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Global records of the invasive freshwater apple snail *Pomacea canaliculata* (Lamarck, 1822)

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Keywords: Africa, Ampullariid, Asia, freshwater, invasive alien species, North America, occurrence, Pacific Islands, South America.

SUMMARY

Pomacea canaliculata (Caenogastropoda: Ampullariidae) is a freshwater snail native to the lower Del Plata basin in South America. However, along with other species collectively known as "apple snails", it has been introduced to many regions outside its natural range. In these areas, it has spread rapidly, causing extensive damage to aquatic crops and adversely affecting the biodiversity and ecological functioning of natural wetlands. This publication aims to present an updated, accurate, and open-access database of *P. canaliculata* occurrence records worldwide. The database is intended to support ecological studies and pest management initiatives, with a particular emphasis on distinguishing *P. canaliculata* from other apple snail species to prevent misidentifications. It compiles all reliable records of *P. canaliculata* from both its native and invaded ranges, offering comprehensive coverage of its global distribution. The result is a dataset of 718 records from 29 countries across Africa, South America, North America, Asia, and the Pacific Islands, reported from the early 20th century to the present. This occurrence dataset is now included in the Global Biodiversity Information Facility (GBIF), hosted by the "Ministerio de Ciencia, Tecnología e Innovación Productiva" under the publisher "Instituto de Ciencias Biológicas y Biomédicas del Sur (INBIOSUR)".

INTRODUCTION

Pomacea canaliculata (Lamarck 1822) is a freshwater snail belonging to the Ampullariidae family, which includes the largest freshwater snails in the world, collectively known as "apple snails" (Hayes et al. 2015). Ampullariids possess both a well-developed gill and a lung, enabling them to thrive in freshwater habitats with low oxygen levels and to withstand dry periods (Seuffert and Martín 2009). *P. canaliculata* is dioecious, undergoes internal fertilization, and deposits distinctive pink egg masses above the waterline, with embryos developing fully within the cleidoic eggs (Pizani et al. 2005). It is a polyphagous species that can feed on a wide variety of trophic resources, including macrophytes, algae, detritus, carrion, other macroinvertebrates and freshwater snails as well as their eggs (Saveanu et al. 2023).

Pomacea canaliculata is native to South America, with its natural distribution range restricted to the lower Paraná, Uruguay, and de la Plata rivers within the lower Del Plata basin (Hayes et al. 2012, Seuffert and Martín 2021). In its natural range, snails are commonly found in quiet and shallow lotic and lentic waterbodies (Fig. 1; Martín et al. 2001). This and other South American apple snails have been introduced to many regions outside their natural ranges, where they have rapidly spread. Due to their preference for macrophytes, they have become serious pests of aquatic crops such as rice and taro (Hayes et al. 2008, Joshi et al. 2017). According to Jiang et al. (2022), *P. canaliculata* is recognized as the gastropod with the highest economic costs globally. This species also poses a significant threat to the biodiversity and functioning of natural wetlands by altering nutrient cycling and primary productivity (Carlsson et al. 2004, Horgan et al. 2014, Gilioli et al. 2017, Martín et al. 2019). Additionally, *P. canaliculata* has been implicated in the recent emergence of human eosinophilic meningitis in Southeast Asia (Martín et al. 2019). For these reasons, *P. canaliculata* has been listed among the 100 worst invasive species globally by the International Union for Conservation of Nature (IUCN; Lowe et al. 2000), although some of the impacts are probably caused by its congener *Pomacea maculata* (Perry 1810), a species with very similar external morphology whose identity was only clarified a few years ago (Hayes et al. 2012, Yang and Yu 2019). The spread and impacts of apple snails around the world and their numerous unique bioecological traits have sparked international interest and led to an exponential growth of publications on this gastropod family (Yao et al., 2023).

Pomacea canaliculata is currently established in various regions around the world, including numerous countries in North and South America, Africa, Asia, and Oceania (Joshi et al. 2017, EPPO 2024). However, many of these records are not fully reliable as they were made prior to the clarification of invasive apple snail identities in Asia (Hayes et al. 2008), North America (Rawlings et al. 2007) and also in the native range (Hayes et al., 2012). Additionally, some records were reported by non-specialized researchers or were simply classified under "*Pomacea*" or "*Pomacea* sp.". Due to this lack of reliable identification, there is a substantial amount of data in the scientific literature and biological databases that have been used or may be considered for future studies regarding geographic distribution patterns, ecological niche modelling, or pest management decisions, that could lead to inaccurate outcomes. To address this issue, our aim is to conduct a comprehensive review of all available reports on *P. canaliculata*, filtering for those with confirmed identities, and ultimately creating a dataset of accurate and up-to-date global records.

