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Diversity and Distribution of the Inland Water Decapods of Sicily (Crustacea, Malacostraca)

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Abstract: The current knowledge of Sicilian inland water decapod malacostracans is scarce and an updated synopsis on species distribution is lacking. Therefore, we reviewed the checklist and recent distribution of Sicilian inland water decapods based on published and unpublished records and novel observations with the aim of providing an exhaustive repository, also to be used as a sound baseline for future surveys. Overall, five native decapod species occur in the study area, i.e., the atyid shrimp *Atyaephyra desmarestii*, the palaemonid shrimps *Palaemon adspersus*, *P. antennarius*, and *P. elegans*, and the freshwater crab *Potamon fluviatile*, and their current local distributions are described. In addition, three alien species were recorded: the common yabby *Cherax destructor* and the red swamp crayfish *Procambarus clarkii*, strictly linked to inland waters, and the Atlantic blue crab *Callinectes sapidus*, a mainly marine species that can also colonise the lower stretches of rivers and coastal brackish waters. The collected data suggest the existence of a partial segregation of native versus non-native species, with the latter currently confined to coastal water bodies and the lower stretches of rivers. Moreover, the exclusively freshwater caridean *A. desmarestii* and *P. antennarius* show a parapatric distribution in the study area, which may suggest the existence of mutual exclusion phenomena. The results obtained raise some concerns about the effects of alien species on the native biota, and dedicated monitoring and management strategies should be implemented in order to better understand and mitigate their impact.

Keywords: alien species; Decapoda; Malacostraca; Mediterranean island

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1. Introduction

Despite their limited extent and their intrinsically vulnerable nature, inland water ecosystems are among the most biologically diverse habitats on Earth [1]. At the same time, they are particularly susceptible to external disturbances [2]. Changes in their hydroperiod or the introduction of non-indigenous species are known to cause severe impacts on these fragile ecosystems, leading to the local or global extinction of several taxa [3–6]. The vulnerability of inland water ecosystems is particularly high in islands and in arid and semi-arid regions, where they are extremely fragile and water demand for human needs is high [3,7,8]. In fact, human activities have often dramatically modified inland water ecosystems, leading to significant habitat alteration and to the decline or loss of freshwater biological diversity [9,10].

To date, the invertebrate fauna inhabiting the inland waters of Sicily is inadequately and unevenly known. Although detailed information is available for some taxa (e.g., non-malacostracan crustaceans; see [11–13]), a wide knowledge gap still remains to be filled for the other taxa, thus preventing an accurate picture of the current biological diversity to

be obtained. This is the case of the decapod malacostracans, which have never been the subject of an accurate synoptic study. In the frame of this work, we carried out an accurate review of the current knowledge about the occurrence and distribution of decapods in Sicilian inland waters, with a focus on the last four decades.

2. Materials and Methods

The study area considered in this work includes Sicily and the small circum-Sicilian islands.

Since our purpose was to obtain information regarding the current distribution of the species in the study area, the review of bibliographical data was limited to papers published after 1980. Therefore, pre-1980 data stored in the CKmap database [14] were not considered. In addition, a set of unpublished occurrence data is reported herein based on observations made by Filippo Amato (F.A.), Andrea Cusmano (A.C.), Reinhard Gerecke (R.G.), Gabriele Giacalone (G.G.), Federico Marrone (F.M.), Fiorenza Provenzano (F.P.), Francesco Paolo Faraone (F.P.F.), Salvatore Russotto (S.R.), Giuseppe Urso (G.U.), and Luca Vecchioni (L.V.). All available data were critically evaluated and, when considered reliable, included in the analyses.

Decapod specimens collected in the frame of this study were identified according to Williams [15], Froglia [16], González-Ortegón and Cuesta [17], Holdich and Vigneux [18], and González-Ortegón et al. [19].

Occurrence localities were used to produce distribution maps based on the UTM 10 × 10 Km grid cells (zone 33N, datum ED50) using the QGIS freeware software v. 3.18 (QGIS Development Team, 2022 [20]).

Based on the complete dataset, cumulative curves describing the increase of sites and grid cells occupied by alien species, as well as alien species richness, are presented.

3. Results

Overall, the occurrence of eight decapod species belonging to six families was reported in 93 sites (see Figures 1 and 2 and Table 1). The first record of an alien decapod in Sicilian inland waters dates to 2002 [21], and a sharply increasing rate of the number of alien species and their distribution sites was observed from 2012 onwards (Figure 3). A checklist of inland water Sicilian decapod fauna is presented below.

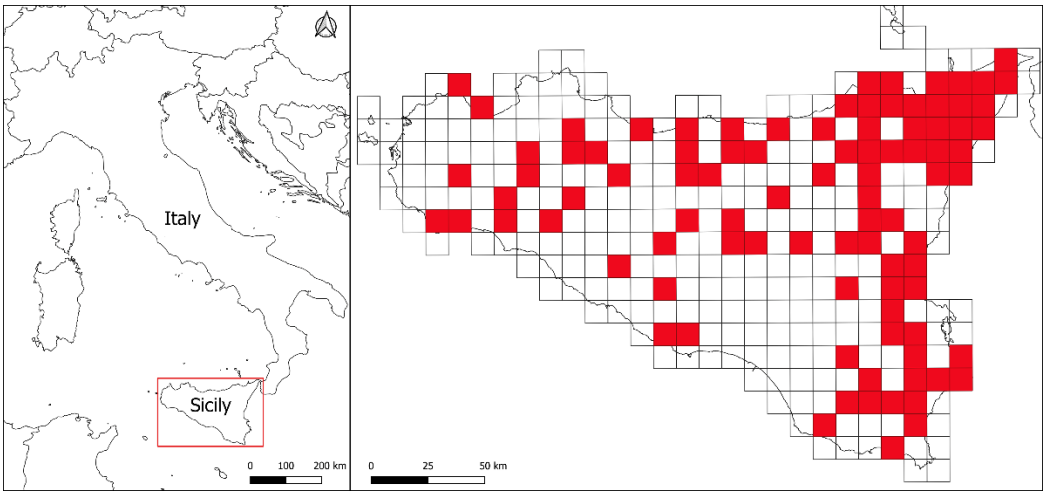

Figure 1. Occurrence sites in the study area based on 10 × 10 km UTM grid square (zone 33N, datum ED50). Both published and novel sites where decapods species were observed are reported.

