Historical Trends of Aquatic Invasive Species Introduction and Establishment in Illinois, USA

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Abstract

Tracking the introduction and establishment of aquatic invasive species (AIS) is important for monitoring the biological and economic health of freshwater environments. The state of Illinois (USA) is a critical region for understanding the threats of AIS because it possesses the only continuous aquatic habitat connecting the Laurentian Great Lakes and Mississippi River Basins. In this study, we update a previous effort to catalogue and evaluate historical AIS records from Illinois. Our updated database shows that there are now at least 92 nonindigenous aquatic species established in Illinois and a further 51 have been recorded as introduced but not established. This is many more species than reported in the earlier database, with this increase made possible due to improved access to data and a longer timeframe of analysis. Rates of introduction and establishment have continued to increase in Illinois over the past century, and we identify new groups of organisms that were not in the previous database. Current sampling efforts are not sufficient to detect the number of invaders present and additional non-native species may be present but not yet recorded. Illinois is likely to remain an important hub for the introduction and spread of invasive aquatic species with implications for freshwater ecosystems across the continent.

Introductions

The spread of aquatic invasive species (AIS) presents a threat to the biodiversity and resilience of freshwater ecosystems across the globe (Gallardo et al. 2015). After being introduced into a new habitat, AIS can outcompete native species, restructure food webs, and transform the abiotic conditions of entire ecosystems (Mills et al. 1994; Gallardo et al. 2015; Havel et al. 2015). Rates of introduction and spread of AIS have steadily increased over the last century and freshwater ecosystems have been impacted more strongly by invaders than other ecosystem types (Havel et al. 2015; Jacobs & Keller 2016). Degradation of the high biodiversity and economic services provided by freshwater systems is often substantial with large impacts for society and economies (Mills et al. 1994; Ricciardi & Rasmussen 1999; Rosaen et al. 2012; Bacher et al 2018). In the United States, the state of Illinois possesses the only continuous aquatic connection (via the Illinois River and Chicago Area Waterway System) between the Mississippi River Basin and the Laurentian Great Lakes Basin, making the state a pivotal gateway for spread of AIS (USACE 2014, Jacobs & Keller 2016).

An effort to catalogue and assess historical records of AIS in Illinois was published in 2016 (Jacobs & Keller 2016). That study aggregated available non-native aquatic species sampling data from multiple academic institutions and state agencies between 1873 and 2012. Due to limitations of the time, the database from the Jacobs and Keller (2016) study is not easily accessible to the public. Further, the Jacobs & Keller (2016) study only considered species records documented through 2012. With the addition of eight years and an increase in records available via online databases, a large amount of new information about Illinois AIS introduction and establishment events has become available (USGS 2020).

The aim of this project was to re-evaluate Illinois' historical AIS records and assess how newly available records shift our understanding of introductions and establishments within the state. We constructed a new database of all non-native aquatic species occurrences in the state of Illinois, covering the years 1842 to 2019. We determined which records were of established populations and which were of introduced species that failed to establish. Records were vetted to determine native/non-native status in Illinois. The database allowed us to quantify trends over time of introductions and establishments in Illinois. This represents an updated and more robust investigation of Illinois' AIS trends which will serve future researchers and management teams addressing this key gateway between two major freshwater basins.

Methods

Database Development

We defined Illinois to include all waterbodies and waterways within the state, including the portions of major rivers that form parts of the state's borders (Mississippi, Ohio, and Wabash) and the portion of Lake Michigan that contacts Illinois. Data collection began in January 2020 and concluded in March 2020. To be included in the database a record needed an unambiguous species identification, geographic location to at least the county level, and a date of collection. Sources for records included the data from Jacobs and Keller (2016), and additional sources (e.g., academic and research institutions) were identified through online searches and contacted for records. All institutions contacted reported that they annually uploaded records to aggregated digital databases, such as the Great Lakes Invasive Network (GLIN) (http://greatlakesinvasives.org) and U.S. Geological Survey's Nonindigenous Aquatic Species (USGS NAS) (https://nas.er.usgs.gov). Records from these databases were downloaded and compiled to form a complete database of occurrence records. Data was cleaned and vetted following the methods of Jacobs and Keller (2016). This involved searching for and removing all duplicates, verifying geographic data, and discarding records that did not identify the organism to species level. Due to the potential for misidentification (Kijewska et al. 2009; Vanhaecke et al. 2012), we did not include records of hybrid species.

