Rendiconti Lincei. Scienze Fisiche e Naturali (2025) 36:647–657
https://doi.org/10.1007/s12210-025-01325-5

RESEARCH PAPER

The introduced red swamp crayfish (*Procambarus clarkii*) Girard, 1852, as prey for birds in Italy: a first citizen science-based checklist

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Received: 6 January 2025 / Accepted: 18 March 2025 / Published online: 7 April 2025

Abstract

Invasive alien species (IAS) are negatively impacting native species and ecosystems worldwide. Among them, the red swamp crayfish (*Procambarus clarkii*) has been extensively studied in Italy due to its detrimental effects on ecosystems and native crayfish species. While extensive data are reported on the diet of *P. clarkii,* less is known about its role in the trophic web as prey for birds. In this study, we gathered online data from scientific databases and citizen science sources for the first time, obtaining information on the bird species preying on *P. clarkii* in Italy. Due to the heterogeneity of collected data, two bird lists were compiled based on record types. When species identification was assessed by the authors, a reliability score was assigned for each crayfish species identification. Using strictly filtered data, we recorded 26 bird species from eight Italian regions. When including all available records, both filtered and unfiltered, two additional regions were identified, bringing the total to 46 bird species. Most of these species are considered strictly carnivorous, but surprisingly, three species (*Anas platyrhynchos*, *Fulica atra*, and *Gallinula chloropus*) are primarily herbivorous. These results indicate (i) the paradoxical role of *P. clarkii* as a prey for a wide range of bird species, including both carnivores and herbivores, and species not exclusively tied to wet ecosystems, (ii) a spatial pattern of predation at a national scale and (iii) the role of citizen science data as a valuable tool for studying the ecology and role of invasive crayfish species in trophic webs.

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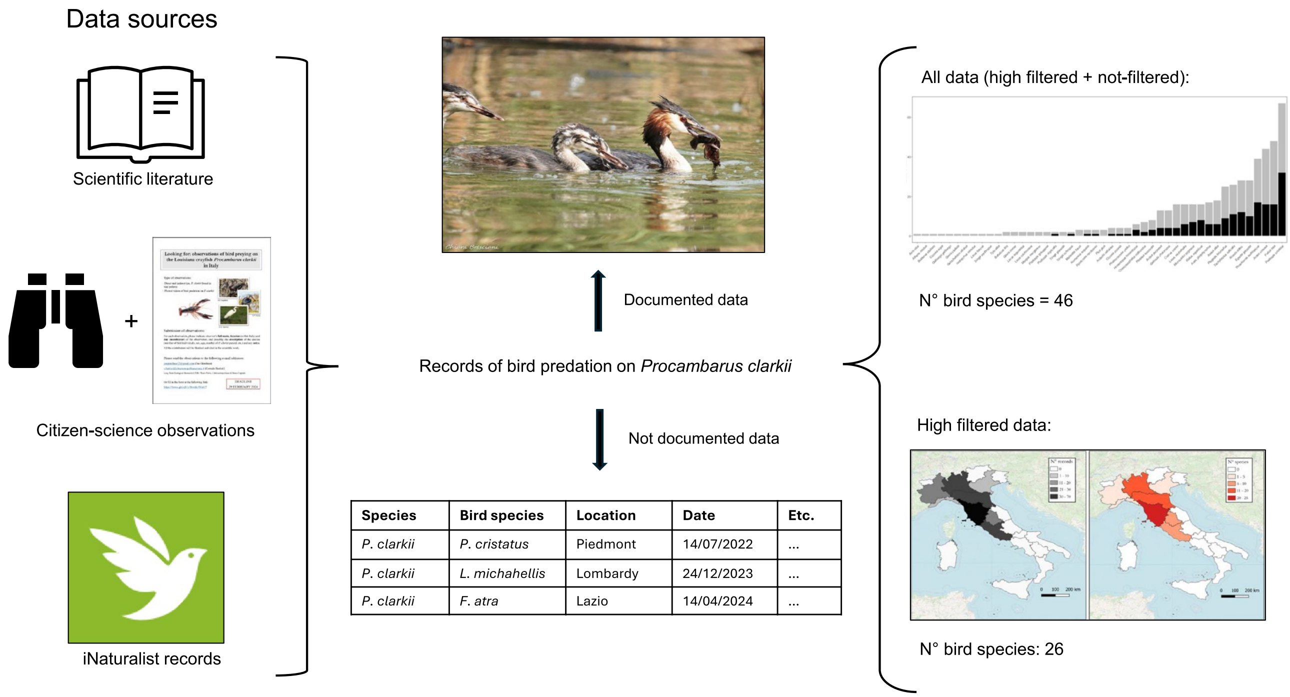
Graphical abstract



Keywords Citizen science · Invasive alien species · Predation · Waterbirds · Wetlands