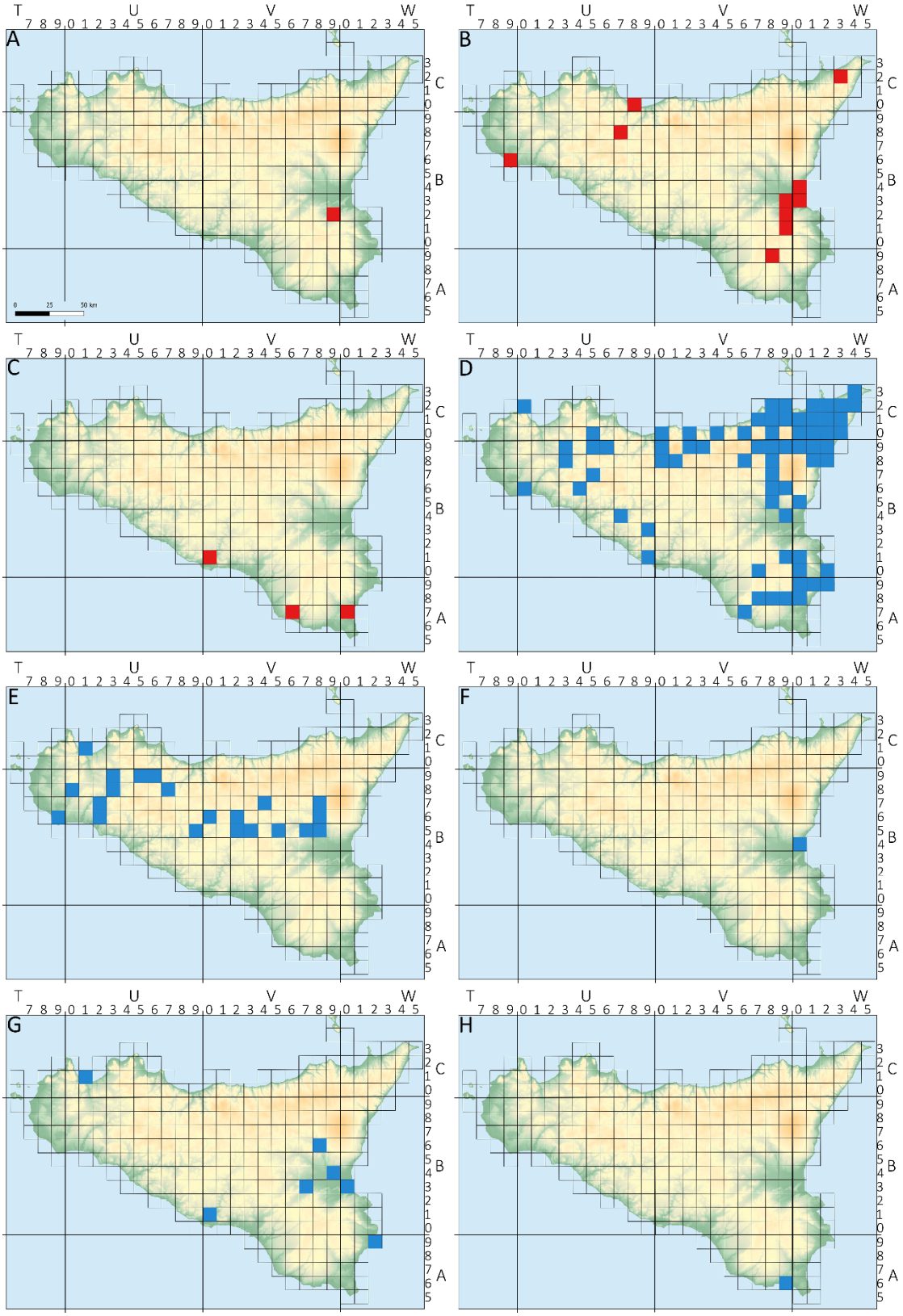

Figure 2. Occurrence sites of decapod species in Sicily. The blue squares represent the native species occurring in Sicily. Conversely, the red squares represent the alien ones. (**A**) *Cherax destructor*; (**B**) *Procambarus clarkii*; (**C**) *Callinectes sapidus*; (**D**) *Potamon fluviatile*; (**E**) *Atyaephyra desmarestii*; (**F**) *Palaemon adspersus*; (**G**) *P. antennarius*; (**H**) *P. elegans*.