Figure 1. *Pomacea canaliculata* snails in its native range in South America (El Huáscar stream, Buenos Aires province, Argentina).

MATERIALS AND METHODS

The records reported in this database were compiled from the following sources:

- Many of the records reported for Argentina, particularly those from the last 25 years, are personal records obtained during field collection trips (Martín et al. 2001, Seuffert and Martín 2013, 2021). These records are based on an extensive survey performed from 1999 to 2019, covering most of the central and northern provinces of Argentina (Salta, Jujuy, Tucumán, La Rioja, Mendoza, San Juan, San Luis, La Pampa, Córdoba, Santiago del Estero, Buenos Aires, Neuquén, Río Negro, Santa Fe, Entre Ríos, Corrientes, Misiones). The southernmost provinces (Chubut, Santa Cruz and Tierra del Fuego) were not included, as *Pomacea canaliculata* is not able to survive the low winter temperatures experienced in these regions (Seuffert and Martín, 2021).

- Other records were obtained from the article by Hylton Scott (1958), which was the first comprehensive examination of the taxonomy and distribution of Argentinian ampullariids. In this study, Hylton Scott reviewed all specimens referred to *Ampullaria canaliculata* Lamarck, 1822 (sic) in the malacological collection of the Argentine Museum of Natural Sciences (MACN Bernardino Rivadavia, Buenos Aires) and reported the corresponding localities, all of which date to the first half of the 20th century. This information was then cross-referenced with the Ampullariidae catalogue provided by Alejandro Tablado from MACN.

- A different source of records was the available scientific literature mentioning *Pomacea canaliculata*. We searched for reliable reports based on the authors' expertise in ampullariid taxonomy and/or those with genetic confirmation of the identity, which included geographic coordinates or at least a precise locality. We paid special attention to those studies that distinguished between the correct and incorrect global records of *P. canaliculata*

and *P. maculata* from the literature, such as Hayes et al. (2012).

- Finally, many records were provided by researchers with extensive expertise in *Pomacea canaliculata* from different countries around the world. These contributors include R. Cowie from the USA, F. Horgan from Ecuador, T.H. Ng from Singapore, J.C.H. Ip and J.W. Qiu from China, Y. Yusa from Japan and G. Aditya from India. They supplied numerous georeferenced locations and provided their expert opinions to help exclude records that pertain to other congeners, such as *Pomacea diffusa*, and particularly the often-confused *P. maculata*.

Some records were excluded from this database because they were deemed to be either misidentified, transient, or not representative of natural climatic conditions. Details are as follows:

- In Argentina, a population of *P. canaliculata* introduced into the drainage channels of CORFO ("Corporación de Fomento del Valle Bonaerense del Río Colorado") in southern Buenos Aires Province (39º23'35"S, 62º36'59"W) with the aim of controlling submerged aquatic weeds (Cazzaniga 1981), and two adult specimens reported from a place in the Limay River (Río Negro Province, Argentina, 38º58'20"S, 68º11'27"W), on a single occasion in 2004 (Darrigran et al. 2011). Subsequent visits to both locations to search for evidence of *P. canaliculata* revealed no adults or eggs (pers. obs.).

- A record from southwestern Siberia (54º25'32"N, 86º27'38"E, Yanygina et al. 2010), restricted to the area of maximal heating in the discharge water channel from a thermal power plant.

- Reports mentioned in the scientific literature with uncertain identity or undetermined records, such as "*Pomacea*" or "*Pomacea* sp.," as well as records referring to localities that could not be accurately locate.

- Records from Europe because the apple snails reported in Spain are *P. maculata* (López et al. 2010; Schrader et al. 2020) and populations of an undetermined *Pomacea* sp. from France and Switzerland were successfully eradicated (EPPO 2018).

- Eight Records from India reported in GBIF since all specimens of *Pomacea* there belong to *P. diffusa* (G. Aditya pers. comm.).