1 Introduction

Invasive alien species (hereinafter IAS) are one of the major drivers of biodiversity loss worldwide (Molnar et al. 2008). By impacting different biological levels (e.g., genetic diversity, populations, and ecosystems), IAS pose significant threats to native species (McNeely 2001), causing substantial damage to ecosystem services and local economies (Charles and Dukes 2008; Holmes et al. 2009; Pejchar and Mooney 2009). The rapid spread of IAS in non-native areas presents a challenge for their management (e.g., Vander Zanden and Olden 2008), especially in regions where the introduction and trade of exotic species has occurred for centuries (Hulme 2009). This issue is particularly pronounced in Europe, a global hub of international trade, which has facilitated the colonization and establishment of several IAS (Keller et al. 2011; Haubrock et al. 2021). In Europe, guidelines for mitigating the negative effects of IAS are outlined in Regulation 1143/2014 (European Union 2014). This regulation includes a list of species of Union concern (the Union list) that must be managed and, when feasible, eradicated (http://data.europa.eu/eli/reg/2014/1143/oj).

Focusing on crayfish, six taxa are included in the Union List: *Faxonius limosus* (Rafinesque, 1817), *Faxonius rusticus* (Girard, 1852), *Orconectes virilis* (Hagen, 1870), *Pacifastacus leniusculus* (Dana, 1852), *Procambarus clarkii* (Girard, 1852), and *Procambarus fallax f. virginalis* (Hagen, 1870). The negative impacts of these crayfish species in Europe are well documented in scientific literature (e.g., Gherardi 2007; Ficetola et al. 2012; Souty-Grosset et al. 2016).

The red swamp crayfish, also known as the Louisiana crawfish (*Procambarus clarkii*) is a crayfish species, native to freshwater systems in Central and North America (Hobbs 1989). Over time this species has become increasingly invasive in Europe, where it thrives in suitable habitats such as wetlands or small rivers (Gherardi 2006; Scalici 2009). The impacts of *P. clarkii* in non-native areas include competition with an eventual displacement of indigenous crayfish species (e.g., Gherardi 2006; Manenti et al. 2014), transmission of the crayfish plague pathogen (the oomycete *Aphanomyces astaci*; Aquiloni et al. 2011), and the consumption of a wide number of native animal and plant species (e.g., Correia 2003; Alcorlo 2004).

The first European observation of *P. clarkii* in the wild occurred in Spain, in 1973 (Gutiérrez-Yurrita and Montes 1999), followed by observations in Germany (mid-1980s), England (1991), France (1976) and Portugal (1979; Souty-Grosset et al. 2016). In Italy, the species was first observed in 1989, in a small stream near Turin (Piedmont, Italy), likely due to the accidental escape of individuals from an astaciculture facility (Delmastro 1992). After its initial introductions, *P. clarkii* rapidly spread across much of northern Italy and has recently been reported in central and southern regions, including small islands (e.g., Morpurgo et al. 2010; Battisti and Scalici 2020). A comprehensive and updated analysis of the distribution and biological invasion of *P. clarkii* in Italy is provided by Lo Parrino et al. (2020).

Extensive scientific literature is available on the ecology and biological traits of *P. clarkii*, including its trophic ecology (Creuhet et al. 2007), population ecology (Donato et al. 2018, Dörr et al. 2021) and reproductive biology (Alcorlo et al. 2008). However, comparatively less information exists about its role as prey for other species, particularly birds. In this context, Giordano and Battisti (2024), have documented predation of *P. clarkii* by nine bird species, including Mallard (*Anas platyrhynchos*), Eurasian Coot (*Fulica atra*), Glossy Ibis (*Plegadis falcinellus*), Squacco heron (*Ardeola ralloides*), Purple Heron (*Ardea purpurea*), Great Egret (*Ardea alba*), Little Egret (*Egretta garzetta*), Common Kingfisher (*Alcedo atthis*) and Common Snipe (*Gallinago gallinago*). Despite these findings, a comprehensive list of the predators feeding on *P. clarkii* in invaded non-native areas (e.g., Europe) is still lacking.

Citizen science, i.e., the public participation in scientific research and knowledge production, offers a promising approach for gathering scientific data and raising awareness about IAS (Pocock et al. 2023). This approach has gained global recognition and is increasingly well-developed, being applied across a wide range of scientific disciplines (Fraisl et al. 2022). Citizen science protocols can be highly effective in generating large datasets within relatively short timeframes, thanks to the active involvement of many social groups (Silvertown 2009). Several examples of citizen involvement in recording IAS are available (e.g., Gallo and Waitt 2011; Cardoso et al. 2017; Howard et al. 2022), including efforts specifically targeting crayfish (Faraone et al. 2017).

Given the generally limited understanding of invasive crayfish as preys, this study aimed to collect and review all available data on *P. clarkii* predation by bird species in Italy. To achieve this, a citizen science approach was employed, resulting in the first national-level list of bird species preying on this invasive crayfish.

