BioInvasions Records (2017) Volume 6, Issue 2: 129–134
DOI: https://doi.org/10.3391/bir.2017.6.2.07

Open Access

Rapid Communication

Closing the circle in the Mediterranean Sea: *Bursatella leachii* Blainville, 1817 (Mollusca: Gastropoda: Anaspidea) has reached Morocco

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Received: 23 November 2016 / Accepted: 16 March 2017 / Published online: 28 March 2017

Handling editor: Stephan Bullard

Abstract

The ragged sea hare *Bursatella leachii* Blainville, 1817 is a circumtropical mollusc species widely distributed both in the Atlantic and the Indo-Pacific, including the Red Sea. Since the mid-20th century, it has been moving east to west in the Mediterranean Sea. The present work reviews the spread of *B. leachii* in the Mediterranean Basin and provides the first record in the Mediterranean Morocco (Marchica coastal lagoon), the 19th country colonized by this taxon out of 23 with Mediterranean Sea coastlines. This study also constitutes the first record from the southern Alboran Sea and represents the westernmost record of the species in the Mediterranean. Although the Red Sea is thought to be the most likely origin (Lessepsian migration) of the Mediterranean populations, phylogenetic and phylogeographic studies would be desirable to assess with certainties both the taxonomy and the proper origin of the species not only in the western part of the basin, but also in the Mediterranean Sea as a whole.

Key words: invasive species, decadanal distributions, Marchica coastal lagoon, southern Alboran Sea

Introduction

Biological invasions are a major threat to marine biodiversity following the spectacular increase of invasions by non-native marine and estuarine species world-wide (Occhipinti-Ambrogi 2007). Although only a small fraction of the many marine species initially introduced outside of their native range become established (Mack et al. 2000), their effects on ecosystem structure and functioning can be dramatic (Molnar et al. 2008). In addition to alterations to community structure, food webs, nutrient and energy cycling, and sedimentation (Molnar et al. 2008), invasive aliens can also cause serious economic and human health damages (Ruiz et al. 1997; Pimentel et al. 2000). Therefore, understanding the role of biological invasions in modifying biodiversity patterns and ecosystem functionality is becoming a major challenge in marine ecology (Borja 2014).

The countries surrounding the Mediterranean Sea are highly concerned by the very large number of successful species introductions. According to the Mediterranean Action Plan for Invasive Species (UNEP-MAP-RAC/SPA 2005), the main known pathways / vectors of species introduction into the Mediterranean Sea are the Suez Canal (the so-called Lessepsian migration), followed by shipping (ballast water and sediments, anchoring and fouling), aquaculture (both marine and brackish species), and trade in live marine species (aquarium activities, fishing baits, seafood). This is in agreement with recent evaluation of pathways at Pan European level (Katsanevakis et al. 2013). According to recent estimates, at least 1,000 alien species have been introduced into the Mediterranean (Zenetos et al. 2010, 2012), and the local marine ecoregions are one of the globally most impacted by biological invasions (Zenetos et al. 2012;

