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Biogeographical homogeneity in the eastern Mediterranean Sea. II. Temporal variation in Lebanese bivalve biota

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ABSTRACT: Lebanon (eastern Mediterranean Sea) is an area of particular biogeographic significance for studying the structure of eastern Mediterranean marine biodiversity and its recent changes. Based on literature records and original samples, we review here the knowledge of the Lebanese marine bivalve biota, tracing its changes during the last 170 yr. The updated checklist of bivalves of Lebanon yielded a total of 114 species (96 native and 18 alien taxa), accounting for ca. 26.5% of the known Mediterranean Bivalvia and thus representing a particularly poor fauna. Analysis of the 21 taxa historically described on Lebanese material only yielded 2 available names. Records of 24 species are new for the Lebanese fauna, and *Lioberus ligneus* is also a new record for the Mediterranean Sea. Comparisons between molluscan records by past (before 1950) and modern (after 1950) authors revealed temporal variations and qualitative modifications of the Lebanese bivalve fauna, mostly affected by the introduction of Erythraean species. The rate of recording of new alien species (evaluated in decades) revealed later first local arrivals (after 1900) than those observed for other eastern Mediterranean shores, while the peak in records in conjunction with our samplings (1991 to 2010) emphasizes the need for increased field work to monitor their arrival and establishment. Finally, the scarce presence (or total absence) in the most recent samples of some once common habitat-forming species, as well as of some other native taxa, confirmed their recent rarefaction (or local extinction), possibly related to their replacement by the aliens *Brachidontes pharaonis*, *Spondylus spinosus* and *Chama pacifica*.

KEY WORDS: Mediterranean Sea · Lebanon · Mollusca · Bivalvia · Alien species · Faunal changes

INTRODUCTION

The present-day autochthonous Mediterranean marine fauna is mostly of Atlantic origin, having originated with the re-establishment of the Atlanto-Mediterranean connection (5.33 million years ago), after the Messinian Salinity Crisis (from 5.971 to 5.33 million years ago; Manzi et al. 2013) had probably nearly exterminated the stenoecious marine biota (Sabelli & Taviani in press). The subsequent 5 million years of evolution within the framework of the complexity of the basin gave rise to the peculiar and variegate Mediterranean assemblage, with the co-occurrence of temperate and subtropical organisms and a main transitional zone between the 2 seas (the Alboran Sea), hosting a mix of Mediterranean and Atlantic species (Bianchi & Morri 2000, Oliverio 2003, Coll et al. 2010).

The opening of the Suez Canal in the south-eastern corner of the Mediterranean in 1869 contributed to changes in the local biodiversity and provided an additional human-induced transitional zone. The spreading of alien species (used here as defined by

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the International Union for Conservation of Nature, see Crocetta 2012) has become one of the main local phenomena affecting species distribution and composition within assemblages (Por 1978, Galil 2009). Mainly confined for over a century along the Levant Sea, alien species of thermophilic origin are currently spreading further to the western and northern Mediterranean, presumably favoured by the general warming of the area (Occhipinti-Ambrogi 2007, Raitsos et al. 2010). Present-day local biodiversity, which is currently threatened by habitat loss and degradation, fishing impacts, pollution, climate change and eutrophication, is also impacted by alien introduction through human activities (e.g. aquaculture, shipping and leisure boating). Prevention and/or control of alien species diffusion have therefore become a major challenge for conservationists (Galil 2009, Zenetos et al. 2012), and the cumulative impact of these biotic and abiotic changes is resulting in the disruption of the original biogeographic pattern within the basin, with several authors drawing attention to the progressive homogenization of Mediterranean marine biota (Bianchi 2007, Lejeusne et al. 2010, Philippart et al. 2011).

The Mediterranean molluscan fauna is considered as the best known in the world, and numerous detailed taxonomic inventories now exist, most of which are specific to sub-regions or countries (Oliverio 2003, Coll et al. 2010). Mollusca, as a 'popular' and thus frequently investigated group, comprise the highest number of known introduced species in the Mediterranean. There are now an estimated ~200 introduced species, more than half of which are with established populations, indicating a high rate of introduction and accounting for ~10% of the Mediterranean Mollusca (slightly more than 2000 species) (Coll et al. 2010, Zenetos et al. 2012). Despite continuous efforts to provide updated datasets for the entire basin, our knowledge of the Levantine area still remains considerably poor when compared with the central and western basin. This is probably due to undersampling due to the absence of recent faunal projects.

