Research Article

From classical collections to citizen science: change in the distribution of the invasive blowfly *Chrysomya albiceps* (Wiedemann, 1819) in Chile

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Abstract

Tracking the invasion of *Chrysomya albiceps* (Wiedemann, 1819) (Diptera: Calliphoridae) in South America has multiple distribution gaps. In the present study, we describe the distribution change of this invasive blowfly through time in Chile, using combined methods of collection of occurrences to fill these distributional gaps. We reconstruct the current distribution with entomological collection data, literature, and citizen science. We found that the distribution of *C. albiceps* expanded only in the central zone of Chile from 2006 to 2011. However, from 2015, the species was recorded in northern Chile, more than 1300 km away from the first locality recorded, through samples and citizen science. We discuss the distribution change and the possible cause of its expansion in the country.

Key words: Calliphoridae, Chilean ecosystems, distribution gaps, integrative collect methods, synanthropy

Introduction

Biological invasions are one of the most important threats to biodiversity (Sala et al. 2000). However, the current distribution of many invasive species is still unknown. *Chrysomya albiceps* (Wiedemann, 1819) (Diptera: Calliphoridae; Figure 1) is an invasive blowfly originally from tropical Africa, and it was introduced accidentally into South America in ships, specifically to Brazil around 1978 (Peris 1987). Other countries invaded were Argentina, Bolivia, Colombia, Costa Rica, Dominica, Guatemala, Nicaragua, Paraguay, Peru, Uruguay and Venezuela (Baumgartner and Greenberg 1984; Guimarães et al. 1978; Mac-Lean and González 2006; Peris 1987; Wolff and Kosmann 2016). This species is considered an invasive blowfly because larvae are facultative predators and very aggressive with other native blowflies such as *Cochlyiomya macellaria* (Fabricius, 1775) (Diptera: Calliphoridae) being able to change even cadaveric fauna (Faria et al. 1999; Faria and Godoy 2001; Rosa et al. 2006). Also, *C. albiceps* have been