2 Materials and methods

The collection of records about crayfish predations by bird species was carried out between December 2023 and June 2024, during a citizen-based campaign promoted on social media platforms (Facebook) and wildlife-photo websites (Table S1). A specifically designed scientific poster (Fig. S1) was used to facilitate data collection of predation events, including those recorded in previous years. The poster included all the necessary information about the required metadata for the records and the submission format.

A further review was conducted using online databases (Google Scholar, Web of Science, and Scopus) and the iNaturalist platform (https://www.inaturalist.org/) to gather more data about predation records. The search terms included all possible combinations of English and Italian translations for: “Red swamp crayfish”, “Louisiana crawfish”, “predation”, “*Procambarus clarkii*”, “bird species” and “Italy”.

The collected records consisted of both direct and indirect observations. Direct records consisted of bird individuals actively preying on crayfish, whereas indirect records were observations of crayfish remains found in bird pellets and necropsies.

Each record was accompanied by the following metadata: the observer’s name, date, location, a brief description of the predation event, and, if available, the identification of the bird and crayfish species. When species data were unavailable, the bird or crayfish were identified by the authors using specific diagnostic keys (e.g., birds: Del Hoyo et al. 1992; systematic order: Baccetti et al. 2021; crayfish: Mazzoni et al. 2004; Souty-Grosset and Fetzner 2016).

All the citizen-science collected records were divided into two categories: (i) image-documented observations (photo, photo sequences or video) and (ii) non-image documented observations (i.e., without visual documentation). To ensure better quality and independence of the data, the observations were first screened. Based on the date, location, author, and species, only one photo per bird individual was counted for all analyses.

For the image-documented record type, where the crayfish identification was unavailable or not explicitly provided during the data collection process, we assigned a reliability score to each record. This score was given based on the reliability of the identification of the crayfish species by the authors.

The diagnostic characteristics considered for species identification, detectable through photos, photo sequences and videos were: (i) red coloration, (ii) absence of branchiocardiac grooves, (iii) presence of a spine on the cheliped carpus, (iv) rough claws with pronounced tubercles, (v) rostrum with diverging edges and (vi) shape of the body (Mazzoni et al. 2004). A score of 0 (lowest reliability) was assigned to records where the crayfish species could not be identified. A score of 1 was given for records where the crayfish species was identified as not *P. clarkii* (i.e., no diagnostic keys for species determination). Finally, a score of 2 (“very likely”) was assigned to records with one diagnostic characteristic, while a score of 3 (“confirmed”) was given to those with more than one. For records where the bird species had not been previously assessed, expert ornithologists (J.G., G.V., and C.B.) visually identified them using widely accepted diagnostic characteristics (e.g., beak, size, plumage), as documented in standard bird guides (e.g., Svensson et al. 2010).

To maintain a conservative approach, we used only high-reliability data (hereafter 'filtered data') for analysis, considering only three-scored values (i.e., confirmed records identified by the authors). Bird identification at the species level was possible for all filtered data due to the high quality of the photos and videos. All other data (scores 0, 1, and 2) were excluded from further analysis due to their low reliability.

From the total number of filtered data (Nr), we determined the number of bird species and families, subdivided by Italian regions (NIR), as well as the number of records per year (Ny). The relative frequencies (fr) of the first two parameters were also calculated. Statistical analyses of differences among frequencies were performed with the chi-square test. All the analyses were performed with R (version 2024.09.1, R Core team 2021). Considering the high number of data collected, the overall high heterogeneity of data, and to avoid further data stratification, the same analyses were conducted using the combination of the highest quality filtered data (3-scored) and all the records where the identification was not directly performed by the authors: not documented citizen science records, bibliographic, and iNaturalist records (hereafter "not-filtered data").

3 Results

A total of 654 records were obtained through data collection. After an initial skimming to remove duplicate records and observations, 406 records (both direct and indirect records) were retained for further analysis. Of these, 356 records were collected through citizen-science efforts (social media and websites), while the remaining records came from bibliographic research ($N = 43$) and iNaturalist ($N = 7$); (2023). Considering only the citizen-science data ($N = 356$), species identification (both for birds and *P. clarkii* specimens) was already provided during data collection for 88 records. For the remaining 268 records, consisting exclusively of direct predations, crayfish, and bird identifications were conducted by the authors: 183 were classified as "3" (confirmed identification of *P. clarkii*), 40 as "2" (very likely), 6 as "1" (not *P. clarkii*) and the remaining 39 as "0" (unidentified crayfish species). For all these records, bird individuals were identified at species level considering the high-quality of the documentation (photos and videos).

