

1 **Title**

2 One century away from home: how the red swamp crayfish took over the world

3 **Running Title**

4 Invasion history of *Procambarus clarkii*

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24 **Keywords:** Alien species; GBIF; Global translocations; Historical distributions;

25 iNaturalist; Invasive species; Pathways of introduction; *Procambarus clarkii*;

26

27 **ABSTRACT**

28 The red swamp crayfish (*Procambarus clarkii*) (hereafter RSC), native to the southern
29 United States and north-eastern Mexico, is currently the most widely distributed
30 crayfish globally as well as one of the invasive species with most devastating impacts
31 on freshwater ecosystems. Reconstructing the introduction routes of invasive species
32 and identifying the motivations that have led to those movements, is necessary to
33 accurately reduce the likelihood of further introductions. In this study, we: i) review the
34 temporal evolution of the scientific literature on the RSC; ii) compile georeferenced,
35 time-explicit records of the species to provide a comprehensive understanding of its
36 global expansion process; and iii) evaluate the potential role of biological supply
37 companies in the translocations of the RSC. The interest of the RSC in scientific
38 research increased steadily since the beginning of the 20th century until stabilization in
39 the late 1960s. The number of studies related to the use of the RSC in aquaculture
40 showed two peaking periods: the years elapsed between 1970s to mid-1980s, and a
41 continuous increase since the mid-1980s. Research on the RSC as an invasive species
42 has only been numerically relevant in recent times, with the number of studies
43 increasing since the 2000s to represent currently around 25% of the scientific
44 production dealing with this species. Although the first introductions of the RSC took
45 place in the 1920s, our synthesis highlights the rapid expansion of the species since the
46 1960s, arguably promoted by the emergence of crayfish industry, but other introduction
47 pathways such as the mitigation of schistosomiasis, potential releases from research
48 experiments, school science programs or pet trade cannot be ruled out. Currently, the
49 RSC is present in 40 countries of four continents and there is still potential for further
50 expansion. Commercial suppliers from native (Louisiana) and non-native (California or
51 North Carolina) areas in the U.S.A. have provided live-specimens of the RSC for
52 scientific research around the world for decades, suggesting that the invasion process of

53 the RSC could be more complex than generally assumed. Tracing the invasion routes of
54 invasive species and understanding the motivations that have led to those movements of
55 species is key to reduce their spread and the likelihood of future introductions.

56

57 **1. BACKGROUND**

58 Humans have transported plants and animals across biogeographical barriers for
59 millennia, for cultural, leisure or commercial purposes (Forcina et al. 2015), albeit this
60 movement of organisms has steeply accelerated since the mid-20th century (Capinha et
61 al. 2015). When released into new areas, some of those transported species are able to
62 survive, reproduce and establish self-sustaining populations, becoming invasive
63 (Blackburn et al. 2011). Invasive species are now a widespread conservation issue and
64 their impacts are considered one of the biggest threats to global biodiversity (Bellard et
65 al. 2016). Identifying the invasion routes through which species are either transported
66 from the native areas to non-native ones or moved among non-native areas is crucial to
67 prevent further spread and to manage future emerging invaders (Estoup and Guillemaud
68 2010; Bertelsmeier et al. 2018).

69 Freshwater ecosystems are amongst the most severely threatened in the world, due
70 to the combination of habitat degradation, hydrological alteration, global warming,
71 overexploitation, water pollution and invasive species (Reid et al. 2019). As a
72 consequence of all these pressures, freshwater biodiversity is currently declining at a
73 much faster rate than in terrestrial or marine environments (WWF 2016; Reid et al.
74 2019). Freshwater ecosystems are among the most invaded ecosystems in the world and
75 particularly susceptible to the impact of invasive species (Ricciardi and MacIsaac 2011;
76 Gallardo et al. 2016). At least sixteen freshwater crayfish species have been introduced
77 into non-native areas worldwide (Logde et al. 2012), some of them being amongst the
78 most impacting invasive species (Twardochleb et al. 2013 and references therein). The

79 magnitude of the impact of invasive crayfish is often related to their frequent role as
80 keystone species in freshwater ecosystems (i.e., due to their high abundances, large size,
81 wide range of trophic interactions and their role as ecosystem engineers), affecting to
82 both lower and upper trophic levels (Geiger et al. 2005; Reynolds et al. 2013).

83 Freshwater crayfish are relatively well-known species and exploited by humans in
84 many regions around the globe (Gherardi 2011). Their accessibility and nutritional
85 value (Tricarico et al. 2008) have contributed to make crayfish a relevant food item for
86 many societies (Holdich 1993; Swahn 2004; Gherardi 2011; Patoka et al. 2016) and a
87 source of economic development (Comeaux 1978; Gutiérrez-Yurrita et al. 1999). The
88 use of crayfish as food is in the roots of several cultural traditions, such as the Swedish
89 crayfish summer festivals, in which families and friends gather to eat crayfish (Edsman
90 2004; Swahn 2004). Being appreciated and easily transported organisms (crayfish can
91 survive prolonged periods out of water, Gherardi and Barbaresi 2000), crayfish species
92 have been introduced into new areas for a long time (Machino and Holdich 2006; Hobbs
93 and Lodge 2010). In Europe, crayfish introductions have occurred at least since the
94 Middle Ages (e.g., Gouin et al. 2003; Swahn 2004; Gherardi 2011). For example, Carl
95 Linnaeus reported the introduction of the noble crayfish (*Astacus astacus*) to Sweden,
96 which was promoted by King John III in the second half of the 16th century (Hobbs et
97 al. 1989). This fact coincided in time with the importation of the Italian crayfish
98 (*Austrapotamobius italicus*) from Tuscany to Spain, a personal initiative of King Philip
99 II to imitate its uses in the Tuscan court (Clavero et al. 2016).

100 North America possesses the largest diversity of freshwater crayfish in the world
101 (382 species, Crandall and Buhay 2007), but little is known of crayfish uses by
102 aboriginal North American inhabitants (Huner 2002). First European settlers noticed the
103 presence of crayfish (e.g., they were already cited by Aldrovandi [1606]) and crayfish
104 could be found in some North American markets since the early 19th century (Comeaux

105 1978). By the early 20th century, three main crayfish industries had been developed in
106 North America, targeting three different genera, namely *Faxonius* (formerly
107 *Orconectes*) (in the Midwest), *Pacifastacus* (in Pacific Northwest) and *Procambarus* (in
108 Louisiana) (Comeaux 1978). These are nowadays the most widely introduced genera
109 worldwide and the ones producing the highest biodiversity impacts (Twardochleb et al.
110 2013). The first introduction of North American crayfish into other continents took
111 place at least since the late 19th century, when the spiny-cheek (*Faxonius limosus*) and
112 the virile (*F. virilis*) crayfish were introduced in Europe (Hobbs et al. 1989). But the
113 most striking invasion process is that of the RSC, currently the most cosmopolitan
114 freshwater crayfish, distributed across all continents except Australia and Antarctica
115 (Loureiro et al. 2015).

116 The origins of exploitation of the RSC is linked to the Cajuns, descendants of the
117 French colonists in Acadia, north-eastern North America, who later settled in the Gulf
118 Coast state of Louisiana in the late 18th century (Gutiérrez 1998). The Cajuns' customs,
119 including the French taste for crayfish, gradually become established in Louisiana and
120 the commercial exploitation of the RSC started growing since the late 19th century
121 (Gutiérrez 1998; see in Brady 2013). The first fishermen harvested crayfish from wild
122 stocks from swamps and marshes in south Louisiana, but water bodies were soon
123 modified or constructed to store catches and allow longer harvesting periods,
124 developing the aquaculture-based crayfish industry (Comeaux 1978). Crayfish
125 production steeply increased in the 1960s, due to the transformation of several lands to
126 that aim, often in combination with rice cropping (i.e., rice-crayfish fields) (Huner
127 2002). Land devoted to crayfish production increased from 400 ha in 1959 to 10,000 ha
128 in 1970 (Clark and Avault 1975) and up to 49,000 ha in 1990 (LSU AgCenter 2016).
129 The Louisiana crayfish industry became the most successful producer and seller of

130 crayfish in North America (Comeaux 1978) reaching a farm-gate value of more than
131 \$200 million (aquaculture plus wild harvested) in 2016 (LSU AgCenter 2016).

132 The high profitability of RSC industry led several entrepreneurs to try to replicate
133 its aquaculture-based production in other areas (Hobbs et al. 1989; Huner 2002; Cheung
134 2010; Brady 2013). Transcontinental movements of the RSC to Africa and Europe gave
135 rise to incipient crayfish industries in countries such as Kenya or Spain (Harper et al.
136 2002, for Kenya; Gutiérrez-Yurrita et al. 1999, for Spain). However, the most striking
137 growth of crayfish production has taken place in China, which has recently overtaken
138 the native production of Louisiana crayfish industry. Chinese production has increased
139 from 6,700 tonnes in the early 1990s (Xia 2007) up to more than one million tonnes in
140 2017, with a current commercial value of \$42 billion (China's Ministry of Agriculture
141 and Rural Affairs 2018).

142 Here, we review the century-lasting invasion history of the RSC in order to
143 describe its expansion, update the knowledge on its global distribution, report the main
144 introduction routes and discuss the main pathways driving the translocations of this
145 species. Based on a review of scientific and grey literature, as well as a collection of
146 records worldwide, we (1) describe the historic variation in the research scope of the
147 RSC from the early 20th century to the present as well as the patterns of knowledge
148 production in the RSC, (2) make a thorough description of introduction and expansion
149 events along the last one century, and (3) explore the role of commercial companies in
150 the expansion of this species. Commercial companies that ship live specimens for
151 different purposes (e.g., aquarium hobby, education or research) may represent a
152 relevant, though overlooked, introduction vector of the RSC worldwide (Chucholl
153 2013). Information related to aquarium species and pet trade is scarce and often
154 inaccessible (see Chucholl 2013), but researchers usually report the provenance of
155 model organisms in their scientific studies. This information could be a useful proxy for

156 the potential role of commercial companies in the translocation of the RSC, and other
157 organisms, around the world.

158

159 **2. HISTORICAL VARIATION IN THE RESEARCH SCOPE**

160 A literature search on the RSC (see Supplementary Material – Appendix III), showed
161 that out of 19,342,413 studies published over the last 95 years (from 1924 to 2019) on
162 zoology, ecology, toxicology, biology, neurology, invasion science, and pet trade, only
163 5,442 (<0.03%) dealt with the RSC. While the total production of studies has constantly
164 increased since the 1950s, the interest in the RSC intensified during the 1960s. Before
165 the early 1960s, the ratio of publication was 1.5 studies on the RSC for each 10,000, but
166 this ratio doubled by the late 1960s, having remained relatively constant since then (Fig.
167 1a).

168 In the beginnings of the global invasion process by the RSC (since 1924 to 1960),
169 there were hardly any scientific studies on the species and very few of them dealt with
170 either aquaculture/fisheries or invasions (Fig. 1b). In that time, studies on the RSC were
171 mainly related to physiology, and the functioning of nervous and motor systems, using
172 crayfish as a model with potential applications to increase knowledge of human
173 locomotion and nervous system (Stark 1968). Physiology studies are still a relevant
174 component of the scientific research focused on the RSC (Fig. 1b). Studies that focussed
175 on the RSC as aquaculture species or its potential in fisheries increased in numbers in
176 two periods: i) between the mid-1960s and the early 1980s, arguably in relation to the
177 growing commercial use of the RSC, reaching up to a 75% out of total number of
178 studies on the RSC in the decade of 1970s; and ii) a current peak after a continuous
179 increase of the scientific production in this area since the mid-1980s. The number of
180 studies dealing with the role of the RSC as an invasive species has notably increased
181 since the 2000s, reaching around 25% of total studies in the decade of 2010s. Overall,

182 our analysis of the scientific literature show that the RSC has long been a model species
183 in experimental biology, that later was studied due to the growing interest as
184 commercial species for food industries and that only in last decades there have been a
185 relevant production of scientific works dealing with the RSC as an invasive species.

186

187 **3. THE INVASION HISTORY**

188 We made an exhaustive search of RSC records both spatially and temporally, by
189 reviewing scientific and grey literature as well as global biodiversity databases (e.g., the
190 Global Biodiversity Information Facility, GBIF; iNaturalist) (see Supplementary
191 Material – Appendix III). After discarding records with duplicate coordinates within the
192 same year, our final dataset included a total of 6,924 RSC records. In order to describe
193 the expansion process of the RSC, we classified records in one of four historical
194 periods: before 1950, 1951-1975, 1976-2000 and 2001-2019, which had 48, 271, 923,
195 and 5,682 records, respectively (Fig. 2 and Fig. 3). The number of records grew
196 progressively since the beginning of the expansion in the 1920s but there was a striking
197 increase in number of records since the 1990s (Fig. 2a), mainly associated to an increase
198 in the available information in Europe as well as both native and non-native areas in
199 North America (Fig. 2b). For example, for the 1951-1975 period there were three RSC
200 records in Europe, a figure that increased to 307 records in the 1976-2000 period and to
201 2,710 records after 2000 (Fig. 2b). This increase in the number of records is linked to
202 the rapid expansion of the RSC across Europe, but also to a generalized increase on the
203 amount of available information on biodiversity (e.g., Boakes et al. 2010). However, the
204 low number of RSC records in Africa (< 1% of total records) and Asia (< 5% of total
205 records) (Fig. 2) could be due to spatial biases in the collection of species occurrence
206 data, which are common to historical and current datasets (e.g., Boakes et al. 2010).
207 Such spatial biases may be even accentuated by the lack of repositories of biodiversity

208 records, as not all countries provide their national biodiversity databases to GBIF.
209 Therefore, the distribution of the RSC in Africa and Asia could be underestimated
210 throughout the different periods considered here.

211

212 THE BEGINNINGS (BEFORE 1950)

213 The RSC was cited for the first time outside of its native range in southern California in
214 1924 when probably several hundreds of individuals were introduced (Holmes 1924).
215 From California the RSC was firstly translocated to Oahu Island, Hawaii, probably in
216 1927 (see Brock 1960) and subsequently in 1934, being expanded to other Hawaiian
217 Islands afterwards (Penn 1954). Brasher et al (2006) reported that live-specimens of the
218 RSC were translocated from California to Hawaii in 1923, which would imply that
219 either crayfish had been introduced into California earlier than 1924 (as reported by
220 Holmes, 1924) or the first introduction into Hawaii occurred later. Also, the RSC was
221 introduced from Louisiana to Japan in either 1927 or 1930 (see references in Kawai
222 2017 and Penn 1954, respectively) and from there to China in 1930 (see Cheung 2010)
223 (Table 1). As in the case of California and Hawaii, it is noteworthy that there is a lack of
224 accuracy in the introduction dates of the RSC into Japan, even though this introduction
225 event is well detailed in the literature. Although the RSC was translocated at large scale
226 before 1950, the RSC did not arrive to Europe until the decade of 1970s.