- Records from some states of USA (Texas, Georgia, Mississippi, Louisiana, South Carolina) reported in GBIF since they were misidentifications of *P. maculata* (R. Cowie pers. comm.).

RESULTS

Data set description

The data were formatted according to the Darwin Core quick reference guide (Darwin Core Maintenance Group 2020, Wieczorek et al. 2012). The dataset lists data of Record-level (institutionCode, basisOfRecord); Occurrence (occurrence-ID, associatedReferences); Location (higherGeography, continent, country, countryCode, stateProvince, locality, decimalLatitude, decimalLongitude); Taxon (scientificName, namePublishedIn, higherClassification, kingdom, phylum, class, order, family, genus, specificEpithet, scientificNameAuthorship, taxonRank, scientificName). The dataset was exported to DARWINCORE format and then uploaded to the IPT of MINCyT (Ministerio de Ciencia, Tecnología e Innovación Productiva, Argentina).

Dataset name: Global records of the invasive freshwater apple snail *Pomacea canaliculata* (Lamarck, 1822).

Character encoding: UTF-8

Format name: Darwin Core Archive format.

Distribution: the data set is available in Global Biodiversity Information Facility (GBIF). GBIF UUID 26820b90-367e-4029-b70c-

db601c591128. Instituto de Ciencias Biológicas y Biomédicas del Sur (INBIOSUR; CONICET-UNS) publishes this resource and is itself registered in GBIF as a data publisher endorsed by GBIF Argentina.

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Taxonomic coverage

General description: All records correspond to *Pomacea canaliculata* (Lamarck, 1822). Special care was taken to discriminate this from other apple snail species, especially *Pomacea maculata*, whose external morphology is very similar and coexists with *P. canaliculata* in many of the invaded regions.

Taxonomic ranks: Species, *Pomacea canaliculata* (Lamarck, 1822).

Common names: apple snail– golden apple snail (GAS).

Quality Control for Taxonomic Data: The identity of the records reported in this dataset was carefully verified. We included records from our own field samplings in Argentina as well as from museum collections. Data obtained from the literature were selected based on the expertise of the authors in ampullariid taxonomy and also included those records with genetic confirmation of species identity. Additionally, we consulted several researchers for reports and their expert opinions on any doubtful records to ensure accuracy.

Temporal coverage

Specimens: The dataset includes records of specimens reported from as early as 1902 in museum collections up to records reported through the present day.

Geographic coverage

Study extent description: The geographic coverage comprises a survey of all available records of the invasive freshwater south American apple snail *Pomacea canaliculata* reported from any place of the world.

Bounding box: minimum longitude 157° 43' 44.4" W; maximum longitude 147° 28' 30" E; minimum latitude 38° 25' 12" S; maximum latitude 39° 54' 46.8" N. The occupied areas extend over 29 countries distributed in Africa, South America, North America, Asia and Pacific Islands. High latitudes are not included in the geographic coverage since this species is not tolerant to freezing and has never reported to survive winter temperatures at latitudes above 40° under natural conditions.

Sampling description

Sampling design: The dataset was created obtaining records of *P. canaliculata* from field samplings, scientific literature, museum collections and catalogues, and by the request to colleagues with expertise in this species.

An R script was used to complete the "stateProvince" fields (Grattarola, 2024). We improved the quality of the final dataset using

Data Validator developed by GBIF (2024) to identify and address potential issues.

Quality control for geographic data: All geographic coordinates were checked by the collector, M. E. Seuffert, to detect georeferencing errors and incorrect locations, ensuring that each point corresponded to a location on the continent and in the correct country. All the locations were georeferenced with the GEOLocate tool and checked visually on the map.

Summary statistics

The dataset comprises a comprehensive survey of all available records of the invasive freshwater South American apple snail, *Pomacea canaliculata*, including both specimen and observation data reported from any location worldwide, whether within its native range or in invaded areas.

This dataset includes 718 records from 29 countries across Africa, South America, North America, Asia, and the Pacific Islands (Fig. 2), spanning reports from the early 20th century to the present day. It compiles all confirmed records of *Pomacea canaliculata* reported worldwide, including 199 from its native range in South America and 519 from invaded areas. The continents with the greatest amount of records are South America (n=361) and Asia (n=277), which makes 88.9% of all records (Fig. 3). The sources from which the records of *P. canaliculata* were obtained were distributed as follows: 77% came from scientific literature, 12% were provided by experts on ampullariids from different parts of the world, and 11% from our own sampling efforts. South American records came from all three sources, Asian records from scientific literature and experts and all other records only from the literature (Fig. 4).