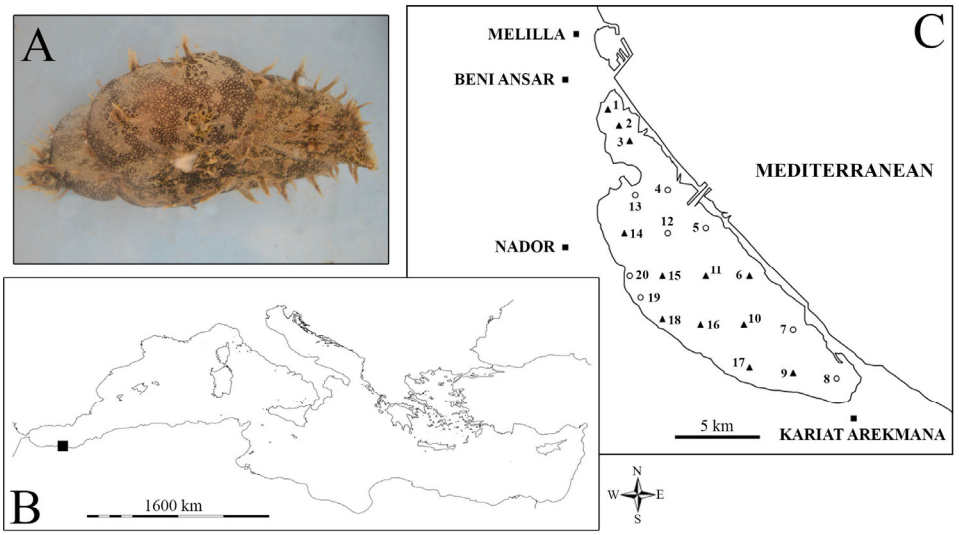

Figure 1. A. *Bursatella leachii* from the Mediterranean Morocco. **B**. Geographical position of the Marchica lagoon within the Mediterranean Sea. **C**. Illustration of the sampling design (stations 1–20). Triangles: stations where *B. leachii* was found.

Katsanevakis et al. 2013, 2015). Whilst the majority of alien species presently occur in the eastern basin (775), a substantial number of species is also known for the western basin (308), the central basin (249), and the Adriatic Sea (190) (Zenetos et al. 2012). However, only few species have colonized all four biogeographic sectors.

Bursatella leachii Blainville, 1817 is one of the more successful colonists in the Mediterranean. Commonly known as the ragged sea hare, it is a circumtropical aplysiid species found nearly worldwide in warm-temperate to tropical marine environments. It is commonly found in intertidal and subtidal zones of sheltered bays and estuarine habitats, typically with sand or muddy bottoms (Rudman 1998), and it is a frequent component of the tropical and subtropical sea grass and mangrove communities (Lowe and Turner 1976). In the mid-1900s, *B. leachii* colonized the Mediterranean Sea, with multiple records tracking its spread around the basin within a timeframe of 60–80 years. The first presumptive report was from the southern Levantine basin in Israel / Palestine Authority (O'Donoghue and White 1940); however, this is unconfirmed due to absence of data accompanying the specimen – see also discussions in Swennen (1961) and exclusion in Por (1978). Subsequent confirmed records since 1955 include Israel, and document it spreading farther and farther west (see Supplementary material Table S1; Figure 2). This led researchers to consider *B. leachii* as the first presumed Lessepsian species to reach the northern Alboran Sea (e.g., Ibáñez-Yuste et al. 2012).

The general interest in biological invasions, as well as the conspicuous number of findings coupled with the highly distinctive characteristic of the species, led several authors to summarize and map the spread of *B. leachii* in the Mediterranean in the recent years (e.g., Oliver and Terrasa 2004; Zenetos et al. 2004; Weitzman 2011; Isprambiente 2011; Ibáñez-Yuste et al. 2012). Moreover, this species has been listed as one of the most widespread, non-indigenous, species in Europe (e.g., Galil et al. 2014, where records from 12 countries were censused). However, the earlier reviews are now outdated and some contain a large number of mistakes and/or omissions. Using as starting point recent records made by some of the present authors, this study reviews *B. leachii* occurrence and spread in the Mediterranean Sea and fills in a gap in the distribution of the species by reporting the first collection of specimens of *B. leachii* in the Mediterranean Morocco (Marchica coastal lagoon, southern Alboran Sea) – thus completing the encirclement of the Mediterranean Basin.

Material and methods

Study area

The Marchica lagoon (35º09′25″N; 002º50′43″W), also called the lagoon of Nador, is the second largest (115 km², 25 km long and 7.5 km wide) lagoon in northern Africa and the unique coastal lagoon on the Mediterranean coast of Morocco (Figure 1B). This lagoon has a maximum depth of approximately 8 meters. It is separated from the Mediterranean Sea by

Table 1. Number of *Bursatella leachii* individuals (abundance) found in each of the twenty sampling stations (see Figure 1) during April–June 2016; mean (± SD; n = 3) depth, salinity, and temperature; and two habitat descriptors (vegetation type and substrate). Abbreviations used: ind. – Indeterminate; M – Mud; SM – Sandy-mud; S – Sand; UV – Unvegetated.

