

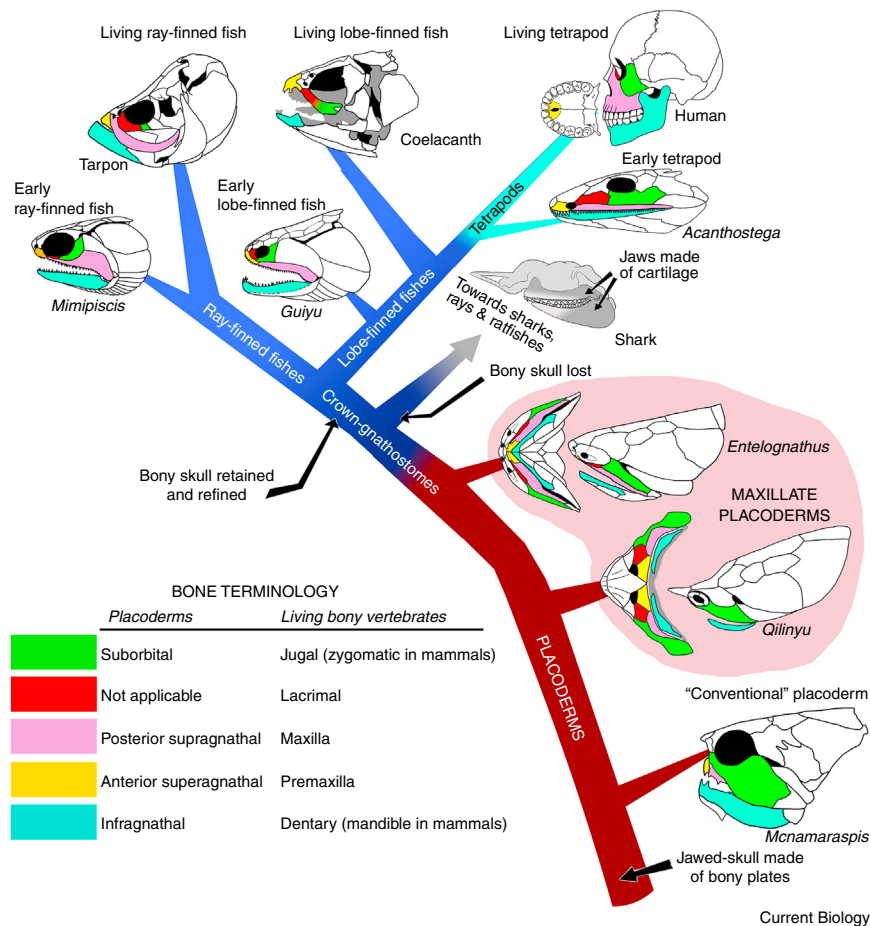


Figure 5. Skeletal innovations in placoderms shaped vertebrate evolution.

Several important skeletal elements of the vertebrate skull originated in placoderms, including the first jawbones and certain cheek and skull-roof bones, whose presence can be traced to extant vertebrates, including humans (from Long (2016), with permission from AAAS; artwork: Brian Choo).

(East Gondwana) but do not appear in the northern hemisphere (Euramerica) until the late Devonian. Endemic freshwater sinolepid antiarchs found in the Late Devonian of China also appear in Australia at the very end of the Devonian, supporting the close proximity of these two geographic regions.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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Social media unveils the hidden but high magnitude of human-mediated biological invasions in China

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Humans are responsible for the release of many non-native animals into the wild. However, these releases occur randomly and are difficult to monitor. Here, using two of the worst invasive herpetofauna as model taxa, we applied an iEcology approach and found a high magnitude of human-mediated releases in China, suggesting this approach can be used to monitor introductions and advise management bodies in a timely manner.

Biological invasion is a significant threat to global biodiversity and society¹. Understanding invasion pathways is critically important to develop timely mitigation strategies for non-native species invasions². For instance, many non-native species, especially animals, are frequently released by humans, both individually and through organized efforts. In contrast to organized religious animal releases, which typically take place at specific dates and locations³, non-organized individual release events, not limited to religious purposes, often occur randomly across spatiotemporal scales. This randomness makes effective monitoring a challenge, thus preventing the proactive control of biological invasions.