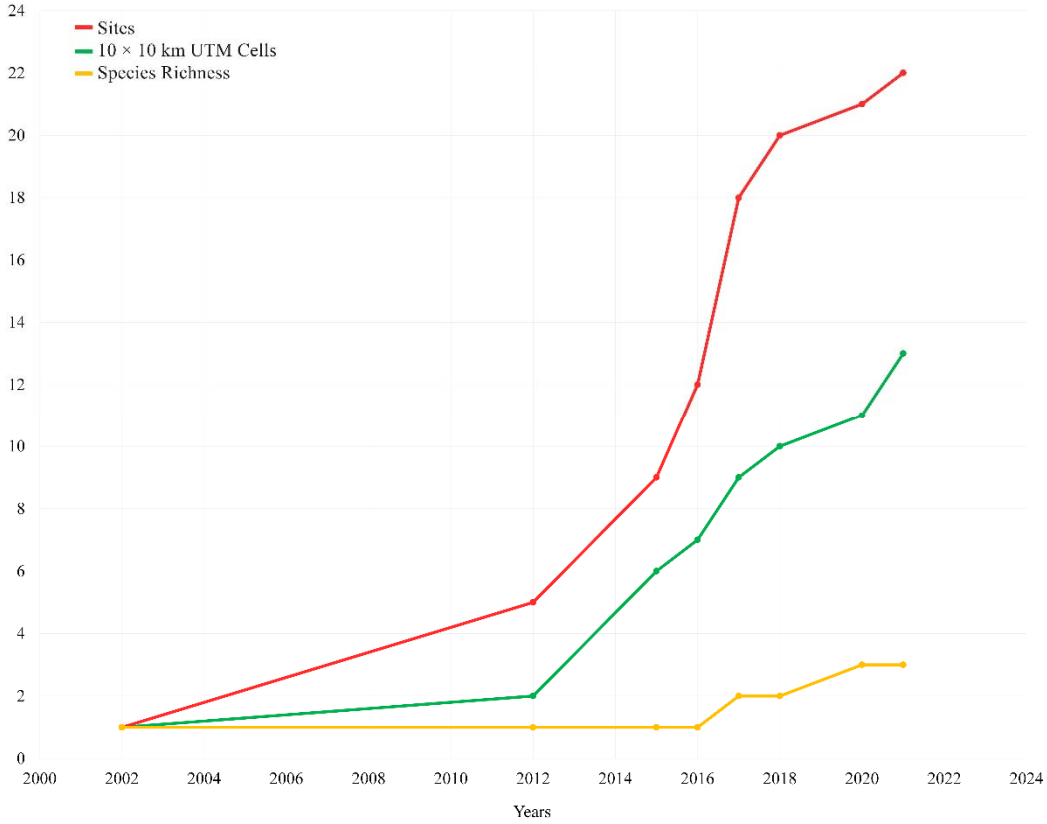

Figure 3. Cumulative curves of decapod NIS occurring in Sicily, from the first reported record in 2002 to today, based on "Sites" (**red** line), "10 × 10 km UTM cells" (**green** line) and "species richness" (**yellow** line) data (see also Table 1).

Infraorder Astacidea Latreille, 1802
Family Parastacidae Huxley, 1879
Genus *Cherax* Erichson, 1846
Cherax destructor Clark, 1936—Figure 2A
References
[22]
Remarks
The common yabby *Cherax destructor* is native to south-eastern Australia and experienced a rapid human-mediated range expansion, colonizing nearly the whole of Australia and Tasmania [23]. Introduced in Europe for aquaculture purposes, the species has been recorded in the wild in Spain [24], France [25,26] and southern Ireland (Julian Reynolds, *pers. observ.*). In Italy, the common yabby was reported to occur only in Latium [27], where the species disappeared a few years after its discovery possibly due to the crayfish plague *Aphanomyces astaci* Schikora, 1906 [28], and in Sicily in the Costanzo Stream (province of Syracuse; [22]—one site, one cell—Figure 2A). However, as reported by Vecchioni et al. [29], the species was not observed in the Costanzo Stream in recent years. Further dedicated surveys aimed at confirming its possible local extinction in Sicily are needed.
Family Cambaridae Hobbs, 1942
Genus *Procambarus* Ortmann, 1905
Procambarus clarkii (Girard, 1852)—Figure 2B
References
[21,22,30–33]. F.A., A.C., F.P.F., F.P. and G.U., *pers. observ.*
Remarks
The North American red swamp crayfish *Procambarus clarkii* is one of the most widespread invasive crayfish species worldwide, and its dramatic impact on native biota is well

known [34,35]. In Italy, the species has had an appalling expansion, due to both natural and anthropogenic determinants, since its first introduction in northern Italy [36], with a remarkable invasion rate [35]. To date, the red swamp crayfish has been observed in Sicily in both lotic and lentic water bodies (reported for 21 sites falling into 10 cells—Figure 2B), within a range of 1 to 388 m of altitude. Its local distribution is ascribed to multiple independent introductions [33]. The species has been reported to act as a vector of toxins and heavy metals to higher trophic levels and is considered responsible for biodiversity loss in the invaded ecosystems (see [37] and references therein).

Infraorder Brachyura Latreille, 1802

Family Portunidae Rafinesque, 1815

Genus *Callinectes* Stimpson, 1860

Callinectes sapidus Rathbun, 1896—Figure 2C

References

[38,39]

Remarks

Considered one of the 100 worst invasive alien species that occur in the Mediterranean Sea [40], the Atlantic blue crab *Callinectes sapidus*, native to the western Atlantic Ocean, has been introduced nearly worldwide [41]. In Italy, the species is widespread and has been reported in the open sea, brackish coastal lagoons, and estuaries [41,42]. In Sicilian inland waters, the species has been recorded with very high densities in coastal ponds at Vendicari [38] and in two rivers (i.e., Irminio and Imera Meridionale [39]) (three sites, three cells—Figure 2C), casting some concerns about its possible impact on the Sicilian pond turtle *Emys trinacris* Fritz et al. 2005 [43,44], an endemic species occurring both in Vendicari coastal ponds and in the Imera Meridionale river.

Family Potamidae Ortmann, 1896

Genus *Potamon* Savigny, 1816

Potamon fluviatile (Herbst, 1758 [in Herbst, 1782–1790])—Figure 2D

References

[14,45–54]. F.P.F., F.M. and S.R. *pers. observ.*; R.G., Unpublished data.