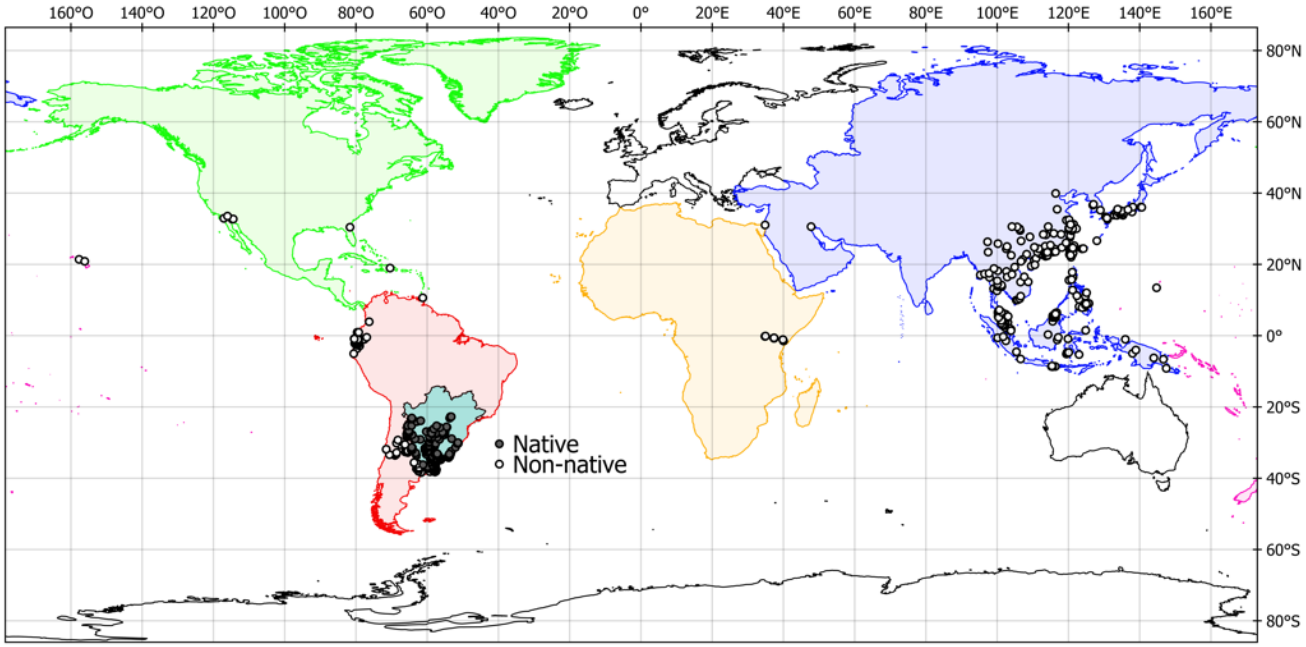

Figure 2. Global native and non-native records of *P. canaliculata* reported in the data set. The basin comprising the native range (Del Plata basin in South America) is shown in light blue. Continents with reported records are indicated in different colours and continents without records are in white.