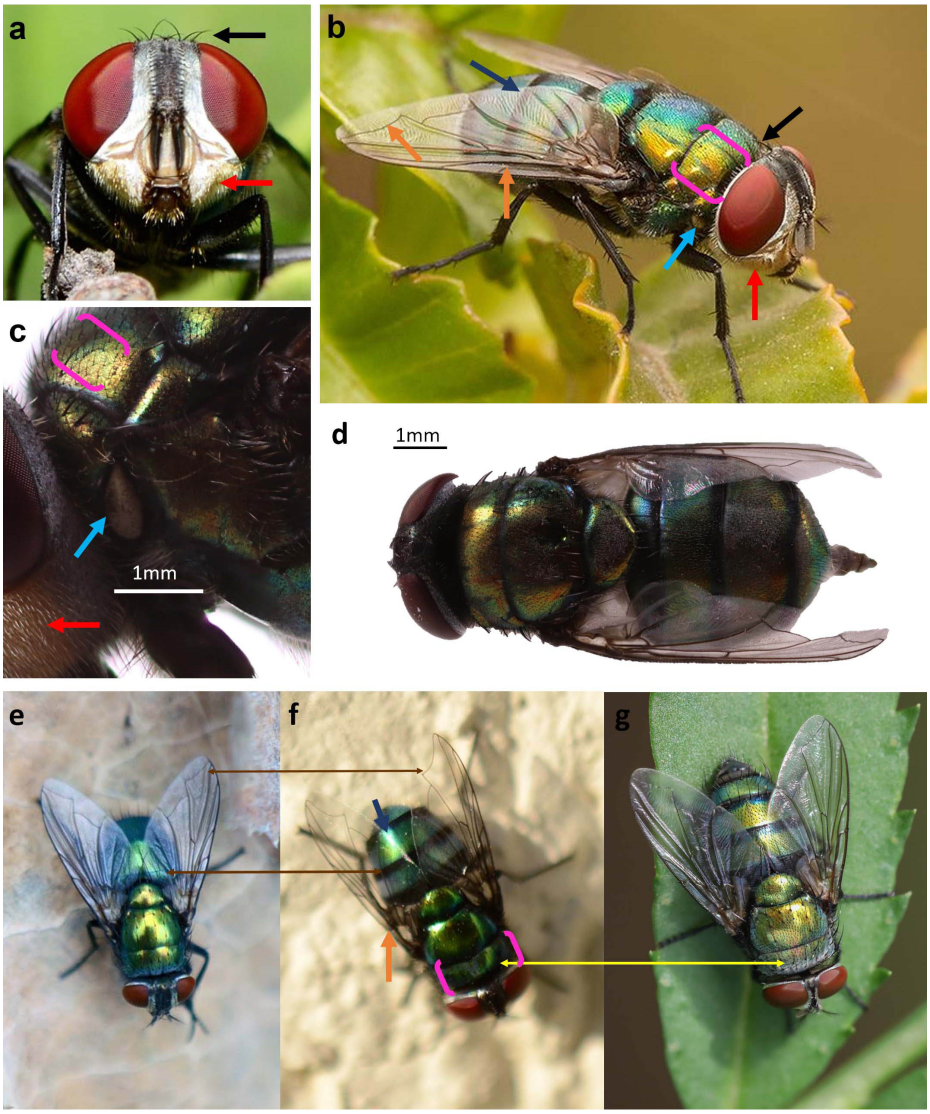

Figure 1. General morphology of *Chrysomya albiceps*: (1) frontal view, photo: Matías Cortes; (2) lateral view, Photo: Diego Reyes; (3) anterior spiracle; (4) dorsal view and (5) comparisons between (a) *Lucilia sericata*; photo by Gabriela Germain Fonck; (b) *C. albiceps*; photos by Gabriela Germain Fonck and (c) *Chrysomya putoria*; photo: Basile Morin (CC BY-SA 4.0). Black arrow shows outer vertical setae; red arrow shows yellowish genae; magenta arrow shows anterior white spiracle; orange arrow shows clear wing and r_{4+5} petiolated; blue arrow shows black bands in posterior margin of tergites; pink bracket shows absent of bluish pollinosity; brown arrow shows main differences between *L. sericata* and *C. albiceps*; yellow arrow show differences in anterior scutum between *C. albiceps* and *C. putoria*.

used as evidence in forensic entomology (Catts and Goff 1992), altering conclusions in murder cases (Grassberger et al. 2003; Thyssen et al. 2018).

Classical methods of collecting blowflies such as systematic traps (e.g. malaise, pan traps or van Someren) as well as cadaveric fauna sampling reported by several authors (see some examples in Baumgartner and Greenberg 1984; Guimarães et al. 1978; Rosa et al. 2006) could be useful to know it distribution. However, these methods only describe the fauna of a small region and similar sampling efforts are required through large spatial extensions to better understand their distribution. On the other hand, several alternatives have been proposed to offset the inadequate knowledge on the distribution of many invasive taxa, such as compilation of biodiversity in public repositories or modeling distribution, but datasets are still scarce for many insects from these sources (Cardoso et al. 2011; Troudet et al. 2017). Thus, datasets used for a particular observed distribution on particular and conspicuous species may be different if we used another method (Barahona-Segovia et al. 2018; Zapponi et al. 2017). Many problems related to this could be solved with citizen science, a socioecological discipline where citizens can contribute to science by recording occurrences of species or environmental phenomena (Roy et al. 2012). Citizen science in invasive species has been very successful in updated distribution on some plagues such as *Halyomorpha halys* (Stål, 1855) (Hemiptera: Pentatomidae; Maistrello et al. 2016); the slug *Arion vulgaris* Moquin-Tandom, 1855 (Stylommatophora: Arionidae; Dörler et al. 2018); some ladybirds such as *Harmonia axyridis* (Pallas, 1773) (Coleoptera: Coccinellidae; Alaniz et al. 2018a), and invasive bumblebees such as *Bombus terrestris* Linnaeus, 1758 (Hymenoptera: Apidae; Montalva et al. 2017). Integrated collection methods, defined as the combination of records from different validly accepted sources (i.e. classical methods + novel methods as citizen science; Barahona-Segovia et al. 2018; Zapponi et al. 2017) for any taxon are an alternative to fill these gaps in distribution and propose political strategies for control and prevention, especially for little-known invasive species.