227 There is a general consensus that the motivation to translocate live-specimens of
228 the RSC in California, Hawaii and Japan, was to provide food for culturing the
229 American bullfrog (*Lithobates catesbeianus*) (Hobbs et al. 1989). The RSC rapidly
230 established viable populations and expanded across rice fields in California (Riegel
231 1959), various Hawaiian islands (Penn 1954) and the Honshu Island in Japan (Kawai
232 2017), being considered as a pest because of its burrowing activity (see Penn 1954).
233 However there was a time-lag between its introduction (1924) and the action measures

234 to 'eradicate' them by mid-twentieth century (Chang and Lange 1967). On the other
235 hand, the RSC was introduced into China in 1930 short after its introduction to Japan
236 (Table 1) by Japanese citizens who presumably used the species as pets (Cheung 2010).
237 Cheung (2010) described that the apprehension of Chinese society to everything that
238 came from Japan in the early 20th century could have stopped the expansion of the RSC
239 to other areas nearby, since Chinese people thought that the introduction of the RSC
240 was a Japanese conspiracy to harm their rice fields. In fact, Chinese population neither
241 appreciated the crayfish nor considered it edible by mid-twentieth century (Cheung
242 2010), a rejection that probably also limited the expansion of the RSC across China in
243 the first decades after its introduction (Xinya 1988) (Fig. 3).

244

245 EXPANSION OF RED SWAMP CRAYFISH INDUSTRY (1951-1975)

246 While the Louisiana crayfish industry was blooming around 1960s (LaCaze 1970; Gary
247 1974), there were numerous attempts to emulate that production system through
248 translocations of the RSC to different areas (see new wild introductions in Fig. 3), either
249 from native area (Louisiana) or from other regions previously invaded (see Table 1). For
250 that purpose, the species was introduced in Africa (Sudan, Kenya) in the late 1960s and
251 Europe (Spain) in the early 1970s. By 1975 the exploitation of the RSC had started to
252 gain importance in different non-native areas, including states of U.S.A. (e.g.,
253 California, see in Huner 1977) and countries such as Kenya, Spain, France and Italy
254 (see Appendix I in Supplementary Material). But introductions also involved other
255 purposes such as mitigation of schistosomiasis (e.g., Uganda and Kenya, Hofkin et al.
256 1991) or supplying the pet market (e.g., Hong Kong, Taiwan or France, Hobbs et al.
257 1989). The motivation for other many introductions remains unclear (e.g., different
258 States of U.S.A. and Mexico, South Africa or Costa Rica) (see Appendix I in
259 Supplementary Material). Apart from the new introductions, the RSC continued

260 expanding in the territories where it had been introduced before 1950, notably in
261 western U.S.A. and Japan (Fig. 3).
262
263 THE GREAT SPREADING WORLDWIDE (1976-2000)
264 In the late 20th century, there was an acceleration of the expansion of the RSC in several
265 non-native areas, including Europe (Gutiérrez-Yurrita et al. 1999; Changeux 2003),
266 China (Xinya 1988), non-native areas in the U.S.A. (Hobbs et al. 1989) and Kenya
267 (Harper et al. 2002). In the last quarter of the 20th century, the RSC also arrived to
268 different countries in South America (Colombia, Ecuador, Venezuela), the Caribbean
269 (Dominican Republic, Puerto Rico), and Africa (Zambia, Egypt) (Fig. 3). In Europe,
270 multiple secondary introductions led to a rapid expansion of the RSC over Spain,
271 Portugal, Italy and France (see Oficialdegui et al. 2019), as well as its arrival to
272 Germany, Belgium, the Netherlands, Switzerland, United Kingdom and several
273 European islands (e.g., Cyprus, Balearic and Canary Islands in Spain, and Azores in
274 Portugal) (see Appendix I in Supplementary Material). Besides, numerous importations
275 of live-specimens took place from Spain and Kenya to French and Italian farms as well
276 as English restaurants since late 1970s to early 1980s (Holdich 1993; Laurent 1990),
277 which could have generated escapes or releases into the wild (Oficialdegui et al. 2020).
278 By the late 1990s, the RSC was the most important farmed freshwater crayfish species
279 in Europe (54.6% of the total European production), being mainly farmed in Spain
280 (Ackefors 1998) but also in Italy (D'Agaro et al. 1999). Moreover, the RSC was highly
281 exploited for recreational fishing (Changeux 2003) and human consumption in France
282 (Holdich 1993).

283 Interestingly, although the RSC was present in China since 1930, only since the
284 early 1980s Chinese scientists initiated aquaculture experiments aimed at setting up
285 crayfish industry (Xinya 1988). The rapid development of these initiatives, together

286 with the growth of commercial sales in pet shops, caused the spread of the RSC across
287 eastern China (Cheung 2010). Thus, the expansion of the RSC in China had a delay of
288 more than 50 years since its introduction and establishment. Time-lags among different
289 stages of the invasion process (e.g., between establishment and spread) are a common
290 feature of several invasion processes (Crooks et al. 1999, Clavero and Villero 2013). In
291 Africa, the main crayfish fishing areas were Lake Naivasha and several watercourses in
292 Kenya (Harper et al. 2002) and the Nile Delta in Egypt (Hamdi 1994). Simultaneously,
293 many other countries (e.g., Puerto Rico, Dominican Republic, Ecuador, Zambia, among
294 others) attempted to culture the RSC by carrying out experiments on its adaptability and
295 suitability indoor or directly in semi-natural areas, often leading to accidental escapes or
296 releases into the wild (see Appendix I in Supplementary Material).

297

298 CURRENT STATUS (2001-2019)

299 The RSC has recently expanded over areas where it had been previously introduced of
300 western and eastern U.S.A., north-eastern Mexico, European countries, China and, to a
301 lesser extent, other territories (Table 1; Fig. 3). Secondary human-deliberated
302 introductions are key in the invasion process, where established populations in invaded
303 areas act as source of new introductions at long- and short-distance (see Oficialdegui et
304 al. 2019). It has also been registered in new areas of Europe (Austria, Hungary, Poland
305 and several Mediterranean islands: Corsica, Sardinia, Sicily and Malta), Africa
306 (Morocco) and Asia (South Korea, Israel and Indonesia) (Fig. 3). The RSC is now
307 present in 40 countries of four continents (Table 1), but there are potential areas for
308 further expansion, as for example, the islands of Indonesia (see in Putra et al. 2018), as
309 well as in territories of southern South America, the Mediterranean Basin, and large
310 parts of Africa and Australia (Larson and Olden 2012). Once the RSC is introduced and
311 established, populations seem to be viable in the long-term (Fig. 3 and Appendix I in

312 Supplementary Material). In fact, most of previously established populations around the
313 world remain at present (except Alaska in U.S.A., Israel and Tenerife Island in Spain, as
314 far as we know). This is an indication that eradication has thus far proven difficult
315 (Gherardi et al. 2011) and calls for an effort to prevent any possible future introduction
316 to new areas.

317

318 **4. COMMERCIAL SUPPLY COMPANIES AS POTENTIAL SOURCE**

319 The use of RSC as model species in scientific studies could give further information on
320 how and where specimens have been obtained from. As such, we identified the origin of
321 RSC in 729 out of 2,053 scientific studies in the selected years (see Appendix III in
322 Supplementary Material for details). Overall, the 67% studies obtained RSC
323 commercially and 33% from the wild. The percentage of crayfish obtained from
324 commercial supply companies seems to have declined over time, with a 73% of the 456
325 studies analysed before 1990 and 56% of the 273 studies analysed after that date (see
326 Appendix III in Supplementary Material). The recent decrease in commercially-
327 obtained RSC in scientific research is arguably related to the increased availability of
328 wild populations nearby due to the continuous expansion of the species since the mid-
329 20th century (Fig. 3).

330 Most of studies based on commercially-obtained crayfish also detailed the
331 commercial company or area from where crayfish were bought. The main suppliers of
332 the RSC worldwide were based in U.S.A. (in the States of Louisiana, California, North
333 Carolina and Wisconsin), which supplied crayfish up to 292 studies (Fig. 4a and Fig.
334 4b). Until 1990, these four source-states of U.S.A. provided crayfish to eight countries,
335 and 24 states of U.S.A., including themselves (Fig. 4a), with an exportation rate of
336 100% for Wisconsin (n = 6), 92% for North Carolina (n = 39), 48% for Louisiana (n =
337 64) and 46% for California (n = 72). From 1991 onwards, the state of Wisconsin lost its

338 role of main supplier of the RSC. The States of Louisiana, California and North
339 Carolina provided crayfish to two countries (Canada and U.S.A.) exclusively, and to 20
340 states of U.S.A. (Fig. 4b), with an exportation rate of 79% for North Carolina (n = 14),
341 74% for Louisiana (n = 62) and 40% for California (n = 5). Importantly, Japan and
342 China have also become important suppliers of the RSC but their exportation rate was
343 very low, mostly supplying themselves (Fig. 4a and 4b).

344 It is noteworthy that most of the main suppliers of the RSC worldwide are based
345 in non-native areas within the U.S.A. (e.g., California, North Carolina and Wisconsin),
346 though crayfish production in the native area could have been reduced as crayfish
347 industry was partly damaged by hurricanes in the 2000s. Moreover, our synthesis
348 showed that there have been more introductions than generally assumed (Fig. 4). For
349 example, even though the RSC is native from Texas or northern Mexico, several
350 introductions events had place from other invaded areas (e.g., California or North
351 Carolina), even scientific studies carried out in Louisiana obtained crayfish from
352 Louisianan and Californian commercial supply companies. Recently, a genetic study by
353 Oficialdegui et al. (2019) showed that two main routes for the RSC invasion seemed to
354 occur in U.S.A. (i.e. westwards and eastwards from the native range) suggesting the role
355 of commercial companies (located in North Carolina and California) in the spread of the
356 RSC within both areas. RSC movements within the United States (Fig. 4) show that
357 while commercial supply companies in California sent crayfish to everywhere,
358 commercial supply companies in North Carolina mainly supplied crayfish to the east of
359 U.S.A., which could explain the results on genetic variability found in western and
360 eastern U.S.A. populations, respectively (Oficialdegui et al. 2019). Though, it is
361 remarkable that some states in the north-eastern U.S.A. (e.g., New York, Massachusetts,
362 Connecticut and Maryland) have received numerous shipments of crayfish from diverse
363 areas (Fig. 4). And also, Canada has long received many shipments of crayfish (Fig. 4)

364 but wild-populations have only been detected recently (iNaturalist 2019). We found an
365 unexpectedly large number of unreported transoceanic RSC translocations to Europe,
366 where the invasion history of the RSC was supposedly well-known (see Appendix I in
367 Supplementary Material). Moreover, while high exportation rates of crayfish were
368 described for commercial supply companies in U.S.A., most of the shipments of
369 crayfish that took place in Asia, albeit within the countries (see Japan and China in Fig.
370 4). And finally, we have found a series of shipments whose suppliers are unknown and
371 their invasion routes cannot be reconstructed. Even though most of specimens used in
372 scientific studies are often sacrificed, before or after the experiments, escapes from
373 research centres have been described in literature (e.g., the exotic mummichog in Spain,
374 Gisbert and López 2007). Beside of research, other pathways of introductions could
375 remain hidden in the translocation of alien species because the uptake of live-crayfish
376 commercially can be extrapolated to schools and universities (Larson and Olden 2008),
377 general citizens, fishermen or farmers who may obtain live-specimens (Lodge et al.
378 2000). Therefore, our review highlights the risk of shipping highly invasive species out
379 of their native area by showing the amount of translocations that have occurred for a
380 long time. In this context, scientific studies focusing on highly invasive species should
381 always indicate where live-specimens come from. Hence, particular attention should be
382 paid to introduction routes of highly invasive species out of their native range.

383

384 **5. MANAGEMENT IMPLICATIONS**

385 Understanding the introduction routes of invasive species and disentangling the
386 motivations that have led to movements of species is crucial to reduce the likelihood of
387 future introductions. Recently, Lockwood et al. (2019) showed that the pet trade of
388 exotic species contributed to the introduction of non-native species worldwide by
389 analysing information across taxa and research disciplines. Linking wild occurrences of

390 invasive species with the introduction pathways such as escapes from aquaculture
391 (Olenin et al. 2008), the releases from pet trade (Chucholl 2013; Patoka et al. 2015;
392 Faulkes 2015) or through educational material (Larson and Olden 2008) is crucial to
393 prevent new emerging alien species in wild. This review shows how multitude long- and
394 short-distance translocations, many of them unreported, have shaped the current
395 distribution of the RSC, the largest for any freshwater crayfish worldwide. The history
396 of this global-scale invasion can be used as a world benchmark for future invasions
397 involving commercially exploited species by helping managers and policy makers to
398 design and implement efficient management strategies such as the implementation of
399 control measures on commercial activities which involve translocations of live
400 specimens. Furthermore, invasive species policies are generally applied at national or
401 smaller scales, often being inconsistent across countries (Peters and Lodge 2009), when
402 movements of alien species are a global issue (Hulme 2009). More efforts should be put
403 in the use of high-impact freshwater species in aquaculture, ornamental and academic
404 purposes, reducing drastically their availability for trade. Additionally, commercial
405 supply companies could play a determining role in raising awareness to potential
406 keepers of invasive species which may end up being released into the wild or escaped.

407

408 **6. SYNTHESIS AND FUTURE PERSPECTIVES**

409 We have described the global-scale, century-lasting invasion process of one of the most
410 harmful invasive species worldwide. Our review combined literature search and
411 hundreds of records from biodiversity databases to show how and why the RSC has
412 expanded its range over the world during the last 95 years, including an exhaustive
413 description on the invasion process in all countries where the RSC is, or is suspected to
414 be, established (see full details in Supplementary Material). Finally, we also pointed out
415 some of the potential pathways of introduction for the RSC and discussed the relevant

416 role of commercial suppliers in the translocation of live-specimens worldwide. Our
417 conclusions are also useful for any other freshwater alien species commercially
418 exploited by humans.