Station	Abundance			Environmental descriptors				
	April	May	June	Depth (m)	Salinity	Temperature (°C)	Marine vegetation	Substrate
1			30	3.4 ± 1.01	37.23 ± 0.21	23.37 ± 2.25	algae ind.	M
2	50	2	14	4.44 ± 0.99	36.97 ± 0.15	22.5 ± 3.15	*Caulerpa prolifera*	SM
3	10	1	3	5.03 ± 0.99	36.9	22.43 ± 3	*Cymodocea nodosa* + *C. prolifera*	SM
4				6.53 ± 0.06	36.7	21.27 ± 2.93	UV	S
5				6.4 ± 1.48	36.6 ± 0.36	21.87 ± 2.60	UV	S
6	3	1		7.47 ± 0.06	36.77 ± 0.06	21.3 ± 3.57	UV	SM
7				3.47 ± 1.06	36.9 ± 0.2	21.9 ± 3.75	*C. nodosa*	SM
8				3.33 ± 0.15	37 ± 0.26	22.6 ± 4.03	algae ind.	M
9	1	7	2	5.33 ± 0.06	36.87 ± 0.15	22.7 ± 3.83	algae ind.	SM
10	4	7	1	7.33 ± 0.12	36.97 ± 0.31	21.97 ± 3.11	UV	SM
11	7		3	7.83 ± 0.65	36.87 ± 0.29	21.4 ± 3.3	UV	SM
12				7.53 ± 0.32	36.37 ± 0.21	21.17 ± 3.02	UV	SM
13				6.77 ± 0.35	36.77 ± 0.06	22.93 ± 3.31	algae ind. + *C. prolifera*	SM
14			2	5.93 ± 0.45	36.73 ± 0.06	21.97 ± 2.89	algae ind. + *C. nodosa*	M
15			2	6.03 ± 0.25	36.7	20.63 ± 3.16	algae ind.	SM
16	3	14	1	4.7 ± 1.04	36.7 ± 0.17	21.97 ± 3.06	algae ind.	SM
17	1	1	10	5.1 ± 0.17	36.73 ± 0.12	22.43 ± 3.39	algae ind.	SM
18		1		2.7 ± 0.75	36.7 ± 0.1	22.53 ± 2.72	algae ind.	SM
19				2.7 ± 0.1	36.67 ± 0.15	22.63 ± 3	algae ind.	M
20				2.33 ± 0.06	36.73 ± 0.21	23.03 ± 2.87	*Gracilaria* spp. + *C. nodosa*	M

a 25 km long sandbar (Lido), with one artificial opening (300 m wide and 6 m deep) that allows water exchange.

In addition to its ecological (Site of Biological and Ecological Interest since 1996; Ramsar Site since 2005) and socio-economic (mainly artisanal fisheries) value, the lagoon is under pressure from a complex mixture of human-mediated stressors (urbanization, pollution, overfishing, tourism, and wastewater, among the others).

Unpublished data

Bursatella leachii specimens were collected as a by-catch species during a survey performed on a monthly basis in the Marchica lagoon, between April and June 2016. The survey consisted of 20 sampling stations (Table 1, Figure 1).

The sampling gear used was a large seine net (110 m long, 11 m height, and 6 mm mesh size), targeting pelagic and demersal fish species. The sampling effort was similar in all the 20 stations, and the data collected is semi-quantitative because retention efficiency of the seine is not known, nor was the swept area necessarily constant. Total length (mm) of each *B. leachii* sampled was measured using Vernier calipers (to 0.1 mm). Individuals were weighed (fresh weight) on an electronic balance (0.01 g). The biomass and the abundance of *B. leachii* were expressed as fresh weight (g) and the number of individuals collected per sampling station, respectively.