Our knowledge of Lebanese marine fauna has a similar history to the rest of the Levant basin. Early pioneering papers provided accurate data on shelled molluscs from 1856 to 1938, while the following decades were rather unfertile until 1971. From then up until 2013, less than 30 papers, notes, abstracts and non-peer-reviewed articles have provided additional scattered information on Lebanese marine bivalve molluscs (Puton 1856, Brusina 1879, Pallary 1911, 1912a, 1919, 1933, 1938, Gruvel & Moazzo 1929, Gruvel 1931, Moazzo 1931, Spada 1971, Fadlallah 1975, Shiber & Shatila 1978, Shiber 1980, Zibrowius & Bitar 1981, 2003, Bogi & Khairallah 1987, Bitar 1996, 2010, 2013, Bitar & Kouli-Bitar 1995a,b, 1998, 2001, Nakhlé et al. 2006, Bitar et al. 2007, Bariche 2012, Crocetta & Russo 2013). However, wide-ranging overviews of the temporal trends and the long-term faunal changes occurring in the area are still lacking.

Using material obtained on field trips within the Programme CEDRE (French-Lebanese cooperation) from 1999 to 2002, enriched by some additions from earlier and later years, this study is the most complete overview of the marine Bivalvia of Lebanon. It aims at: (1) providing an updated checklist of marine bivalve species recorded in Lebanon; (2) investigating historical taxon names based on Lebanese type material and checking their availability as a contribution to Mediterranean bivalve taxonomy; (3) focusing on alien bivalves in Lebanon, providing a checklist of published and unpublished records, with date of the first record, most plausible vector(s) of introduction and the establishment status; and (4) tracing temporal variations and qualitative modifications of the bivalve fauna composition in the framework of current biological pressures.

MATERIALS AND METHODS

Study area

Lebanon is an area of particular significance for the study of marine biodiversity and its recent changes. Lying at the north-eastern tip of the Mediterranean Sea, ~450 km north of the Suez Canal, it is located along the natural pathways of Indo-Pacific taxa spreading from the Red Sea via the prevailing Mediterranean currents (Bergamasco & Malanotte-Rizzoli 2010). Although the main coastal features and the respective communities are similar to those observed along all the Mediterranean shores (Bitar et al. 2007, Bitar 2010), several major engineering species are lacking, such as the seagrass *Posidonia oceanica* (Linnaeus) Delile, 1813 and the sea fans *Paramuricea clavata* (Risso, 1826) and *Eunicella* spp. (Harmelin et al. 2009).

Bibliographic data

An extensive literature survey was conducted using the same methods as Crocetta et al. (2013). Indexed papers were searched, but an attempt to cover the grey literature as much as possible (i.e. non-peer-reviewed and/or non-indexed papers) was also per-

formed. Most of the historical journals are not indexed, and many malacological records are still being published in non-indexed journals, thus allowing only manual searching. In addition, the availability of all historical taxon names based on Lebanese type material was checked.

Sampling

In order to evaluate the current molluscan fauna, the taxonomic composition was the main target of interest. Several sampling localities, covering more or less all of the Lebanese shores, were investigated by 2 of the authors (G. Bitar and H. Zibrowius) between 1999 and 2002 within the framework of the French-Lebanese Programme CEDRE (see Zibrowius & Bitar 2003, Morri et al. 2009). This material was later enriched by additional samples provided by one of the authors (G. Bitar) since 1988. Bivalves were found at 24 sites, with original samples spanning more than 20 yr (Table 1, Fig. 1, see Supplement at www.int-res.com/articles/suppl/b019p075_supp.pdf). Sampling was carried out by snorkelling and SCUBA diving, during daylight hours only, and included different sampling techniques covering highly diversified habitats and approximately all the different accessible biotopes from the intertidal down to a depth of ca. 40 m (e.g. different types of hard and soft substrates, shady overhangs, *Cymodocea* and *Halophila* patches and meadows, caves, harbours, calcareous crusts including scleractinians, serpulids and bryozoans, *Spondylus* and *Chama* facies, infauna of coarse sand or mud) (Table 1, Supplement). The immediate visual recognition of key habitats and organisms was supplemented by underwater photography. When the number of observed individuals was particularly large, most of the largest or more abundant molluscs were released or not sampled after field identification to minimize the impact on the local biota.

