

Mediterranean Marine Science

Vol 12, No 1 (2011)



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doi: [10.12681/mms.53](https://doi.org/10.12681/mms.53)

To cite this article:

ANTIT, M., GOFAS, S., SALAS, C., & AZZOUNA, A. (2011). One hundred years after Pinctada: an update on alien Mollusca in Tunisia. *Mediterranean Marine Science*, 12(1), 53–74. <https://doi.org/10.12681/mms.53>

One hundred years after *Pinctada*: an update on alien Mollusca in Tunisia

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Received: 25 October 2010; Accepted: 21 December 2010; Published on line: 11 April 2011

Abstract

The occurrences of non-indigenous marine molluscs in Tunisia are reviewed, based both on a literature survey and on original material. Species are accepted as established if there are two independent reports, either geographically separate or at least one month apart in time. On these grounds, fourteen species are accepted (twelve alien and two expanding their range from elsewhere in the Mediterranean), three aliens need confirmation but are likely to meet the standards for acceptance in the near future, and five records are rebutted or questioned. Two more species may be considered as cryptogenic, the reports are reliable but there is no clear indication that they are not indigenous. Two of the alien species are reported for the first time in Tunisian waters: the nudibranch *Polycerella emertoni* qualifies as established, and the bivalve *Anadara transversa* is tentatively identified from a live juvenile specimen, which awaits further confirmation.

The occurrence of aliens in Tunisia is balanced between presumably Lessepsian species of tropical Indo-Pacific origin, and species from other sources including species from the tropical Atlantic introduced through shipping. Nevertheless there is a prevalence of Lessepsian species towards the Gulf of Gabès in the south, while the shipping activity in Tunis harbour may be the main pathway of introduction in the north.

Keywords: Alien mollusca; *Polycerella emertoni*; *Anadara transversa*; Tunisia.

Introduction

The fauna of the Mediterranean Sea is known to be undergoing important changes related to the establishment of many exotic species as a consequence of several factors, such as human intervention or climate warming (ZENETOS *et al.*, 2008; 2010). In

this respect, the Mollusca are one of the most intensively studied groups (GOFAS & ZENETOS, 2003; ZENETOS *et al.*, 2004) and may be taken as representative of more general trends in the benthos.

The coastline of Tunisia spans the transition between Eastern and Western basins and therefore is a key area for understand-

ing the progression of alien species in the Mediterranean as a whole. The knowledge of the Tunisian molluscan fauna relies heavily on studies published in the late 19th and early 20th century (DAUTZENBERG, 1883; 1895; PALLARY, 1904-1906, 1914). The rather intensive surveys conducted at that time, although biased towards the Gulf of Gabès, have the advantage of providing a reasonably accurate baseline for the malacofauna in the early 20th century.

This knowledge nevertheless badly needs updating, particularly regarding small and inconspicuous species, recently recognized Mediterranean taxa, and introduced species. At the time when the 'CIESM Atlas of Exotic Species' (ZENETOS *et al.*, 2004) went to press, there were only five Indo-Pacific alien species of molluscs reliably reported in the Tunisian fauna: the gastropods *Cerithium scabridum*, *Melibe fimbriata* and *Bursatella leachii* and the bivalves *Pinctada radiata* and *Fulvia fragilis*. To those the gastropods *Echinolittorina punctata* and *Siphonaria pectinata* may be added, possibly arrived from other parts of the Mediterranean by their own means, and the oyster *Crassostrea gigas* repeatedly introduced for farming. These numbers have now nearly doubled and it is the goal of this paper to analyze the progress of the more ancient immigrants, to report on the input of additional species and to discuss the pathways which are now documented for Tunisia.

Materials and Methods

The records of exotic molluscs in Tunisia have been searched for in the published literature and over the World Wide Web; a particular effort has been made to screen the 'gray' literature, including congress reports and memoirs written for academic degrees. The rationale for evalua-

tion of records follows ZENETOS *et al.* (2004: 31) & ZENETOS *et al.* (2010). Records are considered as established if the species have permanent, self-maintaining populations, and this must be documented by at least two reliable and independent records. Where such records originate from the same authors they ought to be based on separate samples, collected at least one month apart if they originate from the same site. Records are therefore evaluated in one of these categories 'Established, Casual, Questionable, Cryptogenic, or Excluded' following ZENETOS *et al.* (2010), but considering apart the species cultured in marine farming. Contrary to the CIESM Atlas, we also discuss range extensions from within the Mediterranean, therefore including species that were not native to Tunisia but had a historical range elsewhere in the basin and therefore do not qualify as 'alien' species. Records will be presented in chronological order of discovery in Tunisia, established records first, those in need of confirmation next.

Introduction pathways are inferred as Lessepsian for species of Indo-Pacific origin which have been recorded in the Red Sea and Suez Canal and first entered the Mediterranean in the Levantine Sea. Introduction as a consequence of shipping activity is presumed when an alien species is first detected in the vicinity of a major harbour.

Material from around the island of Djerba was examined in the Muséum National d'Histoire Naturelle, Paris. This material was collected in several localities around the island, during one month in 1982 (expedition leader Philippe Bouchet), using scuba diving and an airlift pump on all kinds of substrates. This systematic collecting, not biased towards particular species, is particularly useful for assessing presence/absence

of the common species.

The original records presented in this paper are based on our own ongoing work, dedicated to a survey of selected coastal environments in the Bay of Tunis.

The malacofauna of the infralittoral algal mat was sampled monthly at 1-2 m water depth, on an artificial rocky pier situated at La Goulette (36°49.15'N - 10°18.60'E), from February 2009 to February 2010. Samples were collected on five replicas of squares of 25 x 25 cm. Algae were washed to removing all associated animals and dried for determination of their biomass. The associated fauna proceeding from washing as sieved over a 0.5 mm sieve and preserved in 70% ethanol for picking out specimens.

Samples from soft bottoms at La Goulette were sampled with a dredge at 3-4 m (36°49.1'N - 10°18.9'E) and 10-15 m (36°49.1'N - 10°19.6'E) depth. The dredge was towed for 5 minutes parallel to the shore, at a speed of approximately one knot, and samples were replicated three times. The sample was sieved on a column of sieves of 1 cm, 5 mm, 2 mm and 0.5 mm mesh and preserved in 70% ethanol.