For environmental characterization, temperature and salinity were measured *in situ* by using a Conductivity meter of type Cond 315i / SET (WTW GmbH, Germany). Water depth was estimated using an LCD Digital Sounder (HONDEX PS-7; Honda Electronics CO LTD, Japan). These three variables were expressed as mean ± standard deviation of records obtained per station. Marine vegetation and substrate were evaluated from underwater videos taken at each station by a GoPro HERO3 (GoPro INC., U.S.A.).

Bibliographic data

An extensive search of the scientific literature was undertaken to evaluate and describe temporal changes in the distribution of *B. leachii* in the Mediterranean. Peer-reviewed journals were searched, but an attempt was made to cover the grey literature as much as possible. Literature record listing has been as exhaustive as possible and each record was carefully analyzed, with recourse to the published literature and, where necessary and possible, interviews with the authors. For mapping the temporal spreading of *B. leachii* in the Mediterranean, the data were divided into decades: 1940–1950; 1951–1960; 1961–1970; 1971–1980; 1981–1990; 1991–2000; 2001–2010; and 2011–present.

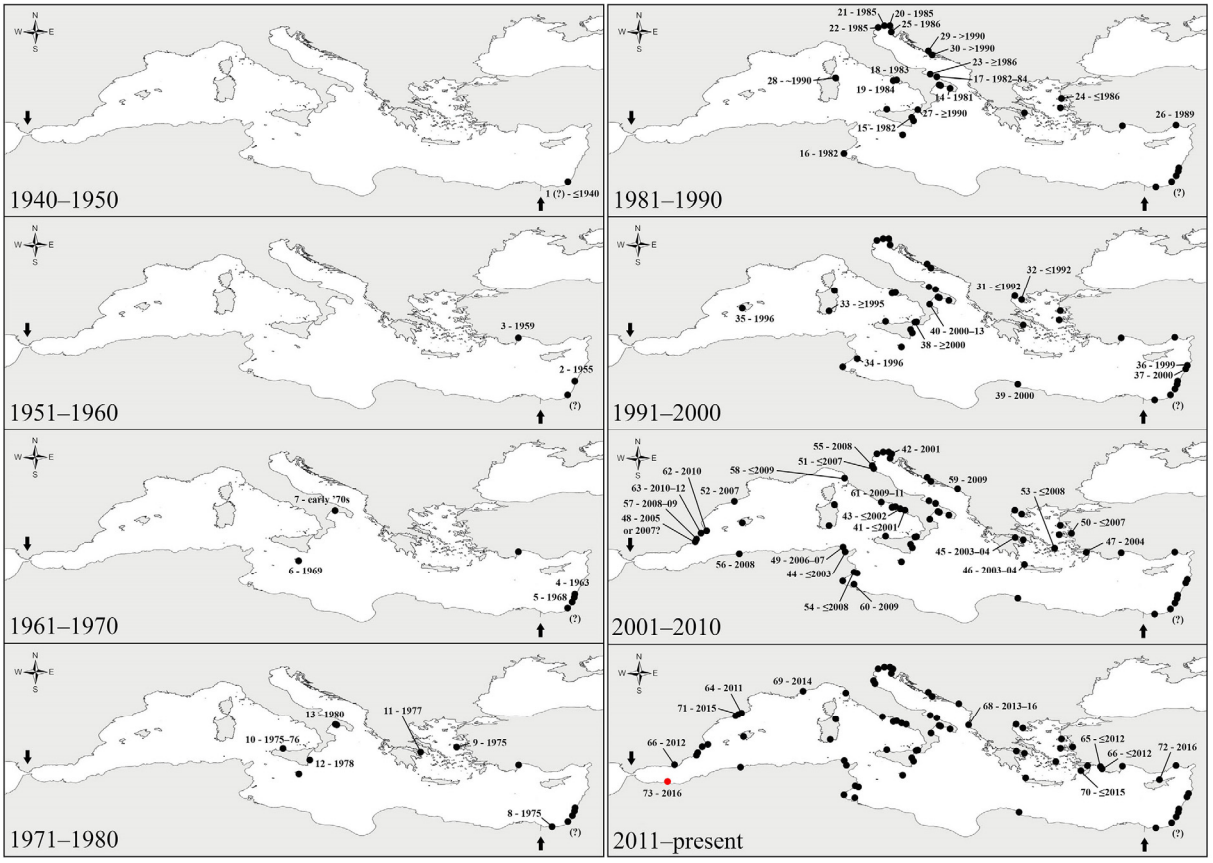

Figure 2. Cumulative Mediterranean spreading of *Bursatella leachi* divided into decades from 1940 to present (1940–1950; 1951–1960; 1961–1970; 1971–1980; 1981–1990; 1991–2000; 2001–2010; 2011–present). Black arrows indicate the Strait of Gibraltar (left) and the Suez Canal (right). First record dates per main invaded areas highlighted. Red dot: present record from the Mediterranean Morocco. References in Table S1.

Results

Unpublished data

Bursatella leachii was widespread in the lagoon and collected from 12 of 20 sampling sites (Figure 1A, C). Specimens were collected from various soft habitats (from mud to sand), most often where marine vegetation was present (Table 1). The depth of sampling stations ranged between 2.3 and 7.8 m, while salinity and temperature fluctuated between 36.4 and 37.2 and between 20.6 and 23.4 °C, respectively (Table 1). No pattern of presence / absence was noticed that appeared to be related to the environmental data collected.

Altogether, 181 *B. leachii* individuals were collected. The abundance of the species ranged between 1 and 50 individuals per station, while the biomass ranged between 1.7 and 85.3 g per station. The total length of individuals collected varied between 26 and 90 mm.