The earliest record for each species was classified as *introduced*. To classify a species as *established*, we consulted our database as well as records held by the U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA), U.S. Army Corps of Engineers (USACE), U.S. Fish and Wildlife Services (USFWS), and relevant literature, to verify that reproducing populations had been reported in Illinois.

We defined aquatic non-native animals as those that met the U.S. Department of Agriculture's (USDA) definition for AIS: *non-native species that live primarily in water rather than on land* (USDA 2019a). Aquatic plants were defined using the USDA Plants' classification of *obligate wetland*: *species that occur under natural conditions in wetlands with a >99% probability* (USDA 2019b). Illinois contains portions of four USDA wetland regions, and we included species classified as *obligate wetland* in any of these regions (USACE 2018). We made a single exception and included *Phragmites australis*. This is classified as a *facultative wetland* species in Illinois, but because of its widespread distribution and large ecological impacts in Illinois wetlands we elected to include it (Able & Ragan 2003; Price et al. 2014). The non-native status of each plant species was verified primarily with the species ranges provided by USGS NAS and USDA Plants (USDA 2019b; USGS 2020). When a species' status could not be determined through these sources, we consulted relevant literature including the Global Biodiversity Information Facility website (GBIF 2020).

Analysis of Introduction and Establishment Records

Three analyses were conducted to investigate how rates of introduction and establishment of non-native aquatic species in Illinois have changed over time. Each of these analyses was conducted separately on the introduction and establishment datasets. First, we calculated the number of new records during each decade of the database (1842-2019; see below) and used linear regression to test whether rates of introduction and establishment have changed. Second, we constructed accumulation curves for introduced and established species and used polynomial regression to assess how the rates of species discovery have changed over time. Finally, following Ricciardi (2006) we investigated longer-term changes in introduction and establishment rates by comparing the average annual rate of discovery over the entire time interval (long-term) to that of the most recent 30 years (short-term).

To determine whether current sampling efforts are sufficient to find all non-native aquatic species in Illinois we plotted the number of established species detected per year against the annual number of records. Number of records per year serves as a proxy for total sampling effort across the state (Ricciardi 2006; Jacobs & Keller 2016), and this analysis allowed us to estimate how changes in sampling effort are related to the total number of established species detected. A logarithmic regression was fit to the data and the graph's asymptote can be used as an indication of how effective recent sampling levels in Illinois have been at detecting the total number of established species. All statistical tests were performed in R (version 3.6.3) with a significance level of $\alpha = 0.05$

Results

Sampling Records

Occurrence records were collected from nine sources (Table 1). The U.S. Geological Survey's datasets provided the majority of records (74.7%), followed by Early Detection & Distribution Mapping System (18.6%), and the Great Lakes Invasive Network (3.8%). After the removal of duplicates, the final database had 120,511 records for 143 non-native species from eight taxonomic groups (Table 2). The earliest record in the database is the sedge *Carex vesicaria*, first recorded in 1842. The full dataset then runs to 2019 and includes 38 additional years relative to Jacobs & Keller (2016). Of the eight broad taxonomic groups (Table 2), non-native plant species occurred in highest numbers (n = 59 species), followed by fishes (n = 46 species), and mollusks (n = 16 species). Common carp (*Cyprinus carpio*) was the most often recorded species in Illinois (n = 71,536 records). Four carp species (*C. carpio*, *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella,* and *Hypophthalmichthys nobilis*) account for 78.96% of all AIS records. Although carp species are widely distributed in Illinois, their high record count is partly a result of intensive sampling efforts of the *USGS Long Term Resource Monitoring – Fish* (Table 1) program, which primarily sampled in the southern portion of the Mississippi River and targets fishes. This program also reports each fish as a record even when multiple fish were captured during a single effort. Other data sources may include multiple individuals in each record.