Although all blowflies are considered an important medical, veterinary and forensic group (Alves et al. 2014; Azevedo et al. 2015; Garcia et al. 2017) their distribution in many Neotropical countries is still poorly understood. Chile has a high deficit of distribution information of their native and exotic Calliphoridae species present in the country, which is reflected in the literature (e.g. many species only show "Chile" as locality; see examples in Mac-Lean and González 2006). The large deficit is due to the absence of a national registry system that allows systematizing the information collected throughout the country. *Chrysomya albiceps* was recorded by Mac-Lean and González (2006) between Coquimbo Region and Metropolitana Region. Later, Ortloff-Trautmann et al. (2013) found this invasive blowfly species in pig carcasses in Metropolitan and Maule Region extending their distribution to south part of central Chile. On the other hand, many records have been compiled with citizen science initiative exclusively in flies through Chile and many of these records can be assigned to this invasive blowfly species, especially from north Chile. The aim of this study is to describe and expand the current distribution of *C. albiceps* in Chile using integrative distribution methods to highlight the importance of novel methods in the study of several invasive species in Neotropical Region.

Materials and methods

Taxonomy

To date, *C. albiceps* has been the only species of this genus recorded for Chile (Mac-Lean and González 2006; Ortloff-Trautmann et al. 2013). To ensure the taxonomic identity of *C. albiceps*, which is similar in appearance to species of the genus *Lucilia* and other species of the genus *Chrysomya,* we checked a set of taxonomic features on all photos collected with citizen science using taxonomical keys according Irish et al. (2014). These traits include: (i) well developed outer vertical setae (black arrow in Figure 1a, b); (ii) genae completely or almost all yellowish (red arrow in Figure 1a, c); (iii) Anterior spiracle white (magenta arrow in Figure 1b, c); (iv) absence of proespisternal setae (magenta arrow in Figure 1b, c); (v) black band present in the posterior tergite (blue arrow in Figure 1b, d) and absent in *Lucilia* species (Figure 1g); (vi) anterior wing cleared and cell r_{4+5} strongly petiolated in *C. albiceps* (orange arrow in Figure 1b, d) and (vii) thorax uniformly bright green color (pink brackets in Figure 1b–d). This last morphological feature is key to separate *C. albiceps* from *C. putoria*, because in *C. putoria*, the anterior scutum have a bluish band of pollinosity absent in our target species (Irish et al. 2014; Figure 1f). These morphological features separate *C. albiceps* from *C. putoria* (morphological differences can be observed in figs. 27 and 29 in Irish et al. 2014). When photos meet a minimum of three of these features, we assigned the photographical record as *C. albiceps* (Supplementary material Table S3).

Classical method dataset

We obtained dataset from three different methods. First, we reviewed several public entomological collections: Museo Nacional de Historia Natural (MNHNCL); Instituto de Entomología de la Universidad Metropolitana de Ciencias de la Educación (IEUMCE); Luis Peña collection, Universidad de Chile (MEUC); Ernesto Khramer collection, Universidad Austral de Chile (UACH); Servicio Agrícola y Ganadero (SAG); Instituto de Investigaciones Agropecuarias (INIA); personal collection of Ramón Rebolledo (UFRO); Universidad de Tarapacá collection (UTA) and the Museo de Zoología de la Universidad de Concepción, (MZUC). Second, also we review literature on Calliphoridae in general or about *C. albiceps,* particularly in Chile. All occurrence data available were extracted and mapped.