419 Although we conducted an exhaustive literature search (scientific and grey
420 literature) on the RSC, issues associated to old literature (e.g., local language or regional
421 reports are hard to find) could have caused information gaps in some invaded areas
422 resulting in biased or underestimated crayfish distribution. Specifically, we were unable
423 to find literature or introduction reports in the first 50 years of the RSC presence in
424 China, albeit the species was allegedly restricted to the first introduction area (Xinya
425 1988). Information on RSC distribution in Africa seemed to be spatially-biased, because
426 many studies focused on Kenya but introduction reports for other African countries
427 were scarce and sometimes unclear (e.g., South Africa, Sudan or Zambia; see Appendix
428 I in Supplementary Material). Therefore, further studies on less represented regions
429 (e.g., Asia or Africa) may acquire information of species distribution data from
430 additional sources such as museum collections which provide an important coverage of
431 species' ranges mainly for the past species' distributions (see Boakes et al. 2010).
432 Another alternative would be to work with local experts who can supply accurate data
433 on past species distribution. While a lot of information is available in public databases,
434 occurrence or introduction reports are sometimes incomplete or inaccurate (e.g.,
435 imprecise geographical coordinates or lack of verification by experts). Even so, we wish
436 to encourage administrations to develop citizen science projects that involve people in
437 the early detection and spread of invasive species (e.g., iNaturalist). Early detection and
438 rapid action response is a cost-effective way of preventing establishment of alien
439 species and avoid devastating impacts in the future.

440

441 **ACKNOWLEDGEMENTS**

442 We are grateful to Biblioteca Campus Cartuja for providing us old literature which was
443 not available online. We also thank David Aragonés from Laboratorio de SIG y
444 Teledetección (LAST-EBD) at Estación Biológica de Doñana (CSIC) and three
445 anonymous reviewers for their valuable comments on the first draft of the manuscript.
446 F.J.O. was supported by a grant associated to the project (RNM-936) funded by the
447 Andalusian Government.

448

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638

639 **Table**

640 Table 1. First reports of red swamp crayfish, *Procambarus clarkii*, over the world.
 641 Number in brackets indicates the total number of countries or states where the red
 642 swamp crayfish is established or probably established. (-) means unknown data. *Italics*
 643 indicate no confirmed information. * indicates eradicated into the country (Israel). Full
 644 information on the spreading of the red swamp crayfish for each country is detailed in
 645 Appendix I and all references are included in Appendix II (Supplementary Material).

<i>Country</i>	<i>Date</i>	<i>Site of introduction</i>	<i>Source</i>	<i>Purpose</i>
AFRICA (8)				
Egypt	1980s	Giza/Cairo/Nile Delta	United States	Aquaculture
Kenya	1966	Solai/Subukia	Kajansi (Uganda)	<i>Aquaculture/Disease</i>
Morocco	2008	Merja Zerga	Seville (Spain)	<i>Aquaculture</i>
Rwanda	2019	Kigali	-	-
South Africa	1962	Potchefstroom	-	<i>Aquaculture</i>
Sudan	1975	Khartoum	Louisiana (US)	Aquaculture
Uganda	1963	Kajjansi	Louisiana (US)	Aquaculture/Disease
Zambia	<1979	Livingstone	Naivasha (Kenya)	Aquaculture
AMERICA (11)				
Brazil	<1986	São Paulo	United States	Pet trade
Canada	2017	Vancouver	-	-
Colombia	1985	Cauca Valley	-	Aquaculture
Costa Rica	1966	Alajuela City	-	-
Dominican Republic	1977	Santo Domingo	United States	Aquaculture
Ecuador	1986	Taura River	-	Aquaculture
Guatemala	2019	<i>Técpán</i>	-	-
Mexico	1955	Cananea	-	-
Puerto Rico	<1978	-	-	<i>Aquaculture</i>
Venezuela	1978	-	Louisiana	Aquaculture
US (39)				
Alabama	1961	Auburn	-	Aquaculture
Alaska	2004	Kenai	-	-
Arizona	1969	Lower Colorado Basin	-	-
California	<1924	Pasadena	Louisiana	-
Colorado	2018	Denver	-	-
Connecticut	2017	Near Norwich	-	-
Delaware	2018	Brandywine Creek	-	-
Dist. of Columbia	2016	Anacostia River	-	-
Florida	1951	Hudson	<i>Louisiana</i>	Aquaculture
Georgia	1989	Athens	-	-
Hawaii	1923	Oahu island	California	Food source
Idaho	1975	Nampa	Nevada/California	-
Illinois	2001	Chicago River	-	-
Indiana	<1986	-	-	-
Kansas	2017	Kansas City	-	-
Kentucky	<1944	-	-	-
Maine	1980	Kennebec River	-	-
Maryland	1963	Patuxent Area	Louisiana	Food source
Massachusetts	2010	Amherst	-	-
Michigan	2013	Holland	-	-
Minnesota	2016	Tilde Lake	-	-
Missouri	2009	Table Rock Reservoir	-	-

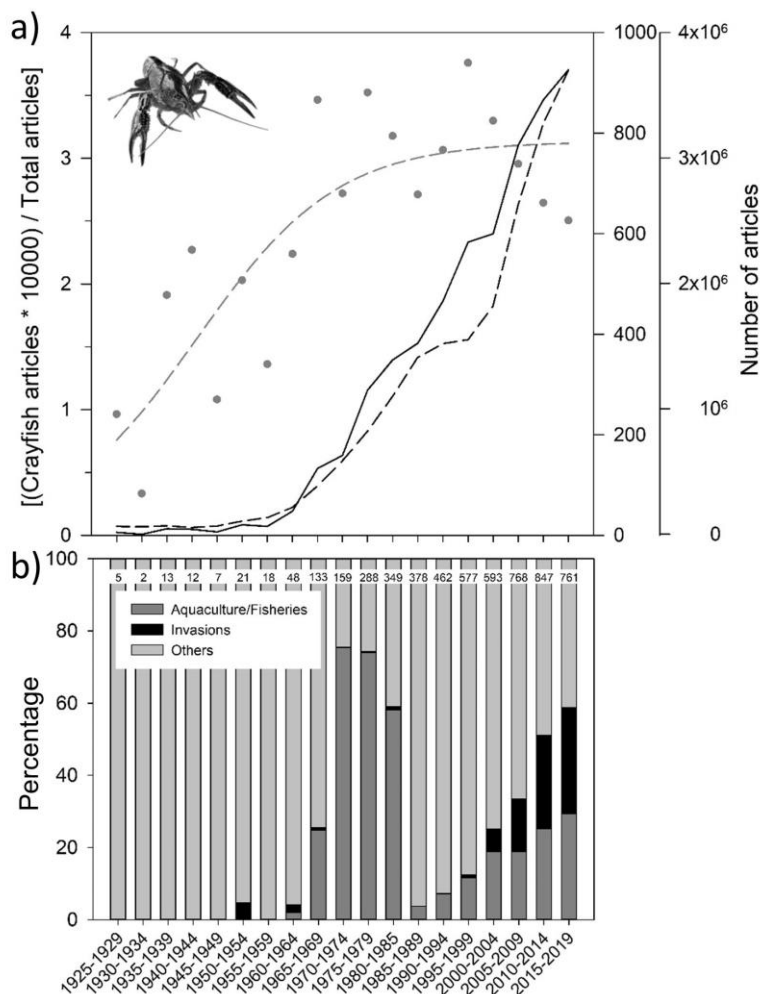
Nebraska	2014	Missouri River	-	-
Nevada	1944	Las Vegas River	California	-
New Jersey	2016	Saxton Lake	-	-
New Mexico	1944	Grande River	-	-
New York State	2002	Long Island	-	-
North Carolina	1980s	-	-	-
Ohio	1967	Sandusky Bay	-	Fishing
Oklahoma	1969	McCurtain Co.	-	-
Oregon	1990s	Willamette Valley	-	-
Pennsylvania	1990	Schuylkill River	-	-
Rhode Island	1970	Arcadia	-	-
South Carolina	<1978	-	Louisiana	Aquaculture
Tennessee	2018	Nashville	-	-
Utah	1978	Tooele Co.	-	-
Virginia	1972	York-Pamunkey	-	-
Washington State	2000	Pine Lake	-	-
Wisconsin	2009	Kenosha Co.	-	-
ASIA (7)				
China	1930	Nanjing	Japan	Pets
Hong Kong	<1960s	Hong Kong	-	Pet trade
Indonesia	2018	Java Island	-	Pet trade
Israel*	2008	Hadera	-	-
Japan	1927/1930	Ōfuna/Kamakura	New Orleans (US)	Food source
South Korea	<2005	Incheon	-	Pet trade
Taiwan	1960s	-	-	Aquaculture/Pet trade
Thailand	1987	Chiang Mai province	United States	Aquaculture
EUROPE (14)				
Austria	<2005	Salzburg	-	-
Belgium	1983-85	Vielsalm	-	Human consumption
Cyprus	<1987	Athalassa dam	-	-
England	1991	Hampstead Heath Park	Kenya	Human consumption
France	1974	Charente-Maritime	Spain/Kenya	Aquaculture
Germany	1975-76	Lake Hechtsee	-	-
Hungary	2015	Budapest	-	Pet trade
Italy	1977	Banna Stream	Spain	Aquaculture
Malta	2016	Fiddien Valley	China	Pet trade/Aquaculture
Poland	2018	Żerań Canal (Warsaw)	-	Pet trade
Portugal	1979	Caia River	Badajoz	Natural dispersion
Spain	1973	Badajoz	Louisiana	Aquaculture
Switzerland	1989	Schübelweiher	-	Fishing
The Netherlands	1985	The Hague	-	Human consumption

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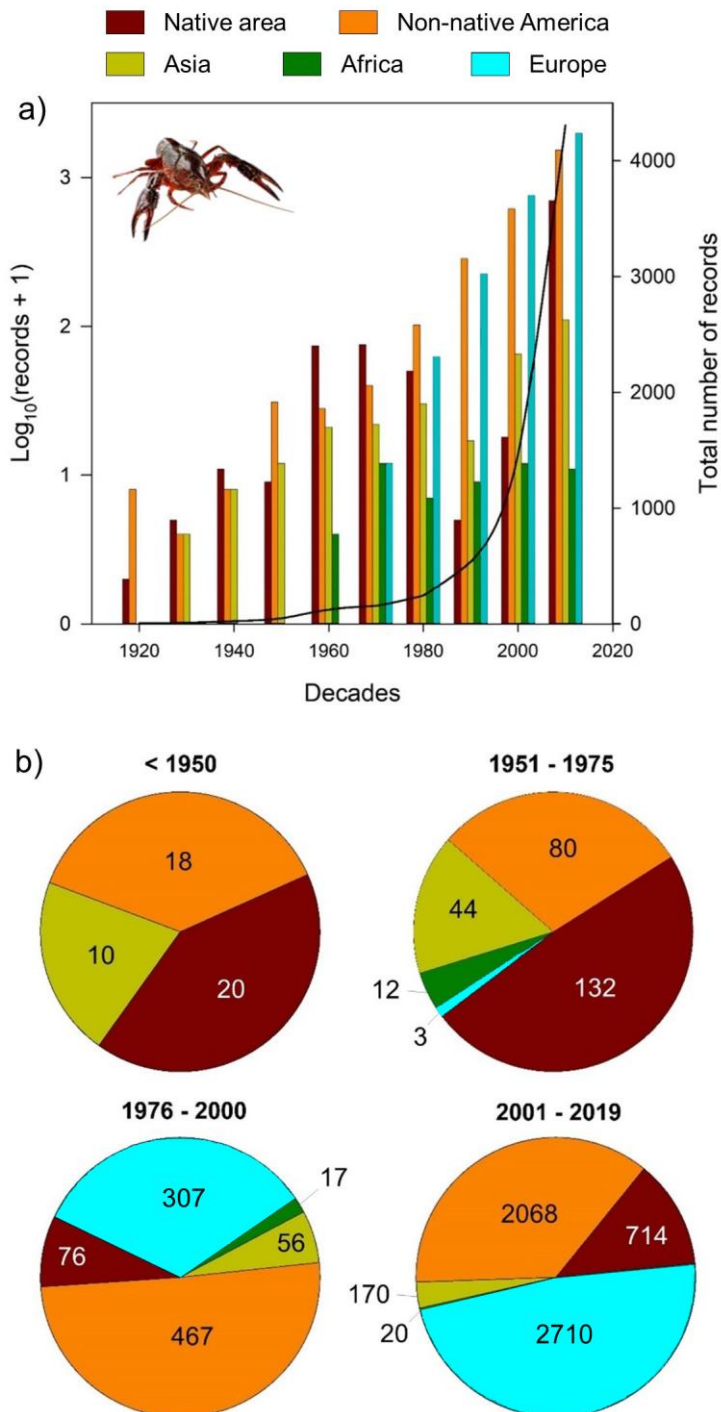
648 **Figure Captions**

649 **Fig. 1.** Dynamic of articles published on the red swamp crayfish over the last ten
 650 lustrums (five-year periods) from 1925 to 2019. A) Black line depicts the number of
 651 scientific manuscripts according to the categories (zoolog* OR *ecolog* OR *toxicol*
 652 OR *biolog* OR *neurolog* OR *invasi* OR "pet trade"). For a better interpretation,
 653 number of articles published on the red swamp crayfish were multiplied by 10,000 and
 654 grey dashed line represents the curve fit on the ratio ($ratio = n * 10000 / N$) as the
 655 number of articles on the red swamp crayfish divided by the total number of scientific
 656 articles. The scientific search was based on title, abstract or keywords. B) Percentage of
 657 published articles on the red swamp crayfish according to two main thematic categories.
 658 Total number of articles based on the red swamp crayfish for each lustrum is indicated
 659 on top of the graph.