Considering only the high-filtered "3-scored" values ($n = 183$), a total of 26 bird species from 12 families (Fig. 1), were identified as predators, with an average of 7.04 ± 7.16 records per species, with *Podiceps cristatus* (32), *Threskiornis aethiopicus* (17), *Ardea cinerea* (16), *Fulica atra* (16), and *Tachybaptus ruficollis* (11) being the most frequent ($fr \geq 0.05$) (Table 1). Differences in the

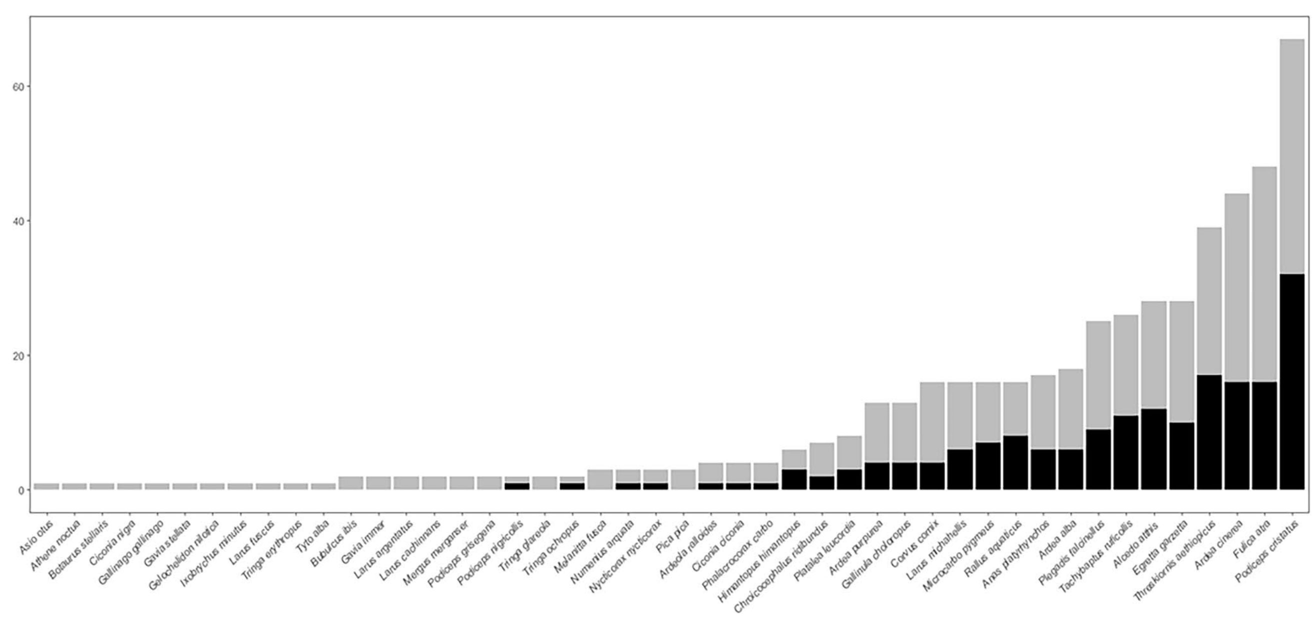


Fig. 1 Histogram of the records collected for each bird species. Black columns represent high-filtered data (3-scored values), while grey columns the non-filtered data (Bibliography, iNaturalist and Citizen-science non-documented data). The image was made with R (version 2024.09.1, R Core team 2021)

Table 1 List of the bird species, with the respective Family, number of three-scored records (n), total number of records (n tot) and their respective total frequency (fr tot)

Family	Species	n	n tot	fr tot	Family	Species	n	n tot	fr tot
Alcedinidae	*Alcedo atthis*	12	16	0.050		*Larus fuscus*	0	1	0.003
Anatidae	*Anas platyrhynchos*	6	11	0.034		*Larus michahellis*	6	10	0.031
	Melanitta fusca	0	3	0.009	Phalacrocoracidae	*Microcarbo pygmaeus*	7	9	0.028
	Mergus merganser	0	2	0.006		*Phalacrocorax carbo*	1	3	0.009
Ardeidae	*Ardea alba*	6	12	0.037	Podicipedidae	*Podiceps cristatus*	32	35	0.109
	Ardea cinerea	16	28	0.087		*Podiceps grisegena*	0	2	0.006
	Ardea purpurea	4	9	0.028		*Podiceps nigricollis*	1	1	0.003
	Ardeola ralloides	1	3	0.009		*Tachybaptus ruficollis*	11	15	0.047
	Bubulcus ibis	0	2	0.006	Rallidae	*Gallinula chloropus*	4	9	0.028
	Botaurus stellaris	0	1	0.003		*Fulica atra*	16	32	0.100
	Egretta garzetta	10	18	0.056		*Rallus aquaticus*	8	8	0.025
	Ixobrychus minutus	0	1	0.003	Recurvirostridae	*Himantopus himantopus*	3	3	0.009
	Nycticorax nycticorax	1	2	0.006	Scolopacidae	*Gallinago gallinago*	0	1	0.003
Ciconiidae	*Ciconia ciconia*	1	3	0.009		*Numenius arquata*	1	2	0.006
	Ciconia nigra	0	1	0.003		*Tringa erythropus*	0	1	0.003
Corvidae	*Corvus cornix*	4	12	0.037		*Tringa glareola*	0	2	0.006
	Pica pica	0	3	0.009		*Tringa ochropus*	1	1	0.003
Gaviidae	*Gavia immer*	0	2	0.006	Strigidae	*Asio otus*	0	1	0.003
	Gavia stellata	0	1	0.003		*Athene noctua*	0	1	0.003
Laridae	*Chroicocephalus ridibundus*	2	5	0.016	Tytonidae	*Tyto alba*	0	1	0.003
	Gelochelidon nilotica	0	1	0.003	Threskiornithidae	*Platalea leucorodia*	3	5	0.016
	Larus argentatus	0	2	0.006		*Plegadis falcinellus*	9	16	0.050
	Larus cachinnans	0	2	0.006		*Threskiornis aethiopicus*	17	22	0.069
					TOTAL	46 species	183	321	1