Third, we used standardized methods for flies employed from January, 2015–March, 2018 in natural and urban areas in different ecosystems and cities. These fieldworks were chosen randomly and realized under the project "*Moscas Florícolas de Chile*" citizen science to capture many fly species from different families and was not made exclusively for Calliphoridae flies. Natural areas (n = 10; Figure 2; Table S2) are represented from northern Chile to Valdivian evergreen forest in a wide latitudinal range and from coastal areas to highlands in a wide altitudinal range (Figure 2; Table S3). These natural areas are characterized for absent or lowest coverage of human perturbation (e.g. urbanization; Figure 2: 7–11). We used collection points that were separated from each other every 100 meters. At each collection

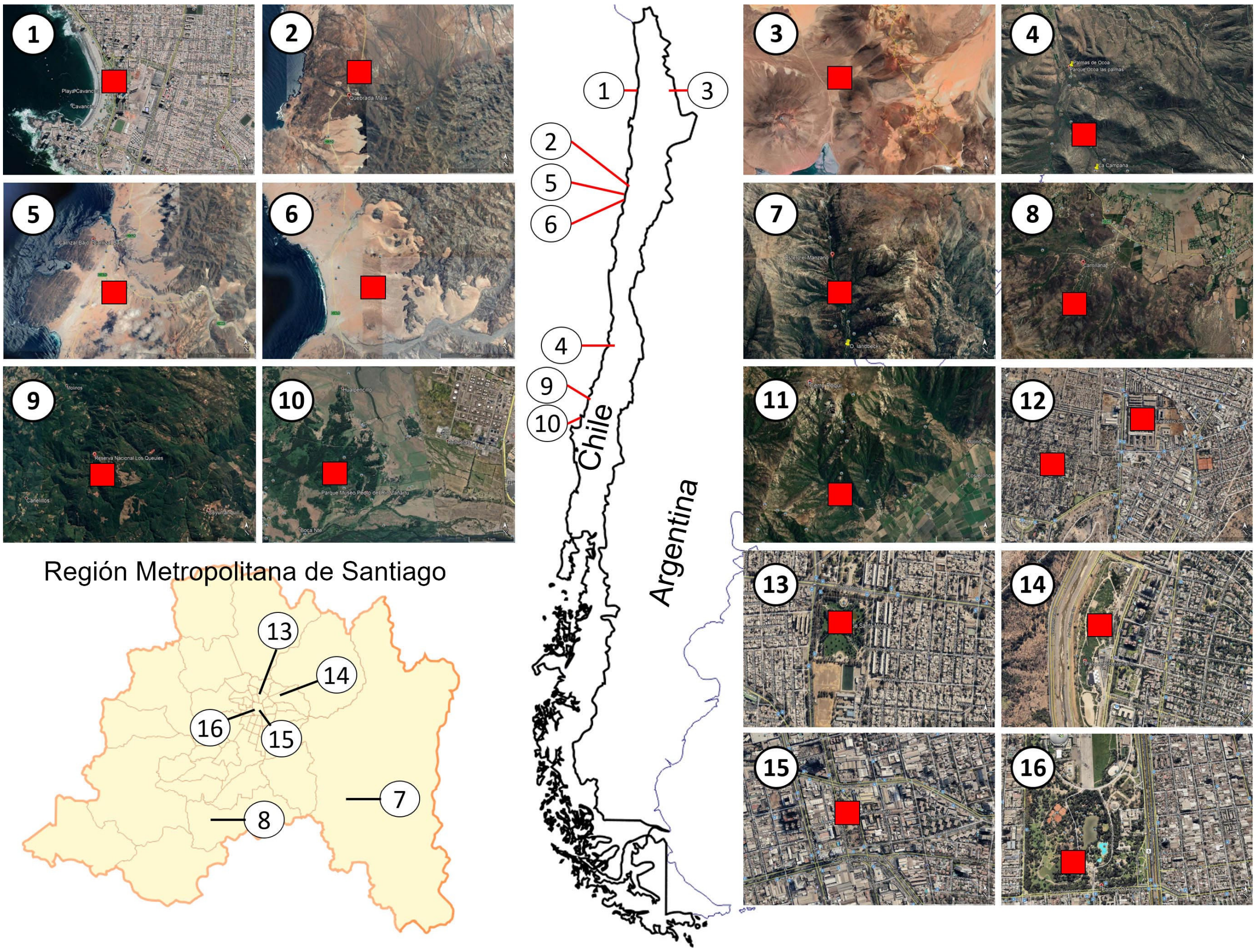

Figure 2. Distribution of sampling sites both in natural as urban areas: (1) Cavancha, Tarapacá Region, 8 m.a.s.l.; (2) Quebrada mala, Atacama Region, 210 m.a.s.l.; (3) Collahuasi, Tarapacá Region, 4166 m.a.s.l.; (4) Palmas de Ocoa, Valparaiso Region, 467 m.a.s.l.; (5) Carrizal Bajo, Atacama Region, 64 m.a.s.l.; (6) Tres Playitas, Huasco Bajo, Atacama Region, 206 m.a.s.l.; (7) El Manzano, Metropolitana Region, 1081 m.a.s.l.; (8) Altos de Cantillana, Metropolitana Region, 563 m.a.s.l.; (9) Reserva Nacional Los Queules, Maule Region, 386 m.a.s.l.; (10) Hualpén, Biobío Region, 41 m.a.s.l.; (11) Cerro Poqui, O'Higgins Region, 474 m.a.s.l.; (12) Cementerio general de Santiago and Cementerio Católico, Recoleta, 530 m.a.s.l.; (13) Parque Santa Mónica, Recoleta, 505 m.a.s.l.; (14) Parque Bicentenario, Vitacura, 639 m.a.s.l.; (15) Parque Bulnes, Santiago Centro, 542 m.a.s.l. and (16) Parque O'Higgins, Santiago Centro, 529 m.a.s.l. Red squares represents collection site.

point, one yellow and one white pan traps was placed forming a quadrant with the other collection points. These colors were chosen because there is a wide range of effectiveness in capturing insects that visit flowers (Vrdoljak and Samways 2012; Saunders and Luck 2013). In addition, in the middle of the quadrant, a yellow and a white pan trap were placed. Also, we used a Malaise trap in the same quadrant for the same number of days. The traps were activated for 4 days and had a mixture of soap and water. Each natural area was replicated as minimum of two times (see Table S2). In parallel, we surveyed 15 points separated by at least 100 m for five minutes using 10 hand entomological net passes. On this field surveys, flies were captured in different substrates visited as scats, carcasses, flowers or other types and noted in Table S2.