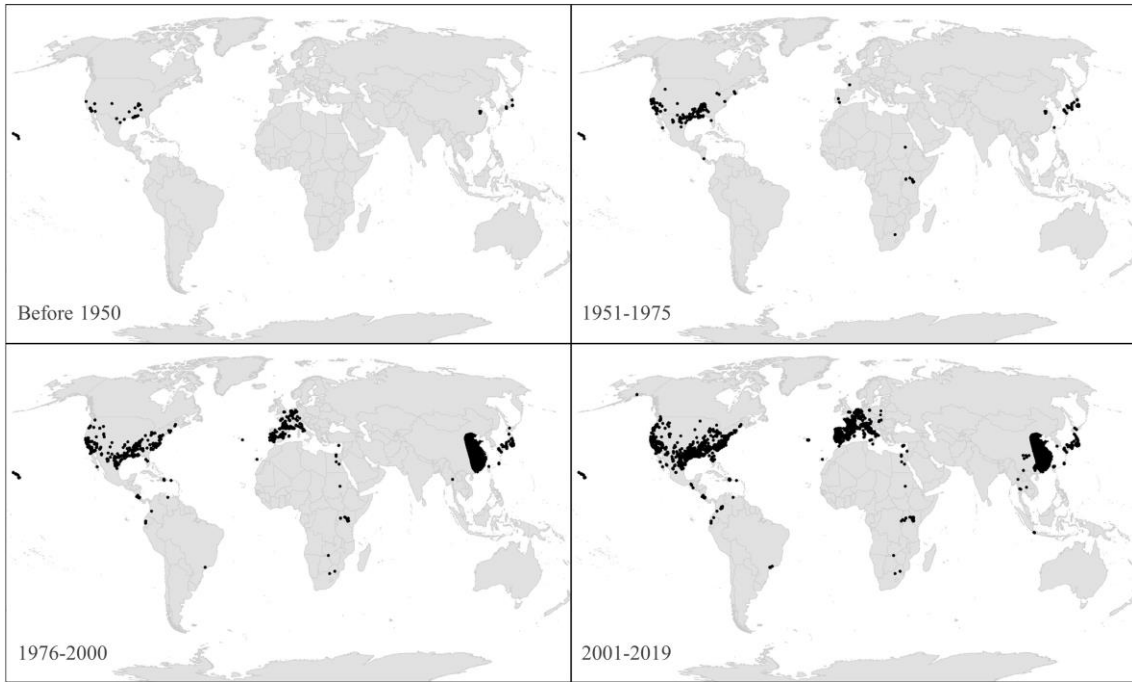
660

661 **Fig. 2.** Red swamp crayfish records along last century. (a) Decadal evolution in the total
 662 number of records (black line) and number of records for different biogeographical
 663 areas (note logarithmic scale of Y axis). (b) Proportion of total number of records for
 664 the four time-periods used in the presentation of our results, showing total numbers for
 665 each biogeographical area: native area, non-native area in America, Asia, Africa and
 666 Europe.



667

668 **Fig. 3.** Occurrence data (black dots) of the red swamp crayfish worldwide split in four
669 periods: before 1950, 1951-1975, 1976-2000, and 2001 to 2019. Depicted area in China
670 indicates the estimated distribution of the red swamp crayfish according to Xinya
671 (1988).

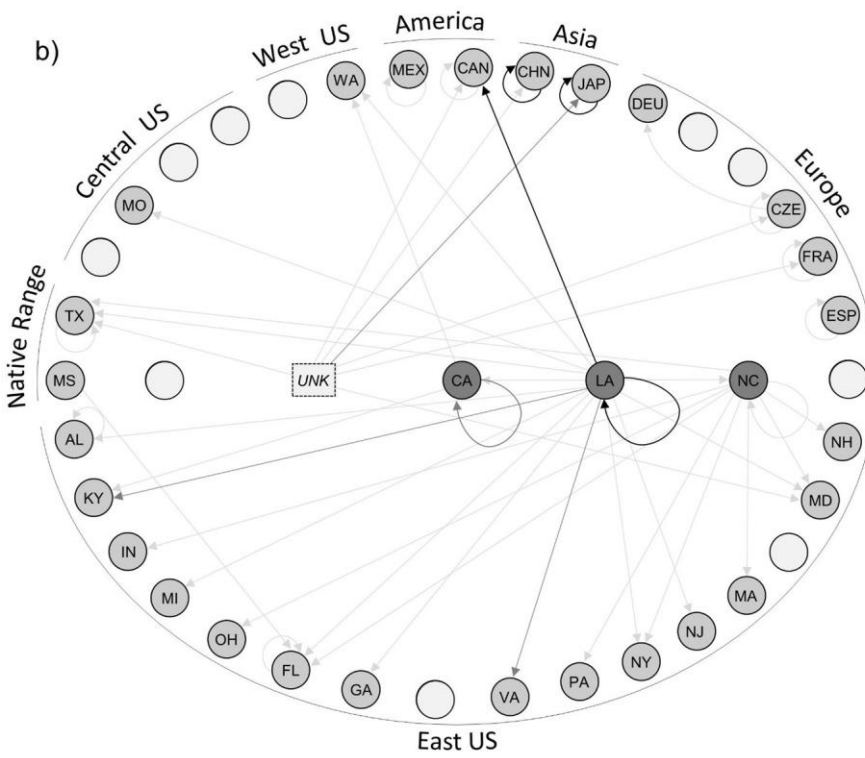
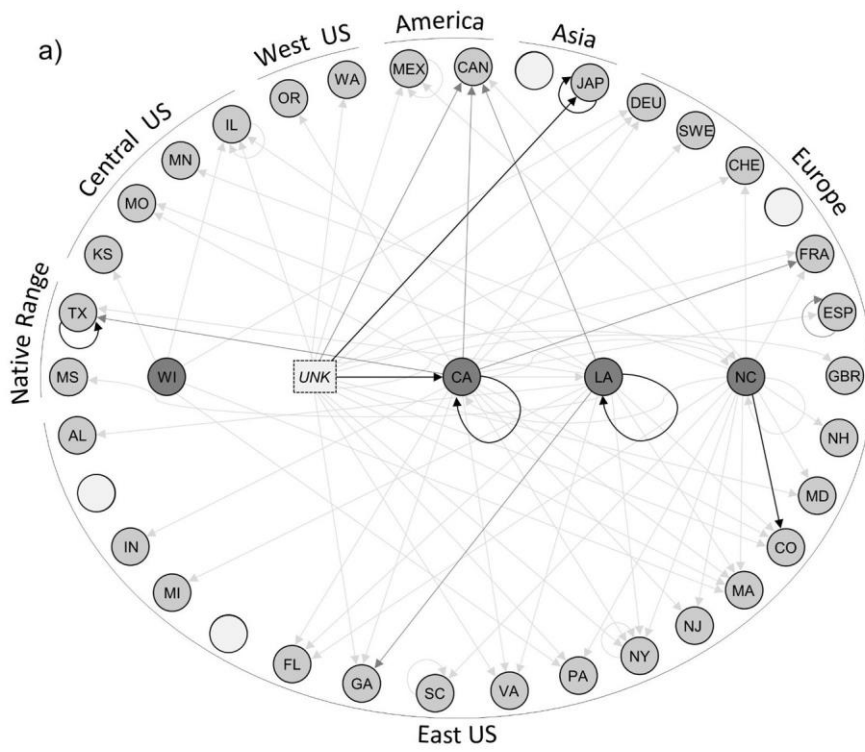


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673

674 **Fig. 4.** Network of the main commercial translocations of the red swamp crayfish (a)
675 since 1961 to 1990; and (b) in 1995, 2000, 2005, 2010 and 2015 based on 334 and 158
676 scientific studies, respectively. The States with main commercial companies are
677 depicted in the middle of the ellipse and recipient States (abbreviates) or countries (ISO
678 codes) around. Empty circles indicate the absence of connexions with that particular
679 State or country in the period. *UNK* shows unknown commercial suppliers. Black, light
680 grey and dark grey arrows depict the direction and frequency of movements of crayfish:
681 casual (<5), semi-frequent (5-9) and very frequent (>10), respectively.

682 ISO country codes: MEX, Mexico; CAN, Canada; CHN, China; JAP, Japan; DEU, Germany; SWE,
683 Sweden; CHE, Switzerland; CZE, Czech Republic; FRA, France; ESP, Spain; GBR, United Kingdom.
684 Abbreviate United States codes: WI, Wisconsin; CA, California; LA, Louisiana; NC, North Carolina;
685 NH, New Hampshire; MD, Maryland; CO, Colorado; MA, Massachusetts; NJ, New Jersey; NY, New
686 York; PA, Pennsylvania; VA, Virginia; SC, South Carolina; GA, Georgia; FL, Florida; OH, Ohio; MI,
687 Michigan; IN, Indiana; KY, Kentucky; AL, Alabama; MS, Mississippi; TX, Texas; KS, Kansas; MO,
688 Missouri; MN, Minnesota; IL, Illinois; OR, Oregon; WA, Washington.
689



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Supplementary Material for

693

One century away from home: how the red swamp crayfish took over the world

694

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Running Title

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Invasion history of *Procambarus clarkii*

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714

Cite this article:

715

Oficialdegui, F.J., Sánchez, M.I. & Clavero, M. One century away from home: how the

716

red swamp crayfish took over the world. Rev Fish Biol Fisheries 30, 121–135 (2020).

717

<https://doi.org/10.1007/s11160-020-09594-z>

718 APPENDIX I. METHODOLOGY FOLLOWED IN LITERATURE SEARCHES

719 In order to evaluate the evolution of knowledge production involving the RSC (Objective 1 -
720 Historical variation in the research scope), we conducted a keyword-based search using the ISI
721 Web of Science (WOS). On April 15th 2019 we searched for the terms “*procambarus clarkii*”
722 OR “*cambarus clarkii*” OR “*procambarus (scapulicambarus) clarkii*” in the title, abstract and
723 keywords, and the total number of studies was counted up to 2019. To refer the results of our
724 search to the overall scientific production, we also compiled the yearly production of scientific
725 studies in a pool of disciplines and themes that could involve crayfish-based research, by using
726 the search (*zoolog* OR *ecolog* OR *toxicol* OR *biolog* OR *neurolog* OR *invasi* OR
727 "pet trade"). Combining both searches, we calculated for each year between 1924 (the year of
728 the first introduction of the RSC outside its native range) and 2019 the number of studies
729 dealing with the RSC for every 10,000 scientific studies. We then assessed the temporal
730 variation of the scope of the research involving the RSC, with a focus on the disciplines related
731 to the introduction and invasive character of the species, particularly aquaculture/fisheries and
732 invasion science. To do so, in addition to the synonymous scientific names (see above), we
733 added the following terms in our search: AND aquacul* OR astacicul* OR fisher* (for
734 aquaculture/fisheries) and AND invasi* (for invasions).

735 In order to describe the progress of the global invasion of the RSC during the last century
736 (Objective 2 – The invasion history), we collected spatially-explicit records of the species in
737 both native and non-native ranges. The search included the review of the existing scientific and
738 grey literature as well as a compilation of geo-referenced, time-explicit records from on-line
739 repositories of biodiversity data, namely the Global Biodiversity Information Facility (GBIF,
740 www.gbif.org), the U.S. Geological Survey (USGS, www.usgs.gov) and the iNaturalist
741 platform (iNaturalist, www.inaturalist.org). Whenever a record from the literature referred to a
742 political entity (region or county) instead of a specific locality, we assigned the record the
743 coordinates of the centroid of the political entity. We split the RSC records in four time-periods:
744 before 1950, 1951-1975, 1976-2000, and 2001-2019. As result of our search, we present a
745 summary of the global expansion process, but full territory-specific information on this process,

746 including all consulted bibliographic sources, is provided as Supplementary Material in
747 Appendix I.

748 To evaluate the role of biological supply companies as potential introduction pathways of
749 live RSC worldwide (Objective 3 - Commercial supply companies as potential source), we did a
750 literature search on the ISI Web of Science (WOS) using the topic "*Procambarus clarkii*" as
751 well as making use of the old literature. In doing so, we obtained all those research studies that
752 used the RSC as study model. In the screening process, we only used those scientific studies
753 that detailed the source of the RSC (i.e., provenance from wild captures or obtained from
754 commercial supply companies) and destination (i.e., where the study was carried out) in
755 materials and methods section. For the latter, we also used author's affiliations, information on
756 the place where the experiments were performed and acknowledgements for destination
757 accuracy. In case of having no data or confusing information, studies were discarded from the
758 literature search to avoid overestimation of connexions between sites. While wild source of the
759 RSC (captures from the wild) was added as a record of presence in invaded areas (see paragraph
760 above), the commercial source (crayfish obtained from commercial supply companies) was used
761 as a proxy of the potential translocations of the RSC worldwide because anyone can buy live-
762 specimens from anywhere. As our main interest was to detect first translocations outside of its
763 native range in the beginning of the invasion process, we exhaustively analysed all studies
764 published annually until 1990. However, given the drastic increase in the number of published
765 manuscripts on the RSC from 1990 to present ($n = 3,924$) together with the increased
766 probability to capture wild crayfish nearby because of its global expansion, we selected
767 available scientific studies published every five years (1995, 2000, 2005, 2010 and 2015) as a
768 representation of the last 30 years.

769

770 **APPENDIX II. INVASION HISTORY BY COUNTRIES**

771 **AFRICA**

772 Established (Egypt, Kenya, Morocco, South Africa, Uganda and Zambia), probably
773 established (Rwanda and Sudan) and unclear presence (Gabon).

774

775 *Egypt*

776 The red swamp crayfish was successfully introduced from U.S.A. in Giza, Cairo and
777 Nile Delta in the early 1980s for commercial aquaculture (Hamdi 1994). Ten years after
778 its first introduction, its distribution had extended from Nile Delta to Assiute and Qena
779 Governorates in the Centre of Egypt (Saad and Emam 1998). A natural colonization
780 from Sudan seems to be no probable because there were no records from the upper Nile
781 or Lake Nasser, South Egypt (Fishar 2006). A consequence of its spread may be due to
782 the possibility of buying live-specimens in markets of Alexandria (Zaglol and Eltadawy
783 2009). Currently, it is widely established in lower Nile river, mainly in the mouth.

784

785 *Gabon*

786 Although the occurrence of the red swamp crayfish was not detected, there were
787 enquiries on feasibility of culturing the red swamp crayfish in Gabon by Goldschmidt
788 (1995). No updated information was found about the species.

789

790 *Kenya*

791 An unspecified number of the red swamp crayfish from Uganda was originally
792 introduced in 1966 into two dams located at Solai and Subukia, within the Rift Valley
793 (Oluoch 1990). Around 1970, approximately 300 specimens of the red swamp crayfish
794 from the Subukia dam were introduced into Lake Naivasha (Oluoch 1990), where
795 population increased few years later as a potential aquaculture species (Parker 1975;

796 Lowery and Mendes 1977a). In 1975, commercial exploitation began and many
797 exportations to Europe carried out until European banned in 1983 (decree of 21 July
798 1983) (Gherardi et al. 2011). The red swamp crayfish was expanded within the country
799 during the 1970s, leading to the occupation of major river systems (Athi/Galana river,
800 common in the Karen Pools, Nairobi River, Ewaso Ng'iro river, Gathanje reservoir and
801 Nzoia River) with the exception of Tana River, Lake Rudolf and Lake Natron (Huner
802 1977; Lowery and Mendes 1977b; Harper et al. 2002; Foster and Harper 2006).
803 Introductions were encouraged not only by the possible commercial activity, but also by
804 its assumed role as a biological control on schistosome snail vectors (Hofkin et al.
805 1991). In 1991, it was abundant in Eldoret river system and, by the 2000s, it was
806 expanded to Lake Ol Bolossat, Gilgil and Malewa rivers (Foster and Harper 2007). No
807 updated information was found about the species.