number of species records were statistically significant ($\chi^2 = 181.99$; $p < 0.001$).

Out of the total 183 records, two lacked geographic information ("not specified"). The remaining 181 records were collected from 8 Italian regions (mean number of records per region: 18.03 ± 20.05; $n = 8$; Table 2), with the highest number of records reported from Tuscany (69), Lombardy (26), Emilia-Romagna (25) and Lazio (21); (Fig. 2). Most species were observed in Tuscany (22), Emilia-Romagna (16) and Lombardy (11); mean number of species per region: 9.63 ± 6.59; (Fig. 2, Table 2). Differences in the number of records per region were statistically significant ($\chi^2 = 31.571$; $p < 0.001$).

Table 2 List of the Italian regions, number of three-scored records (n), number of total records (n tot) and the total frequencies (fr_n), the number of species from the three-scored records (S), the total number of species and the total frequencies (fr_S)

Regions	n	n tot	fr_n	S	S tot	fr_S
Calabria	0	2	0.006	0	2	0.043
Emilia-Romagna	25	41	0.131	16	21	0.457
Latium	21	41	0.128	9	13	0.283
Liguria	4	4	0.012	2	2	0.043
Lombardy	26	67	0.215	11	27	0.587
Marche	0	1	0.003	0	1	0.022
Piedmont	13	35	0.109	5	15	0.326
Tuscany	69	87	0.271	22	25	0.543
Umbria	14	21	0.065	7	12	0.261
Veneto	9	14	0.044	5	9	0.196
Total	181	313	1	26	46	1
Not specified (within Italy)	2	8			8	

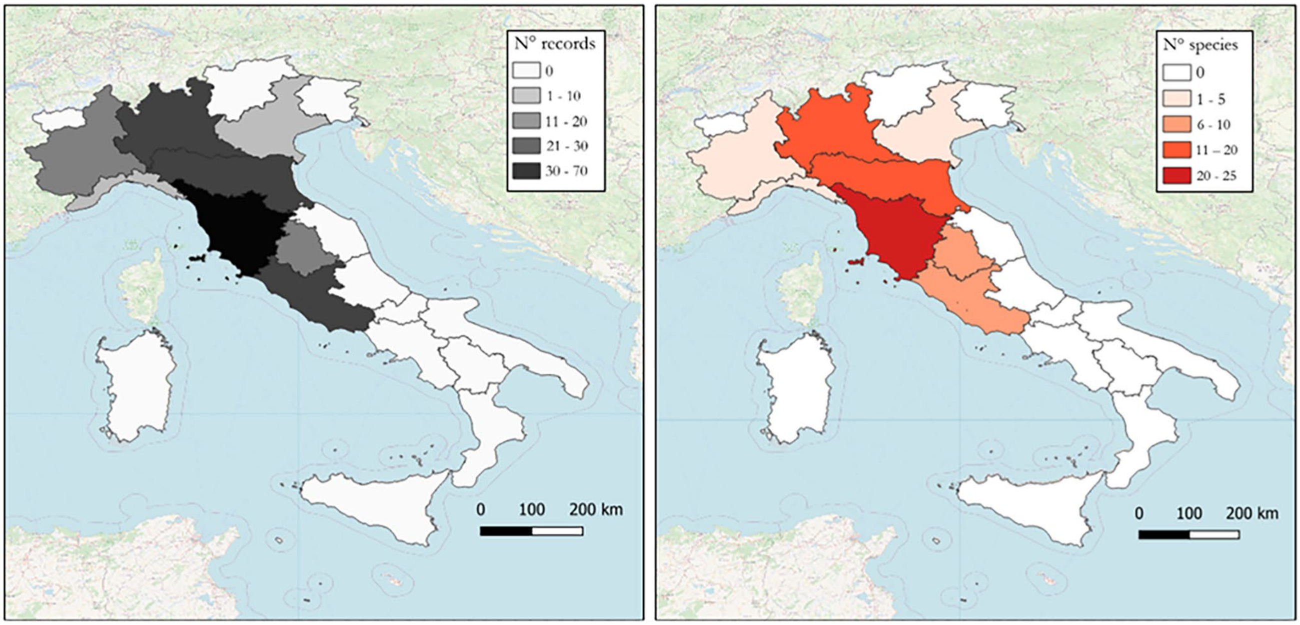


Fig. 2 Image of the distribution of the records (sx) and species (dx) across the Italian regions using filtered data. The scale of grey and red represent respectively the number of records and number of species. The image was made with QGIS 3.34.13 (http://www.qgis.org); (QGIS.org 2024)