Social media like X, Instagram, YouTube, TikTok, and WeChat are the most popular communication platforms for sharing human daily activities worldwide, and have been



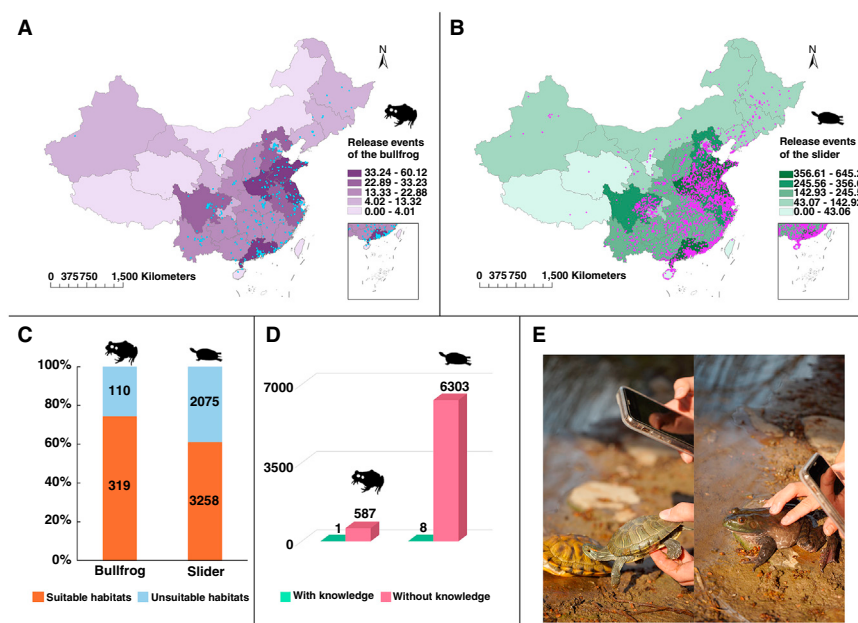


Figure 1. Spatial distribution of invasive species release in China.

Corrected spatial distributions after accounting for sampling bias of release events for two non-native invasive animals in China from Douyin videos across the years 2017 to 2022. Different panels show the spatial pattern of release events using ‘love’ as a keyword to create the background data to control for reporting biases (A for the American bullfrog and B for the red-eared slider; for methodological details see Supplemental information). The points show original coordinates of reported animal release events. Map images created using the National Geographic Information Resources Directory Service System. (C) The proportion of suitable and unsuitable habitats for the two invasive animals from Douyin videos. (D) The proportion of videos representing releasers with and without ecological knowledge on the two invasive animals. (E) Pictures showing animal release events recorded on social media (the pictures were taken by Zhuo Yan). (Bullfrog silhouette: Chuanxin Yu/PhyloPic; slider silhouette: Edwin Price/PhyloPic.)

leveraged by ecologists through an approach referred to as ‘iEcology’⁴. Users share their daily experiences including animal release on the platforms, which provides a unique opportunity to supervise non-native species introductions and facilitate management efforts through the extraction of key information on released species, including time and location of release, in a high-efficiency way. Although the application of social media data in invasion biology has been extensively discussed⁵ and used to identify introduction events of invasive species⁶, there has been a lack of studies capturing the large-scale distributions and magnitude of human release of invasive non-native animals.

Douyin, boasting 809 million users in 2022, stands as one of China’s largest social media platforms. It offers a particularly robust interactive platform and convenient features, motivating users to post videos. Consequently, Douyin hosts numerous short videos

related to animal release, providing an ideal framework for investigating the prevalence of non-native animal releases in China. In this study, we collaborated with Douyin by extensively collecting data on release events involving two of the worst invasive vertebrates — the American bullfrog (*Lithobates catesbeianus* = *Rana catesbeiana*, hereafter the ‘bullfrog’) and the red-eared slider turtle (*Trachemys scripta elegans*, hereafter the ‘slider’) throughout the whole country. These two species are ideal for this study because they have been widely introduced in China through the pet trade or aquaculture and have easily identifiable body features⁷. Moreover, turtles are regarded as a longevity symbol and frogs as ‘pest-control-helpers’ in China, and thus citizens without much ecological and taxonomic knowledge usually release them in the field.