Remarks

Potamon fluviatile belongs to the subgenus *Euthelphusa* Pretzmann, 1962, which occurs in the western Mediterranean area and on the Balkan peninsula and includes *P. pelops* [55] and *P. algeriense* Bott, 1967 [56,57]. *P. fluviatile* is the only native freshwater crab species occurring in peninsular Italy and the Sicilian–Maltese archipelago, where it is not homogeneously distributed despite its striking molecular homogeneity [53]. The species is absent in Sardinia and on smaller islands [16,58–60]. Its current distribution seems to be due to a natural spread of the species, which occurred about 15,000 years ago [50,53,55]. The freshwater crab is reported for 119 sites falling into 69 cells (Figure 2D), where it colonizes both lotic and lentic water bodies, within an observed range of 16–1200 m in altitude. According to the IUCN red list, the species is assessed as "Near threatened" (https://www.iucnredlist.org/details/134293/0 (accessed on 2 March 2022), [60]) since it has undergone a considerable rarefaction and reduction in abundance within the entire distribution area due to habitat destruction, pollution, and overbuilding [61]. The species is neither mentioned in the "Habitats Directive" (EU Directive 92/43/CEE), nor is it protected at a national level.

Infraorder Caridae Dana, 1852

Family Atyidae De Haan, 1849

Genus *Atyaephyra* de Brito Capello, 1867

Atyaephyra desmarestii (Millet, 1831)—Figure 2E

References

[14,48,49,62–64]. F.M., *pers. observ.*; R.G., Unpublished data.

Remarks

The caridean *A. desmarestii* is a eurythermal and euryhaline species widespread throughout the Maghreb and western Europe, whereas the closely related shrimp populations occurring in the Balkan Peninsula and in the Middle East belong to different species [65]. In Italy, the

species occurs in Friuli Venezia Giulia, in lakes and rivers on the Tyrrhenian watershed (Tuscany, Umbria, Latium, Campania, Basilicata), in Sardinia, and in Sicily [66]. In Sicily, the species has been found between 3 and 620 m a.s.l. in both lentic and lotic water bodies (31 sites, 21 cells—Figure 2E), mainly in oxygen-rich waters with the presence of macrophytes, although the species has also been routinely observed along the muddy shores of artificial reservoirs. Garcia-Muñoz et al. [64] and Christodoulou et al. [65] included some Sicilian specimens in their phylogeographical analyses, showing the absence of a clear geographically based pattern of genetic diversity. According to the IUCN red list, the species has been assessed as being of "Least Concern" (https://www.iucnredlist.org/species/197932/2505632 (accessed on 2 March 2022), [67]).

Family Palaemonidae Rafinesque, 1815

Genus *Palaemon* Weber, 1795

Palaemon adspersus Rathke, 1836—Figure 2F

References

[49]

Remarks

The Baltic shrimp *Palaemon adspersus* is an euryhaline species widely distributed in lagoons, estuaries, and littoral zones of the Mediterranean and Baltic seas. The species was introduced in the Caspian and Aral Sea, and in the north-eastern Atlantic Ocean [19,68]. The only Sicilian population known to date was found by Ferrito [49] in the Simeto River (province of Catania—one site, one cell—Figure 2F), but the species is likely much more widespread in Sicilian estuaries.

Palaemon antennarius H. Milne Edwards, 1837—Figure 2G

References

[14,49,69]. F.M. and L.V., *pers. observ*.

Remarks

This palaemonid species occurs in Albania, Croatia, Greece, Montenegro, Slovenia, and Italy [70]. *Palaemon antennarius* is a euryhaline species living in both fresh and brackish waters, such as lagoons and estuaries, among the vegetation of lentic or weakly flowing water bodies. In the study area, the distribution of the species is mostly linked to the lower course of rivers of south-eastern Sicily (eight sites, seven cells—Figure 2G), within an altitude range of 1 to 216 m a.s.l. (see Table 1). Jabłońska et al. [69] investigated the phylogeography of the species and ascribed the Sicilian *P. antennarius* populations to a well-characterised clade inhabiting the Apennine peninsula and Sicily, whereas the Balkan populations currently ascribed to *P. antennarius* are genetically closer to the congeneric *P. minos* Tzomos and Koukouras, 2015. According to the IUCN red list, the species has been assessed as being of "Least Concern" (https://www.iucnredlist.org/species/197950/25061 91 (accessed on 2 March 2022), [67]).

Palaemon elegans Rathke, 1836—Figure 2H

References

F.M., *pers. observ*.

Remarks

The littoral shrimp *Palaemon elegans* is a common marine coastal species that inhabits tidal rockpools and seagrasses [17]. The native distribution range of the species includes the eastern Atlantic Ocean, the Mediterranean Sea, and the Black Sea [71]. Recently, the species was also found to occur in the Baltic Sea, where it is considered an invasive species [69]. Although *P. elegans* is well known in marine coastal areas in Sicily (e.g., [72]), this is the first report of the species in Sicilian inland waters. The littoral shrimp was found in "Pantano Bruno" (province of Ragusa—one site, one cell—Figure 2H), a coastal marsh which, despite its proximity to the sea, has no direct connection with it. When the species was collected (16 December 2006), the water temperature was 13.4 °C and the electrical conductivity 18,390 µS/cm.

Table 1. List of the novel and published localities of the decapods occurring in Sicily. Geographical decimal coordinates are reported according to the WGS84 datum. UTM coordinates are reported by 10 × 10 km grid square (zone 33N, datum ED50).