Table 1: Data sources and the corresponding number of records used for the creation of the AIS database. Sources: Early Detection & Distribution Mapping System (EDDMapS), Great Lakes Invasive Network (GLIN), Illinois Natural History Survey (INHS), United States Geological Survey (USGS) Long Term Resource Monitoring (LTRM) and Nonindigenous Aquatic Species (NAS). Note: INHS and USGS LTRM possessed multiple databases with different management teams – the name of each sub-database is denoted next to the parent entity name (Vegsrs = vegetation stratified random sample; Vegtransect = vegetation transect sample).

Database	Number of Records
EDDMapS	25,776
GLIN	5,231
INHS - Crustaceans	252
INHS - Fish	1,486
INHS - Mollusks	2,264
USGS LTRM - Fish	83,609
USGS LTRM - Vegsrs	186
USGS LTRM - Vegtransect	716
USGS NAS	19,026
Total Records	138,546
Number of Duplicates	18,035
Final Total (Duplicates Removed)	120,511

Table 2: Taxonomic groups and the number of species in each that has been introduced and established in Illinois.

Group	# Introduced	# Established
Plants	59	41
Fishes	46	28
Mollusks	16	10
Crustaceans	15	10
Coelenterates	2	0
Diatoms	3	1
Parasitic Worms	1	0
Reptiles-Crocodilians	1	0
Total Species	143	92

Introduction and Establishment

Of the 143 non-native aquatic species that have been recorded in Illinois, 92 are established (119,769 records) and 51 have failed to establish (742 records). Species that failed to establish have generally been recorded infrequently and are native to regions that are climatically different to Illinois. For example, water lettuce (*Pistia stratiotes*), a floating aquatic plant native to Florida, has been recorded in Illinois XX times but has not persisted through winter to become established (USGS 2020). Likewise, the American alligator (*Alligator mississippiensis*), native to the southern US, has been recorded on four occasions but has not become established.

Our methods were slightly different to those of Jacobs and Keller (2016). First, we did not include records of hybrids because of difficulties with identification and the lack of genetic confirmation for these records. The Jacobs and Keller (2016) database included nine hybrids as introduced and established. Second, we removed seven plant species that were included in Jacobs and Keller (2016) because they are not considered to be obligate aquatic. If Jacobs and Keller (2016) had rejected hybrids and only included obligate aquatic species, they would have found 83 introduced and 44 established species, as opposed to the 99 introduced and 60 established species they reported. A final difference in methods is that we included species that have been recorded in the Illinois portion of Lake Michigan but not elsewhere in Illinois. This accounted for eight introduced species in our database, three of which have only been recorded after the Jacobs and Keller (2016) study, and two established species.

The number of newly introduced species per decade increased between 1842 and 2019. (Figure 1; linear regression, n = 18 decades, coefficient = 0.098, r^2 = 0.606, p = 0.0001). Over the same period, the number of newly established species recorded per decade also increased (Figure 1; linear regression, n = 18 decades, coefficient = 0.064, r^2 = 0. 0.571, p = 0.0002). A second-order polynomial regression is a good fit to the cumulative number of introductions ($y = 0.004x^2 - 15.81x + 14{,}600$, r^2 = 0. 977, p = <2.2e-16) and establishments ($y = 0.003x^2 - 11.22x +$

10,400, r^2 = 0. 981, p = <2.2e-16) per year (Figure 2). The average rate of new introductions was 0.803 per year (1 every 14.9 months) for the entire timespan (1842 to 2019) and 1.9 per year (1 every 6.3 months) for the most recent 30 years (1989-2019). For new establishments, the average rate was 0.517 per year (1 every 23.2 months) for the entire timespean and 1.2 per year (1 every 10 months) for the most recent 30 years (1989-2019).

The number of established species reported per year has increased over time (Figure 3). The largest number of established species reported in a single year was in 2014, when 57 species were recorded. We plotted the annual number of sampling records (a proxy for sampling efforts) against the annual number of established species recorded and observed a logarithmic relationship (Figure 3). The curve becomes approximately horizonal at around 34 established species per year, which indicates that current sampling methods and level of effort are sufficient to record approximately 34 of the 92 established species in Illinois each year.