Bibliographic data

The overall Mediterranean records of *B. leachii*, summarized in Table S1 and decadanal maps, show a clear east-west progression (Figure 2). With the addition of this study, the species is now confirmed from 19 out of 23 countries surrounding the Mediterranean Sea, based on data extracted from > 100 studies (Table S1). However, the species could be present in three of the remaining countries because there are records in the neighbouring countries, and the absence of records may be due to a lack of field research (Monaco, Bosnia & Herzegovina and Syria); or it may be truly absent in at least two of them just simply due to the very limited coastline available (Monaco and Bosnia & Herzegovina). *B. leachii* has also not yet been detected in Gibraltar, the western-most point in the Mediterranean Sea, but again it has a very limited coastline. The pattern of east-west

spread was similar to other well-known Lessepsian invaders, with early records from the eastern Mediterranean until the 1970s, followed by a progressive colonization of the central Mediterranean during ~1970–1980, and subsequent spread to the Adriatic Sea and the western Mediterranean during the 1980s and the 1990s, respectively (Figure 2). However, some initially isolated records from areas far from those already impacted (e.g., early records in the central Mediterranean, subsequent records in the northern Adriatic Sea) may indicate a possible primary event or secondary spread, through shipping.

Discussion

This study showed that *Bursatella leachii* was widespread in the Marchica lagoon, where it has thrived in various habitats, and can be even considered as becoming a nuisance because it clogged fishing nets during our sampling. Our observations are consistent with those from many localities around the Mediterranean, as *B. leachii* often becomes very abundant and invasive during some periods of the year, although it subsequently disappears (Zenetos et al. 2004; Crocetta et al. 2013). The same holds for habitat preference within the Mediterranean, as it was often reported on soft and vegetated habitats, sometimes with *Cymodocea nodosa* (Ucria) Ascherson and *Caulerpa prolifera* (Forsskål) J.V. Lamouroux (Table S1).