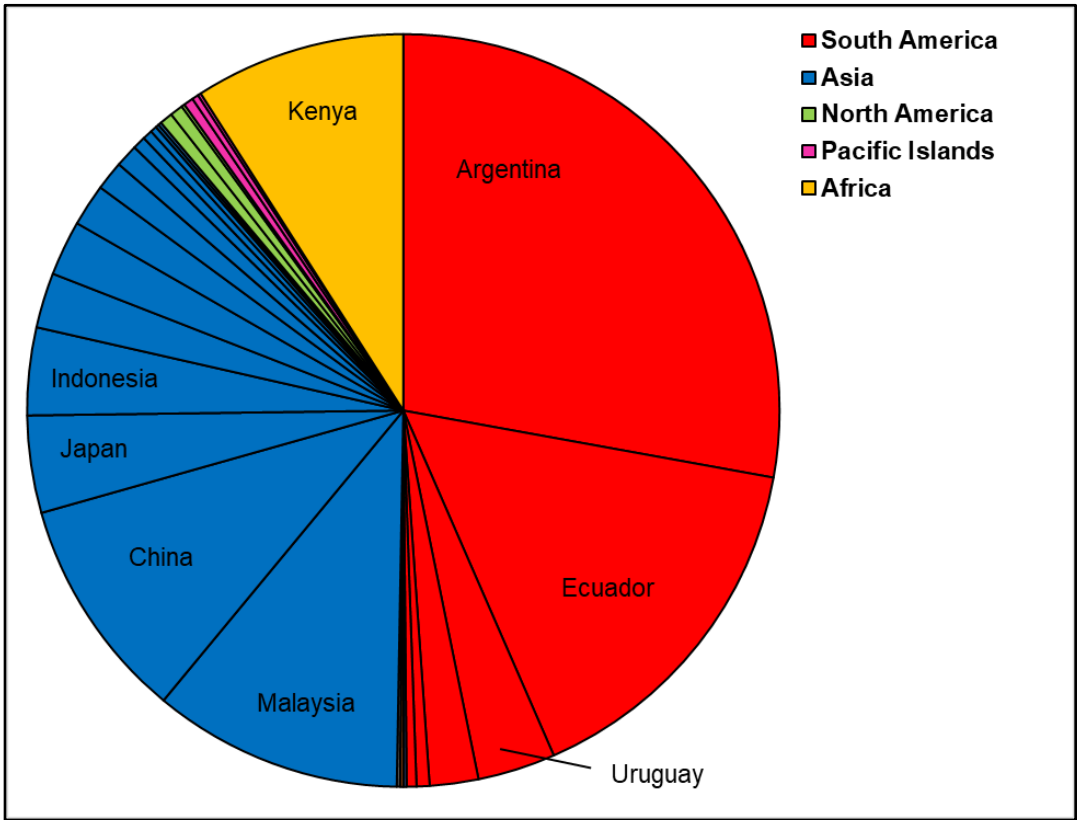

Figure 3. Pie chart showing *P. canaliculata* records from different continents: South America, Asia, North America, Pacific Islands and Africa; the names of the countries with more than 20 records are specified in the corresponding pieces (only Argentina and Uruguay are included in the native range).

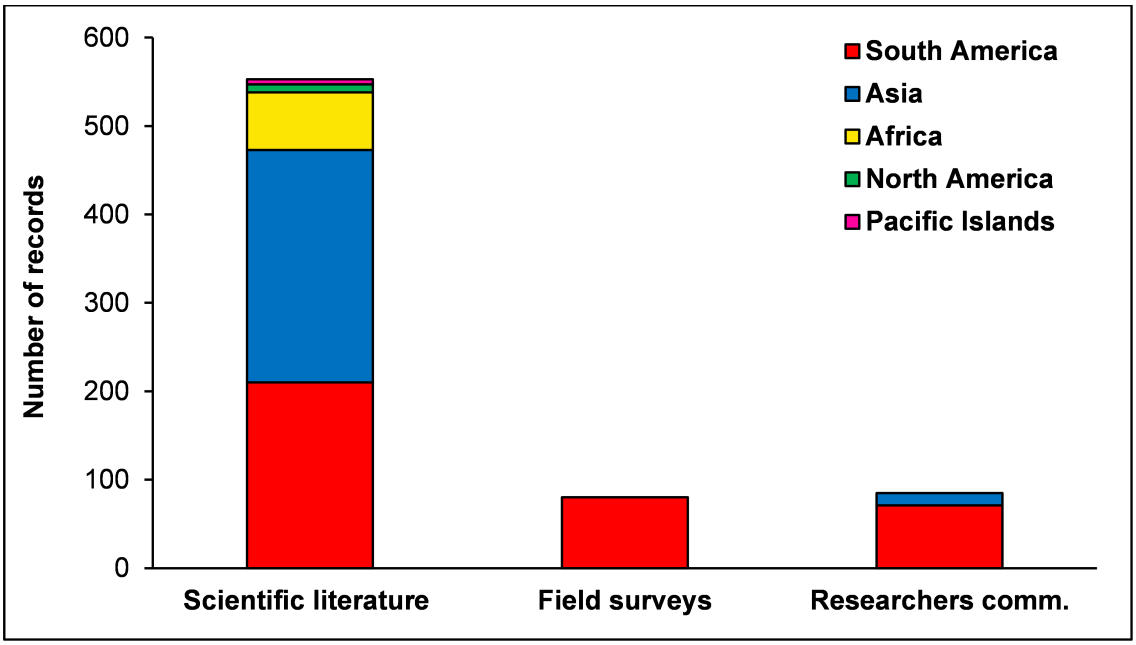

Figure 4. Bar chart showing the three sources where *P. canaliculata* records from different continents were obtained: reports from scientific literature, obtained from field surveys or provided by communication form researchers with expertise in Ampullariidae worldwide.