Province	Locality	Latitude N	Longitude E	Elevation (m a.s.l.)	UTM	Year	Source
Atyaephyra desmarestii							
Agrigento	Lago Arancio	37.636616	13.056858	178	UB26	2007	F.M.
Caltanissetta	Bompensiere, T. Belici o F. Salito	-	-	200	UB95	1985	R.G.
Caltanissetta	M. Capodarso, F. Salso	-	-	300	VB25	1985	R.G.
Caltanissetta	Ponte Cinque Archi	37.608363	14.131327	340	VB26	2007	[63]
Catania	Fiume Simeto, Barcavecchia	-	-	178	VB86	1988–1989	[49]
Catania	Fiume Simeto, Ponte dei Saraceni	37.700852	14.799691	362	VB87	1988–1989	[49]
Catania	Fiume Simeto, Ponte Pietralunga	37.575195	14.865077	92	VB85	1988–1989	[49]
Catania	Paternò, F. Simeto	-	-	65	VB85	1985	R.G.
Enna	10 km W Enna	-	-	-	VB35	1981	[62]
Enna	Catenanuova, F. Dittaino/S.S. 192	-	-	128	VB75	1985	R.G.
Enna	F. Dittaino, b. Staz. Dittaino	-	-	240	VB55	1985	R.G.
Enna	Nicosia, F. Salso b. Brücke S.S. 117	-	-	550	VB47	1985	R.G.
Enna	Nicosia, T. Mandre, o. Fitto di Sperlinga	-	-	550	VB47	1985	R.G.
Enna	Nicosia, T. Mandre, o. Fitto di Sperlinga	-	-	550	VB47	1985	R.G.
Enna	Villadoro T. Mandre, o. Mdg. T. Feliciosa	-	-	620	VB47	1985	R.G.
Enna	Villadoro T. Mandre, u. Poggio Pioppo	-	-	590	VB47	1985	R.G.
Palermo	Fiume San Leonardo	-	-	170	UB78	1990	[48]
Palermo	Foce San Bartolomeo	-	-	-	UC11	1986	[14]
Palermo	Foce San Bartolomeo	38.021531	12.904877	3	UC11	2007	F.M.
Palermo	Gorgo del Drago	37.901121	13.412594	340	UB69	1990	[48]
Palermo	Lago Garcia	37.787894	13.098285	193	UB38	2009	F.M
Palermo	Lago Scanzano	37.911915	13.370565	518	UB59	2007	F.M.
Palermo	Marianopoli, T. Belici/Staz. M.'poli	-	-	330	VB06	1987	R.G.
Palermo	Poggioreale, F. Belice	-	-	100	UB27	1986	R.G.
Palermo	Ponte Calatrasi	37.844329	13.119190	201	UB39	2009	F.M.
Palermo	S.C. Villarmosa, F. Imera o P. 5 Archi	-	-	350	VB26	1986	R.G.
Palermo	T. Belici u. Brücke bei, Staz. Marianopoli	-	-	330	VB06	1985	R.G.
Palermo	Torrente Frattina	37.861300	13.303000	370	UB59	2004–2008	[64]
Trapani	Castelvetrano, F. Grande/C.da Pozzillo	–	-	90	UB08	1986	R.G.
Trapani	Gorgo Alto	37.612702	12.649468	3	TB96	2014	F.M.
Trapani	S. Ninfa F. Grande, u. Borgo di Buturro	-	-	115	UB08	1986	R.G.
Callinectes sapidus							
Agrigento	Fiume Imera Meridionale	37.138833	13.916907	8	VB01	2021	[39]
Ragusa	Fiume Irminio	36.775803	14.596793	4	VA67	2021	[39]
Siracusa	RNO "Oasi Faunistica di Vendicari"	36.787487	15.094653	1	WA07	2020	[38]
Cherax destructor							
Siracusa	Torrente Costanzo	37.257818	14.920217	52	VB92	2017	[22]
Palaemon adspersus							
Catania	Fiume Simeto, Ponte Primosole	37.400180	15.064910	5	WB04	1988–1989	[49]
Palaemon antennarius							
Agrigento	Fiume Salso (Fiume Imera Meridionale)	37.157800	13.926400	13	VB01	2016	[69]
Catania	Fiume Simeto	37.604500	14.828500	117	VB86	2016	[69]
Catania	Fiume Simeto, Ponte Giarretta	37.457342	14.915137	22	VB94	1988–1989	[49]
Catania	Foce del Fiume Simeto	37.399878	15.086196	1	WB03	1985	[14]
Catania	Stagno agricolo Palagonia	37.350584	14.676467	152	VB73	2011	F.M.
Enna	Fiume Salso, Masseria d'Aragona	37.647130	14.772840	216	VB86	1988–1989	[49]
Palermo	Foce San Bartolomeo	38.023677	12.906666	5	UC11	1990	[14]
Siracusa	Fiume Ciane	37.042005	15.234638	4	WA29	2021	F.M.; L.V.
Palaemon elegans							
Ragusa	Pantano Bruno	36.697897	14.986846	1	VA96	2006	F.M.