From a biogeographic point of view, our record is the westernmost report of the species in the Mediterranean Sea as a whole, and the first from the southern Mediterranean in Morocco. Regarding its presence in the Mediterranean coastlines of the latter country, we found much confusion in the literature. Several recent studies list the species as present based on González García et al. 1996 (sic! for 1998a) (e.g., Murillo and Murcia 2009; Doneddu 2010), or simply list it as recorded from the Nador Lagoon with no references (e.g., Otero et al. 2013) or with a "1996" date (e.g., Weitzman 2011), but presumably referring again to the same article or simply uncritically citing distributional data listed in other articles. However, no actual records are present in González García et al. (1998a), whilst a citation of this species for the Marchica lagoon (as "Marchica de Melilla") is present in an unpublished report that was available on the internet until recent years (González García et al. 1998b), although apparently again referring to the González García et al. (1998a) book. Attempts to resolve the issue by contacting the authors of the González García et al. (1998a, b) "papers" failed; therefore, we consider the earlier statements unsubstantiated.

Bursatella leachii was often assumed to have been introduced into the Mediterranean either by ships from tropical Atlantic, or via the Suez Canal (Zenetos et al. 2004). However, based on its putative first record in the Mediterranean being from Israel / Palestine Authority, its recent dispersal pattern (Table S1; Figure 2), and confirmed records from the Suez Canal (El Qantara, Egypt: see Barash and Danin 1973), most workers in the recent years considered this species to be a truly Lessepsian invader (Zenetos et al. 2010; Galil et al. 2014, 2016) that progressively colonized the Mediterranean Sea through secondary autonomous spreading. Indeed the extended veliger stage would aid such a "natural" dispersal (Paige 1986; Zupo et al. 1990). Moreover, it seems highly unlikely that the entry of such a prominent creature through the Strait of Gibraltar would remain undetected for so long, especially given the interest in recreational scuba diving and the many dedicated professional and amateur malacologists in the western tip of the Mediterranean Sea. However, although faunal findings and empirical observations point out the Red Sea as the origin of this species, phylogenetic and phylogeographic studies on taxa with similar distribution and spread pattern have already highlighted contrary results (e.g., Valdés et al. 2013; Tsadok et al. 2015). In addition, it is surprising that its presence in the Suez Canal area was missed until quite recently (see also discussions in Por 1978) and how a potential Lessepsian invader was able to permanently colonize even the colder Mediterranean areas. In the light of these observations, and despite our discussion of this taxon as a Lessepsian invader in agreement with current literature, a molecular study would be desirable to assess the global taxonomy of the species (possible cryptic species) and the geographic origin of the species / specimens recorded not only in the western part of the basin, which may be more influenced by larval dispersal through the Gibraltar Strait, but also in the Mediterranean Sea as a whole.

Acknowledgements

The sampling survey was undertaken in the framework of an international cooperation between Le Conservatoire du Littoral, Agence de l'Eau Rhône-Méditerranée-Corse, the Ecocean Society, University Mohammed V in Rabat, Institut National de Recherche Halieutique, Observatoire de la Marchica, and Fondation Mohammed VI pour l'environnement. M. Selfati thanks the "Agence de l'Eau Rhône Méditerranée Corse" and the Ecocean Society for their financial support. The study of *Bursatella leachii* Mediterranean spreading was partially funded by the East and South European Network for Invasive Alien Species - a tool to support the management of alien species in Bulgaria (ESENIAS-TOOLS) (EEA funded - Contract No. Д-33-51/30.06.2015) (F. Crocetta). The authors are also grateful to the local fishermen for their help during field work and to Serge Gofas (Spain), Joachim Langeneck (Italy), Vesna Macić (Montenegro), and Miquel Pontes (Spain) for providing articles upon request.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Published records of *Bursatella leachii* Blainville, 1817 from the Mediterranean Sea.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2017/Supplements/BIR_2017_Selfati_etal_TableS1.xls