Up to date, the only continent, aside from Antarctica, where this species is absent is Europe, given that the only established apple snail species is *P. maculata*, reported in rice fields and wetlands of the Ebro Delta in north-eastern Spain (López et al. 2010; Schrader et al. 2020). Besides, incipient populations of *Pomacea* sp. reported in France and Switzerland were successfully eradicated (EPPO 2018).

In Oceania, *P. canaliculata* is present only on some Pacific Islands (Hawaii, Guam, and Papua New Guinea) and has not been reported in Australia to date. However, it has been warned since the late 20th century that large regions of Australia are at risk of invasion by this species due to the climatic similarity with its native range (Baker 1998; Seuffert and Martín 2024).

Kenya is the only African country with confirmed records of *P. canaliculata*, where it was detected relatively recently, in 2020, and has been established in the Mwea irrigation scheme (Buddie et al. 2021, Djeddour et al. 2021). However, there are extensive regions with suitable climatic conditions, especially in the southern part of the continent (Seuffert and Martín 2024), now facing a higher risk of invasion, as established populations of this species already exist in Kenya.

In Asia, the species is primarily found in southern and eastern regions, where the climatic conditions have facilitated its establishment and subsequent role as an agricultural pest (Joshi et al. 2017, Seuffert and Martín 2024). Additionally, there are isolated reports from Iraq (Al-Khafaji et al. 2016) and Israel (Roll et al. 2009), the latter established in outdoor pools or ponds but systematically eradicated. India is up to date free of this species (G. Aditya, pers. comm.) but is climatically suitable for its invasion (Baker 1998; Seuffert and Martín 2024). Moreover, *P. diffusa* is the only non-native apple snail present there, which has entered India through the ornamental fish trade (G. Aditya, pers. comm.).

In North America, *P. canaliculata* has been reported in Mexico (Campos et al. 2013), the Dominican Republic (Hayes et al. 2012), and three U.S.A. states (Florida, Arizona, and California) (Rawlings et al. 2007); the most widespread exotic apple snail in the United States is *P. maculata* (Joshi et al. 2017). The native range of *P. canaliculata* in South America is within Del Plata basin, encompassing regions of southern Brazil, Uruguay, Paraguay, and Argentina (Hayes et al. 2012, Seuffert and Martín 2021). Over recent decades, this species has expanded westward and southward beyond its natural limits, largely due to human activities, resulting in its occupation of new basins in Argentina (Seuffert & Martín 2021). Additionally, *P. canaliculata* is present in two areas of central Chile (Letelier and Soto-Acuña 2008, Jackson and Jackson 2009, Almendras García 2021) and is well established in Ecuador, where it has invaded most major rice-growing regions since its introduction in 2005 (Horgan et al. 2021). Other South American records include isolated reports from Peru (Ramírez et al. 2020), Colombia (Hayes et al. 2012) and Trinidad and Tobago (Mohammed 2015).

The first report of *P. canaliculata* outside its native range was its expansion beyond the limits of its original distribution in La Plata basin in Argentina during the middle of the 20th century and gradually expanded to southwards and westwards (Fig. 5; Seuffert and Martín 2021). The first transoceanic report of this species was its introduction in Taiwan in 1979 as a protein food source Afterwards, the snails escaped from the breeding facilities into natural water systems and expanded to paddy fields and wetlands. During the 80's and 90's *P. canaliculata* gradually invaded all south and east Asia. The next invaded region was some Pacific Islands, as Hawaii and Guam in 1989 and Papua New Guinea in 1991. After that, it was reported in the states of California (1997), Florida (1997) and Arizona (2005). Other American countries invaded were Ecuador and Colombia in 2005, Chile and Mexico in 2009, Trinidad in 2014 and