In the temporal analysis, one record lacked a specified year of reporting ("not specified"). The remaining 182 records spanned 12 different years, from 2008 to 2024 (Table 3). The highest number of records were from the most recent years: 2023 ($n = 58$), 2022 ($n = 37$), and 2021 ($n = 22$).

From the combination of the filtered and not filtered data (i.e., iNaturalist, Bibliographic sources and undocumented citizen-science records), a total of 46 bird species from 15 families were identified across 321 records, with an average of 6.98 ± 8.57 records per species (Tab. 1). Bird species with overall higher frequency ($fr \geq 0.05$) were *Podiceps cristatus* (35), *Fulica atra* (32), *Ardea cinerea* (28) and *Threskiornis aethiopicus* (22). Differences in the number of species records were statistically significant ($\chi^2 = 473.9$; $p < 0.001$).

Out of the total 321 records, 8 lacked geographic information ("not specified"). With the inclusion of non-supervised data, two additional Italian regions (Calabria and Marche) were added, bringing the total to 10 regions. The mean number of records per region was 31.6 ± 29.2; $n = 10$; Table 2). The highest number of records was reported from Tuscany (87), Emilia-Romagna (41) and Lazio (41) and Piedmont (45); (Fig. S2). Most species were observed in Lombardy (27), Tuscany (25) and Emilia-Romagna (21) with an average number of species per region: 12.7 ± 9.5 (Tab. 2). Differences in the number of records per region were statistically significant ($\chi^2 = 239.81$; $p < 0.001$).

Finally, 23 records lacked a specified reporting year ("not specified"). The remaining records spanned every year between 2006 and 2024. The highest number of records were obtained in 2023 ($n = 82$), 2022 ($n = 53$), and 2021 ($n = 33$); (Table 3).

Table 3 List of the sampling years in which were collected the three scored records (n), all the records (n tot) and the respective total frequencies (fr_n); und. years': undetermined years

Years	N	n tot	fr_n
2024	14	21	0.070
2023	58	82	0.275
2022	37	53	0.178
2021	22	33	0.111
2020	12	19	0.064
2019	14	26	0.087
2018	7	14	0.047
2017	7	10	0.034
2016	4	10	0.034
2015	0	6	0.020
2014	2	7	0.023
2013	3	8	0.027
2012	0	1	0.003
2011	0	1	0.003
2010	0	1	0.003
2009	0	2	0.007
2008	2	2	0.007
2007	0	1	0.003
2006	0	1	0.003
Total	182	298	1
Und. years	1	23	

4 Discussion

We gathered a substantial number of records of birds preying on *P. clarkii*, primarily through the distribution of a scientific flyer shared across social media groups and wildlife photography websites. The high number of records obtained and their heterogeneity, highlight the widely recognized value of citizen science (e.g., engaging birdwatchers and social media users) as an important resource for ecological research (Dickinson et al. 2010; Kobori et al. 2016). In contrast, a significantly smaller portion of records was obtained through reviews of scientific literature, emphasizing the complementary role of integrating alternative data sources with conventional methodologies (MacPhail and Colla 2020; Di Febbraro et al. 2023).

However, citizen science data can be subject to bias, including uneven spatial coverage, inconsistent sampling effort, and variation in the quality of photo and video documentation (Isaac et al. 2014; Geldmann et al. 2016). In this regard, citizen science data may have been influenced by factors such as the distribution (e.g., Aquiloni et al. 2010), density, and behavior of crayfish, the characteristics of wetland ecosystems, and the nature and distribution of citizen participation (Brown et al. 2019). For instance, nature photographers may have disproportionately focused on charismatic species rather than less visually appealing ones, potentially introducing bias in bird species quantification (e.g., Stoudt et al. 2022). Moreover, most of the records were obtained in Central and Northern Italian regions, likely reflecting sampling biases, such as an unequal density of observers (birdwatchers and nature photographers) and the bird distribution and phenology (e.g., Courter et al. 2013), that may have affected the geographic distribution of our data. Given the high heterogeneity of data used in this study (i.e., documented, undocumented, and raw records), data filtering was essential for subsequent analyses. Additionally, selecting diagnostic features that were clearly visible in photos and videos, was critical for accurately identifying crayfish species (following Mazzoni et al. 2004). The most readily detectable traits in photo and video documentation were the bright red coloration and the presence of the spine on the cheliped carpus. Meanwhile, body shape and other morphological features were employed for finer discrimination among sympatric crayfish species (e.g., *F. limosus*; Bruno et al. 2024).