All samples were later sorted at the lab, each size fraction separately, to separate the molluscs. All shelled species were then dried, whereas selected specimens including all opisthobranchs were kept in ethanol. This material was then sorted down to species level and identified.

Results

(1) Species recorded prior to the completion of the CIESM Atlas (2002) and considered as established (Table 1)

Pinctada radiata (Leach, 1814) is the oldest reported Lessepsian migrant in the Mediterranean. It was first found in the Mediterranean at Alexandria in 1874

(ZENETOS *et al.*, 2004 and references therein) and first appeared in Gulf of Gabès prior to 1892. DAUTZENBERG (1895) gave a wealth of details regarding early reports on the species and noted that it was invasive by 1892, whereas it was not detected in a previous survey in 1882. It is today one of the most common molluscs on the whole Tunisian coast and is locally a dominant species, particularly in Gulf of Gabès. However its distribution seems to end abruptly at Bizerte (ZAKHAMA-SRAIEB *et al.*, 2009; TLIG-ZOUARI *et al.*, 2010) and the reports in the Western Mediterranean are scanty (e.g. BOUDOURESQUE, 1999). It is uncommon in our material from Tunis Bay.

The valid name for this species has been debated although there is a consensus among recent authors on using the name *radiata* for the Red Sea/Mediterranean species (WADA & TËMKIN, 2008). The type locality was nevertheless stated, with a question mark, as Caribbean and the name is also used for the very similar, if not identical, Western Atlantic species otherwise known as *P. imbricata* (Röding, 1798).

Echinolittorina punctata (Gmelin, 1791) is a predominantly tropical eastern Atlantic species with an extensive historical range in the southern Mediterranean, along the Moroccan and Algerian and along the Egyptian and Levantine coasts (PALLARY, 1912). ANTIT *et al.* (2007) supported the view that the species arrived in Tunisia and Sicily at some time in the first half of the 20th century since it is unlikely that MONTEROSATO (1878) and PALLARY (1914) would have missed it in their respective areas if it had existed at their time.

Crassostrea gigas (Thunberg, 1793) has been repeatedly introduced for aquaculture since at least 1932, first in the Ghar el Melh lagoon, formerly known as Porto Farina

Table 1

List of ascertained exotic molluscs in Tunisian waters, in chronological order of earliest record (second column); third column indicates the first published report of the species and the reference to the earliest finding, if different; fourth column the geographic origin (ATL: Western Atlantic; IP: tropical Indo-Pacific, MED: other parts of the Mediterranean; TP: temperate North Pacific; WA: tropical West Africa); fifth column the suspected pathway of introduction; sixth column detail of current occurrence within Tunisia

(N: North coast, T: Gulf of Tunis, H: Gulf of Hammamet, G: Gulf of Gabès).
The last column indicates our statement of the status of the species, as discussed in the text.

Species	Year	First published report [Report of earliest occurrence]	Origin	pathway		occurrence		status	
						N	T		H
<i>Pinctada radiata</i> (Leach, 1814)	<1890	DAUTZENBERG, 1895	IP	lessepsian	N	T	H	G	invasive
<i>Echinolittorina punctata</i> (Gmelin, 1791)	<1950	ENZENROß & ENZENROß, 2001 [ANTIT <i>et al.</i> , 2007]	MED	own means	N	T			established
<i>Crassostrea gigas</i> (Thunberg, 1793)	<1932	DANTAN & HELDT, 1932	TP	farming	N				farmed
<i>Melibe viridis</i> Kelaart, 1848	1982	CATTANEO-VIETTI <i>et al.</i> 1990 [this paper]	IP	(combined)				G	established
<i>Bursatella leachii</i> de Blainville, 1817	1982	ENZENROß & ENZENROß, 2001 [this paper]	IP	lessepsian		T		G	established
<i>Fubvia fragilis</i> (Forsk å 1775)	1990	PASSAMONTI, 1996 [BEN SOUISSI <i>et al.</i> , 2003]	IP	lessepsian		T		G	established
<i>Ruditapes philippinarum</i> (Adams & Reeve, 1850)	1996	BEN SOUISSI <i>et al.</i> , 2005	TP	(unknown)		T		G	established -
<i>Cerithium scabridum</i> Philippi, 1848	1997	ENZENROß & ENZENROß, 2001 [this paper]	IP	(combined)		T		G	established
<i>Siphonaria pectinata</i> (Linné, 1758)	<1998	ENZENROß & ENZENROß, 2001	MED	own means	N	T			established
<i>Favorinus ghanensis</i> Edmunds, 1968	2003	BEN SOUISSI <i>et al.</i> , 2004	WA	shipping		T			established -
<i>Erosaria turdus</i> (Lamarek, 1810)	2003	WIMART-ROUSSEAU & WIMART-ROUSSEAU, 2004	IP	lessepsian				G	established
<i>Musculista senhousia</i> (Benson in Cantor, 1842)	2004	BEN SOUISSI <i>et al.</i> 2005	TP	(unknown)		T			established
<i>Mitrella psilla</i> (Duclous, 1846)	2008	ANTIT <i>et al.</i> , 2010	WA	shipping		T			established
<i>Polycerella emertoni</i> Verrill, 1881	2009	this paper	ATL	shipping		T			established

(DANTAN & HELDT, 1932, as *Crassostrea angulata*) and later in the Bizerte lagoon and nearby Lake Ichkeul (AZOUZ, 1966; MEDHIOUB & ZAOUALI, 1988; DRIDI *et al.*, 2006). Populations were generally not self-sustained and successful reproduction was only reported in 2002-2003 for the Bizerte Lagoon (DRIDI *et al.*, 2006).