808

809 *Morocco*

810 The first introduction of the red swamp crayfish in Morocco took place in the late 1990s
811 and early 2000s when juveniles were intentionally introduced by an eel farmer in Ghard
812 and Larache regions (Yahkoub et al. 2019). According to El Qoraychy et al. (2015), this
813 species is still abundant in Merja Zerga, a permanent biological reserve. The current
814 distribution of the red swamp crayfish in Morocco has been mainly identified at swamps
815 and rice fields between the provinces of Tanger-Tetouan-Al Hoceima and Rabat-Salé-
816 Kénitra in North Morocco (El Qoraychy et al. 2015).

817

818 *Rwanda*

819 The red swamp crayfish has been recently found in a pond in the surroundings of the
820 capital, Kigali, in 2019 (iNaturalist 2019). No further information about its introduction
821 has been found.

822

823 *South Africa*

824 In 1962, two unconfirmed specimens of the red swamp crayfish were allegedly caught
825 in Potchefstroom near Johannesburg, but no established populations were detected (van
826 Eeden et al. 1983). Despite of their concerns, South African aquarists were rearing the
827 red swamp crayfish illegally and selling in pet shops until 1987, when the Cape
828 Department of Nature and Environmental Conservation confiscated all specimens from
829 pet shops in East London, George, Cape Town and Kimberley (Anonymous 1987). In
830 1988, an established population was recorded in Driehoek Farm, near Dullstroom
831 (Schoonbee 1993). By ending of the 1980s, the species spread over Crocodile River
832 basin and until 1993, when an eradication programme was put into practice (Schoonbee
833 1993). However, no monitoring was performed until 2016, when Nunes et al. (2017)
834 found again low densities of the red swamp crayfish near Crocodile River.

835

836 *Sudan*

837 In 1975, several hundreds of specimens of the red swamp crayfish were shipped from
838 Louisiana to Khartoum by the Ministry of Agriculture of Sudan to examine the species'
839 suitability for rearing activities (Huner 1977). This introduction was accomplished by
840 private interests with full government approval (Huner and Avault 1978). However,
841 after the successful commercial boom of the red swamp crayfish in Europe, another
842 event of introduction could have occurred into Sudan from Spain (National Research
843 Council 1976). No updated information has been found about the species.

844

845 *Uganda*

846 As an attempt to control the schistosomiasis snail vector, the red swamp crayfish was
847 introduced in Uganda from Louisiana around 1963 (Hobbs 1976; Stoneham 1976).

848 Until 1977, it was only well-established in isolated ponds in Kajjansi Fish Farm near
849 Entebbe, where it had been introduced, without spreading to other major basins (Huner
850 1977; Huner and Avault 1978). Yet in 2006, the red swamp crayfish was present in the
851 first place where it was introduced, near Entebbe close to Lake Victoria, but it was
852 expanded to Lake Bunyonyi (SW Uganda) and also recorded downstream of River
853 Kagera (Foster and Harper 2007). No updated information has been found about the
854 species.

855

856 *Zambia*

857 A legally authorized importation of 300 adults of the red swamp crayfish from Lake
858 Naivasha, Kenya, into a private experimental pool at Livingstone was made in the late
859 1970s (Grubb 1979) and subsequently transported to some fish farms in the Copperbelt
860 Province to be used in aquaculture. After a flood, the red swamp crayfish allegedly
861 escaped from this farm and entered in the Kafue basin. Currently, this species is
862 established in the Kafue and Zambezi rivers (pers. comm. to F. J. Oficialdegui).

863

864 AMERICA

865 Established (Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala,
866 Mexico, Puerto Rico, Venezuela and United States), probably established (Canada) and
867 unclear presence (Belize and Nicaragua).

868

869 *Belize*

870 Although there are studies about the presence of the red swamp crayfish (Hobbs et al
871 1989; Huner and Barr 1991), neither full description in references nor available
872 information was found about the species in the country.

873

874 *Brazil*

875 The first report of the red swamp crayfish dated back between the ending 1970s and
876 early 1980s (Huner 1986b). The red swamp crayfish began to be imported from US to
877 be sold as a pet in the 1980s and their availability in shops only decreased after its ban
878 in 2008 (Magalhães and Andrade 2014). Multiple releases led to the establishment of
879 wild populations over several areas in Southeast Brazil near Sao Paolo (Magalhães et al.
880 2005). Currently, this species is established in some locations in the surroundings of São
881 Paulo city, in São Paulo County (Loureiro et al. 2015).

882

883 *Canada*

884 The presence of the red swamp crayfish was recently reported near Vancouver in 2017
885 and near Toronto in 2019 (iNaturalist 2019). In 2018, news highlighted that more than
886 900 kg of live-crayfish coming from Maryland and Arkansas were seized in Michigan
887 before crossing the Canada border (<https://bit.ly/2FXTapW>), which might present a high
888 invasion risk for the country.

889

890 *Colombia*

891 The red swamp crayfish was introduced for experimental aquaculture by a commercial
892 enterprise in Cauca Valley in 1985 but its geographical origin remains unknown
893 (Flórez-Brand and Espinosa-Beltrán 2011). Some specimens from the captive pool used
894 in the experiments were accidentally released to wild in the basin of the Palmira river,
895 Cauca Valley in 1988 (Arias-Pineda and Rodríguez, 2012). Due to multiple secondary
896 introductions after this escapement, the red swamp crayfish rapidly spread over the
897 entire department of Cauca Valley (Flórez-Brand and Espinosa-Beltrán 2011), arriving
898 to Cundinamarca region near Bogotá (Campos 2005). Currently, this species is

899 established in Cundinamarca, Cauca Valley and Boyacá regions (Arias-Pineda and
900 Pedroza-Martínez 2018; Pachón and Valderrama 2018).

901

902 *Costa Rica*

903 The red swamp crayfish was introduced around 1966 in a small reservoir near Alajuela
904 City (Centre Costa Rica) but its geographical origin remains unclear. From there, it
905 appeared in the surroundings of San Carlos where it was successfully established
906 (Huner 1977). Although Nannes' letters informed that the red swamp crayfish had
907 escaped from ponds to natural systems, no apparent problems were detected in that
908 period (Nanne, 1975). In 1994, it was already present in Cartago, Heredia, Alajuela,
909 Guanacaste and Limón regions (Cabrera 1994). Currently, no additional information is
910 updated (pers. comm. to F.J. Oficialdegui).

911

912 *Dominican Republic*

913 The first reports of the red swamp crayfish dated back to 1977 when it was introduced
914 by people of the US Peace Corps to be cultured under controlled conditions at the
915 experimental stations at the Fisheries Experimental Station in Nigua (20 km south-
916 western of Santo Domingo) and at the National Rice Experimental Station in Juma (80
917 km north of Santo Domingo) (Huner and Avault, 1978). Currently, the red swamp
918 crayfish is listed as one of the invasive species into the country and it is regularly
919 captured in wetlands of Ozama River, surroundings of Santo Domingo and also
920 northwards in Hatillo Dam, Cotuí (pers. comm. to F. J. Oficialdegui).

921

922 *Ecuador*

923 In 1986, the red swamp crayfish was introduced in the rice fields near Taura River (SW
924 Ecuador) in the province of Guayas and subsequently, being expanded to the bordering

925 region of Los Ríos in 1988 for aquaculture purposes in a similar way to rice fields in
926 Louisiana (Salvador and Leyton 2000). Recently, in 2013, it was detected in Lake
927 Yahuarcocha, province of Imbabura (North), where fishermen started to capture them
928 (Riascos et al. 2018).

929

930 *Guatemala*

931 Although its occurrence in the country is cited long ago (Hobbs 1989), no reports on its
932 distribution have been found. Recently, the red swamp crayfish has been observed near
933 Tecpán belonging to Department of Chimaltenango in South Central Guatemala
934 (iNaturalist 2019).

935

936 *Mexico*

937 Campos and Rodríguez-Almaráz (1992) detailed the distribution of the red swamp
938 crayfish how native to North-Eastern Mexico, naturally inhabiting the basin of the
939 Bravo River, but the species had also been widely introduced throughout the country
940 (out of that basin). Although Re-Araujo (1994) cited its occurrence in the State of Baja
941 California Norte since the 1930s, albeit no confirmed. Other reports dated back from
942 1962, detected the red swamp crayfish in Conchos River near Camargo (Chihuahua)
943 and near Cananea (Sonora) (Hobbs 1962). It was reported in 1968 south of Ensenada,
944 Baja California (Clark and Ralston 1975). The range of the species expanded notably
945 through Northern Mexico during the 1980s (Campos and Rodríguez-Almaráz 1992; Re-
946 Araujo 1994). In early 21th century, new records were reported from Baja California
947 Sur, Durango and Sinaloa, focusing on the expansion into new states and basins of the
948 country (Hernández et al., 2008). The red swamp crayfish is currently widespread
949 throughout Northern Mexico, but is also present to southwards in the State of Chiapas

950 (Álvarez et al. 2011; Torres and Álvarez 2012; Franco-Sustaita 2014; Rodríguez-
951 Almaraz and García-Madrigal 2014).

952

953 *Nicaragua*

954 According to Huner (1977), only one specimen of the red swamp crayfish was found in
955 Nicaragua, next to the Costa Rican border. The record seemed to be a result from a
956 natural dispersion event from Costa Rica rather than an international importation (Huner
957 1977). Neither a full description nor available information has been described about the
958 species.

959

960 *Puerto Rico*

961 Personal communications cited that the red swamp crayfish was being cultured in
962 controlled laboratory systems in Puerto Rico (Huner and Avault 1978). The species was
963 available from aquarium shops at least up to the 2000s, but, even though releases have
964 occurred, established populations are not known in the wild (Williams et al. 2001).
965 Since the 2000s, the red swamp crayfish is enlisted into species prohibited from
966 importation into Puerto Rico (Williams et al. 2001). No further information about its
967 current distribution is known (pers. comm. to F.J. Oficialdegui).

968

969 *Venezuela*

970 Approximately 1,200 specimens of the red swamp crayfish were shipped from
971 Louisiana to Venezuela in 1978 with the aim of studying its suitability for culture in the
972 country (Huner and Avault 1978). Years later the red swamp crayfish was captured in a
973 pond of the Officers Club in Caracas and it is commonly available at pet shops in the
974 city (Rodríguez and Suárez 2001).

975

976 *United States*

977 States belonging to mostly the native area were not enlisted below: Arkansas (AR),
978 Louisiana (LA) Mississippi (MS), and Texas (TX) or without accurate information
979 about an introduction event or it is not present in the States: Iowa (IA), Montana (MT),
980 New Hampshire (NH), North Dakota (ND), South Dakota (SD), Vermont (VT), West
981 Virginia (WV) and Wyoming (WY).

982

983 Alabama (AL)

984 The red swamp crayfish is native to the Southwest of State (Hobbs 1989), but in 1961, it
985 was introduced at Auburn University Aquaculture Station and they would have been
986 well established on the area ten years later (Huner and Avault 1978). This species is
987 now known to be present in the Tennessee, Mobile, Black Warrior, Cahaba, Coosa,
988 Tallapoosa and Escambia river systems (Schuster and Taylor 2004; Shelton-Nix 2017).

989

990 Alaska (AK)

991 One specimen of the red swamp crayfish was found in the city of Kenai in May of 2004,
992 who might come from release of a private aquarium (Tunseth 2004). However, no
993 population is known to be established in wild yet (Nagy et al. 2019).

994

995 Arizona (AZ)

996 First evidences of the red swamp crayfish was found into stomach of striped bass in
997 Lower Colorado Basin, close to the Californian border in 1969 (Edwards 1974). In
998 1989, it was present along Verde River within Tonto National Forest (USGS 2019) and
999 currently, it is found in Lower Colorado Basin, Salt River, a tributary of Hassayampa
1000 River, canals of Phoenix and San Pedro River (Marsh 1999; Moody and Taylor 2012).

1001

1002 California (CA)

1003 The red swamp crayfish was present into a stream near Pasadena, Los Angeles County,
1004 in 1924 (Holmes 1924). However, its first introduction must have taken place earlier
1005 because there was a translocation of live-specimens of the red swamp crayfish from
1006 California to Oahu, Hawaii in 1923 (see Brasher et al. 2006). Few years later, in 1932, it
1007 was introduced as frog food in a farm of Lakeside, San Diego County (Riegel 1959).
1008 The species was also present in Santa Rosa region before the 1940s, which might be the
1009 original population that colonized Las Vegas River few years later (Hobbs and Zinn
1010 1948), and in Santa Barbara (Penn, 1954). During the 1950s, the red swamp crayfish
1011 was well established in southern and central California, being the only freshwater
1012 crayfish found in south of Tehachapis Mountains (Riegel 1959) and it was regularly
1013 taken in the Sacramento-San Joaquin Delta during the 1960s. By the 1970s, the red
1014 swamp crayfish was causing crop damage and levee destruction in rice fields of the
1015 Sacramento River delta, where the species was being exploited at small scale (Huner
1016 1988). By then, it was well established in San Francisco Bay (Ruiz *et al.*, 2000) and
1017 collected from Sweetwater River in San Diego National Wildlife Refuge (Cohen and
1018 Carlton, 1995). However, there were areas such as Topanga Creek near Los Angeles
1019 that, though was surrounded by the red swamp crayfish decades before, remained no
1020 infested until 2001 (RCDSMM *unpublished data* in Garcia et al. 2015). Attempts to
1021 eradicate were carried out by active removal efforts, but low flows and below average
1022 rainfall in 2011-2014 facilitated anew its extensive establishment (Garcia et al. 2015).
1023 Currently, it is widely distributed across the entire State (Nagy et al. 2019).

1024

1025 Colorado (CO)

1026 In 2018, one specimen of the red swamp crayfish has been observed into a city lake in
1027 Denver (iNaturalist 2019). No further information about its introduction has been found.

1028

1029 Connecticut (CT)

1030 In 2017, the red swamp crayfish has been detected in Indiantown Brook, a tributary to
1031 Thames River near Norwich (iNaturalist 2019). No further information about its
1032 introduction has been found.

1033

1034 Delaware (DE)

1035 In 2002, some specimens of the red swamp crayfish were being reared for culture
1036 research at Department of Agriculture and Natural Resources (Gherardi and Daniels
1037 2004). However, there were not wild reports until some recently established populations
1038 in Brandywine Creek (North) and Broad Creek (South) (Nagy et al. 2019), probably by
1039 its proximity to Maryland and Pennsylvania States where was established before.

1040

1041 District of Columbia (DC)

1042 Some occurrences has been reported recently in the northern half of the state
1043 (iNaturalist 2019), however, little is known about its introduction.