Laboratory work and updated taxonomy and nomenclature

Upon arrival at the laboratory, samples were either dry preserved after removing the soft parts or fixed in 2% buffered formaldehyde and then transferred to 100% EtOH. They are currently preserved at the Dipartimento di Biologia e Biotecnologie 'Charles Darwin', La Sapienza University (Rome, Italy). Very worn specimens were discarded to exclude taphocoenotic contamination as much as possible. Identifi-

Table 1. Localities where bivalve species were found, with coordinates and depth ranges (see also Fig. 1). Details of biotopes from which the collections were made are reported in the Supplement under each species

No.	Site	Latitude (°N)	Longitude (°E)	Depth (m)
1	Ramkine Island	34° 29′ 47″	35° 45′ 38″	0–15
2	Tripoli	34° 27′ 28″	35° 49′ 34″	0–5
3	Anfeh	34° 21′ 43″	35° 43′ 36″	10–24
4	Chekka	34° 19′ 12″	35° 43′ 14″	3–6
5	El Heri	34° 18′ 37″	35° 41′ 51″	1–5
6	Ras El Chakaa	34° 18′ 47″	35° 40′ 59″	0–20
7	Chak El Hatab	34° 17′ 36″	35° 40′ 17″	9–14
8	Selaata	34° 17′ 03″	35° 39′ 31″	0–35
9	Batrou	34° 15′ 13″	35° 39′ 19″	2–9
10	Kfar Abida	34° 14′ 02″	35° 39′ 15″	1–12
11	El Barbara	34° 11′ 32″	35° 37′ 19″	26–28
12	Jbail	34° 07′ 18″	35° 38′ 28″	1–17
13	Tabarja	34° 01′ 55″	35° 37′ 26″	0–25
14	Aquamarina	34° 00′ 51″	35° 37′ 57″	10–25
15	Beirut	33° 54′ 55″	35° 31′ 57″	0–34
16	Raoucheh	33° 53′ 18″	35° 28′ 01″	7–10
17	Khaldeh	33° 46′ 44″	35° 28′ 10″	0
18	Saadiyat	33° 41′ 49″	35° 25′ 54″	0
19	Saida	33° 34′ 00″	35° 22′ 10″	10–31
20	El Zahrani	33° 29′ 46″	35° 20′ 01″	11–24
21	El Kassmieh	33° 20′ 22″	35° 14′ 19″	42–44
22	Tyr	33° 15′ 56″	35° 11′ 24″	0–15
23	El Bayada	33° 09′ 96″	35° 10′ 85″	3–5
24	Nakoura	33° 06′ 57″	35° 07′ 11″	3–5

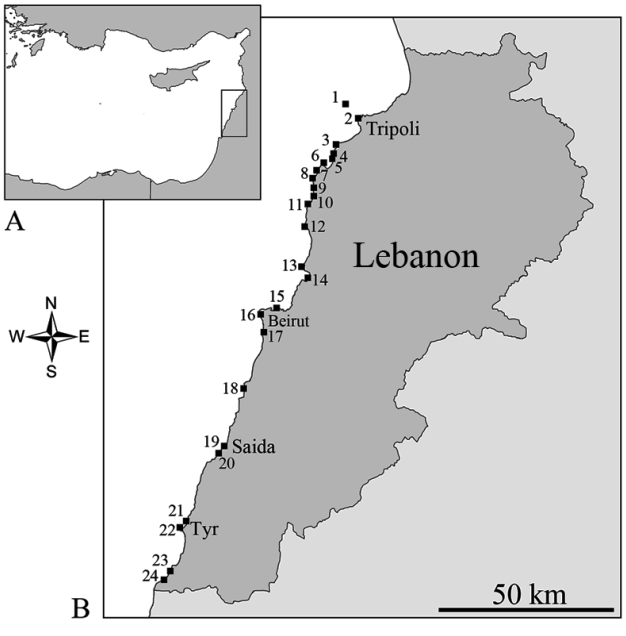

Fig. 1. Study area. (A) The eastern Mediterranean Sea. (B) Sampling sites. Numbers as in Table 1

cations were carried out by the first author (F. Crocetta) to species level, when possible, according to the most recent bivalve guides (Oliver 1992, Zenetos et al. 2004, Huber 2010, Gofas et al. 2011), as well as modern specialist papers (see Supplement). Updated taxonomy and nomenclature follow the World Register of Marine Species (WoRMS; www.marinespecies.org/, last accessed 16 June 2013) with a few exceptions (taxa listed as a still unsolved complex, if current knowledge does not allow correct identification of taxa from the morphology/anatomy alone, and new synonymies proposed). The authorities of the molluscan species listed below are mostly only reported in the Supplement.

Comparisons between past and modern bivalve fauna

Bibliographic data were re-analysed and taxonomically adjusted to allow comparisons. Most of the typical Mediterranean species are taxa clearly recognized by malacologists for centuries, thus suggesting that their presence/absence cannot have gone unnoticed. Using the bibliographic data available, the past (before 1950) and modern (after 1950) bivalve faunal lists were qualitatively compared. Special emphasis was given to alien species, for each of which the following data are provided: published and unpublished records from the coastal and offshore territorial seawaters of Lebanon, date of first record, most plausible vector(s) of introduction and establishment status, mostly following the terminology used in Crocetta (2012).