Considering the filtered data (3-scored records) and higher taxonomic classifications, a significant number of records were obtained for the families Ardeidae, Podicipedidae, Rallidae, and Threskiornithidae. The differences in the number of species records are strongly influenced by the behavior of bird species (Morelli et al. 2022). More human-tolerant species, such as *Fulica atra* (e.g., Zhang et al 2018), are more likely to be reported while foraging compared to more elusive reed-bed bird species (e.g., *Botaurus stellaris*, Puglisi et al. 2001) which are less frequently documented with photos or video. Although *P. clarkii* is commonly found in riparian vegetation along streams and small lakes (Aquiloni et al. 2005), it serves as a food resource not only for species restricted to open-water habitats but also for urban-adapted bird species (e.g., Corvidae, Giordano and Battisti 2024). These findings also highlight the presence of an alien trophic chain (*T. aethiopicus* preying on *P. clarkii*; Cucco et al. 2021), which has already been documented in the scientific literature (Amori and Battisti 2008; Strong and Pemberton 2001).

At the species level, the highest number of records were obtained for predominantly carnivore water-related species (feeding mostly on vertebrates and invertebrates), with *P. cristatus, T. aethiopicus*, *A. cinerea*, and *T. ruficollis,* as confirmed by analyses on both filtered and unfiltered data. The only exception was *F. atra*, which is primarily herbivorous (e.g., Mouronval et al. 2007; Metna et al. 2015). Additionally, *G. chloropus* and *A. platyrhynchos*, two species with predominantly herbivorous diet (e.g., Mouronval et al. 2007; Lardjane-Hamiti et al. 2015), were also observed preying on *P. clarkii*, but they were represented by fewer records (<16). As hypothesized by Giordano and Battisti (2024), the consumption of *P. clarkii* by herbivorous species may indicate either slight dietary changes, with a possible increase in the animal intake, or an opportunistic foraging behavior facilitated by the crayfish's availability. However, more studies, including metagenomic analyses (e.g., Oehm et al. 2017), are needed to confirm this potential dietary shift, also considering the phenology of the bird species.

The spatial data, considering both the three-scored values and all collected records (filtered and unfiltered), indicate that Northern and Central Italian regions contain the greatest number of records collected, with Lombardy (in the North) and Tuscany (in Central Italy) also showing greater species diversity. Lombardy and Tuscany are highly populated regions and an unequal distribution of birders and nature photographers may have introduced a bias in our dataset. This suggests that as observations accumulate at the regional level, the recorded diversity of crayfish predators increases, reflecting either a greater variety of potential predators in larger regions or the presence of critical habitats where interactions between *P. clarkii* and bird species are particularly pronounced. The distribution map of *P. clarkii* provided by Lo Parrino et al. (2020) confirms the species' widespread presence in these regions, including at the provincial level (Fig. 3). Additionally, the richness of bird species in these areas is already well-documented (Lardelli et al. 2022). Temporal trends indicate that *P. clarkii* was being preyed upon while its invasion was still ongoing in Italy (Lo Parrino et al. 2020). Our results show that the first recorded

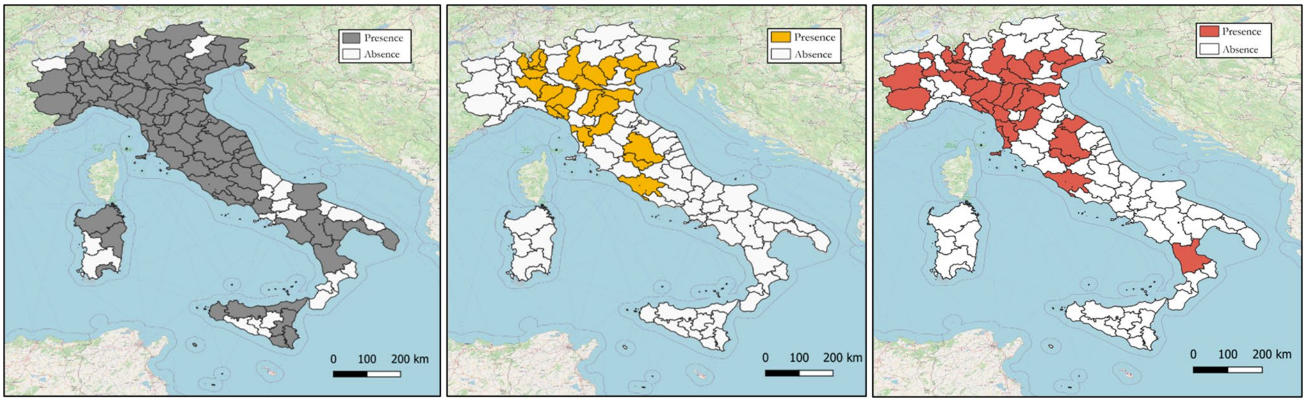


Fig. 3 Comparisons between the latest distribution map of *P. clarkii* in Italy (left, data from Lo Parrino et al. 2020) and the citizen-based records maps (3-scored records in the center and all data on the right) show that all recorded predation events fall within the species' distribution range. The image was made with QGIS 3.34.13 (http://www.qgis.org; QGIS.org 2024)