Table 1. *Cont.*

Province	Locality	Latitude N	Longitude E	Elevation (m a.s.l.)	UTM	Year	Source
Potamon fluviatile							
Agrigento	Fiume Sosio	-	-	-	UB57	2006–2010	[51]
Agrigento	Fiume Sosio, Chiusa Sclafani	37.646213	13.274429	227	UB46	2015	F.P.F.
Agrigento	Lago San Giovanni	37.309064	13.766020	309	UB93	2020	S.R.
Agrigento	Vallone di Gaffe	37.166953	13.826678	133	UB91	2021	S.R.
Agrigento	Vallone Ponte	-	-	-	UB74	2006–2010	[51]
Catania	Fiume Alcantara	-	-	-	VB99	2006–2010	[51]
Catania	Fiume Alcantara	-	-	-	WB19	2006–2010	[51]
Catania	Fiume Alcantara	-	-	-	WB28	2006–2010	[51]
Catania	Fiume Dirillo	37.121792	14.720373	333	VB70	2021	F.P.F.
Catania	Fiume Fiumefreddo	-	-	-	WB18	2006–2010	[51]
Catania	Fiume Fiumefreddo	-	-	-	WB28	2006–2010	[51]
Catania	Fiume Flascio	-	-	-	VB89	2006–2010	[51]
Catania	Fiume Salso, Masseria d'Aragona	37.647130	14.772840	216	VB86	1988–1989	[49]
Catania	Fiume Simeto	-	-	-	VB85	2006–2010	[51]
Catania	Fiume Simeto	-	-	-	VB87	2006–2010	[51]
Catania	Fiume Simeto	-	-	-	VB88	2006–2010	[51]
Catania	Fiume Simeto, Barcavecchia	37.643436	14.810196	178	VB86	1988–1989	[49]
Catania	Fiume Simeto, Ponte Giarretta	37.457342	14.915137	22	VB94	1988–1989	[49]
Catania	Fiume Simeto, Ponte Passo Paglia	37.767350	14.799940	466	VB88	1988–1989	[49]
Catania	Fiume Simeto, Ponte Pietralunga	37.575195	14.865077	92	VB85	1988–1989	[49]
Catania	Leucatìa	-	-	-	WB05	2006–2010	[51]
Catania	Presso Randazzo	37.903491	14.937369	817	VB99	2018	F.P.F.
Catania	S. Maria di Licodìa	-	-	-	VB96	2006–2010	[51]
Catania	Torrente Cutò, Vitalone	37.864230	14.771510	750	VB79	1988–1989	[49]
Catania	Torrente Saracena	-	-	-	VB89	2006–2010	[51]
Catania	Torrente Saracena, Chiusitta	-	-	1200	VB89	1988–1989	[49]
Messina	Barcellona Pozzo di Gotto	-	-	-	WC12	2006–2010	[51]
Messina	Faidda	37.811389	14.615833	792	VB68	2013	[52]
Messina	Fiumara Corsari	-	-	-	WC43	2006–2010	[51]
Messina	Fiumara Elicona	-	-	-	WC01	2006–2010	[51]
Messina	Fiumara Fantina	-	-	-	WC10	2006–2010	[51]
Messina	Fiumara Floripotema	-	-	-	WC21	2006–2010	[51]
Messina	Fiumara Floripotema	-	-	-	WC22	2006–2010	[51]
Messina	Fiumara Marmora	-	-	-	WC43	2006–2010	[51]
Messina	Fiumara Niceto	-	-	-	WC32	2006–2010	[51]
Messina	Fiumara of Agrò	-	-	-	WC20	2006–2010	[51]
Messina	Fiumara Rodia	-	-	-	WC43	2006–2010	[51]
Messina	Fiumara Santa Lucia	-	-	-	WC21	2006–2010	[51]
Messina	Fiumara Santa Venera	-	-	-	WC11	2006–2010	[51]
Messina	Fiumara Sinagra	-	-	-	VC81	2006–2010	[51]
Messina	Fiumara Tarantonio	-	-	-	WC43	2006–2010	[51]
Messina	Fiumara Tono	-	-	-	WC43	2006–2010	[51]
Messina	Fiume Fiumedinisi	-	-	-	WC30	2006–2010	[51]
Messina	Fiume S. Paolo	-	-	-	WB09	2006–2010	[51]
Messina	Fiume S. Paolo	-	-	-	WB19	2006–2010	[51]
Messina	Fiume Simeto, Ponte Bolo	37.833160	14.794980	622	VB88	1988–1989	[49]
Messina	Fiume Tusa	37.936647	14.301381	175	VB39	2013	F.P.F.
Messina	Fonte Camaro	-	-	-	WC42	2006–2010	[51]
Messina	Giardini Naxos, F. Alcantara	-	-	20	WB28	1985	R.G.
Messina	Mistretta	37.952067	14.375715	276	VC40	2015	F.P.F.
Messina	Moio Alcantare, F. Alcantara o. Brücke	-	-	525	WB09	1985	R.G.
Messina	Peloritani, Altolia, Bach o. Altolia	-	-	315	WC31	1985	R.G.
Messina	Stretta di Longi	38.049757	14.763471	241	VC71	2013	F.P.F.
Messina	Torrente Briga	-	-	-	WC31	2006–2010	[51]
Messina	Torrente Gualtieri	-	-	-	WC21	2006–2010	[51]
Messina	Torrente Gualtieri	-	-	-	WC22	2006–2010	[51]
Messina	Torrente Licopeti, presso Malabotta	37.947890	15.007134	739	WC00	2016	F.P.F.
Messina	Torrente Mela	-	-	-	WC21	2006–2010	[51]
Messina	Torrente Petrolo	-	-	-	WB29	2006–2010	[51]
Messina	Torrente Roccella	-	-	-	WB09	2006–2010	[51]
Messina	Torrente San Basilio	-	-	-	VC80	2006–2010	[51]
Messina	Torrente Sinagra	38.069470	14.871745	317	VC81	2020	F.P.F.
Messina	Torrente Timeto, Patti	38.076461	14.971427	222	VC91	2011	F.P.F.