RESULTS

An updated checklist of 114 taxa of bivalves recorded in Lebanon, including bibliographic records and original data from field samplings, is reported in Table 2 (96 native species: ca. 84%) and Table 3 (18 alien species: ca. 16%). Full details are reported in the Supplement at www.int-res.com/articles/suppl/b019p075_supp.pdf. The obtained faunal data were divided into the 2 main periods (past: before 1950, and modern: after 1950) to allow comparisons and trace temporal variations and qualitative modifications of the local bivalve fauna.

Before 1950: past molluscan assemblage

The 79 taxa reported as occurring along the Lebanese shores before 1950 are listed in Tables 2 & 3 (see also Supplement). Among them, 21 bivalve taxa have been historically described based on Lebanese material, and their current status is reported in Table 4. Eleven of them are *nomina nuda* (ICZN 1999: Art. 12), 8 have infrasubspecific rank and thus are not available (ICZN 1999: Art. 45.5, 45.6), whilst *Ostrea stentina* var. *syriaca* and *Syndosmia cottardi* var. *orientalis* are available, having evidently being instituted as geographic races and thus are of subspecific rank. They are here considered as synonyms of *Ostrea stentina* and *Scrobicularia cottardi*, based on the available type material (Muséum National d'Histoire Naturelle: MNHN-25215) and the original figure (see Pallary 1938, his Fig. 17, Plate II), respectively. The 75 native species (ca. 95%) (Table 2) mainly comprised well-known macrobenthic taxa. There were only 4 alien species (ca. 5%) (Table 3, Fig. 2A): *Brachidontes pharaonis*, *Pinctada imbricata radiata*, *Malleus regula* and *Mactra olorina*.

After 1950: modern molluscan assemblage

The modern records of 38 taxa were traced in the literature (Tables 2 & 3). Their critical re-assessment, together with the analysis of material obtained from field samplings (1032 complete specimens and 1045 loose valves) provided additional records of 74 taxa (Tables 2 & 3). Fifteen native (*Musculus subpictus*, *Limatula* cfr. *gwyni*, *Lucinella divaricata*, *Megaxinus unguiculinus*, *Bornia geoffroyi*, *Kurtiella bidentata*, *Coripia corbis*, *Coripia jozinae*, *Digitaria digitaria*, *Gonilia calliglypta*, *Parvicardium scriptum*, *Spisula subtruncata*, *Arcopella balaustina*, *Hiatella arctica* and *Thracia phaseolina*) and 9 alien (*Lioberus ligneus*, *Spondylus* sp., *Dendostrea folium*, *Chama asperella*, *Afrocardium richardi*, *Fulvia fragilis*, *Mactra lilacea*, *Petricola fabagella* and *Sphenia rueppellii*) taxa were first recorded in Lebanon, with a total of 67 native (ca. 80%) and 17 alien (ca. 20%) species reported after 1950 (Fig. 2A). Among them, 2 species deserve attention (Fig. 3). *Lioberus ligneus*, widespread in the South African and Indo-Pacific provinces, including the Red Sea (Oliver 1992, Huber 2010), is recorded here for the first time in the Mediterranean, based on 7 loose valves and 1 complete specimen sampled in 2 different localities in 1999 and 2000 (Sites 1 and 19, see Supplement). Distinctive shell features with respect to the congeneric *L. agglutinans* are the weaker umbones and the less tumid shape, which is more expanded dorsally. Notably, the specimen recorded in Egypt by Pallary (1912b) as *Modiola agglutinans* Cantraine

Table 2. Native bivalves from Lebanon according to past (before 1950: B 1950) and modern (after 1950: A 1950) data (see Supplement at www.int-res.com/articles/suppl/b019p075_supp.pdf for details). ×: literature records; +: unpublished data; ?: doubtful identification