Melibe viridis Kelaart, 1858 (= *M. fimbriata* Alder & Hancock, 1864) is an Indo-Pacific species whose occurrence in the Mediterranean was first recorded in Greece (THOMPSON & CRAMPTON, 1984). Although its occurrence in Tunisia was first formally reported on by CECALUPO *et al.*

(2008), a Tunisian specimen was represented in the Atlas of Mediterranean Nudibranchs of CATTANEO-VIETTI *et al.* (1990). The species was present in the Gulf of Gabès as early as 1982 as documented by photographs taken during the MNHN expedition (Fig. 1), that is more or less simultaneously with the discovery of the Greek populations.

Bursatella leachii de Blainville, 1817 is at the forefront of progression of Lessepsian immigrants towards the western Mediterranean. Its existence in Gulf of Gabès was also documented by the MNHN expedition in 1982 (Fig. 2), nearly two decades before the first published report for Tunisia



Fig. 1-2: Opisthobranch molluscs photographed during the expedition of Muséum National d'Histoire Naturelle to Djerba, in May 1982. 1. *Melibe viridis*. 2. *Bursatella leachii* (Photographs by Claude Huyghens and Françoise Danrigal).

(ENZENROß & ENZENROß, 2001, collected in 1996). *Bursatella leachii* has made its way along the Italian coasts of the Tyrrhenian sea (FASULO *et al.*, 1984), to the Balears (OLIVER & TERRASA, 2004), to the Spanish eastern peninsular coast (WEITZMANN *et al.*, 2009; RAMOS-ESPLÁ *et al.*, 2010) and, within Tunisia, to the north coast (ZAKHAMA-SRAIEB *et al.*, 2009). In all cases it seems to favour lagoonal or lagoon-like environments and to have a discontinuous distribution.

Fulvia fragilis was first reported in Tunisia by PASSAMONTI (1996), in Gulf of Gabès, but actually has been there at least since 1990 (BEN SOUISSI *et al.*, 2003) and not in the 1982 material in MNHN. It was common a few years later (ENZENROß & ENZENROß, 2001, collected 1996-1998). It is still common on the whole coast and has, like *Bursatella leachii*, reached far into the Western basin; in eastern Spain since 2002 (ZENETOS *et al.*, 2004; TAMAYO GOYA, 2008) and in southern Italy (CROCETTA, 2005; CROCETTA *et al.*, 2008).

Ruditapes philippinarum (Adams & Reeve, 1850) has been reported in the southern section of the Lac de Tunis coastal lagoon since 1996 (BEN SOUISSI *et al.*, 2005). By 2005 it is reported by these authors as still rare and restricted to 'a restricted biotope close to the Gulf of Tunis'. It was further reported from the Gulf of Gabès area by ZAMOURI-LANGAR *et al.* (2006). We have not seen it in our material from La Goulette, in which the native *Ruditapes decussatus* (Linné, 1758) still seems healthy. Nevertheless the two species are known to compete for the same poorly sorted sediments in areas of low hydrodynamism and *Ruditapes philippinarum* has displaced the native species elsewhere (e.g. PRANOVI

et al., 2008 and references therein). This is an invasive species which must be watched for and should by no means be introduced deliberately, since it poses a risk for local extinction of *R. decussatus*.

Cerithium scabridum Philippi, 1848 is a very early settler in the Eastern Mediterranean but its colonization history is more haphazard. Documented on the Levantine coast in the late 19th - early 20th century (PALLARY, 1912), it did not reach Sicily (Brucoli) until 1972 (DI NATALE, 1978). Nevertheless, this species was not seen during the collecting expedition of the Muséum National d'Histoire Naturelle of Paris at Djerba in 1982, therefore was probably not present at that time. It was present at Djerba in 1997 (material in MNHN, Paris, collected by SG) and its occurrence in Tunisia since 1998 was first reported by ENZENROß & ENZENROß (2001). Larval dispersal should not be a limiting factor for this species with planktotrophic larvae, but the noteworthy occurrence of several native species of *Cerithium* in Tunisian waters, particularly the Gulf of Gabès (NORDSIECK, 1974), may have hampered its progression for some time. It is now common, and locally invasive, along the whole coast and it has been recently reported in Greek waters, filling backwards the gap in its Mediterranean distribution (ZENETOS *et al.*, 2009). Nevertheless, its progression towards the Western basin is shy, currently limited to the extreme south of peninsular Italy (CROCETTA *et al.*, 2008).

Siphonaria pectinata was reported as early as 1998 from Tabarka and Bizerte (ENZENROß & ENZENROß, 2001) and in 2007 from La Marsa in the Gulf of Tunis (ANTIT *et al.*, 2007) and currently persists or progresses in these localities. Like *Echinolittorina punctata*, it has an historical range inside the Mediterranean, on the Span-

ish, Moroccan and Algerian coasts (MONTEROSATO, 1878), but contrary to *Echinolittorina punctata*, its arrival on the Tunisian coast is recent and has been witnessed in recent surveys.

(2) Species reported posterior to the completion of CIESM Atlas (2002) and considered as established

These are the species meeting the criterion of two or more independent observations (Table 1).

Favorinus ghanensis Edmunds, 1968 is a tropical West African species reported by BEN SOUISSI *et al.* (2004) near Radès, in connexion with the commercial harbour of Tunis and quite close to the site where we reported *Mitrella psilla* (see below). There are no reasons to doubt the validity of this record, which is based on samples during January and March 2003 and substantiated by a photograph published on the Sea Slug Forum on the Internet <<http://www.seaslugforum.net/showall/favoghan>>. Although the species qualifies as established with the criterion of two independent records, it must be kept in mind that nudibranchs are prone to punctual outbreaks, so that a further record would be desirable to ascertain whether the population is stable. Unlike many species in the genus which feed on the egg masses of other nudibranchs, this species has been reported as grazing on the Bryozoan *Zoobotryon verticillatum* (Delle Chiaje, 1822) (EDMUNDS, 1975)

Erosaria turdus (Lamarck, 1810) was about to be left out of the CIESM Atlas by ZENETOS *et al.* (2004), then documented only from scanty records of one specimen on the Levantine coast and one in the Suez Canal. Living specimens were first reported at the island of Djerba in October 2003 (WIMART-ROUSSEAU & WIMART-ROUSSEAU, 2004; BOYER & SIMBILLE, 2006) and si-

multaneously by BEN SOUISSI *et al.* (2005) based on trawling in late 2003 and 2004 in the Gulf of Gabès. It now seems to be common throughout the Gulf of Gabès area (ROBIN, 2007) and is easily found because of its habit of entering the clay pots used in octopus fisheries. The species was also reported on the Libyan coast on the Internet forum 'cowries.info' of Felix Lorenz <<http://cowryforum.bboard.de/board/ftopic-41123903nx25725-183.html>>. The Mediterranean populations have been named as a distinct subspecies *E. turdus micheloi* by CHIAPPONI (2009), but the settlement of this species in the Mediterranean is so recent that this taxonomic distinction is questionable.