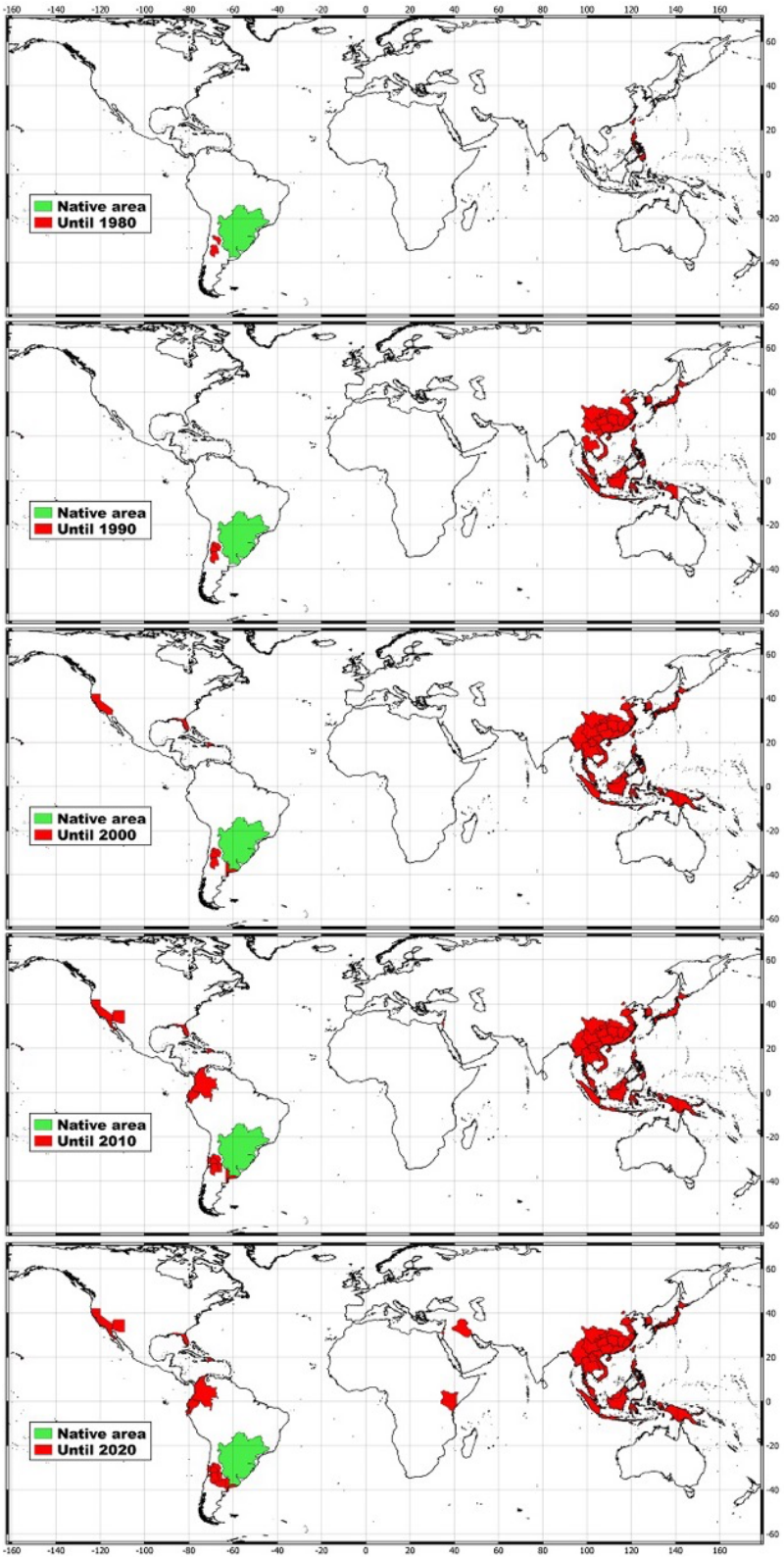

Figure 5. Timeline of the spread of *P. canaliculata* from its native area of distribution to all invaded regions worldwide until today. The invasion process is divided by decades, showing in red the cumulative invaded areas until 1980, 1990, 2000, 2010 and 2020 (the last new invaded area was reported in 2020). The native area is showed in green in all maps and in red the invaded countries of first-order administrative units (states, provinces, etc.) in China, United States, Mexico, Argentina and Chile.