Family	Taxon	B 1950	A 1950	Family	Taxon	B 1950	A 1950	Family	Taxon	B 1950	A 1950
Solemyidae	*Solemya togata*	×		Lucinidae	*Megaxinus unguiculinus*		+	Tellinidae	*Peronaea planata*	×	+
Nuculidae	*Nucula nucleus*	×	+	Thyasiridae	*Thyasira flexuosa*	×			*Psammotreta cumana*	×	
Nuculanidae	*Nuculana pella*	×	+	Chamidae	*Chama gryphoides*	×	×, ?		*Tellina nitida*	×	
Arcidae	*Arca noae*	×	×, +		*Pseudochama gryphina*	×			*Tellina pulchella*	×	+
	Barbatia barbata	×	×, +	Kelliidae	*Bornia geoffroyi*		+	Donacidae	*Donax semistriatus*	×	+
Noetiidae	*Striarca lactea*	×	×, +		*Bornia sebetia*	×	+		*Donax trunculus*	×	×
Glycy-	*Glycymeris bimaculata*	×	?		*Kellia suborbicularis*	×			*Donax variegatus*	×	+
merididae	*Glycymeris nummaria*	×	×	Montacutidae	*Kurtiella bidentata*		+		*Donax venustus*	×	+
	Glycymeris pilosa	×	?	Carditidae	*Cardita calyculata*	×	×, +	Semelidae	*Abra alba*	×	+
Mytilidae	*Lioberus agglutinans*		×, +		*Cardites antiquatus*	×	+		*Abra segmentum*	×	
	Lithophaga lithophaga	×	×, +		*Coripia corbis*		+		*Scrobicularia cottardi*	×	
	Modiolus barbatus	×	+		*Coripia jozinae*		+	Solecurtidae	*Solecurtus strigilatus*	×	
	Musculus costulatus		×, +		*Glans trapezia*	×	×, +	Veneridae	*Callista chione*	×	
	Musculus subpictus		+	Astartidae	*Digitaria digitaria*		+		*Chamelea gallina*	×	+
	Mytilaster minimus	×	×, +		*Gonilia calliglypta*		+		*Dosinia lupinus*	×	+
	Mytilus galloprovincialis	×			*Goodallia triangularis*	×	+		*Gouldia minima*	×	+
Pinnidae	*Pinna nobilis*	×	+	Cardiidae	*Acanthocardia tuberculata*	×	×, +		*Irus irus*	×	×, +
Pectinidae	*Flexopecten hyalinus*	×	+		*Cerastoderma* spp. *glaucum* complex	×	×		*Lajonkairia lajonkairii*	×	×, +
	Mimachlamys varia	×	×, +		*Parvicardium exiguum*		×		*Petricola lithophaga*	×	+
	Pecten jacobaeus	×			*Parvicardium scriptum*		×, +		*Pitar rudis*		×, +
	Talochlamys multistriata		×		*Papillicardium papillosum*	×	+		*Polititapes aureus*	×	×, +
Spondylidae	*Spondylus gaederopus*	×	×	Mactridae	*Mactra* spp. *stultorum* complex	×	×, +		*Venerupis corrugata*	×	
Anomiidae	*Anomia ephippium*	×	×, +		*Spisula subtruncata*		+		*Venerupis decussata*	×	
Limidae	*Lima lima*	×	×, +	Mesodesmatidae	*Donacilla cornea*	×			*Venerupis geographica*	×	×, +
	Limaria tuberculata	×		Solenidae	*Solen marginatus*	×			*Venus verrucosa*	×	×, +
	Limatula cfr. *gwyni*		+	Pharidae	*Ensis ensis*	×		Corbulidae	*Corbula gibba*	×	+
Ostreidae	*Ostrea edulis*		×		*Ensis minor*	×		Gastrochaenidae	*Rocellaria dubia*	×	
	Ostrea stentina	×	+		*Pharus legumen*	×		Hiatellidae	*Hiatella arctica*		+
Lucinidae	*Ctena decussata*	×	×, +	Tellinidae	*Angulus incarnatus*	×		Pholadidae	*Barnea candida*	×	
	Loripes lucinalis	×	+		*Arcopella balaustina*		+		*Pholas dactylus*	×	
	Loripinus fragilis	×	+		*Gastrana fragilis*	×		Thraciidae	*Thracia phaseolina*		+
	Lucinella divaricata		+		*Moerella distorta*	×		Pandoridae	*Pandora inaequivalvis*	×	

Table 3. Alien bivalves from Lebanon according to past (before 1950: B 1950) and modern (after 1950: A 1950) data, with first record dates (FRD), plausible vectors of introduction along the Lebanese shores (V) and known establishment status (ES) (see Supplement for details). ×: literature records; +: unpublished data; AS: alien spreading via Suez Canal; U: unknown; E: established; C: casual