Table 1. *Cont.*

Province	Locality	Latitude N	Longitude E	Elevation (m a.s.l.)	UTM	Year	Source
Messina	Torrente Tripi	-	-	-	WC01	2006–2010	[51]
Messina	Vallone Canneto	-	-	-	VC40	2006–2010	[51]
Messina	Vallone Mascarino	-	-	-	VC60	2006–2010	[51]
Messina	Vallone Munofu	-	-	-	WB29	2006–2010	[51]
Messina	Vallone San Nicola	-	-	-	WC21	2006–2010	[51]
Messina	Viadotto Ponte Naso, Torrente Sinagra	38.145044	14.803335	16	VC82	2013	F.P.F.
Palermo	Castelbuono	37.950334	14.094915	194	VC20	2015	F.P.F.
Palermo	Fiume Pollina	37.914406	14.147270	200	VB29	2018	F.P.F.
Palermo	Fiume Pollina	-	-	-	VC20	2006–2010	[51]
Palermo	Gole del Frattina	37.865758	13.301096	463	UB59	2016	F.P.F.
Palermo	Gole di Tiberio	37.954672	14.148456	89	VC20	2013	F.P.F.
Palermo	Gorgo del Drago	37.901121	13.412594	340	UB69	1990	[48]
Palermo	Imera Settentrionale	-	-	-	VB09	2006–2010	[51]
Palermo	Imera Settentrionale	37.860660	13.894776	180	VB09	2017	F.P.F.
Palermo	Imera Settentrionale	37.858300	13.897000	174	VB09	2014	[53]
Palermo	Lago di Piana degli Albanesi	37.971015	13.302485	607	UC50	2021	F.P.F.
Palermo	Madonie F. Pollina, o. Mdg. F. Buonanotte	-	-	50	VC20	1985	R.G.
Palermo	Madonie, Castelbuono, T. Vicaretto/S.S. 286	-	-	320	VB29	1985	R.G.
Palermo	Madonie, Castelbuono, Vne. Dei Mulini/S.S. 286	-	-	350	VB29	1985	R.G.
Palermo	Madonie, Pollina-Tal, T. Grosso u. C. Parissi	-	-	350	VB29	1985	R.G.
Palermo	Polizzi Generosa	37.812536	13.999416	-	VB18	2004	[50]
Palermo	Scillato	37.860412	13.895252	177	VB09	2017	F.P.F.
Palermo	Torrente Fichera	-	-	-	VB08	2006–2010	[51]
Palermo	Torrente Frattina	-	-	-	UB59	2006–2010	[51]
Palermo	Torrente Frattina	37.861300	13.303000	370	UB59	2014	[53]
Palermo	Torrente Giardinello	37.915746	14.133376	234	VB29	2017	F.P.F.
Palermo	Torrente presso Fiume Pollina	37.915535	14.133192	237	VB29	2018	F.P.F.
Palermo	Torrente Roccella, presso Collesano	37.946262	13.923581	214	VC00	2017	F.P.F.
Palermo	Torrente Vicaretto	-	-	-	VB29	2006–2010	[51]
Palermo	Vallone Nocilla	-	-	-	UB69	2006–2010	[51]
Ragusa	Fiume Irminio	36.788600	14.602000	18	VA67	2014	[53]
Ragusa	Ragusa	36.924437	14.722580	-	VA78	2005	[50]
Ragusa	Torrente Tellesimo	36.948889	14.850833	338	VA88	2011–2012	[54]
Siracusa	Cava Carosello	36.939827	15.019083	324	WA08	2019	S.R.
Siracusa	Cava dei Molini	-	-	-	WB01	2006–2010	[51]
Siracusa	Fiume Anapo	-	-	-	WB00	2006–2010	[51]
Siracusa	Fiume Cassibile	36.988200	15.026800	406	WA09	2014	[53]
Siracusa	Fiume Cassibile	-	-	-	WA19	2006–2010	[51]
Siracusa	Fiume Ciane	-	-	-	WA29	2006–2010	[51]
Siracusa	Fiume Ciane	-	-	-	WB20	2006–2010	[51]
Siracusa	Fiume Tellaro	36.883700	14.950400	95	VA98	2014	[53]
Siracusa	Fonte Paradiso	-	-	-	VB91	2006–2010	[51]
Siracusa	Iblei, Mte. S. Venere, Contr. Ceusa, Quelle	-	-	520	VB91	1985	R.G.
Siracusa	Iblei, Sortino, F. Anapo/Staz. ENEL	-	-	163	WB01	1985	R.G.
Siracusa	Sortino	37.152035	15.037073	250	WB01	2012	F.P.F.
Siracusa	Sortino	37.147198	15.052666	178	WB01	2012	F.P.F.
Siracusa	Sortino, Fiume Anapo	37.137540	15.039070	202	WB01	2012	F.P.F.
Siracusa	Torrente Calcinara	37.140200	15.029100	264	WB01	2014	[53]
Siracusa	Valle Pantalica	-	-	-	WB00	1990	[47]
Siracusa	Vallone Zappardino	-	-	-	VC92	2006–2010	[51]
Siracusa	-	-	-	-	WA08	1998	[45]
Trapani	C.da Acci, RNO "Zingaro"	-	-	-	UC02	1992	[46]
Trapani	C.da Acci, RNO "Zingaro"	38.123697	12.768234	577	UC02	2004	F.M.
Trapani	Fiume Belice	-	-	-	UB38	2006–2010	[51]
Trapani	Fiume Belice	-	-	-	UB39	2006–2010	[51]
Trapani	Fiume Modione	-	-	-	UB06	2006–2010	[51]