Musculista senhousia (Benson in Cantor, 1842) was found in 2004 in the Tunis Lagoon, and in the navigation channel which separates its southern and northern parts. It inhabits hard substrates, seaweed and even the outer shells of larger molluscs. The citations of this species are scanty (N. Zamouri comm. pers. May 2005; BEN SOUISSI *et al.*, 2005 [October]; DIAWARA *et al.*, 2008), but independent and so far refer to the Tunis coastal lagoon. We have found many small-sized specimens, including very small juveniles, in our samples at La Goulette (Fig. 3), therefore documenting its incursion into the open sea. In the algae of La Goulette, it is found along with the superficially similar native species *Musculus costulatus* (Risso, 1826), with which it may be in competition.

Mitrella psilla (Duclou, 1846) was first collected in June 2008 and reported by ANTTI *et al.* (2010). This was stated as the first instance of a tropical West African species entering the Mediterranean, an assertion which should be qualified with the slightly earlier report of *Favorinus ghanensis* in the same area (see above). The species has now been

followed throughout the sampling survey in the infralittoral algae of La Goulette (Table 2) and the egg capsules were observed in many samples (Figs 5-8). The egg capsules are of a semitransparent texture, barrel-shaped attached by their base to the substrate and reinforced laterally by small vertical ridges; the upper surface acts as an operculum to release the juvenile snail. Each capsule contains a single developing individual, which in the later stages is easily identified by the dark spiral line on the protoconch, characteristic of the species.

Polycerella emertoni Verrill, 1881 is here reported for the first time in Tunisian waters (Figs 9-10), and is abundant in our material at distinct sampling stations and seasons (Table 3). Its occurrence in the vicinity of Tunis harbour is not surprising, being a species prone to introduction elsewhere (ZENETOS *et al.*, 2004 and references therein). In the Mediterranean it has been recorded from

Western Italy, Malta and Greece. Furthermore, it is associated with the Bryozoan *Zoobotryon verticillatum* (Delle Chiaje, 1822) which itself is recognized worldwide as an invasive species in the fouling community (AMAT & TEMPERA, 2009) and is listed in the Global Invasive Species Database (Invasive Species Specialist Group <www.issg.org/> of the IUCN Species Survival Commission). *Polycerella emertoni* was first detected in small numbers in our sample of June 2009 and was later specifically searched for during sorting. It has achieved large numbers in the samples of January, February and March 2010 (Table 3). The species may have been present in the Bay of Tunis for a long time and remained unnoticed because it is extremely inconspicuous. The population is well established and reproduces, as can be documented from the multiple egg masses observed together with the specimens. Live specimens collected in January 2010 were brought to the lab for photography.

Table 2
Abundance of *Mitrella psilla* in the samples studied in algal wash at La Goulette (36° 49.15'N - 10° 18.60'E). A, adults; M, medium-grown specimens, more than half the adult size but without formed peristome as on figure 8; J, juveniles; E: egg-cases.

Date	R1				R2				R3				R4				R5			
	A	M	J	E	A	M	J	E	A	M	J	E	A	M	J	E	A	M	J	E
27/02/2009		1	2		3	-	2	-	4	1	3	-	-	-	-	-	1	-	-	-
31/03/2009																				
29/04/2009	2	-	1				2						-	1	2	1	-	8	1	
27/05/2009	11	12	8		3	3	2						2	1	1	-	20	7	4	-
29/06/2009	-	3	3	2	-	2	1	-	-	-	1	-	-	-	-	-	-	2	1	-
23/07/2009		2	2		-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	3
18/08/2009	2	4	4		-	-	1	0	-	-	2	-	-	-	1		-	-	1	-
29/09/2009	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29/10/2009	-	-	-	-	9	3	-	13	1	-	1		1	-	-	-	3	-	4	4
24/11/2009			2	-			3		1		2		-	-	-	1	-	-	-	-
23/12/2009	5		9	7	6	3	-	-	3	-	19	-	2	1	3		-	-	2	-
19/01/2010	-	-	1	-	1	1	5	-	-	-	-	-	-	-	1	1	1	-	-	1
23/02/2010	3	1	10	10	5	-	3	-	3	6	1	2	4	-	1	-	-	-	3	-

Table 3
Abundance of *Polycerella emertoni* in the samples studied at La Goulette
(36° 49.1'N - 10° 18.9'E, 3-4 m and 36° 49.1'N - 10° 19.6'E, 10-15 m).

	3-4 m R1	3-4 m R2	3-4 m R3	10-15 m R1	10-15 m R2	10-15 m R3
29/09/2009						
29/10/2009						
24/11/2009						
23/12/2009	0	2	7			
19/01/2010	127	68	66	0	57	25
22/02/2010	16	23	48	135	48	38
31/03/2010	77	29	180	120	33	23

(3) Species reported as alien or possibly alien on the Tunisian coast, in need of confirmation (Table 4)

This section includes (1) 'promising' casual records based on only one recent observation, where the context allows the expectation of a confirmation in the near future and (2) records where some elements allow doubt as to their validity.

Tornus jullieni Adam & Knudsen, 1969 is a West African species reported by PIANI & BRINI (1984) based on a single shell collected on the East coast of Djerba (33° 46'50"N, 11° 03'28"E, plotted from indications in the text) in August 1973. It has never been reported again anywhere in the Mediterranean or NW Africa and thus, more than a quarter of a century later, this record should be left as questionable rather than venturing possible explanations.