We applied a different protocol in urban areas. We selected sampling points in urban parks or garden surrounded of areas with high percentage of urbanization (i.e. + 90%) mainly in the Metropolitana Region. We installed, when was possible, five baits of fresh feces (from domestic dogs and for replace pan traps frequently removed by people) to attract blow flies, separated by at least 100 m and placed into public gardens or urban flower patches. These baits can attract gravid females because scats emanate dimethyl trisulfide (Brodie et al. 2016). Baits were revised every day two times (11:00 and 17:00 hrs) by four days continuously active. In parallel, flower patches (in the same area where we installed the baits) were sampled using entomological net to collect actively by hand for 10 minutes and 10 hand entomological net passes. All substrates surveyed with presence of *C. albiceps* are presented in Table S1. Captured flies were identified using taxonomic keys (Amat et al. 2008; Irish et al. 2014) and deposited in MNHNCL, MEUC and the first author's collection.

Citizen science dataset

We used "*Moscas Florícolas de Chile*" as citizen science using social media platform and *group* tool (www.facebook.com/groups/774986852548819/). The dataset obtained includes: 1) the most specific possible location (e.g. streets or coordinates); 2) date of photographic capture; and 3) the original photo of the fly in our social media group (social media voucher in Table S3). Then, interaction with citizen scientist was key to obtain reliable information about the records according to Devictor et al. (2010). This dataset (and other records) are available to check in Table S3. In order to more confidence in citizen science records, we collected individuals in some localities reported when it was possible through years and sampling using a net on flowers, carcasses, scats or another substrates for three days and eight hours per day (24 hrs in total). Citizen science records confirmed with field collecting are showed in Table S1.