Discussion

AIS Records

Records were found for 120,511 occurrences of 143 non-native aquatic species in Illinois spanning the years 1842 to 2019. This is a 441% increase in number of records, an additional two groups (parasitic worms and diatoms), and a 44.4% increase in the number of species, relateive to the findings of the Jacobs & Keller (2016) study. The large increase in records and species can be attributed to the addition of records from 2013 to 2019 and broader access to historical records facilitated by recent improvements in online data repositories.

Introductions

Cumulative introduction records increased at an exponential rate in Illinois from 1842 to 2019 (Figure 2). This finding is consistent with the results in Jacobs & Keller (2016); however, our results are supported by a much larger pool of records and include an additional 38 years of data. The average rate of discovery for new introductions (0.803 species per year) for the full database and has more than doubled to 1.9 over the past 30 years. This represents an increase to both the *entire* and *recent* introduction discovery rates compared to Jacobs and Keller (2016; 0.71 and 1.33 respectively). Our database uncovered 55 species introductions not detected by the Jacobs and Keller (2016) database (for the same pre-2013 period) and 10 new species introductions post-2013. This increase could be caused by increased sampling, improved access to records, and/or by increased releases. Regardless of the cause, the data presented in this paper make clear that the release of non-native aquatic species in Illinois is higher than was previously believed. As the range of species available through trades increases, and as the region warms under climate change, it is reasonable to expect that more of these species will become established.

Establishments

The rate of discovery of established species in Illinois per decade has significantly increased over time (Figure 1). The Jacobs & Keller (2016) study did find an increase but not one that was statistically significant. Rates of establishment have more than doubled from the full dataset to the most recent thirty years (from 0.517 to 1.2 per year). This is substantially larger than that found by the Jacobs and Keller (2016) study (0.43 and 0.57 respectively). This change in the establishment rate indicates the number of invaders able to survive introduction and become invasive in Illinois is both greater than previously thought and increasingly rapidly. This finding is further emphasized by the fact that our database uncovered 38 established species not detected by the Jacobs and Keller (2016) database (for the same pre-2013 period) and four new species establishments post-2013, which represents a 70% increase in established species detected in our database compared to Jacobs and Keller (2016). This highlights that new establishments are still occurring within Illinois.

Current sampling efforts detect an average of roughly 34 established species per year in Illinois (Figure 3), or approximately one third of the 92 species that have been recorded as established. This indicates that many taxa are not being effectively sampled for and raises the possibility that there may be established species that have not yet been discovered. It is also possible that some species that were previously established are no longer extant in the state. For example, *Juncus compressus* was recorded as established in 1984 but has not been recorded in the state since 2011. The lack of recent records may be a result of limited sampling, a declining population, or localized extinction. The management and eradication of established species is often laborious and expensive (Keller et al. 2008), making early detection a priority for preventive efforts. Additional sampling could help to locate incipient invasions early and increase the chances that they could be eradicated or their spread controlled. It would also help to determine when populations are expanding and shrinking in density and geographic area, each of which is important for management efforts.

The data gathered for this study has been made publicly available on the USGS NAS database platform which is the leading source of aggregated non-native aquatic species information for North America (USGS 2020). Our analysis shows that more non-native aquatic species have been introduced to Illinois – and that more of these species have become established – than was previously known. Further, rates of new records of introduction and establishment are higher now than they have ever been. The addition of this data will help researchers and

management teams understand Illinois' AIS historical and current trends, informing future studies and management efforts. The location of Illinois at the nexus of the Mississippi and Great Lakes Basins makes this database particularly useful for understanding and managing continent-wide spread of AIS. At a broader scale, our results show that there is value in consistently updating datasets of AIS through both new sampling and recording efforts and through re-assessment of previous records as historical data is made more readily available.

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Competing Interests:

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions:

Both authors contributed to the study conception and design. Data collection, cleaning, and analysis were performed by Carter Cranberg with input from Reuben Keller. The first draft of the manuscript was written by Carter Cranberg and both authors worked on subsequent versions of the manuscript. Both authors read and approved the final manuscript.