Crepidula fornicata (Linné, 1758) was reported from trawl samples collected in the Gulf of Gabès (FEHRI-BÉDOUI, 1986) and the species has never been seen again in Tunisia. The most likely pathway for this species, which is invasive in Western Europe, would be the importation of oyster spat for marine farming. There is no such activity in the Gulf of Gabès and we can suspect that the record was based on a very large spec-

imen of the native *Crepidula moulinsii* Michaud, 1829.

Acteocina knockeri (Smith, 1872) is a tropical West African species recorded by HOENSELAAR & GULDEN (1991) from a single shell collected in March 1989 in the Kerkennah islands at Sidi Youssef (34° 39'26"N, 15° 58'13"E, plotted from indications in the text). It was never mentioned again but in this case a confusion is possible with the very similar Indo-Pacific *Acteocina mucronata* (Philippi, 1849) which is definitely established along the Levantine coast (ZENETOS *et al.*, 2004). Further records are nevertheless needed to substantiate the report from Tunisia.

Saccostrea cucullata (Born, 1778) was reported, without details of exact localities and material examined, by ROMDHANE & TRITAR (2002) from the north coast [of Tunisia] at 25-30 m and the Bizerte channel. These authors explain the finding as a possible range extension from the Adriatic. However, the Adriatic records refer to a different species *Saccostrea commercialis* (Iredale & Roughley, 1933) and were never ascertained after 1990 nor outside the Venice Lagoon (see ZENETOS *et al.* 2004 and references therein). *Saccostrea cucullata* is a prevalently intertidal species in its

Table 4
List of cited exotic or cryptogenic molluscs in Tunisian waters, in need of confirmation. Conventions and abbreviations as for Table 1.

Species	Year	First published report [Report of earliest occurrence]	Origin	pathway	occurrence	status
<i>Tormis jullieni</i> Adam & Knudsen, 1969	1973	PIANI & BRINI, 1984	WA	(unknown)	G	questionable
<i>Crepidula fornicata</i> (Linné, 1758)	1984	FEHRI-BÉDOUI, 1986	ATL	(unknown)	G	questionable
<i>Acteocina knockeri</i> (Smith, 1872)	1989	HOENSELAAR & GULDEN, 1991	WA	(unknown)	G	questionable
<i>Saccostrea cucullata</i> (Gmelin, 1791)	<2002	ROMDHANE & TRITAR, 2002	IP	(unknown)	N	questionable
<i>Discodoris lilacina</i> (Gould, 1852)	2003	BEN SOUJISSI <i>et al.</i> , 2005	?	cryptogenic	T	cryptogenic
<i>Chromodoris quadricolor</i> (Rüppel & Leuckart, 1830)	2003	BEN SOUJISSI <i>et al.</i> , 2004	IP	lessepasian	G	casual
<i>Cellana rota</i> (Gmelin, 1791)	<2007	ZAOUALI <i>et al.</i> , 2007	IP	lessepasian	G	casual
<i>Monetaria annulus</i> (Linné, 1758)	2007	BEN SOUJISSI & ZAOUALI, 2007	IP	(unknown)	G	questionable
<i>Alvania dorbignyi</i> (Audouin, 1826)	2007	CAMPANI, 2008	?	cryptogenic	N	cryptogenic
<i>Anadara transversa</i> (Say, 1822)	2010	this paper	ATL	(combined)	T	casual

native area (LAM & MORTON, 2004) and we consider that this record must be considered as unwarranted unless further confirmed.

Chromodoris quadricolor (Rüppel & Leuckart, 1830) is cited from the Bibane Lagoon near the Libyan border by BEN SOUJISSI *et al.* (2004), collected in May 2003 at 5 m depth with abundant sponges. This species is a good candidate for becoming an established species in the Mediterranean. There is probably no connection between this and the first Mediterranean report in northern Italy in 1986 (see ZENETOS *et al.*, 2004) but the species has been recently reported on the Turkish coast (ÖZTÜRK & CAN, 2006).

Discodoris lilacina (Gould, 1852) was reported from the southern section of the Lac de Tunis coastal lagoon by BEN SOUJISSI *et al.* (2005), and this record is supported by a photograph. Illustrations in colour, of specimens from the same source collected in January and March 2003, are also given on the Sea Slug Forum of the Internet <<http://www.seaslugforum.net/find/discmacu>> and there reidentified as the native species *Discodoris maculosa* (Bergh, 1884). The first report of *Discodoris lilacina* in the Mediterranean was that of VALDÉS & TEMPLADO (2002) and is based on specimens collected on the Levantine coast, but earlier BARASH & DANIN (1977) used the name *Discodoris concinna* (Alder & Hancock, 1864) for this species, a species which also has an Indo-Pacific type locality (in Madras, India). There is considerable taxonomic confusion regarding this species which belongs to a

complex of morphologically similar forms occurring in many tropical and temperate areas of the world. DAYRAT (2010) attempted a revision of this complex, using for it the genus *Tayuva* Marcus & Marcus, 1967 and taking the option to subsume several species worldwide into *Tayuva lilacina* ('*Tayuva lilacina* of the Indo-West Pacific' for *Doris lilacina* Gould, 1852 with a type locality in Hawaii, '*Tayuva lilacina* of the Panamic Eastern Pacific' for *Tayuva ketos* Marcus & Marcus, 1967, '*Tayuva lilacina* of the Caribbean' for *Peltodoris crucis* Bergh, 1880 and '*Tayuva lilacina* of the Eastern Atlantic and Mediterranean' for *Doris maculosa* Bergh, 1884). Dayrat writes that the real *Tayuva lilacina* (i.e. his '*Tayuva lilacina* of the Indo-West Pacific') is rare in the Indian Ocean and that all records under the names *lilacina* or *concinna* in the Red Sea are mostly based on another species *Sebadoris fragilis* (Alder & Hancock, 1864) (see discussion in DAYRAT, 2010: 126-127). Therefore, the most likely outcome is that the Tunisian specimens are not Red Sea immigrants but belong to the native member of the complex, *Discodoris maculosa*, as stated on the Sea Slug Forum.