Statistical analysis

To evaluate the contribution of citizen science to the knowledge of this invasive blowfly species, we used a simple comparison of distributions between the citizen science program (N = 28) and classical collect methods (N = 17), using a 10 km^2 grid for each cell (Zapponi et al. 2017). The difference in the number of records per cell was tested with a chi-squared test. We used the package rCAT for the analysis of occupied cells (Moat and Bachman 2007). All data analyses and maps were performed in R software (R Core Team 2019).

Results

We obtained a total of 56 records. However, we excluded 11 records from citizen science data because the photography was unclear to identify the species according our criteria. Therefore, we used 45 records: 17 records were obtained through classical methods such as entomological collections

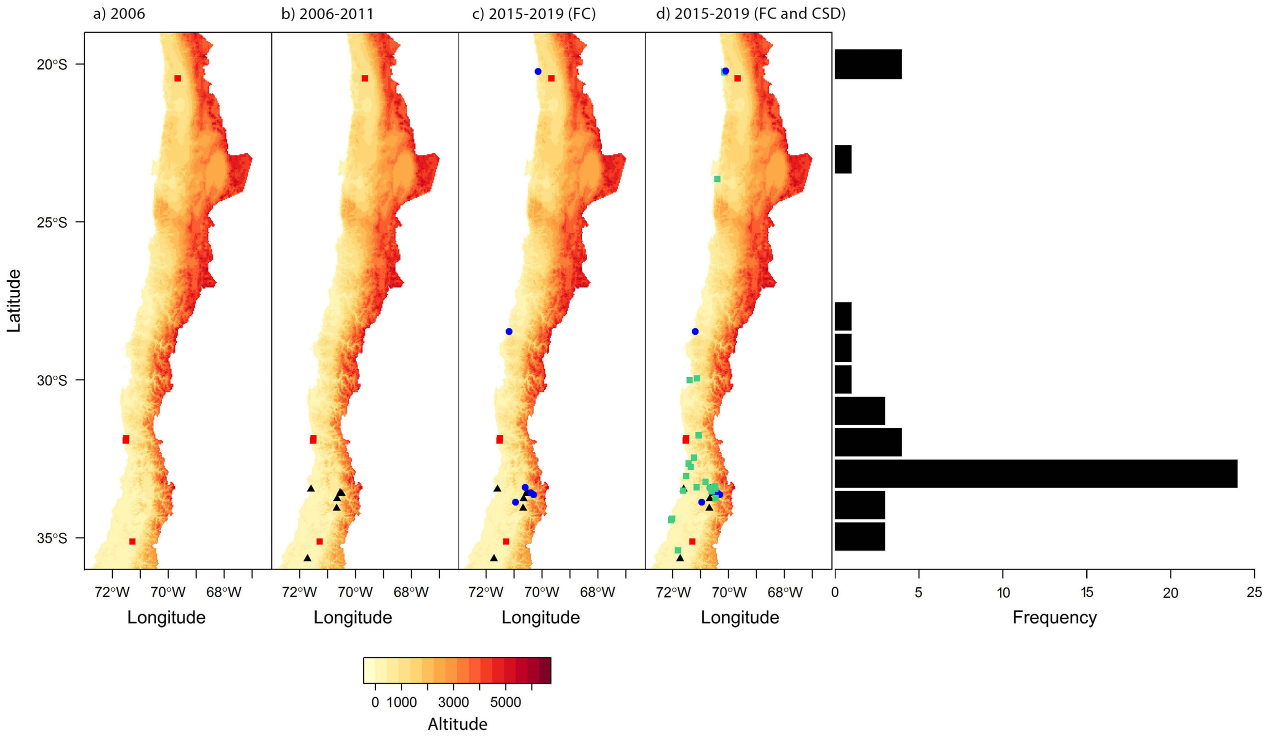

Figure 3. Occurrences of *Chrysomya albiceps* (Wiedemann) in Chile from May 2006 to May 2018. a) red squares = IEUMCE in Mac-Lean and González 2006, UTA and PCFS; b) black triangles = Ortloff-Trautmann et al. 2013; c) blue circles = field collecting (FC) and d) green squares = citizen science (CSD). Black bars represent the cumulative frequency of records per latitude.