Family	Taxon	B 1950	A 1950	FRD	V	ES
Arcidae	*Anadara natalensis*		×	1992 (present study)	AS	C
Mytilidae	*Brachidontes pharaonis*	×	×, +	before 1929 (Gruvel & Moazzo 1929)	AS	E
	Lioberus ligneus		+	1999 (present study)	AS	C
Pteriidae	*Pinctada imbricata radiata*	×	×, +	before 1911 (Pallary 1911)	AS	E
Malleidae	*Malleus regula*	×	×, +	1929–1930 (Pallary 1938)	AS	E
Spondylidae	*Spondylus spinosus*		×, +	1999 (present study)	AS	E
	Spondylus sp.		+	2003 (present study)	U	C
Ostreidae	*Dendostrea folium*		+	2012 (present study)	AS	E
Chamidae	*Chama asperella*		+	1999 (present study)	AS	C
	Chama pacifica		×, +	1999 (Crocetta & Russo 2013)	AS	E
Cardiidae	*Afrocardium richardi*		+	1999 (present study)	AS	C
	Fulvia fragilis		+	2003 (present study)	AS	E
Mactridae	*Mactra lilacea*		+	2002 (present study)	AS	C
	Mactra olorina	×		before 1929 (Gruvel & Moazzo 1929)	AS	C
Veneridae	*Gafrarium savignyi*		×, +	before 1998 (Bitar & Kouli-Bitar 1998)	AS	E
	Petricola fabagella		+	2000 (present study)	AS	C
Myidae	*Sphenia rueppellii*		+	2000 (present study)	AS	C
Laternulidae	*Laternula anatina*		×	before 1987 (Bogi & Khairallah 1987)	AS	C

(his Table XVIII, Figs. 36 & 37 only) presumably belongs to the same species. Conversely, the identification of *Spondylus* sp. is somehow puzzling. It may belong to *Spondylus nicobaricus* Schreibers, 1793 (M. Huber pers. comm.), but we prefer to keep it here as unidentified, pending more detailed analysis and further specimens.

Table 4. Bivalve nominal taxa historically described on type material from Lebanon, arranged in systematic order (see Supplement for details). *nn*: *nomen nudum*; inf: infrasubspecific rank; a: available

Author	Proposed taxon	Status
Pallary (1938)	*Pectunculus violacescens* var. *alba*	*nn*
Pallary (1919)	*Modiola barbata* var. *minor*	*nn*
Pallary 1919)	*Pinna nobilis* var. *nana*	inf
Pallary (1912a)	*Meleagrina occa* var. *minor*	inf
Pallary (1938)	*Meleagrina albina* var. *minor*	inf
Pallary (1938)	*Malleus regula* var. *minor*	inf
Pallary (1933)	*Ostrea stentina syriaca*	*nn*
Pallary (1938)	*Ostrea stentina* var. *syriaca*	a
Pallary (1938)	*Jagonia decussata* var. *parva*	inf
Pallary (1938)	*Kellya sebetia* var. *minor*	inf
Pallary (1938)	*Cardita calyculata* var. *major*	inf
Puton (1856)	*Mactra stultorum* var. *compressa*	*nn*
Pallary (1938)	*Mactra corallina* var. *trigona*	inf
Pallary (1938)	*Fragilia fragilis* var. *syriaca*	*nn*
Pallary (1938)	*Donax semistriata* sous-var. *minor*	*nn*
Pallary (1938)	*Donax trunculus* var. *minor*	*nn*
Pallary (1933)	*Syndesmia cottardi orientalis*	*nn*
Pallary (1938)	*Syndosmia cottardi* var. *orientalis*	a
Pallary (1938)	*Tapes aureus* var. *minor*	*nn*
Pallary (1912a)	*Tapes geographicus* var. *minor alba*	*nn*
Pallary (1938)	*Corbula gibba* var. *minor*	*nn*

Special emphasis on alien species

The combined literature–material approach provided a list of 20 alien species in Lebanon (see Table 3 and Supplement for details), but the presence of 2 of them (*Spondylus groschi* Lamprell & Kilburn, 1995 and *Spondylus* cf. *multisetosus* Reeve, 1856) is excluded here as this was based on 1 specimen and on a worn loose valve that falls within the variability of *Spondylus spinosus* (see Supplement). Ca. 95% of the alien species in Lebanese waters are Erythraean species, and this value will rise to 100% if the tentative identification of *Spondylus* sp. as *S. nicobaricus* Schreibers, 1793 is confirmed (Table 3). However, only 8 of them were here considered established, while the remaining 10 taxa are currently known on the basis of a few sporadic specimens and are therefore considered casual (Table 3, Supplement). Further field studies may confirm their local establishment or, possibly, their ephemeral presence. The rate at which first records of alien molluscan species were reported, estimated per decade, is listed in Table 3 and plotted in Fig. 2B.