Monetaria annulus (Linné, 1758) was reported by BEN SOUISSI & ZAOUALI (2007) as collected in spring 2006 from several points of the infralittoral of the Kerkenah Islands, and off Tripoli, Libya. This is far from being the first report of this species in the Mediterranean (see e.g. LOCARD, 1886: 94). There are holdings in the 19th century collection of Muséum National d'Histoire Naturelle, Paris, of ornaments labelled as coming from Tunisia and made with shells of this species, which was widespread throughout Africa as a currency and a material for handicraft. Therefore, we believe that such records must await repeated observations of living animals in the same

way as *Erosaria turdus*, before the species can be taken as an element of the Mediterranean fauna.

Cellana rota (Gmelin, 1791) was reported by ZAOUALI *et al.* (2007) from the piers of the commercial harbour of Zarzis, near the Libyan border, and also from Tripoli, Libya. This occurrence seems straightforward since this species is in clear progress, or even invasive, on the Levantine coast (MIENIS, 2002). Further expansion is predictable and the species may soon prove to be established in Tunisia. The question of whether this is the valid name depends on the resolution of the taxonomic controversy over whether this is a synonym of *Cellana radiata* (Born, 1778) or a separate species (e.g. DEKKER & ORLIN, 2000).

Alvania dorbignyi (Audouin, 1826) was recorded from Tabarka by CAMPANI (2008) and our own shore collections from Salakta, in the Gulf of Hammamet in 2007 also yield many specimens of this species. There is some uncertainty regarding whether this species is an immigrant in the Mediterranean, or just a native species which was overlooked due to its overall similarity to the well-known *Alvania montagui* (Payraudeau, 1826). The only grounds to consider this species as possibly Indo-Pacific are that most of Savigny's material, from which the taxon was described, originated from the Red Sea, but actually it also contains a few Mediterranean shells (BOUCHET & DANRIGAL, 1982). Even if a native Mediterranean species, one cannot rule out a recent progression within the basin, but its absence in the 19th century checklists is far less conclusive than in the case of *Echinolittorina punctata*.

Anadara transversa (Say, 1822) is one of the three introduced species of *Anadara* currently recorded in the Mediterranean. A juvenile living specimen (Figs 11-12) of

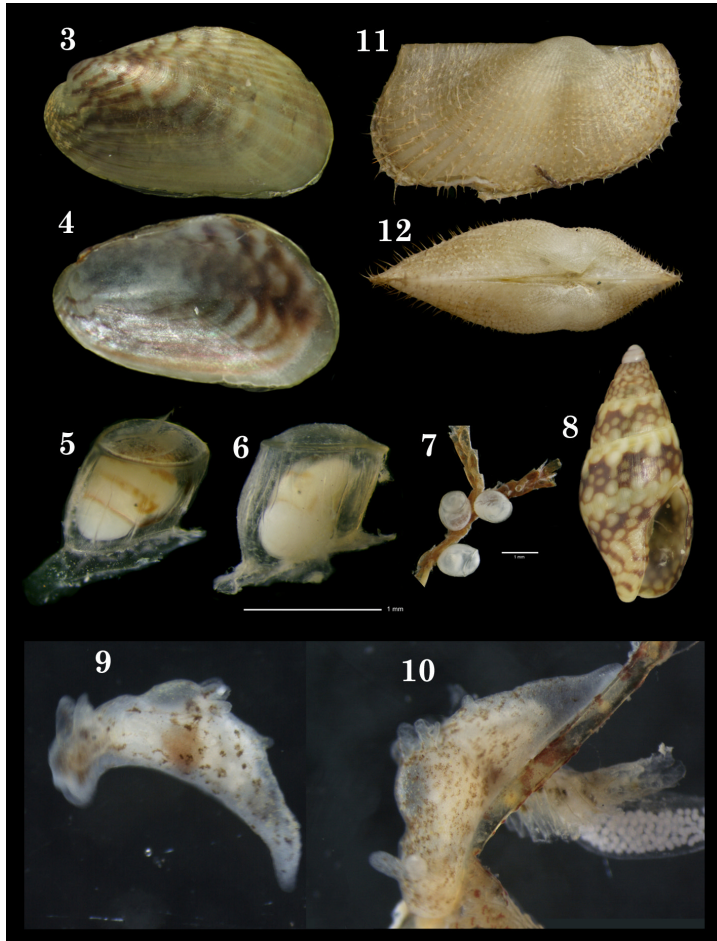


Fig. 3-12: Alien species of molluscs collected since year 2008 in Gulf of Tunis. 3-4: Specimen of *Musculista senhousia* collected in algal wash at La Goulette (actual size 10 mm). 5-7: Egg capsules of *Mitrella psilla*, collected 23.01.2010 at La Goulette in infralittoral algae; scale bars are 1 mm. 8: Adult specimen of *M. psilla*, same locality. 9-10: *Polycerella emertoni*, specimens from off La Goulette, 10-15 m collected 19.01.2010. The specimen on the right has just produced an egg mass (actual size ca. 3 mm). 11-12: Juvenile specimen of *Anadara* sp. tentatively identified as *Anadara transversa* (Say, 1822), off La Goulette, 10-15 m collected 19.01.2010.

an *Anadara* species collected off La Goulette on a soft bottom at 10-15 m is at present the only clue we have to the arrival of one of these species on the Tunisian coast. The native *Anadara polii* (Mayer, 1868) is definitely shorter at this size and lacks the long bristles in the intercostal spaces, but we do not

know the juvenile stage of the native *Anadara corbuloides* (Monterosato, 1880). Therefore, we prefer to await the collection of somewhat larger individuals before venturing a species-level identification. ALBANO *et al.* (2009) considered from morphological and molecular data that this species,

hitherto known in the Mediterranean as *A. demiri* (Piani, 1982) was very similar, if not identical, to the Western Atlantic *A. transversa* (Say, 1822).