(n = 4), literature (n = 6) and field collections (n = 7; Table S1), while the remaining 28 records were obtained through citizen science. The distribution initially reported by Mac-Lean and González (2006) was from the Coquimbo Region to the Metropolitana Region (n = 2). However, we complemented the distribution from Tarapacá to Maule Region by our entomological collection review (Figure 3a, Table S1). Ortloff-Trautmann et al. (2013) presented six new records, which were obtained from human and pig carcasses, which filled the distribution in central Chile from the Metropolitana Region to the Maule Region (Figure 3b). Records obtained by field collection (Table S1), six were in the Metropolitana Region, with total abundances of flies captured between 1–8 individuals and one record of *C. albiceps* in Huasco, Atacama Region with two individuals (new locality with this method). Of these occurrences, 35.29% (n = 6), 23.52% (n = 4), 17.64% (n = 3) and 23.52% (n = 4) were obtained from natural, rural, semirural and urban areas, respectively (Table S1). Substrates visited and recorded in different habitat were represented by flowers (n = 5; 29.41%), human, pig and fish carcasses (n = 8; 47.05%; Mac-Lean and González 2006; Ortloff-Trautmann et al. 2013) and others (n = 4; 23.52%) and listed in Table S1. Adult flies were never captured on pet scats. The distribution reported by this method was from Tarapacá Region to the Metropolitana Region; Huasco (28 °S) and Iquique (20 °S) appear as new record for northern Chile (Figure 3c). From the 28 records obtained by citizen science, 57.14% (n = 16), 7.14% (n = 2), 25% (n = 7), 7.14% (n = 2) and 3.57% (n = 1) showed three, four, five, six and seven morphological features respectively (Table S3). Occurrences were recorded both urban areas as in natural areas with 32.14% each (n = 9), while 35.8% (n = 10) were recorded in semi-urban zones. The distribution reported by citizen science methods was associated with coastal areas from Iquique to Pichilemu (39.39%; Figure 3d) and 60.60% in interior areas such as valleys or urban zones. Records from the Metropolitana Region reached 42.42% and Antofagasta city is a new record by this method. Of these occurrences, 39.29% (n = 11) of records were obtained landing o visiting flowers, while 60.71% (n = 17) were recorded in other substrates (Table S1).

Finally, classical methods and citizen science distribution are combined in Figure 3d. Differences in occupied cells between citizen science and classic methods were not statistically significant ($\chi^2 = 0.6410$, df = 1, $p = 0.4233$); 22 and 17 cells were occupied, respectively. However, these methods shared only 18.5% of the occupied cells.

Discussion

Chrysomya albiceps is considered an invasive blowfly species in the Neotropics, associated with tropical or subtropical weather (Baumgartner and Greenberg 1984; Guimarães et al. 1978; Wolff and Kosmann 2016). Its distribution has critical gaps, which is an important issue due to their forensic and medical importance. Citizen science is an alternative method recommended by different authors to fulfill this Wallacean shortfall and achieve an integrated distribution (Alaniz et al. 2018a; Barahona-Segovia et al. 2018; Cardoso et al. 2011; Montalva et al. 2017). Integrated sources of occurrences are more informative than the use of only one. We showed that classical methods or citizen science alone do not provide enough information. In fact, although the records of occupied cells between citizen science and classic methods were not significantly different, only 18.5% of cells were shared, which shows that these methods can complement each other. On the other hand, citizen science is more practice and reliable for conspicuous species as large saproxylic beetles (Zapponi et al. 2017); bumblebees (Montalva et al. 2017) or bright and colorful species (Alaniz et al. 2018a, b; Barahona-Segovia et al. 2018). Related to use flies in this project types, many species could not be suitable for citizen science due to cryptic morphology and other scientific or societal shortfalls (Cardoso et al. 2011), but many others are possible. Even though *C. albiceps* could be confounded with other species as *C. putoria*, another invasive blowfly species (Baumgartner and Greenberg 1984), morphological differences are easily separated with photo. *Chrysomya putoria* present a bluish pollinosity in the anterior scutum while it is absent in *C. albiceps*, which is completely bright green (Irish et al. 2014; see Figure 1f, g). Despite our project is limited to choose a small species number as target to study under this method, it is completely practicable for large or conspicuous species such as *Aneriophora aureorufa* (Philippi, 1865) (Alaniz et al. 2018b) or *Myopa metallica* Camras, 1992 (Barahona-Segovia et al. 2017, 2018) with the aim to decrease the distributional gaps.