We obtained a total of 426,351 short-form animal release videos, including 34,433 videos specific to

frogs (8,185) and turtles (26,248) across the whole country from 2017 to 2022 (see Supplemental information). These videos were screened manually by at least three co-authors with invasive amphibian and reptile experience to extract information objectively. After removing unusable videos, we kept 19,090 frog and turtle release videos used for further analyses. To protect the privacy of users, all collected data were processed anonymously.

Our results showed a very high magnitude of human release of the two invaders (588 events for bullfrog, an average of 17 ± 3 (SE) events per province; 6,311 for slider, 186 ± 37 per province) in China. We found that the most prevalent places of animal release are reported in the Yangtze River and southeast coast (Figure S1A,B), even after accounting for reporting biases of releases of the two invaders among provinces (Figures 1A,B and S1C,D; for details see Supplemental information). However, considering the fact that a large part of releases will necessarily go undetected, either because they were not captured on video or the videos were not retrieved with search keywords, our results likely represent an underestimation of the true release intensity.

Importantly, we found that 62.08% of release events of the two invaders (74.36% for bullfrog and 61.09% for slider) occurred in suitable habitats (e.g., still or slow-flowing waters) for establishment (Figure 1C). In order to validate this result, ecological niche modeling analysis showed that there was indeed a higher habitat suitability at release grids than non-release ones (Figure S2A,B). In addition, field surveys using the bullfrog as an example also detected the presence of self-sustaining propagules at two release sites (Supplemental information).

Unfortunately, we found that releasers generally lacked knowledge of the ecological impacts of invasive species. Only a few videos for the bullfrog (1/588, 0.17%) and for the slider (8/6311, 0.13%) showed that users have good ecological knowledge (Figure 1D).

In recent years, Chinese governments have increasingly prioritized legislation aimed at

preventing animal-release-induced biological invasions. Our study indicates that social media platforms like Douyin could be one promising avenue to obtain accurate information on non-native species release and strengthen cooperation to monitor enigmatic introductions. For instance, scientists can collaborate closely with social media platforms to routinely extract information. This would provide governments with management guidance by effectively monitoring hotspots of animal release events in time. Meanwhile, our study suggests governments could use official accounts on social media platforms to broadcast scientific education videos and promote public awareness of biological invasion impacts, especially for those unfamiliar with invasive species⁶. The ‘Douyin nature’ module stimulates users to protect threatened species by gamifying video creation. Similar work could be performed to encourage citizens in general, not just youths and students⁹, to increase their knowledge of invasive species and stop releasing them. Our present study only focused on the two most recognizable species to guarantee the accuracy of evaluation. Yet there is still a large proportion of videos with unidentified species. The accuracy of animal recognition thus needs to be enhanced, for example through emerging technologies such as artificial intelligence, which could be applied to social media platforms to facilitate invasive species identification, along with the aid of taxonomists and invasion biologists¹⁰.

SUPPLEMENTAL INFORMATION

Supplemental information contains two figures, experimental procedures, acknowledgments, and author contributions and can be found with this article online at <https://doi.org/10.1016/j.cub.2023.12.007>.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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Letter

Conservation action should come before publication

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With regard to the recent discovery by Menchetti *et al.*¹ of the red imported fire ant in Sicily, we highlight the delay in communicating the observation and we call upon the scientific community to ensure that any records of new invasive alien species are reported immediately after detection, before publication of details. We call upon scientific journals to ensure that the peer-review process does not hinder management action by having authors declare that they have adhered to regulations regarding invasive alien species, especially reporting, as is mandatory in the case of animal ethics statements and research permits. In several instances, failure to do this has had negative consequences that could have been averted².

Menchetti and colleagues¹ reported the establishment of the red imported fire ant *Solenopsis invicta* in Sicily, the first population of this species in Europe. *S. invicta* is one of the most harmful invasive alien species, severely impacting biodiversity, economy, as well as human and livestock health; it is included among 100 of the worst invasive alien species by the IUCN invasive species specialist group³ and among the top 10 invasive alien species with most documented negative impacts on nature's contributions to people by the recent IPBES assessment on invasive alien species⁴; it has also been included in the list of invasive alien species of Union concern by the European Union Regulation 1143/2014 since July 2022.

In their paper, Menchetti and colleagues¹ documented 88 nests extending over about 4.7 hectares