Discussion

Chronology of first arrival and rate of influx

Almost one century separates the arrival of the first alien species in Tunisian seas and the next batch, which would include *Bursatella leachii*, *Melibe viridis* and *Fulvia fragilis* in the late 20th century (Fig. 13). Leaving aside the cupped oyster *Crasostrea gigas* voluntarily introduced for farming, this represents only three additions of extra-Mediterranean species in this long interval of time. The rather intensive collecting expedition of MNHN in 1982, although mostly unpublished, provides an archive of specimens indicating that this is not an artefact and that, at least in the Gulf of Gabès, the numbers were really low and the alleged newcomers are really new to the fauna.

According to ZENETOS *et al.* (2008) a total of 903 alien species, among which are 216 molluscs, have been incorporated into the Mediterranean waters. With 94

species (20 molluscs) added between 2005 and 2008, the increase is 10,2% (9,2% for molluscs) and averages one species every 9 days (one mollusc every 42 days). Within Tunisia, the numbers are far from being so impressive but the acceleration in the last decade is comparable or, if anything, is sharper, with three species (*Mitrella psilla*, *Cel-lana rota*, *Monetaria annulus*) added to the previously recorded 17 (cryptogenic and intra-Mediterranean not counted), making an increase by 17% between 2005 and 2008.

Origin of the newcomers

In the Mediterranean as a whole most of the alien species are thermophilous species of Indo-Pacific origin and their establishment in the Mediterranean is seen by POR (2009, 2010) as the result of congruence between the present Climate Optimum (which is expressed in the warming of the sea), the opening of the Canal of Suez as a pathway from the Indo-Pacific area, and the renewed entry of species through the Straits of Gibraltar. POR therefore suggested that the migration of these tropical species to the Mediterranean basin represents a certain restoration of the ancient Tethyan biota.

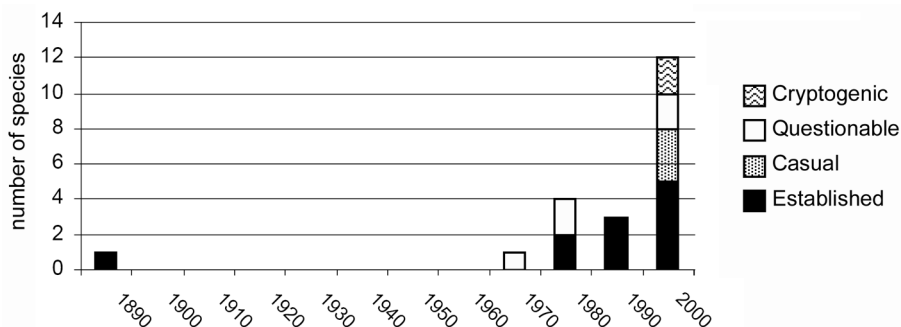


Fig. 13: Chronogram of arrival of the alien species of molluscs on the Tunisian coasts, distributed according to establishment status. Mediterranean and farmed species not included.

This view should be considerably qualified when coming to the Tunisian coast. Among the twelve established alien species in the littoral of Tunis, three have an Atlantic origin (*Favorinus ghanensis*, *Mitrella psilla*, *Polycerella emertoni*) and three more (*Crassostrea gigas*, *Ruditapes philippinarum* and *Musculista senhousia*) have a temperate North Pacific origin (Table 1; Fig. 14). These species appear in the Gulf of Tunis and on the northern coast and, with the exception of *Ruditapes*, they have not reached the southern coast and the Gulf of Gabès, which has the warmer sea surface temperature. Up to now, they have relatively low density of population and rate of spread, and they cannot be considered as 'invasives', although the impact on native populations should be studied.

Of the six established alien species coming from the Indo-Pacific region, five first arrived in the Mediterranean through the Suez Canal and one (*Melibe viridis*) via shipping. Two of these (*Melibe viridis* and *Erosaria turdus*) are restricted to the southern coast of Gabès, probably in relation to the warm climate of this area. The other four (*Cerithium scabridum*, *Bursatella leachii*, *Pinctada radiata* and *Fulvia fragilis*) are present in nearly the whole coast, from Gabès to Bizerte, but still they are more abundant in the

southern area (ENZENROß & ENZENROß, 2001; CECALUPO *et al.*, 2008).

When considering Tunisia as a whole, the sources of alien species are much more balanced than in the Eastern Mediterranean, reflecting the position of this coastline at the transition between the Eastern and Western basins. In the detail, the invasion history of the Gulf of Gabès is definitely separate from that of the Gulf of Tunis and the north coast.

Pathways of introduction

The complicated history of *Cerithium scabridum* indicates that it started its journey into the Mediterranean as a plain Lessepsian species, then its arrival in Sicily around a major harbour has generally been interpreted as helped by shipping and finally, the distance across the Sicily Straits to Tunisia can be easily bridged by its planktonic larvae. *Melibe viridis* first appeared in the Mediterranean in Greece, not on the Levantine coast and therefore is not held as a Lessepsian despite its Indo-Pacific origin. Again, the leg from the Ionian coast of Greece to Tunisia can best be explained by its own means of dispersal, as such light-bodied nudibranchs can not only disperse as larvae but also drift as adults.

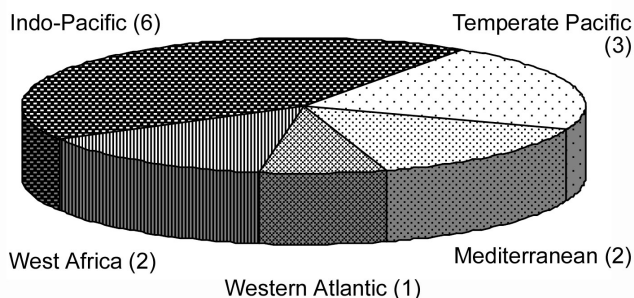


Fig. 14: Origin of the non-indigenous species of molluscs established on the Tunisian coasts.

