should also be listed. In addition, prohibiting further importation of the invasive species can prevent individuals from being introduced to new areas of the United States where the species would not otherwise have arrived and can reduce the propagule pressure that could introduce hardier individuals (Briski et al. 2018). Furthermore, many imported animals carry parasites and pathogens harmful to native species, and stopping the continued

importation can reduce those threats that cause disease. Just as important, the shipment jurisdictions, other than the continental United States, are all islands distant from the U.S. continent (Hawaii, Puerto Rico, and the U.S. territories) and are extremely vulnerable to invasive species (Vitousek 1988; Lowe et al. 2004; Reaser et al. 2007), and listing would reduce the threat to the islands. Moreover, if a control method is eventually found for a listed species, eradication is more likely to succeed without additional individuals continually being imported. Lastly, the Federal listing can provide States and other jurisdictions with the technical information they need to pursue additional restrictions not federally authorized under 18 U.S.C. 42, such as transport into a State, possession, and sale. Thus, preventing the importation of additional individuals of established injurious species should not be considered a failure.

Conclusion

The high effectiveness rate for prevention of establishment that we found supports using predictive risk assessments and designating species as injurious at the earliest stage in the invasion process. Of the 307 species listed for invasiveness, 94% were listed before they became established, and all remain not established (“very effective”). The listings were considered “effective” for the 4% that remained within the State they were established in at listing. Only 19 species (6%) were listed after establishment, and they remain established. While listing is most effective when done preemptively, it can also be effective to list species after they are established. This analysis reveals the effectiveness of the widely utilized preemptive listings and the benefits of listing species as injurious even after they become established.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Species listed as Injurious, including listing dates, occurrence in the wild, and population establishment.

This material is available as part of online article from:

http://www.reabic.net/journals/mbi/2021/Supplements/MBI_2021_Jewell_Fuller_SupplementaryTable.xlsx