1044

1045 Florida (FL)

1046 The red swamp crayfish is native to the North-western Florida (Hobbs 1989), however,
1047 Penn (1954) reported an introduction of 700-900 crayfish at a private crayfish farm near
1048 Hudson, Pasco County, in 1951, but this introduction seemed to have been unsuccessful
1049 (Rhoades 1976; Huner 1977). In the late 1970s, approximately 5,000-6,000 adult the red
1050 swamp crayfish brought from Louisiana were introduced into cultured ponds near West
1051 Palm Beach (Huner and Avault 1978). Currently, it is widely distributed across the State
1052 with established populations in Lake Rousseau, ponds near Tampa, near Orlando,

1053 Wakulla Springs, Lake Alice in Gainesville and Guana River near San Agustín
1054 (iNaturalist 2019).
1055
1056 Georgia (GA)
1057 The red swamp crayfish was introduced at some time after Hobbs' study (1981) because
1058 it was not included there but its presence downtown Athens has long been known
1059 (around 1989), and it has recently spread to Oconee River and its tributaries (Nagy et al.
1060 2019). One single specimen appeared in Gwinnett County in 2007. By 2008, it was
1061 collected from Etowah River (Skelton 2010). Currently, it is distributed in the northern
1062 areas, mainly in the surrounding area of Atlanta but also near Columbus and Augusta
1063 (iNaturalist 2019).

1064

1065 Hawaii (HI)

1066 The first introduction of the red swamp crayfish remains unclear because it was
1067 introduced from California to Oahu Island, Hawaii in 1923 or 1927 (see Brasher et al.
1068 2006; see Brock 1960), originally to serve as food for bullfrog breeding facilities (Huner
1069 1977). In 1934, a new batch of 400 specimens of the red swamp crayfish was carried
1070 from Santa Barbara, California, to a frog farm in Oahu Island, Hawaii (Penn 1954). Few
1071 years later, the red swamp crayfish was introduced from Oahu to the island of Hawaii
1072 and Maui in 1937 and 1939 (Brock 1960). By 1954, red swamp crayfish was widely
1073 distributed on the islands of Kauai and Maui and it was established on Molokai by
1074 1977, where it was rapidly considered a pest. Currently, it is widely distributed in Oahu,
1075 Kauai (pers. comm. to F.J. Oficialdegui) and West Maui Forest Reserves (iNaturalist
1076 2019).

1077

1078 Idaho (ID)

1079 The red swamp crayfish was first detected in 1975, when several specimens were
1080 collected near Nampa, Canyon County (Clark and Wroten 1978). Currently, it appears
1081 in Snake River around Morley Nelson Snake River Birds of Prey National Conservation
1082 Area (Department of Fish and Game, Idaho) and some of its tributaries such as Salmon,
1083 Clearwater and Selway Rivers (pers. comm. to F.J. Oficialdegui).

1084

1085 Illinois (IL)

1086 The red swamp crayfish is native from Southern Illinois (Pope, Johnson, Massac,
1087 Union, Pulaski, and Alexander counties) between Mississippi and Ohio basins (Hobbs
1088 1989). However, its invasive range in the State has been artificially expanded. In 2001,
1089 it was collected from Chicago River (Taylor and Tucker, 2005) and from Dead River
1090 near Lake Michigan in 2004, subsequently, it has spread to surroundings of Chicago in
1091 last few years (i.e.: DuPage county in 2010 and McHenry County in 2017) (Nagy et al.
1092 2019).

1093

1094 Indiana (IN)

1095 Eberly (1954) did not include the red swamp crayfish on his list of the distribution of
1096 Indiana crayfish, but studies developed in the 1980s already cited this species within the
1097 state (Huner 1986; Hobbs 1989). The red swamp crayfish was considered one of the
1098 rarest species over this state, it restricted to extreme South-western Indiana, streams in
1099 Posey, Vanderburgh and Warrick counties (Page and Motessi 1995). However, in 2000,
1100 red swamp crayfish could be collected from Lake Michigan (North-Western of the
1101 state). The ongoing market and pet trade of this species was surely the reason by which
1102 this crayfish was spreading into the West Branch of the Grand Calumet River, border
1103 Illinois and Indiana (Simon, 2001). No updated information has been found about the
1104 species.

1105

1106 Kansas (KS)

1107 In 2017, one specimen of the red swamp crayfish was detected near Kansas City

1108 (iNaturalist 2019). No further information about its introduction has been found.

1109

1110 Kentucky (KY)

1111 The red swamp crayfish is native to the Southwestern of the State (Hobbs 1989). This

1112 species was supposedly introduced few years before 1944 because Rhoades (1944)

1113 enlisted the species, being considered as a new entry. Currently, it has only observed in

1114 the southwest of the State near Mississippi River where it is native from (iNaturalist

1115 2019).

1116

1117 Maine (ME)

1118 In Martin's study (1997), the red swamp crayfish was not enlisted as species introduced

1119 in the State, however, it is found in Kennebec river system since 1980 (Nagy et al.

1120 2019).

1121

1122 Maryland (MD)

1123 The red swamp crayfish was introduced in 1963 from Louisiana at Patuxent Wildlife

1124 Research Area (20km northeast of Washington D.C.), to serve as food for wading birds

1125 (Kilian et al. 2009). In 1981, a new batch purchased in Louisiana was carried to

1126 Pocomoke and Nanticoke rivers to try crayfish culture. From that original stock, more

1127 introductions occurred legally into other basins until 1990. Since then, other

1128 translocations might have occurred but there are no confirmed evidences, due to the

1129 establishment of aquaculture permit regulations. In 2006, it was well established in

1130 Chesapeake Bay, Delmarva Peninsula and all 14 watersheds of the Coastal Plain of

1131 Maryland (Kilian et al. 2009). These last occurrences may have resulted from
1132 introductions by anglers (Kilian et al. 2010). Currently, it is still established in the same
1133 areas (iNaturalist 2019).

1134

1135 Massachusetts (MA)

1136 In 2010, the red swamp crayfish was detected near University of Massachusetts in
1137 Amherst (iNaturalist 2019). In 2012, it was collected in Salisbury pond, Worcester, in
1138 order to study changes in water quality (Davis 2013).

1139

1140 Michigan (MI)

1141 First specimens of the red swamp crayfish were found in south-eastern shore of Lake
1142 Michigan near Holland in 2013, and four years later, a few established populations have
1143 been found eastwards, near Kalamazoo and Oakland county (Nagy et al. 2019). In
1144 addition, the red swamp crayfish is currently established in 30 small ponds near Novi
1145 and also, in Sunset Lake near Vicksburg (pers. comm. Michigan Department of Natural
1146 Resources) and also observed near Gaylord, northern of State (iNaturalist 2019).

1147

1148 Minnesota (MN)

1149 Only two specimens of the red swamp crayfish have been collected from Tilde Lake in
1150 2016 (Minnesota Department of Natural Resources).

1151

1152 Missouri (MO)

1153 One specimen of the red swamp crayfish was collected in a survey carried out in Table
1154 Rock Reservoir in 2009 (DiStefano et al. 2015). Recently, it has been observed in St.
1155 Louis and surroundings (iNaturalist 2019).

1156

1157 Nebraska (NE)

1158 In 2014, the red swamp crayfish was found in a bait dealer's tank located on the
1159 Missouri River. Currently, it is distributed in the Missouri River downstream of Gavins
1160 Point Dam and in Lake Yankton (Schainost 2016).

1161

1162 Nevada (NV)

1163 Hobbs and Zinn (1948) collected several specimens of the red swamp crayfish in Las
1164 Vegas River in the fall of 1944. By the mid-1950s, the species was well established in
1165 southern Nevada (Penn 1954). Two decades later (Rhoades 1976), it was still thriving,
1166 even though there were state law prohibits selling and transporting them, probably
1167 responding to damages of irrigation systems in this very arid region (Huner 1977). The
1168 decline of the bass fishery (*Micropterus salmoides*) since the late-1970s led to an
1169 interest in crayfish stocking in Lake Mead as food source for fishes, which took place in
1170 1988 with four releases, each one involving 1600 crayfish (Hager 1990). During 1986-
1171 1987, an exhaustive crayfish survey was carried out and low densities of the red swamp
1172 crayfish were found (Leavitt et al. 1989). Currently, it is also distributed in Ash
1173 Meadows across lower Colorado Basin, Southwest (Paulson and Martin 2014).

1174

1175 New Jersey (NJ)

1176 Some occurrences has been reported recently in the northern half of the state
1177 (iNaturalist 2019; Nagy et al. 2019), however, little is known about its introduction.

1178

1179 New Mexico (NM)

1180 One specimen was collected in Grande River in northern New Mexico in 1944 (Nagy et
1181 al. 2019). Recently, some populations of the red swamp crayfish have been detected
1182 across the Grande River from Albuquerque to El Paso (iNaturalist 2019)

1183

1184 New York State (NY)

1185 It is now established in New York State, at least from 2002, when the red swamp
1186 crayfish was found in Long Island and lower Hudson River system (Nagy *et al.*, 2019).

1187

1188 North Carolina (NC)

1189 First introduction events seem to have occurred in the beginning of 1980s but without
1190 information on localities and dates (Huner and Barr 1983; Huner 1986a). However, it
1191 can confirm because the red swamp crayfish was already sold on seafood markets in
1192 Raleigh in 1985 (Nagy *et al.* 2019). Cooper *et al.* (1998) reported wild populations of
1193 the red swamp crayfish in the Neuse, Tar-Pamlico, Yadkin-Pee Dee, and Cape Fear
1194 River basins, which might have originated from accidental releases from aquaculture
1195 facilities or aquarists. Besides of new locations in already invaded basins, Fullerton and
1196 Watson (2001) also reported the red swamp crayfish in Broad, Pasquotank, Waccamaw
1197 river basins. By 2007, it was present over almost all territory of the State (Cooper and
1198 Armstrong 2007).

1199

1200 Ohio (OH)

1201 First report of the red swamp crayfish dated back to 1967 in Sandusky Bay, after this
1202 first introduction, the red swamp crayfish was subsequently coming up on its tributaries
1203 in Sandusky County (Norrocky 1983). They started to be collected from several State
1204 Fish Hatcheries from various counties (e.g. Erie, Sandusky, Ottawa and Madison) in
1205 1982 (Norrocky 1983). The heterogeneous distribution in Ohio (Northern of the State in
1206 Sandusky Bay, Northeastern near Cleveland and Centre near Columbus) suggested that
1207 it had not dispersed naturally from its native range (Norrocky 1983). Currently, it is still

1208 established in the same dispersed areas previously colonized, reaching the surroundings
1209 of Cincinnati in 2014 (iNaturalist 2019).

1210

1211 Oklahoma (OK)

1212 The red swamp crayfish is native to the south-eastern corner of the State (Hobbs 1989)
1213 but it is out of its native area in McCurtain County since 1969 (Reimer 1969) and after
1214 in Okfuskee County (Jones et al. 2005). Recently, it has been observed near Tulsa and
1215 in Veterans Lake near Sulphur in the South of Oklahoma (iNaturalist 2019).

1216

1217 Oregon (OR)

1218 By the ending of 1990s, the red swamp crayfish was established in ponds and streams
1219 throughout the Willamette Valley (Pearl et al. 2005). A recently exhaustive sampling
1220 showed the widespread distribution of the red swamp crayfish in Western part of the
1221 State (Pearl et al. 2013; Nagy et al. 2019; iNaturalist 2019)

1222

1223 Pennsylvania (PA)

1224 First report dated back to 1990 in the Schuylkill River (SE of Pennsylvania), after that, a
1225 few of established populations have been found near Philadelphia (Lieb et al. 2011).
1226 Currently, it is mainly established in the eastern of the State (iNaturalist 2019).

1227

1228 Rhode Island (RI)

1229 A female of the red swamp crayfish was found in a pond in northern Arcadia,
1230 Washington Co. in 1970 (Crocker, 1979). However, no occurrence of the red swamp
1231 crayfish in inland waters of the State have been found on ongoing surveys (pers. comm.
1232 to F. J. Oficialdegui).

1233

1234 South Carolina (SC)

1235 During the 1970s, several aquaculture enterprises began to be developed in this state
1236 carrying on the red swamp crayfish from Louisiana (Huner and Avault 1978). Because
1237 of the existence of several production sites of crayfish over the state, the species is
1238 widely distributed into the State (Eversole and Jones 2004; iNaturalist 2019).

1239

1240 Tennessee (TN)

1241 This species is native from the Mississippi basin in western of this state (Hobbs 1989)
1242 but it has been detected currently in J. Percy Priest Lake near Nashville and near
1243 Manchester (iNaturalist 2019).

1244

1245 Utah (UT)

1246 First reports of the red swamp crayfish dated back to 1978 when some specimens were
1247 collected near St. John in Rush Valley, Tooele County. In following surveys of 1983,
1248 the species was still present in the area (Johnson 1986). Currently, it has been observed
1249 in Jordan River through Salt City (iNaturalist 2019).

1250

1251 Virginia (VA)

1252 One specimen of the red swamp crayfish was collected in 1972 in the York-Pamunkey
1253 drainage and another in the Potomac watershed in 1992 (US National Museum of
1254 Natural History 2011). Currently, it is widely expanded across the State, for example, it
1255 was found westwards to eastwards, in ponds of Blacksburg, Sweet Briar Lake, James
1256 River in Wingina, Briery Creek Lake, Broad Branch, Maury Lake and False Cape State
1257 Park (iNaturalist 2019).

1258

1259 Washington State (WA)

1260 Three live-specimens of the red swamp crayfish were captured in fall 2000 during a
1261 routine survey in Pine Lake in the Pacific Northwest State of Washington (Mueller,
1262 2001; Larson 2007). Between 2007 and 2009, the red swamp crayfish was collected
1263 from 11 lakes in the Puget Sound lowlands (Larson and Olden 2013).

1264

1265 Wisconsin (WI)

1266 An established the red swamp crayfish population occupied a private subdivision pond
1267 in Sam Poerio Park in Kenosha County, but it was eradicated in 2009 (Behm 2009). In
1268 the same year, other populations appeared in Washington County (Wisconsin
1269 Department of Natural Resources,
1270 <https://dnr.wi.gov/topic/Invasives/fact/RedSwampCF2012.html>).

1271

1272 ASIA

1273 Established (China, Japan, South Korea, Taiwan and Thailand), probably established
1274 (Hong Kong and Indonesia), unclear presence (Vietnam) and eradicated (Israel).