References

1. Able KW, Ragan SM (2003) Impact of common reed, *Phragmites australis*, on essential fish habitat: influence on reproduction, embryological development, and larval abundance of mummichog (*Fundulus heteroclitus*). Estuaries 26:40–50
2. Bacher S, Blackburn T, Essl F, Genovesi P, Heikkilä J, Jeschke J, Jones G, Keller R, Kenis M, Kueffer C, Martinou A, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson D, Roy H, Saul WC, Scalera R, Kumschick S (2018) Socio-economic impact classification of alien taxa (SEICAT). Methods Ecol Evol 9:159–168. 10.1111/2041-210X.12844
3. Gallardo B, Clavero M, Sánchez M, Vilà M (2015) Global ecological impacts of invasive species in aquatic ecosystems. Glob Change Biol 22. 10.1111/gcb.13004
4. GBIF (2020) GBIF home page. Available from: https://www.gbif.org. Accessed: 2020
5. Havel J, Kovalenko K, Thomaz S, Amalfitano S, Kats L (2015) Aquatic invasive species: challenges for the future. Hydrobiologia 750:147–170
6. Jacobs A, Keller R (2016) Straddling the divide: invasive aquatic species in Illinois and movement between the great lakes and Mississippi basins. Biol Invasions 19. 10.1007/s10530-016-1321-0
7. Keller R, Frang K, Lodge D (2008) Preventing the spread of invasive species: economic benefits of intervention guided by ecological predictions. Conserv biology: J Soc Conserv Biology 22:80–88. 10.1111/j.1523-1739.2007.00811.x
8. Kijewska A, Burzynski A, Roman W (2009) Molecular identification of European flounder (*Platichthys flesus*) and its hybrids with European plaice (*Pleuronectes platessa*). ICES J Mar Sci 66:902–906. 10.1093/icesjms/fsp110
9. Mills E, Leach J, Carlton J, Secor C (1994) Exotic species and the integrity of the great lakes. Bioscience 44. 10.2307/1312510
10. Price AL, Fant JB, Larkin DJ (2014) Ecology of native vs. introduced *phragmites australis* (common reed) in Chicago-area wetlands. Wetlands 34:369–377. https://doi.org/10.1007/s13157-013-0504-z
11. Ricciardi A, Rasmussen JB (1999) Extinction rates of North American freshwater fauna. Conserv Biol 13:1220–1222
12. Ricciardi A (2006) Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity. Divers Distrib 12:425–433. https://doi.org/10.1111/j.1366-9516.2006.00262.x
13. Rosaen AL, Grover EA, Spencer CW(2012) The costs of aquatic invasive species to great lakes states. Anderson Economic Group LLC. (Accessed online 02/20/2021 at: https://www.andersoneconomicgroup.com/Portals/0/upload/AEG%20Report%20-%20AIS%20Econ%20Impact-Final.pdf)
14. U.S. Army Core of Engineers (2014) The GLMRIS report: Great Lakes and Mississippi River Interbasin study. USACE, Washington, D.C.
15. U.S. Army Core of Engineers (2018) The national wetland plant list. Washington, D.C. USACE. Version 2018. Accessed at: http://wetland-plants.usace.army.mil/nwpl_static/v34/home/home.html
16. U.S. Department of Agriculture (USDA) (2019a) Aquatic invasives. In USDA National Invasive Species Center. Version 2019. https://www.invasivespeciesinfo.gov/aquatic#:~:text=Aquatic%20(water%2Ddwelling)%20invasive,on%20land%20(terrestrial%20habitats)

17. U.S. Department of Agriculture (USDA) (2019b) The PLANTS Database. United States Department of Agriculture Natural Resources Conservation Service National Plant Data Team. http://plants.usda.gov
18. U.S. Geological Survey (2020) Nonindigenous Aquatic Species Database. Gainesville, FL. http://nas.er.usgs.gov
19. Vanhaecke D, Garcia de Leaniz C, Gajardo G, Young K, Sanzana J, Mancilla G, Fowler D, Howes P, Argüello C, Consuegra S(2012) DNA barcoding and microsatellites help species delimitation and hybrid identification in endangered galaxiid fishes. PloS One 7 e32939 10.1371/journal.pone.0032939