Peru in 2019. During the past few years, this species arrived in the middle east, Israel before 2009 and Iraq in 2013. Finally, in 2020 *P. canaliculata* reached for the first time the African continent (in 2006 it has been reported in the Reunion Island, EPPO 2024), being found in the Mwea irrigation scheme in Kenya 2020 (all dates detailed in Supplementary Material 1).

DISCUSSION

The records reported in this dataset provide a valuable resource for researchers and decision-makers globally, as *Pomacea canaliculata* exhibits unique traits that set it apart from other invasive apple snails. For example, this species can tolerate a wider range of temperatures than other *Pomacea* species, likely due to its extensive native range, making it the apple snail that reaches the southernmost latitudes in the world (Martín et al. 2001). In invaded paddy fields in Asia, *P. canaliculata* can endure overwintering conditions in temperate regions where other apple snails, such as *P. maculata*, cannot (Matsukura and Yoshida 2024). Additionally, *P. canaliculata* shows greater tolerance to desiccation compared to other species (Yoshida et al. 2014). The problems caused by this species in aquatic crops in South and East Asia have prompted numerous studies on its biology and ecology, including several on its current range, its potential distribution and the expected changes under a global climate change scenario. Understanding the identity of invasive alien species, both in paddy fields and natural wetlands, is essential for designing effective control measures and predicting potential expansion ranges or new areas of invasion. *P. canaliculata* is capable of establish in more temperate regions as compared to other apple snails. This information is particularly important in the context of global climate change, which may cause some distribution areas to contract while others to expand (Seuffert and Martín 2024). Recently, Wang et al. (2024) analyzed the potential distribution of *Pomacea canaliculata* under climate change in China, using global records for model calibration. However, the records retrieved from biodiversity databases such as GBIF were often inaccurate, including several locations where this species is reported but confirmed to be absent according to apple snail experts. Similar issues with occurrence records have been identified in other studies analyzing the distribution of this species, particularly in Asia (detailed in Seuffert and Martín 2024). Future potential areas of invasion are likely to vary among different invasive apple snails due to their specific life history traits and native ranges, thus accurate records are essential for enhancing these predictions.

Many temperate, subtropical, and tropical regions around the world are climatically suitable for *P. canaliculata*, especially Central and South America, southeastern North America, southern Africa (including Madagascar), southern Europe, southern and eastern Australia, southern and eastern Asia, and numerous Pacific islands (Baker 1998, Lei et al. 2017, Seuffert and Martín 2024). Many of them are already inhabited by *P. canaliculata*, but in some of these areas, such as India, Australia and Europe, no reports of this species currently exist. This could be due to the snails actually being absent or to undersampling in these areas. Regions that, besides their suitable climatic conditions, exhibit abundant water resources and extensive agricultural activities, such as rice cultivation, are particularly at risk for the negative impacts of this invasive freshwater snail. Proactive measures are essential to prevent the introduction and subsequent ecological and economic impacts associated with this species. It is therefore recommended to actively search for *P. canaliculata* snails to detect them as early as possible and facilitate eradication efforts, as has already been achieved in parts of Europe (EPPO 2018). In areas where the species is confirmed to be absent, strict precautionary measures should remain in place to prevent its potential introduction, such as through quarantine, environmental monitoring and inspection protocols.

CONCLUSIONS

This publication aims to present an updated, accurate, and open-access database of *P. canaliculata* occurrence records worldwide, intended to support ecological studies and pest management initiatives. One of the main contributions of this database is to distinguish as accurately as possible the records of *P. canaliculata* from those of other apple snail species to prevent misidentifications. It compiles all reliable records of *P. canaliculata* from both its native and invaded ranges, offering comprehensive coverage of its global distribution. The result is a dataset of 718 records from 29 countries across Africa, South America, North America, Asia, and the Pacific Islands, reported from the early 20th century to the present. This occurrence dataset is now included in the Global Biodiversity Information Facility (GBIF), hosted by the "Ministerio de Ciencia, Tecnología e Innovación Productiva" under the publisher "Instituto de Ciencias Biológicas y Biomédicas del Sur (INBIOSUR)". This database is dynamic and will be kept updated. New records will be gradually added as they are reported, both in already occupied regions and in new, yet uninvaded areas. For this reason, we also encourage anyone willing to contribute new records to the database to contact the authors via email to help further enrich it.

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SUPPLEMENTARY MATERIAL

Year of the first record of *Pomacea canaliculata* in each country.

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