1275

1276 *China*

1277 In 1930, Japanese transported the red swamp crayfish from Japan to a garden in
1278 Nanjing, Jiangsu region, without clear reasons (Cheung 2010). Apparently, Japanese
1279 civilians brought and reared them as pet during the second Sino-Japanese war (1937-
1280 1945) and released them in wild before going back to Japan at the end of the war
1281 (Cheung 2010). However, local Chinese people considered its introduction as a
1282 Japanese conspiracy to destroy rice fields (Xinya 1988). Because of its Japanese
1283 connotations, Jiangsu people did not like and, by consequence, did not eat the red
1284 swamp crayfish until the 1980s. For this reason, its Chinese distribution was closely
1285 located around Nanjing but it was quickly spread across Eastern China in the 1980s

1286 (Xinya 1988), until reaching Hong Kong in the Southeast (Hobbs et al. 1989).
1287 Nowadays there is a big business around crayfish harvesting and commercial use
1288 (Cheung 2010). Currently, the red swamp crayfish is widely distributed in more than 20
1289 China's provinces, being widely distributed in the middle and lower reaches of Yangtze
1290 River, where concentrate the main production areas of the red swamp crayfish (Gong et
1291 al. 2012) but also, there are established population going northwards and southwards
1292 from Yangtze River.

1293

1294 *Indonesia*

1295 Indonesia is considered as one of the most suppliers of ornamental crayfish, the red
1296 swamp crayfish among them (Patoka et al. 2015). Although the import of the red swamp
1297 crayfish is banned since 2014, its culture and transport are legal within the country.
1298 When the red swamp crayfish was introduced remains unknown. Nowadays, the red
1299 swamp crayfish is present in pet shops of the country and few wild populations have
1300 been found in wild in Java Island, Cisaat Subdistrict (Putra et al. 2018) and Halimun
1301 mountain (pers. comm. to F. J. Oficialdegui).

1302

1303 *Hong Kong*

1304 The red swamp crayfish is cited in the city as pet and it is a likely source of the
1305 Taiwanese populations (Hobbs et al. 1989). Currently, it has been observed in Hong
1306 Kong Island (iNaturalist 2019).

1307

1308 *Israel*

1309 In 2008, the red swamp crayfish was fortuitously found in a temporary pond near
1310 Hadera, 40 km northward from Tel-Aviv (Wizen et al. 2008) and attempts, allegedly
1311 successful, to eradicate them were carried out by Israel Nature and Parks Authority

1312 (INPA). The provenance of this population is still unknown. Currently, no presence of
1313 the red swamp crayfish is detected over this country (pers. comm. to F. J. Oficialdegui).

1314

1315 *Japan*

1316 Of an initial uptake of one hundred red swamp crayfish, only twenty survived and were
1317 introduced into Japan in the late 1920s (1927 or 1930, the precise date is not clear in
1318 literature) to serve as food for the American bullfrog, *Lithobates catesbeianus* (Penn
1319 1954; Huner 1977; Kawai 1999; Cheung 2010). They were the survivors of an original
1320 shipping of 100 individuals from New Orleans (US), which were transported in beer
1321 barrels by the manager of a bullfrog farm in Kanagawa prefecture, Honshū Island. The
1322 species spread over Honshū Island due to its use as family pets (Sako 1987; Kawai
1323 2017). The absence of episymbiont branchiobdellidan worms living on Japanese the red
1324 swamp crayfish, suggest is thought to be related to the deficient transport conditions of
1325 the first introduction event and suggests that all the red swamp crayfish currently found
1326 over Japanese Archipelago are descendants of the 20 specimens released in Kanagawa
1327 in 1927 (Kawai and Kobayashi 2005; Kawai 2017). The species spread rapidly
1328 throughout the country and, by the 1950s, it was very abundant and caused agricultural
1329 damages on rice fields (Penn 1954). By 1975, the red swamp crayfish was already
1330 present in all Japanese Prefectures, with the exception of Hokkaido (Takeda 1975) and
1331 by the 1990s it occupied the whole country (Kawai 1999). The rapid spread of the red
1332 swamp crayfish from a single introduction point observed in Hokkaido and other
1333 Japanese islands suggests that unreported or illegal introductions have occurred across
1334 the Japanese archipelago (Kawai 2017). Currently, it has been also found in Okinawa
1335 Island (iNaturalist 2019).

1336

1337 *South Korea*

1338 Although little is known about the first introduction and distribution of the red swamp
1339 crayfish, some specimens were bought for research studies in a fish market of Incheon
1340 around 2005 (Ahn et al. 2006). Recently, it has been observed in South Jeolla Province
1341 in the southwest of South Korea (iNaturalist 2019).

1342

1343 *Taiwan*

1344 First reports of the presence of the red swamp crayfish come from the 1960s (Chen et al.
1345 2003). Aquaculture and pet trade were the main pathways of introduction in the island
1346 (Hobbs et al. 1989; Gao and Hong 2001) and subsequently, escapes and releases directly
1347 to wild caused its spread across the island. Currently, populations of the red swamp
1348 crayfish are widely established around Taipei, North Taiwan (iNaturalist 2019).

1349

1350 *Thailand*

1351 First introductions of the red swamp crayfish dated back to 1987 coming from US when
1352 this species started to be commercialized for aquaculture purposes in Chiang Mai
1353 province, northern of Thailand (Vidthayanon 2005; pers. comm. to F. J. Oficialdegui).
1354 Currently, it is located in wild (River Kwai, western Thailand) and, it is relatively easy
1355 to find it on websites of pet shops in many cities.

1356

1357 *Vietnam*

1358 In 2008, the red swamp crayfish was translocated from China to the northern provinces
1359 of Vietnam (Phú Thọ Province) with the purpose of raising commercial farming
1360 techniques. Currently, this species has not been encountered in surveys across
1361 freshwater bodies ([https://nongnghiep.vn/su-nguy-hai-cua-tom-hum-nuoc-ngot-
1362 post241883.html](https://nongnghiep.vn/su-nguy-hai-cua-tom-hum-nuoc-ngot-post241883.html)).

1363

1364 EUROPE

1365 Established (Austria, Belgium, Cyprus, England, France, Germany, Hungary, Italy,
1366 Malta, Poland, Portugal, Spain, Switzerland and the Netherlands) and unclear presence
1367 (Luxembourg and Slovakia).

1368

1369 *Austria*

1370 In the 1990s, no red swamp crayfish was found in the wild, but it was on sale in aquarist
1371 shops as "Red Lobster" (Pöckl 1999). Due to accidental releases from aquaria, there
1372 were at least two sightings near Salzburg where might become established (Strasser and
1373 Patzner 2005). A recent review shows its presence in this country (Holdich et al. 2009;
1374 Kouba et al. 2014) but no updated information has been found about the species.

1375

1376 *Belgium*

1377 The first specimen of the red swamp crayfish was found dead in the reservoir of
1378 Vielsalm during the first Belgian survey during the years 1983-1985 (see in Boets et al.
1379 2009). This specimen might have originated from a nearby restaurant. This finding was
1380 allegedly casual because the red swamp crayfish was not considered present in Belgium
1381 until more than ten years later (Arrignon et al. 1999). In 1996, a living individual in a
1382 pond nearby Cerfontaine was found during a large scale distribution survey of crayfish
1383 in Wallonia. In 2008, the red swamp crayfish was found in the nature reserve
1384 Zammelsbroek in Zammel. In 2009, populations of the red swamp crayfish were found
1385 there in three ponds situated northeast of the nearby River Grote Nete. The scattered
1386 distribution of the red swamp crayfish in Belgium suggests that the species probably
1387 escaped from nearby private ponds or was deliberately released by amateurs keeping
1388 crayfish as a hobby (see in Figure 5, Boets et al. 2009).

1389

1390 *Cyprus*

1391 It had allegedly been introduced to Cyprus in the 1980s, where it flourished in the
1392 Athalassa dam and subsequently, it was introduced into two other dams (Stephanou
1393 1987). Currently, it is still present in the Cyprus Island (Kouba et al. 2014) and newly
1394 observed in Athalassa National Forest Park (iNaturalist 2019).

1395

1396 *England*

1397 Specimens of the red swamp crayfish was imported for educational or recreational
1398 purposes as pets in domestic aquaria and culture trials several times during the 1980s
1399 (Dawes 1981), subsequently released into aquatic ecosystems (Goddard and Hogger
1400 1986; Hobbs et al. 1989). These introductions came from Kenya into wholesale fish
1401 markets (Goddard and Hogger 1986; Unpublished data). Subsequently, the red swamp
1402 crayfish was present at low levels in a roadside ditch in Tilbury and River Lee in 1990
1403 (Ellis, unpublished data). However, a high density of the red swamp crayfish was
1404 recorded in Britain in 1991 in the Men's Bathing Pond at Hampstead Heath in North
1405 London (Richter 2000) and at two separate locations in Kent during 1994 (Foster 1996).
1406 There were some occurrences in Regents Canal, London, in 2000 (Richter 2000) and
1407 later, a suspicious population in a small fishing lake near Windsor in May 2012. During
1408 surveys carried out between 2008 and 2010, the species was found in four other ponds
1409 within Hampstead Heath Park. The current distribution range of this species remains
1410 small in England (Ellis et al. 2012).

1411

1412 *France*

1413 The red swamp crayfish was introduced in 1974 in a fish farm near the Charente river in
1414 Western France (Arrignon et al. 1999) and later, unconfirmed reports indicated that
1415 attempts to import red swamp crayfish in France was carried out (Huner and Avault

1416 1978). Changeux (2003) performed a national survey on the presence of native and
1417 invasive crayfish since 1977, aiming at documenting crayfish distribution in the country
1418 in France. Before the 1990s, there were many scattered occurrences of the red swamp
1419 crayfish in France. For example, by 1978, it was found on the dam of Rouvière, in a
1420 tributary of Le Vidourle River between Hérault and Gard regions, where posteriorly its
1421 fishing was allowed (Laurent et al. 1991). in the swamps of Brière as consequence of
1422 one crayfish that escaped from a private crayfish farm in 1981 and posterior expansion
1423 by fishermen who sold it in live markets (Arrignon et al. 1999), in region of Pays de la
1424 Loire (Loire-Atlantique since 1984 and Mayenne since 1985-1987). Thus, the red
1425 swamp crayfish was already present over 10 departments from 7 regions by 1990,
1426 mainly Western France. Five years later, in 1995, its distribution range had reached 33
1427 departments from 12 regions, particularly marshy and rice area in Brittany, Atlantic and
1428 Mediterranean watersheds/seaboards including the Camargue (Rosecchi et al. 1997;
1429 Arrignon et al. 1999; Changeux 2003). Later, there were other occurrences in different
1430 departments until reaching up to 49 departments from 16 regions in 2001 (see Figure 6
1431 in Changeux 2003) and it was present in 61 departments by 2006 (see Figure 7 in Collas
1432 et al. 2007), reaching high population densities in Southwestern France. It was found in
1433 the Vosges department in 2008, along the upper part of the Meurthe River, northeast
1434 France (Collas et al. 2008). In the Ardennes Department, adjacent department to
1435 Belgium, it has been present in several rivers, including the Chiers River, which are
1436 tributaries of Belgian rivers (CETE de l'EST 2011). Its quick spreading was probably
1437 caused by large illegal translocations from surrounding countries (Laurent 1995b) and
1438 not only, there were importations from further countries like Kenya since 1976 (Laurent
1439 1990). Approximately, 170 tons were imported to France from Kenya where they were
1440 sold until France imposed import ban of live crayfish (Laurent et al. 1991). As an
1441 example, the estimated exportation of crayfish companies in rice fields of Seville was

1442 around 300 tons, of which 78.1% was sent to French markets in the 1990s (Gutiérrez-
1443 Yurrita et al. 1999). In fact, the red swamp crayfish was widely expanded in France in
1444 1995 and researchers looked for a biological control to decrease the extensive
1445 populations in rivers around Paris (Laurent 1995a). At the beginning of 21th century,
1446 Poitou-Charentes and Aquitaine regions (Southwest France) produced annually more
1447 than 200 tons of the red swamp crayfish (Changeux 2003). Currently, the red swamp
1448 crayfish is widely distributed over West and South of France but also there are
1449 established populations in Centre and North of France (Kouba et al. 2014; GBIF 2019;
1450 iNaturalist 2019).

1451

1452 *Germany*

1453 The red swamp crayfish may have been located near Ulm since 1975-1976, this
1454 presumption is based on local fishermen who asserted catching an exotic crayfish
1455 species (Chucholl 2011). In 1993, it was discovered in 16 localities of North Rhine-
1456 Westphalia (Löbf 1995; Groß et al. 2008). The commercial success in other bordering
1457 countries could have been the trigger of introductions over this area. The discontinue
1458 distribution pattern of this species in the area could have been consequence of
1459 translocations by men (Lake Hechtsee and Lake Riedheim) and subsequent active
1460 spread to surrounding habitats. By 2011, the estimated population was of approx.
1461 13,400 crayfish in Lake Riedheim but any commercial activity was still developed
1462 (Chucholl 2011).

1463

1464 *Hungary*

1465 The first record of the red swamp crayfish was in Lake Városligeti in Budapest in
1466 January 2015, subsequently, it was found in tributary streams of Danube River near
1467 Budapest in 2016 and in the drainage area of the River Tisza in 2017 (Gál et al. 2018).

1468 The probability of establishment in the country is high and pet trade is the likely
1469 pathway of introduction because this species is found in Hungarian pet shops (Weiperth
1470 et al. 2019).