Figures

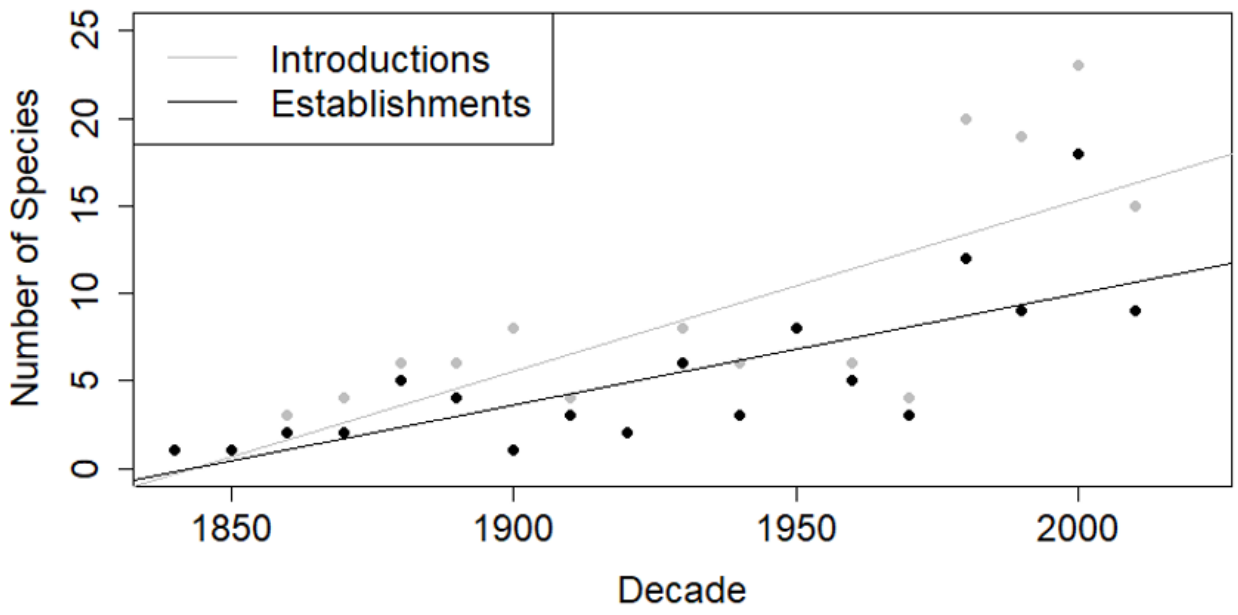

Figure 1

The number of introduced (gray dots) and established (black dots) species discovered per decade. Lines fitted by linear regression for introductions (y = 0.098x – 179.931, r² = 0.606, *p* = 0.0001) and establishments (y = 0.064x – 117.946, r² = 0.571, *p* = 0.0002).