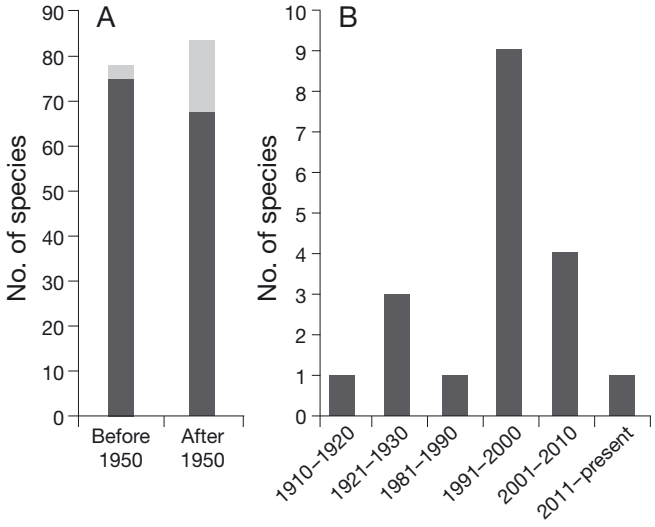

Fig. 2. (A) Past (before 1950) and modern (after 1950) native (dark grey) and alien (light grey) Lebanese bivalve fauna. (B) Rate of first reports of alien molluscan species in Lebanon. The 1931–1980 gap is due to the lack of records (see 'Introduction'). See Tables 2 & 3 for details

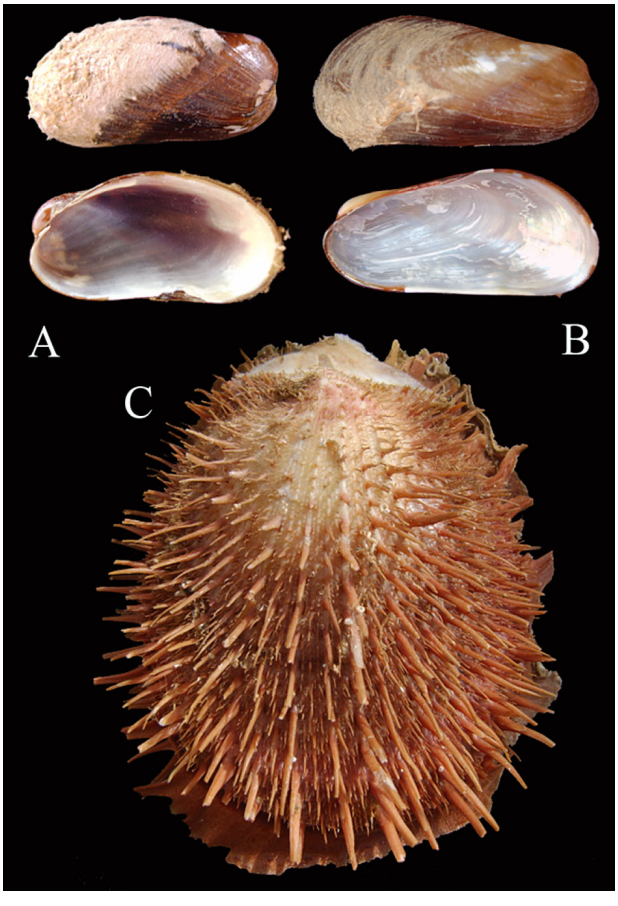

Fig. 3. Bivalves from Lebanon (not to scale, sizes reported as maximum height × maximum width). (A) *Lioberus agglutinans* (Cantraine, 1835), 16 × 31 mm. (B) *Lioberus ligneus* (Reeve, 1858), 17 × 35 mm. (C) *Spondylus* sp., 72 × 60 mm

DISCUSSION

Bivalves are an important component of benthic marine ecosystems and constitute the second most diverse class of Mollusca after gastropods. Many of them are well studied, not only as biodiversity components (Giacobbe 2002, Rabaoui et al. 2009) or indicators of ecosystem instability (Occhipinti-Ambrogi et al. 2005, Nerlovi et al. 2011), but because they often serve as pollution indicators (Morcillo et al. 1999) or are commercially exploited (Voultsiadou et al. 2010, Katsanevakis et al. 2011). So far, ca. 400 native bivalve species and less than 100 alien bivalve species have been recorded in the Mediterranean Sea (Coll et al. 2010, Zenetos et al. 2012). However, considering the continuous description of new species in the Mediterranean (more than 100 molluscs during the last 10 yr alone, Crocetta et al. 2012), the unexpected results obtained by the combined use of molecular and morphological approaches (Calvo et al. 2009, Guarniero et al. 2010), and the increasing trend of colonization of the Mediterranean Sea by alien species (Galil 2009, Zenetos et al. 2012), these figures are deemed to increase in the near future.