Abiotic conditions such as temperature could explain the distribution of *C. albiceps*. This invasive blowfly species is native to tropical areas; therefore Mediterranean ecosystems or areas with subtropical influence would be suitable areas according to Baumgartner and Greenberg (1984). Figueroa-Roa and Linhares (2002) suggested that low temperatures affect the presence of *C. albiceps* negatively in southern Chile. Our study could represent the baseline for a future niche modelling for this species in Chile (or Neotropical Region) and fill the large gaps.

It is unknown how this species was introduced to Chile. Several classical collection methods in dead human bodies and other substrates between Arica and Punta Arenas showed a distribution between the Metropolitana Region (−33.47; −70.64) and the Maule Region (−35.11; −70.28), concentrated in central Chile (i.e. latitude 33; Mac-Lean and González 2006; Ortloff-Trautmann et al. 2013). The citizen science dataset also showed a similar distribution in central Chile. Moreover, it contributed with records in places where this species was not known to be present. One hypothesis is that *C. albiceps* colonize from north to central Chile because it is a strong flier; this blowfly species can move about 1.3 km/day, reaching a distance of 560 km in only 12 months (Baumgartner and Greenberg 1984) and therefore, it can colonize from neighbor countries to far lands in few years, especially in suitable environmental and habitat conditions. Another possibility is that *C. albiceps* may use mechanical human vectors (Gagné 1981) and invade from other Chilean Regions or neighboring countries. Our data fill the gap in the distribution of this blowfly species, but do not allow us to conclude the beginning and progress of the invasion.

Flies are not charismatic insects and many records of *C. albiceps* are overrepresented in central Chile, where the human population is concentrated, as in other citizen science projects in invertebrates (Alaniz et al. 2018a). Citizen science is popular in Chile to obtain records of several insects and has been used for many studies (Alaniz et al. 2018a, b; Barahona-Segovia 2019; Barahona-Segovia et al. 2018; Montalva et al. 2017). In our study, *C. albiceps* was recorded more frequently on natural areas than rural areas, cities or towns, in concordance with larvae found in human bodies sampled by Ortloff-Trautmann et al. (2013). The lack of records in both natural and semi-urban areas may be due to the difficulty of citizens to distinguish *C. albiceps* from other species similar in color such as *Lucilia sericata*, or because this species is in low abundance. Our study is valuable due to potential negative effects of *C. albiceps* on forensic, medical and veterinary results due to the modification of the ensemble of native flies produced by this invasive species (Grassberger et al. 2003). This species could also negatively affect the ecosystem services that native blowflies or other decomposer species offer to human disciplines. Negative effects have been found in native *C. macellaria* in other Neotropical countries (Faria et al. 1999; Faria and Godoy 2001; Rosa et al. 2006) and could affect to Chilean species as the giant *Neta chilensis* (Walker, 1837) and infrequent genus *Toxotarsus* Macquart, 1851, which could change the decomposition rate in Chilean ecosystems.

Citizen science has increased through years not only for invasive species, since also for endemic and native animals and plants in all continents, where citizens using several social media platforms and online resources to gain precision in the records. Using single or some methods and excluding others, increase the probability of uncertainly in the distributional limits for important species to agriculture, forestry, and science in general. In conclusion, integrative information for distribution has improved the knowledge of many invasive species. In the future, distribution information of *C. albiceps* and other invasive species could be an important management tool to provide justice, medical solutions, or a better life to different human components as well as to protect the native biodiversity and its processes.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Distribution records of the invasive blowfly *Chrysomya albiceps* (Wiedemann, 1819), methods occupied and substrates surveyed.

Table S2. Natural and urban areas surveyed in different regions and ecosystems of Chile.

Table S3. Electronic voucher for every citizen science recorded.

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