Table 1. *Cont.*

Province	Locality	Latitude N	Longitude E	Elevation (m a.s.l.)	UTM	Year	Source
Procambarus clarkii							
Catania	Canale Buttaceto	37.437703	15.047918	7	WB04	2017	[33]
Catania	Fiume Gornalunga	37.388865	15.078404	2	WB03	2016	[22]
Catania	Foce Fiume Simeto	37.400072	15.064382	1	WB03	2016	[22]
Messina	Pantani di Venetico	38.212611	15.364333	6	WC32	2017	[33]
Messina	Venetico, pozze artificiali	38.195686	15.384248	124	WC32	2015	[22]
Palermo	Fiume San Leonardo	37.842270	13.562021	243	UB78	2018	F.A.; G.G.; F.P.F.; F.P.
Palermo	Lago Rosamarina	37.938619	13.635133	170	UC80	2012	[30]
Ragusa	Fiume Irminio	36.996840	14.778049	388	VA89	2017	[33]
Ragusa	Lago Santa Rosalia	36.974803	14.776731	374	VA89	2015	[22]
Siracusa	Fiume San Leonardo	37.342701	15.081742	3	WB03	2015	[22]
Siracusa	Fiume San Leonardo	37.343166	15.088748	3	WB03	2017	[33]
Siracusa	Lentini, canale	37.282435	14.970489	19	VB92	2018	A.C.
Siracusa	Lentini, stagno agricolo	37.360270	14.913601	20	VB93	2017	G.U.
Siracusa	Torrente Costanzo	37.252467	14.912453	60	VB92	2016	[22]
Siracusa	Torrente Margi	37.214115	14.891158	192	VB91	2015	[22]
Trapani	Lago di Murana	37.626475	12.634279	4	TB96	2017	[33]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.620374	12.641136	4	TB96	2012	[31]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.611327	12.651033	3	TB96	2012	[31]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.609080	12.655051	2	TB96	2002	[21]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.620374	12.641136	6	TB96	2012	[32]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.612475	12.649554	3	TB96	2012	[32]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.611327	12.651033	3	TB96	2012	[32]
Trapani	RNI "Lago Preola e Gorghi Tondi"	37.609080	12.655051	2	TB96	2012	[32]

4. Discussion

The unpublished data and the critical review of the existing literature made it possible to produce an updated checklist and distribution maps for Sicilian decapod inland water fauna, including five native (i.e., *Atyaephyra desmarestii*, *Palaemon adspersus*, *P. antennarius*, *P. elegans*, and *Potamon fluviatile*), and three alien (*Callinectes sapidus*, *Cherax destructor* and *Procambarus clarkii*) species, i.e., three brackish water species were added to the list reported by Hupalo et al. [73] for the Island. Among the decapods reported in the present work, some are primarily marine species, i.e., *Callinectes sapidus* and *Palaemon elegans*, which are known to be able to colonize transitional or inland water environments (e.g., [41,72,74]). Conversely, we excluded from the current review those species whose occurrence in inland waters is only occasional and limited to river mouths and coastal lagoons in direct connection to the sea (e.g., [75,76]).

Overall, the retrieved data show a good coverage of the Sicilian territory (about 27%, i.e., 93 cells occupied by at least one record out of 343 total cells), with the significant exceptions of the area that includes the "Piana di Gela" and "Monti Erei" and of the western coastal area of the island, where no records are available despite the occurrence of suitable habitats. No decapods are known to date for the small circum-Sicilian islands, which is possibly due to the scarcity of the surface permanent hydrographical network occurring there. However, it should be considered that the vast majority of the records pertains to large-bodied, charismatic species (*P. fluviatile*, 69 cells, *P. clarkii*, 10 cells), so that the actual distribution of palaemonid and atyid shrimps in Sicily is certainly underestimated. It is also worth stressing that some of the occurrence data should be taken with caution, as they could be the result of erroneous identifications, especially when the occurrence of a species was reported without iconographic support in the frame of papers not focused on crustaceans. For example, the report of *Palaemon antennarius* from "Gorgo del Drago" (province of Palermo, see [48]) is probably due to a misidentification of *Atyaephyra desmarestii* (F.M., *pers. observ.*).

Based on available data, the atyid *Atyaephyra desmarestii* seems to be rather frequent in north-western and central Sicily but absent in the south-eastern part of the island. Conversely, the distribution of the palaemonid shrimp *Palaemon antennarius* appears to be scarcely represented in northern and western Sicily, with the single record for Trapani

province in need for being validated, and more frequent in south-eastern Sicily. Further studies on the distribution of caridean species in Sicilian inland waters are to evaluate whether there is a complementary distribution pattern between these two species, or the observed pattern is rather due to the non-representativeness of currently available data (see Figure 2E,F and Table 1).

The occurrence of non-indigenous species (NIS) represents a significant risk for native biota both through direct impact and parasite spill-over [37,77–79]. Introduced decapods are considered among the most concerning NIS in inland waters [80]. In Sicily, the current impact of NIS is exerted mainly on permanent water bodies, whereas temporary ones have been to date less affected [8]; moreover, *Procambarus clarkii*, *Cherax destructor*, and *Callinectes sapidus* are to date mostly limited to low altitudes and lowland stretches of rivers (with few exceptions, see Table 1). Conversely, *Atyaephyra desmarestii* and *Potamon fluviatile,* i.e., the most widespread native decapods occurring in Sicily, have most of their populations currently located in the upper parts of the river watersheds. Accordingly, a spatial segregation between native and non-native species seems to be in place. Nevertheless, in some cases, native and non-native species co-occur, as for the crabs *Callinectes sapidus* and *Potamon fluviatile*, coexisting in the Irminio river (province of Ragusa).

The trend observed in Sicily for NIS is rather worrying. Based on the available evidence, the first finding of an alien decapod species [21] was not followed by its spreading on the island nor by the introduction of other species for about ten years. Later, from 2012 onwards, a steep rate of increase for both the number of alien species and their local distribution was observed (Figure 3). Such an increase in the number of NIS occurring on the island and their local distribution was most likely mediated by several drivers, such as the ease of buying species on the global market through websites, to limited environmental awareness, and to the current absence of a proper legislation actively regulating the amateur and commercial breeding of species with high invasive potential. Inland waters are facing several threats causing significant risks for their biota [4,81], especially in arid and semi-arid regions and insular habitats [3,82]. To date in Sicily, the biota of permanent water bodies is scarcely known, and the basic knowledge needed to preserve or manage them is limited. Moreover, in contrast to what happens in other Italian regions (e.g., Abruzzo, Emilia Romagna, and Tuscany, see [83], no specific legislation on the protection of native decapod crustaceans is currently in force in Sicily. We hope that the present work might be a useful tool for stressing the need for further, more detailed, surveys aimed at filling current knowledge gaps regarding the presence and distribution of decapod species in Sicilian inland waters.

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