The 114 Lebanese species listed here belong to 39 families and 87 genera. The richest family is Veneridae Rafinesque, 1815 with 15 species (ca. 13%), followed by Mytilidae Rafinesque, 1815 with 9 species (ca. 8%) and Tellinidae Blainville, 1814 with 8 species (ca. 7%). The genus *Donax* Linnaeus, 1758 is the most diverse, with 4 species (ca. 3.5%). This still represents a particularly poor fauna, accounting for ca. 26.5% of the native and alien Mediterranean bivalve species (Coll et al. 2010). Even if the absence of several common species with Atlantic–Mediterranean distribution and of Mediterranean endemics from the Lebanese and, more generally, the eastern Mediterranean fauna may be plausible, the possibility that the very low bivalve biodiversity recorded here is at least partially an underestimation should not be dismissed. The deep waters of the Levant basin have not been intensively explored (Bogi & Galil 2004, 2013, Galil 2004), and the Lebanese area, in particular, has not been sampled deeper than ~40 m. Therefore, these data clearly suggest that thorough investigations are still needed for a better understanding of the whole eastern Mediterranean fauna. However, the 24 new records reported here, including the first record of *Lioberus ligneus* in the Mediterranean Sea, highlight the importance of continuous field sampling in filling geographic gaps.

Admittedly, our Lebanon data are based on a sampling methodology not specifically aimed at this group of molluscs, since our new material, in particu-

lar, originates from general sampling of benthic marine species and communities. Therefore, many tiny and cryptic species might have been overlooked, and the lack of specific surveys focused on this class may have prevented an exhaustive work. Notwithstanding the limitations of these qualitative samples, some interesting conclusions may be drawn. In fact, when comparing faunal data obtained during the past and modern periods of investigation, 2 issues were raised. On the one side, an increase in local biodiversity may be perceived, with 79 taxa recorded before 1950 and 84 after 1950 (Fig. 2A). On the other side, remarkable local shifts in faunal composition, previously suggested for the eastern Mediterranean shores on the basis of visual assessments only (Mienis 2003, Galil 2007, Bitar 2010), were here demonstrated with sound data. In fact, even if the new records of native species mainly concerned small-sized species, and may be presumably attributed to an incomplete previous investigation, the scarcity (or total absence) in our most recent samples of once common native habitat-forming species such as *Mytilus galloprovincialis*, *Mytilaster* spp., *Spondylus gaederopus* and *Chama gryphoides*, along with some other native taxa, would suggest their recent rarefaction (or local extinction), possibly related to their replacement by the aliens *Brachidontes pharaonis*, *Spondylus spinosus* and *Chama pacifica*. In addition, the wide beds of these habitat-forming alien species observed during our study suggest an establishment for a relatively long time. However, the rate of recording of new alien species (evaluated on decades) revealed an absence of records prior to 1900 (see Puton 1856) and only sporadic findings in 1911 to 1930 (see Pallary 1911, 1912a, 1919, 1933, 1938, Gruvel & Moazzo 1929, Gruvel 1931, Moazzo 1931) (Table 3, Fig. 2B), with only 4 alien species (ca. 5% of the past species, ca. 3.5% of the total historical list) recorded within the past molluscan biota. The well-known alien species recorded early in Lebanon (*Brachidontes pharaonis*, *Pinctada imbricata radiata*, *Malleus regula* and *Mactra olorina*) are indeed among the first Mediterranean colonizers (see review in Zenetos et al. 2004), and thus an early presence along the Lebanese shores is not surprising (Table 3, Fig. 2A). Conversely, 17 alien species (ca. 20% of the modern species, ca. 15% of the total historical list) are recorded within the modern molluscan biota, a proportion within the range of 10 to 20% commonly estimated for the entire Levantine fauna (Zenetos et al. 2010). Higher proportions (~ 34%) have been previously noted for other molluscan groups (Crocetta et al. 2013), but the strong morphological resemblance among some Mediterranean and Red Sea species suggests that a final assessment of these figures will require the use of molecular data to confirm the identifications of taxonomically difficult species, including cryptogenics. Finally, although the peak in records in conjunction with our field work (1991 to 2010) is obviously due to the increased sampling, our data clearly show a late alien species arrival into Lebanon, especially when compared with other eastern Mediterranean countries such as Egypt and Israel (Zenetos et al. 2004, Galil 2007). This is paralleled by a similar pattern noted for other unmistakable macrobenthic alien bivalve taxa (e.g. *Chama pacifica*, *Fulvia fragilis* and *Gafrarium savignyi* [= *G. pectinatum sensu auct.*]), whose first Mediterranean records date back to the beginning of the 20th century (Tillier & Bavay 1905, Moazzo 1939) but whose definitive spreading only occurred decades later. A plausible hypothesis is that this is related to the recent temperature increase in the Mediterranean, which has made it, first the eastern basin, and thereafter the entire Mediterranean, progressively more suitable for biological invasion by tropical species (Oliverio & Taviani 2003).

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