From these examples it is clear that Tunisia is certainly not the first foothold in the Mediterranean for most of the species discussed herein, and that the pathway of introduction from the area of origin may involve a combination of various means. Of the 12 established aliens, only *Mitrella psilla* and *Favorinus ghanensis* had their first Mediterranean report in Tunisia. Both are tropical West African species and their introduction is considered mediated by shipping in the large commercial harbour of Tunis. This may not be straightforward from current shipping routes, where ship movements from West Africa into the Mediterranean account for only 4,1% of total movements, while more than half originate from NW Europe and Morocco (DOBLER, 2002). Even if routes are occasional, there may be a 'West African connection' from which these species will start their movements through the Mediterranean. They did not enter gradually through the Straits of Gibraltar, where the fauna is well known and where recent surveys would have detected them if they were present.

The Western Atlantic *Polycerella emertoni*, and *Anadara transversa* if confirmed, have certainly been conveyed through shipping at some stage (see GALIL *et al.*, 2008) but their arrival in Tunisian waters is best explained as a secondary introduction by their own means of dispersal with pelagic larvae from other parts of the Mediterranean (southern Italy, Malta ...) where they are already established.

Composition of the invaders

Of the fourteen molluscs (twelve alien and two Mediterranean) recently incorporated in the Tunisian fauna, five bivalves are filter-feeders, five gastropods are generalist grazers scrubbing off detritus or microalgae from the substrate. Therefore the

majority of the established species are generalists. The diet of *Mitrella psilla* is not known; whereas some species of *Mitrella* are known as specialists feeding on the egg masses of other molluscs (RUEDA *et al.*, 2009), other columbellids seem to be also generalist detritivores or omnivores. Cowries may be algal grazers or sponge feeders, and the exact diet of *Erosaria turdus* is not known. Only the two nudibranchs *Favorinus ghanensis* and *Polycerella emertoni* are definitely specialist grazers, but their prey are fouling bryozoans like *Zoobotryon*, so that the vector of their introduction will carry the supporting host as well. On the whole, the successfully installed species are predominantly generalist feeders, meeting one of the conditions for being a prospective invader.

Among the 18 molluscan species stated as invasive somewhere in the Mediterranean (ZENETOS *et al.*, 2010), five or six (*Cerithium scabridum*, *Bursatella leachi*, *Pinctada radiata*, *Musculista senhousia*, *Ruditapes philippinarum*, and maybe *Anadara transversa*) are found in Tunisia, although not necessarily invasive there. This supports the now well-known statement of 'introduced here, introduced elsewhere'. Two of them are of Indo-Pacific origin, therefore not so much supporting POR's (2010) view that thermophilic aliens of Tethyan origin should be more 'at home' and less invasive than those of other origins.

Conclusions and Perspectives

Is Tunisia prone to marine invasions? Factors that have been considered to promote the influx of alien species include (1) a local fauna with relatively low species diversity ('oligospecific') and (2) the area being repeatedly furnished with introduced individuals. Both factors are relevant in Tunisia. In the Gulf of Gabès, the number of

species is relatively low even if abundance of particular species may be extreme, and in this respect the Gulf very much resembles the large Mediterranean lagoons which are a haven for alien species. On the other hand, the highly impacted area of Tunis harbour, with important international shipping activity, may be a major promoter for new and unexpected introductions into the Mediterranean.

Two major pathways must therefore be watched for in the future. One of them is the progress of Lessepsian migrants out of the ca. 1800 km long blackout of the Libyan coast, with the casual *Cellana rota* and *Chromodoris quadricolor* as forerunners. The other one is the occurrence of alien species in the Tunis harbour and lagoon. Introduction through aquaculture seems less important than in other parts of the Mediterranean.

The role of the increase of sea surface temperatures in the acceleration of the process should not be underestimated. Intra-Mediterranean movements were not considered in the CIESM Atlas but there is a growing body of evidence that some tropical species with a historical Mediterranean range, including molluscs, are expanding their range inside the Mediterranean. The cases of *Echinolittorina punctata* and *Siphonaria pectinata* were discussed at length by ANTIT *et al.* (2007) but another species in progress is *Eastonia rugosa*, a native element of the Tunisian fauna since PALLARY (1914) now found as far north as the coast of Latium in Italy (ALBANO, 2006), and Valencia in Spain (TAMAYO GOYA, 2008). The role of temperature change is obvious when it results in range extensions of Mediterranean species, but it may be a factor in the success of many alien thermophilic species, which may have had the opportunity in the past and failed

to become established until the environment met their own requirements. In this scenario, the littoral of Tunis could be a small scale model for the entire Mediterranean basin, because of its transient role. The first event would be the arrival of new tropical species, most of them from the Indo-Pacific area, on the southern coast and some from the Atlantic area on the northern coast. The second consequence would be the spread of the Indo-pacific immigrants towards the northern coast. The rate of immigration and the speed of spread along the Tunisian littoral would indicate the degree of 'tropicalization' of the Mediterranean as a whole.

The next item on the agenda is not only to make counts of newcomers. We now need an appraisal of the share that the naturalized species take of the marine environment, and of the extent to which there is competition with local species. This will require baseline studies to know which species are dominant or otherwise important in communities unaffected by alien biota, and time series in communities where the alien species have become incorporated.

Acknowledgements

Photographs of living animals from Djerba are part of the collection in the Muséum National d'Histoire Naturelle, Paris and were taken by Claude Huyghens and Françoise Danrigal during the 1982 expedition. The authors are grateful to Mr. Pasquale Micali for sending juveniles of the different Mediterranean species of *Anadara* for comparison to Dr. Rudo von Cosel for advice on some West African bivalves, to Dr. Argyro Zenetos for help with some 'gray' literature references and thoughtful suggestions on the draft and to Fabio Crocetta for some corrections and for calling our at-

tention on an overlooked reference. The collecting in Bay of Tunis would not have been possible without the skilful assistance at sea of Mr. Nassime Ben Ahmed and overall Mr. Habib Agrebi.

We are also grateful to Mrs. Jamila Ben Souissi for assistance in obtaining collecting permits. The stay of Mouna Antit in Málaga was made possible with a 'bourse d'alternance' from the Ministère de l'Enseignement Supérieur de la Recherche Scientifique et de la Technologie and later from the research unit 'Biologie de la Reproduction, du Développement et de Biosystématique Evolutive' of Tunis-El Manar University.

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