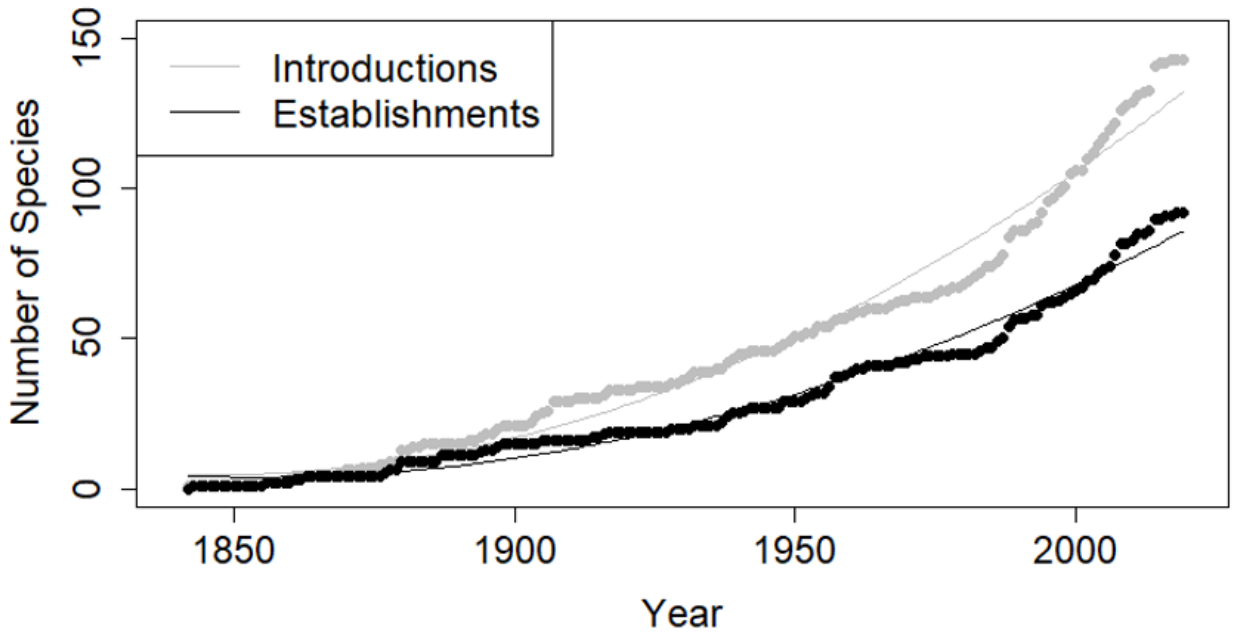

Figure 2

The cumulative numbers of introduced (gray) and established (black) species between 1842 and 2019. Lines fitted by a second-order polynomial regression for introductions ($y = 0.004x^2 - 15.81x + 14{,}600$, $r^2 = 0.977$, $p = <2.2e\text{-}16$) and establishments ($y = 0.003x^2 - 11.22x + 10{,}400$, $r^2 = 0.981$, $p < 2.2e\text{-}16$).

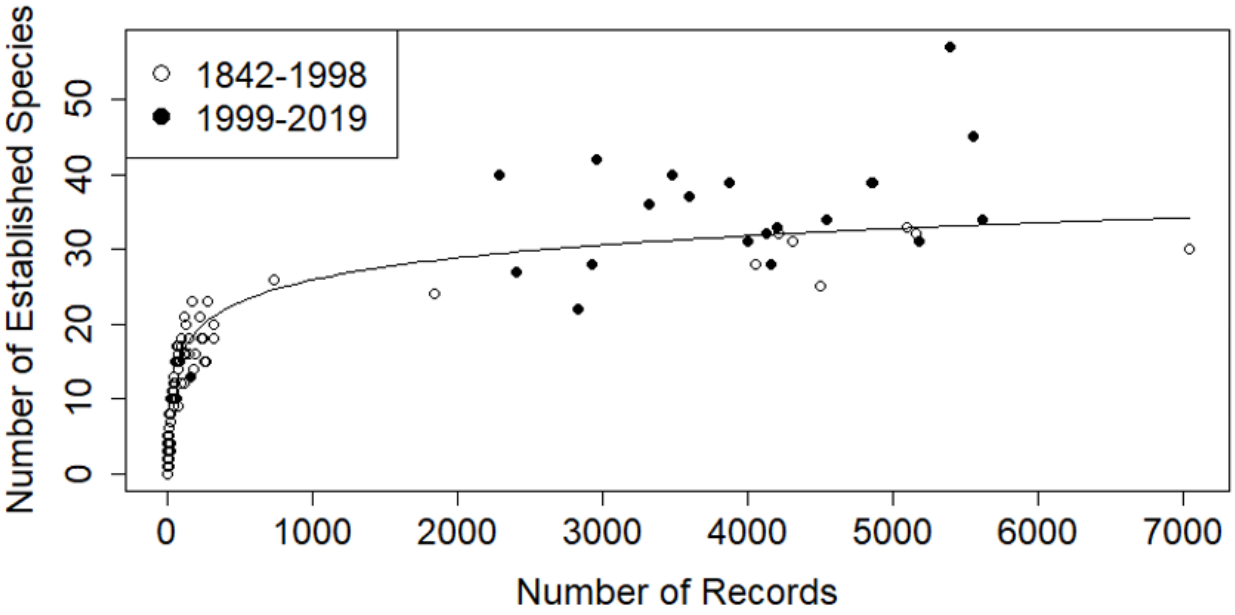

Figure 3

Annual number of established non-native species discovered compared to the annual number of records from 1842 to 2019. Line fitted by a logarithmic regression ($y = 4.276\ln(x+1) - 3.679$, $r^2 = 0.903$, $p = 2e\text{-}16$). Black circles represent the most recent 20 years of records (i.e., 1999 to 2019).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ILAISDatabase.csv