1471

1472 *Italy*

1473 Although the red swamp crayfish was being experimentally reared in a farm from 1977-
1474 1985, the first report of red swamp crayfish in wild was in Banna River, within Po
1475 Basin in Piemonte, where the red swamp crayfish appeared in 1989 after escaping from
1476 the installation (Delmastro 1992). By posterior samplings over the area during the
1477 following years, the occurrence of the red swamp crayfish was confirmed, even the
1478 species had spread to the entire Piedmont province (Delmastro 1999). Posteriorly,
1479 juvenile crayfish were collected during the sampling season in Lake Massaciuccoli,
1480 Tuscany, Italy, in 1994. Their provenance seemed to be cultured animals in a crayfish
1481 farm that, after its bankrupt in 1993, there were fortuitous releases to wild (Baldaccini
1482 1995). Few years later, this species was especially abundant in this Lake and
1483 surrounding areas (Gherardi et al. 1999). In fact, this lake may have been the origin of
1484 future introductions in other regions of Italy (Aquiloni et al. 2010). Moreover, Barbaresi
1485 et al. (2007) hypothesized that foreign introduction may have happened, concretely, one
1486 population of Florence could have come from China following the immigration of a
1487 Chinese community to Florence. Others occurrences also appeared in Reno River
1488 drainage area, Emilia-Romagna, since 1995 (Mazzoni et al. 1996). Due to translocations
1489 by man, it started to appear in the many other regions of north-central Italy. This
1490 crayfish was found in Iseo Lake in 1991 (Delmastro 1992), Garda Lake (I. Confortini,
1491 pers. comm. to Aquiloni et al. 2010) which is placed between the provinces of
1492 Lombardia and Veneto (P. Turin, pers. comm. to Aquiloni et al. 2010). By 1994, it was
1493 present near Verona, province of Veneto (Morpugo et al. 2010), reaching Seriola

1494 Channel, between Padua and Venice in 2002 (Mizzan and Vianello 2007). However, the
1495 distribution of the red swamp crayfish in Lombardy was mainly located to southwestern
1496 of the region between 1994 and 2006 (e.g., provinces of Pavia, Milano and Lodi) (see
1497 Figure 1 in Fea et al. 2006). This species was also present in Region of Liguria
1498 (Gherardi et al. 1999) and by 2009, some specimens appeared in Tagliamento, Meduna,
1499 Torre river basins and mouth of Isonzo river in Friuli Venezia Giulia (De Luise 2010).
1500 Moreover, it was found in central provinces like Umbria (Dörr et al. 2001), the
1501 Marches, Abruzzo (Gherardi et al. 1999) and Latium (Chiesa et al. 2006) where it was
1502 well established (see Table 1 and references in Gherardi et al. 1999; Barbaresi and
1503 Gherardi 2000). In Lake Trasimeno, Umbria, the red swamp crayfish seems to have
1504 been introduced since 1985 and captured by fishermen to sell in local markets (Dörr et
1505 al. 2001). In addition, it was found in several lakes of this province, Lake Piediluco, and
1506 the neighbouring province of Rieti in Lake Ventina, being well established in
1507 surroundings areas of lakes and streams in the early 2000s (Dörr et al. 2001). Regarding
1508 on Southern of Italic Peninsula, the occurrence of this species was not reported until
1509 recently (see Table S1 in Cilenti et al. 2017). Concretely, this species appeared in
1510 Bradano River and San Giuliano Lake in Basilicata (Caricato et al. 2013), in Campania
1511 region was detected near Napoli where control and eradication efforts were made
1512 (Stinca 2013), present in Tarsia Lake and in middle course of Crati River in Calabria by
1513 2012 (Sperone et al. 2015). In Puglia, first report of this species dated back to a
1514 sampling on Lesina lake in 2007, it might have colonized the lake for accidental release
1515 from aquaculture activities (Florio et al. 2008). Recently, juvenile of the red swamp
1516 crayfish were repeatedly observed in an artificial drainage ditch in Melissano (Lecce),
1517 located in the southwestern area of the Salento Peninsula in 2016 (Cilenti et al. 2017).
1518 In Sicily, the first finding of the red swamp crayfish was in June 2002, where a
1519 specimen and several crayfish exoskeleton were found in The Nature Reserve of Priola

1520 and Gorghi Tondi Lakes in western Island (D'Angelo and Lo Valvo 2003; Dörr et al.
1521 2006). Since there were no farming activities of this species in the nearby areas, the
1522 hypothesis was a release of some specimens by people keeping crayfish for recreational
1523 purposes. Moreover, this may be confirmed by the observation in the same period of
1524 one individual of the turtle Red-eared Slider, *Trachemys scripta*, another exotic species
1525 usually kept in captivity (D'Angelo and Lo Valvo 2003). Since then, the red swamp
1526 crayfish appeared in far locations of the Island; for example, it was found in Rosamarina
1527 Lake during 2012-2013 (Di Leo et al. 2014). The present situation over the Island is
1528 detailed by Faraone et al. (2017) using a citizen science approach. In this study, they
1529 found this species in different river basins or lakes, separated by hundred kilometres
1530 from previous invaded areas, suggesting multiple independent releases in wild (see
1531 Table 1 for more details). On the other hand, in Sardinia, first specimens were found in
1532 the northern part of the island (Gallura area) between 2000 and 2002, after then, more
1533 specimens were consecutively recorded to west- and southward expansion (Coghinas
1534 River and watercourses along Tyrrhenian coast). Since 2010, it is also present in southern
1535 part of the island, near to Cagliari (see regional reports within Cilenti et al. 2017).
1536 In Italy, the presence of nonindigenous species in the wild has always been related to
1537 aquaculture activities, in fact, the distribution of farms in the late 1990s mostly
1538 overlapped with the occurrence of new reports of invasive crayfish (see Fig. 2 and Fig.
1539 3 in Gherardi et al. 1999).

1540

1541 *Luxembourg*

1542 The red swamp crayfish was no present in Luxembourg before 2009 (Arrignon et al.
1543 1999; Holdich et al. 2009; Kouba et al. 2014). However, as some populations have
1544 established themselves in neighbouring countries, it may be possible that the species
1545 was already present but not yet detected in some ponds or rivers (Delsinne et al. 2013).

1546

1547 *Malta*

1548 The first specimens of the red swamp crayfish were captured at Fiddien Valley, Western
1549 of Malta, in September, 2016 (Vella et al. 2017). Genetically-based, the origin of this
1550 invasive population might be attributed to Asia because of commercial agreements or
1551 pet trade from other European countries that act as invasion hubs (Oficialdegui et al. *in*
1552 *review*).

1553

1554 *Poland*

1555 The red swamp crayfish was firstly detected in Żerań Canal and Krasieński Garden near
1556 Warsaw as well as in Dąbie Pond near Krakow in 2018 (Maciaszek et al. 2019). It is
1557 likely that the pathway of introduction was the pet trade because only few individuals
1558 were detected and both locations are far away each other, which seem to indicate a
1559 possible release from aquaria (Maciaszek et al. 2019).

1560

1561 *Portugal*

1562 Although the spreading of this species has been related to the attempt to create
1563 commercially exploitable breeding populations (Gutiérrez-Yurrita et al. 1999), the first
1564 introduction in Portugal was probably the result of the natural dispersion from a
1565 naturalized population near Badajoz in 1979 (Ramos and Pereira 1981). This species
1566 was subsequently colonizing new basins northwards and southwards of Portugal from
1567 the initial introduction point in Caia River in 1979. For example, first occurrences of the
1568 red swamp crayfish were found in Tagus (1986), Guadiana (1986), Mondego (1987),
1569 Sado (1990) and Douro basin (before 1993) (for more details, see references in
1570 Gutiérrez-Yurrita et al. 1999) being established in Maças River, North-east of Portugal,
1571 by the ending 1990s (Bernardo et al. 2011) and Minho region in the beginning of 2000s

1572 (Moreira et al. 2015). This expansion did that the annual production was around 700
1573 tons in Portugal during the 1980s (Gutiérrez-Yurrita et al. 1999) but this market may
1574 have grown up to 3,000 tons in the ending 1990s. Such was the case that some
1575 companies (Dutch company) was valuing to move a crayfish processing factory to the
1576 Mondego Valley and export crayfish to North European markets (see in Gutiérrez-
1577 Yurrita et al. 1999). In addition, new populations of the red swamp crayfish were not
1578 limited to Iberian Peninsula but also, the red swamp crayfish arrived to São Miguel,
1579 Azores, Portugal by human mediated, it is believed that some crayfish were released
1580 from aquaria into Peixe Lagoon (Correia and Costa 1994).

1581

1582 *Slovakia*

1583 Although there were no wild populations, Stloukal and Vitázková (2009) mentioned the
1584 fact that the red swamp crayfish occurs in garden ponds and might present a high
1585 invasion risk in Slovakia.

1586

1587 *Spain*

1588 The first importation was made on 13th and 14th June 1973 in two shipments from New
1589 Orleans (Louisiana) to near Badajoz. That introduction was sponsored by private
1590 interests with the approval of the Ministry of Agriculture (Huner 1977; Habsburgo-
1591 Lorena 1978). A total of 250 females and 240 males were sent by plane in plastic bags,
1592 filled with 1/3 water and 2/3 oxygen. Crayfish were housed in four isolated earth ponds
1593 near rice fields and a fence was installed to avoid releases to any other water body.
1594 However, some crayfish were found on surrounding irrigation channels where they were
1595 easily caught. Although half of the first introduction crayfish died during the first year,
1596 the survival ones were success and in summer 1974, some around 500 crayfish were
1597 recaptured and they found females with up to 400 juveniles (Habsburgo-Lorena 1978).

1598 On May 10, 1974, another importation of 500Kg was made into the province of Seville,
1599 near Alfonso XIII, Isla Mayor, a village in the middle of the rice growing area. Crayfish
1600 were released into abandoned ponds, indeed, crayfish importations attempted to
1601 substitute an important eel business, which existed before. That time, there were
1602 important and considerable losses, indeed, it was estimated that only a 20% survived;
1603 however, once seen that the rest of crayfish were a great success, fishermen
1604 disseminated crayfish in nearby rivers and irrigation channels (Habsburgo-Lorena,
1605 1978). Since the moment when it became clear that this species had adapted, it was
1606 obvious that money was to be made on it and it was posteriorly expanded by fishermen
1607 throughout Spain, France and Italy during the period from the late 1970s into the late
1608 1980s (Gutiérrez-Yurrita et al. 1999; Henttonen and Huner 1999; Oficialdegui et al.
1609 2019). By 1976, there was a commercially exploitable production in the rice fields. In
1610 fact, captures increased from 480 crayfish in 1975, 1,843 kgs. in 1976, 9,800 kgs. in
1611 1977 up to 13,119 kgs. by the end of May 1978 (Habsburgo-Lorena, 1978). Few years
1612 later, the annual the red swamp crayfish production was around 2,900 tons in Spain,
1613 reaching the maximum Spanish production of 5,000 tons during 1987 (Gutiérrez-Yurrita
1614 et al. 1999). In 1976, the red swamp crayfish was already present in Doñana National
1615 Park, concretely in the Rocina stream (north of the Park) and Las Nuevas Canal (near
1616 mouth of Guadalquivir river) (Algarín 1980) and by 1977, the Rocina had become a
1617 fishing site. In 1979, the red swamp crayfish had arrived to rivers and streams of
1618 bordering provinces (Cadiz and Huelva). The economic benefit of this species
1619 encouraged different owners of rice fields to transfer to other regions of the country, in
1620 this way, it was introduced into Tablas de Daimiel, Ciudad Real, before 1978, the rice
1621 fields of Valencia in 1978 and Ebro Delta in 1979. It also appeared in the province of
1622 Zamora in 1979 (Alonso et al. 2000). By the ending 1980s, it allegedly appeared in
1623 Minho River (Sousa et al. 2013). It was introduced into Cuenca in 1986, occupying

1624 mostly entire province by 2000 and almost region of Castilla La Mancha by 2006 (see
1625 Fig. 2 and Fig. 4 in Alonso and Martínez 2011; respectively). Due to crayfish plague,
1626 there was a vertiginous decrease of captures of *Austrapotamobius italicus* in all regions
1627 between 1974 and 1980 in Ebro basin (where European crayfish is mostly distributed)
1628 (Fernández 2004). It was attributed to the introduction of the red swamp crayfish and
1629 not by occurrence of signal crayfish few years later (Alonso and Martínez 2011; pers.
1630 comm. to F.J. Oficialdegui).

1631 In addition, the spreading of the red swamp crayfish was not limited to Iberian
1632 Peninsula, indeed, red swamp crayfish arrived (by human-dispersal) to The Balearic
1633 Islands in 1993 and to San Andrés steep river bank, Tenerife Island, Canary Islands in
1634 1997 (see reference in Gutiérrez-Yurrita et al. 1999). In fact, Alonso et al. (2000)
1635 mentioned that there already were dense population of the red swamp crayfish in the
1636 most of provinces in Spain (mainly the south half of Spain), excepting Lugo in Galicia.
1637 During the 1990s, there were multiples translocations of crayfish between Portugal and
1638 Spain to furnish crayfish food companies and the red swamp crayfish market mainly
1639 exported frozen animals from rice fields in Seville to Valladolid and Madrid (Gutiérrez-
1640 Yurrita et al. 1999) and therefore, it would not be rare that there have been
1641 translocations of live animals for culture in own ponds (pers. opinion). Lake Chozas,
1642 León, Northwest Spain, has been regularly monitored since 1994 without any
1643 occurrence of the red swamp crayfish, the presence of red swamp crayfish in 1997
1644 indicated that an introduction may have occurred in 1995 or 1996 (Rodríguez et al.
1645 2003). In 1999, the distribution of the red swamp crayfish was deeply analysed by grid
1646 in Extremadura region and sampling a total of 79,03% of this region, the occurrence of
1647 the red swamp crayfish was detected in a 69,77% (see Figure 3 in Pérez-Bote et al.
1648 2000). In La Rioja region, the red swamp crayfish is found along the watershed of Ebro
1649 River, downstream of its tributaries (e.g., Tirón, Oja, Najerilla, Leza-Jubera, Cidacos or

1650 Alhama rivers) and irrigation channels (Gobierno de La Rioja). Currently, the most part
1651 of Spanish territory (excepting high altitudes) is infected by the red swamp crayfish
1652 (Kouba et al. 2014; Oficialdegui et al. 2019; GBIF 2019; iNaturalist 2019)

1653

1654 *Switzerland*

1655 By 1989, the red swamp crayfish was illegally introduced in two ponds (Schübelweiher
1656 and Rumensee) near Zurich probably to replace the *Astacus astacus* population that had
1657 collapsed due to crayfish plague *Aphanomyces astaci*. In the mid-1990s, estimated
1658 population size was around 13,000 crayfish and Swiss Prime Court decided to poison
1659 the ponds to avoid an increase of those populations; however, it was immediately
1660 challenged by the local population. Then, other options were valuated as for example to
1661 try to minimise emigration or diminish the red swamp crayfish population by intensive
1662 trapping. Moreover, introductions of predatory fishes or eels were also considered as
1663 treatments to avoid the spreading of this population (Frutiger et al. 1999).

1664

1665 *The Netherlands*

1666 The first specimens of the red swamp crayfish known in the wild were released by a
1667 restaurant owner in 1985, in The Hague (Soes and Koese 2010). Initially, it was
1668 assumed that the species would not become establish permanently and its presence
1669 would therefore be casual. However, it was already well established in the Netherlands
1670 by 2010 (see Figure 19a in Soes and Koese 2010; Koese and Evers 2011). It was
1671 regularly reported in a number of ponds and streams, especially in the west of the
1672 country (Amsterdam, Utrecht and Den Haag), but also near the Belgian border (Breda,
1673 Tilburg), and from some localities in the east (Koese and Evers 2011). The distribution
1674 of the red swamp crayfish is closely associated with urban concentrations, reflecting the
1675 fact that the species mainly entered in the Netherlands through the consumption and

1676 aquarium trades (Soes and Koese 2010). Currently, the red swamp crayfish is widely
1677 distributed in Western of the country (Kouba et al. 2014).
1678

1679 **APPENDIX III. LIST OF LITERATURE CITED IN INVASION HISTORY BY**
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