predation events occurred in 2006 and 2007, approximately 20 years after *P. clarkii* was first documented in the wild, in 1989 (Delmastro 1992). However, peaks in the number of records were obtained in 2022 and 2023, considering both datasets. Given potential biases in record detection, temporal trends may reflect an increase in public engagement in reporting observations, possibly driven by growing awareness of invasive species and their ecological impacts (e.g., Novoa et al. 2017).

Compiling a list of predatory bird species can highlight the potential role of the invasive alien crayfish as a newly available food resource. Similar to other non-native species (Schlaepfer et al. 2011), *P. clarkii* presents a paradoxical status: it acts both as a predator of several native animal and plant species (e.g., Correia 2003, Correia et al. 2005) and as a prey for numerous bird species (Correia 2001; Giordano and Battisti 2024), as well as other vertebrates (for mammals: see Beja 1996). Notably, some of these predators are in demographic decline and of conservation concern (e.g., Poulin et al. 2007; Ferreira et al. 2019). As suggested by Tablado et al. (2010), while *P. clarkii* may represent a widely available prey for threatened species, it may also drive species at lower trophic levels towards extinction. This dual impact underscores the need for a comprehensive cost–benefit analysis in its management, by evaluating the net balance between potential positive impacts on species in numerical decline and the well-documented negative impacts (Correia 2003; Alcorlo 2004; Gherardi 2006; Manenti et al. 2014). Therefore, the integration of this invasive species into food chains highlights the complexity of managing its impacts (Loureiro et al. 2018).

Despite evidence that this invasive species represents a food resource for many birds, including species of conservation interest, our data represent only an initial exploratory and primarily descriptive analysis. This preliminary investigation does not allow us to assess any population-level effects on either prey or predators. For instance, we cannot determine whether *P. clarkii* is an occasional or frequent prey item for the recorded bird species, nor whether its consumption has any impact on predator populations. Further studies should investigate the actual role of bird predation as a potential control mechanism or, conversely, whether predation selectively removes crayfish with lower fitness, leading to a paradoxical effect on prey populations and adult/juvenile ratios. For example, variation in bird density across habitats and seasons may influence the proportion of different crayfish age classes at various sites (Poulin et al. 2007; Meineri et al. 2014) and potentially facilitate the dispersal of this non-native species (e.g., Anastácio et al. 2014). Furthermore, *P. clarkii* exhibits remarkable behavioral flexibility when facing new predators (Gherardi 2006), a trait that warrants further investigation.

Future studies are needed to quantify the potential biases influencing these differences, such as predator diversity, prey distribution and abundance, the availability of native prey for birds, and variations in citizen participation. A controlled field sampling design is essential to assess the role of birds in controlling the invasive *P. clarkii* and to better understand how these factors relate to the invasion of this IAS in Italy.

Despite these limitations, this initial investigation allowed us to: (i) compile a list of species that prey on *P. clarkii* and map the distribution of this prey–predator relationship at a national scale; (ii) highlight that not only carnivorous species prey on crayfish, but also herbivorous species incorporate this crustacean into their diet; and (iii) identify predators that are not directly associated with wetland ecosystems. Future research should examine the long-term implications of *P. clarkii*'s role in bird trophic webs and its impact on non-native ecosystems.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12210-025-01325-5.

Acknowledgements We would like to thank all the citizen scientists who provided videos, images, and data. We are also grateful to the members of Facebook groups and pages who contributed to the data collection: "CISO- Centro italiano studi ornitologici", "EBN Italia il birdwatching italiano", "GOL (Gruppo Ornitologico Lombardo)", "Conoscere gli Uccelli", "Birdwatching & Wildlife", "Gli amici del Parco e della Piana di Sesto Fiorentino", "Tringa-FVG", "Lifeclaw", "Amici di Torre Flavia", "Manzolino-Tivoli" and "Italian Ornithology" (see Supplementary materials Tab. S1). Two anonymous reviewers provided useful comments and suggestions to the first draft of the manuscript.

Author contributions J.G. carried out the citizen-science survey and bibliographic review; J.G., C.B., M.S., D. T., G.V., S.B. wrote the main manuscript. All the authors reviewed the manuscript.

Funding Open access funding provided by Università degli Studi di Torino within the CRUI-CARE Agreement. This research was conducted without funding.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval No human participants and/or animals have been involved in this research.

Consent for publication No human participants have been involved in this research.

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