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research paper

Increase in knowledge of the marine gastropod fauna of Lebanon since the 19th century

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ABSTRACT.—We hereby review and update the current state of knowledge on the Lebanese gastropod biota based on published literature and the study of new samples. Review of 1543 published records yielded 237 gastropod taxa. New samples from the Lebanese coast yielded 2414 living specimens and 4003 empty shells, belonging to 188 taxa. Forty-six of the taxa are new records for the Lebanese fauna, bringing the gastropods known from Lebanon to 283 species. Literature records also included 71 nominal gastropod taxa based on type material from Lebanon, including 3 genera, 8 species, and 60 subspecific units. Of these, only 13 are retained as available. Of the 283 gastropod taxa known from Lebanon, 41 are aliens and 7 are cryptogenic. The majority of nonnative taxa were recorded only during the last decades, particularly from 1980 to 2019. Results from the present study question the common assumption that this region has extremely low native diversity. The flora and fauna of the Lebanese coast remain relatively unexplored and our data support the perception that several formerly abundant species have recently collapsed. Despite these advances, the lack of scientific data on biodiversity and community structure of Lebanese habitats and geographic zones is likely to hamper conservation actions and legal protection of critical species. We therefore recommend additional field and laboratory research to increase knowledge of both taxonomic composition and species' distributions in Lebanon and elsewhere in the easternmost Mediterranean Sea.

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The Mediterranean Sea has a long history of scientific exploration and is commonly considered a biodiversity hotspot, hosting approximately 17,000 marine species (Coll et al. 2010). Mollusca make up one of the most species-rich phyla in the area due to their ecological disparity, promoting colonization of virtually all marine environments, assisted by the long tradition of extensive field studies and taxonomy, which led to a good knowledge of the diversity of this group in the region (Coll et al. 2010, Sabelli and Taviani 2014). The Mediterranean basin is divided into different

biogeographic areas, each having specific oceanographic features (Bianchi 2007). Among these areas, the easternmost part of the basin, the Levant Sea (comprising essentially Turkish, Syrian, Lebanese, Israeli, Egyptian, and Cypriot territorial waters) is mostly oligotrophic due to the semiarid climate of the surrounding land masses with limited precipitation and low river runoff, except for the Nile River delta area. It also has a relatively narrow continental shelf and is distant from the nutrient-rich inflow of Atlantic water (Bariche 2010). This is reflected in the progressive eastward decline of various well-known Mediterranean species, such as the endemic sea grass *Posidonia oceanica* (*see* Online Appendix 1 for species authorities), or the complete absence of others, such as cnidarians genera *Corallium*, *Eunicella*, and *Paramuricea*; this has contributed to the general perception of a west–east Mediterranean biodiversity gradient, with a richer western part of the basin and an impoverished Levant basin (Morri et al. 2009, Crocetta et al. 2013a). The easternmost Mediterranean is also the region that seems to be most subject to biological invasions. This phenomenon was usually explained by addressing the vicinity to the Suez Canal (for species invading the Mediterranean Sea from the Red Sea) coupled with the presence of a sort of ecological vacuum, driven by subtropical climates and the thermal limits of Atlantic species (Bouillon et al. 2004, Voultsiadou 2009), resulting in ecological niches being available for potential newcomers (Oliverio and Taviani 2003).

The 220-km coast of Lebanon is well defined in the previous statements, hosting a large number of alien species, several of which are well established and outcompete native taxa (e.g., Zibrowius and Bitar 2003, Harmelin-Vivien et al. 2005, Crocetta et al. 2013a, Bitar et al. 2017). On the other hand, Lebanese biodiversity, whatever its actual magnitude, is also exposed to the effects of four commercial ports, at least 15 fishing harbors, many pipelines for petroleum imports, various industries, three power plants, and fuel tank farms. It is further affected by illegal or unregulated fishing practices (e.g., use of explosives and ichthyocides) and the unrelenting rise of pollution from sources including illegal sewage discharge and rivers carrying pollutants from agricultural, industrial, and urban activities (Bariche 2010, Badreddine et al. 2018).

Despite the relevance to Mediterranean marine biology, the easternmost Mediterranean marine ecosystem and its fauna and flora have been insufficiently and discontinuously investigated, in terms of both spatial and temporal distribution of its components (Azov 1991, Fredj et al. 1992, Arvanitidis et al. 2002). Thus, with the main aim to increase the overall knowledge of mollusk biodiversity in the easternmost Mediterranean Sea, we initiated a program of revision of the marine Mollusca of Lebanon (Crocetta et al. 2013a,b, 2014). Based on an exhaustive literature search and study of many previously-unpublished samples, we tested whether the low diversity commonly assumed for this area is real or an artefact caused by scarce field research and scientific exploration and general taxonomic impediments. In the present study, we critically review the knowledge of the Lebanese Gastropoda. In addition, as a contribution to the general knowledge of the Mediterranean molluscan biota, we have also screened the nomenclature of all nominal taxa originally described from the area. Finally, we focus on the region's alien fauna. The final corpus of this revision (Crocetta et al. 2013a, b, 2014) is expected to prepare and be the background for further studies, assessments, and conservation programs, and prove useful for long-term comparisons.

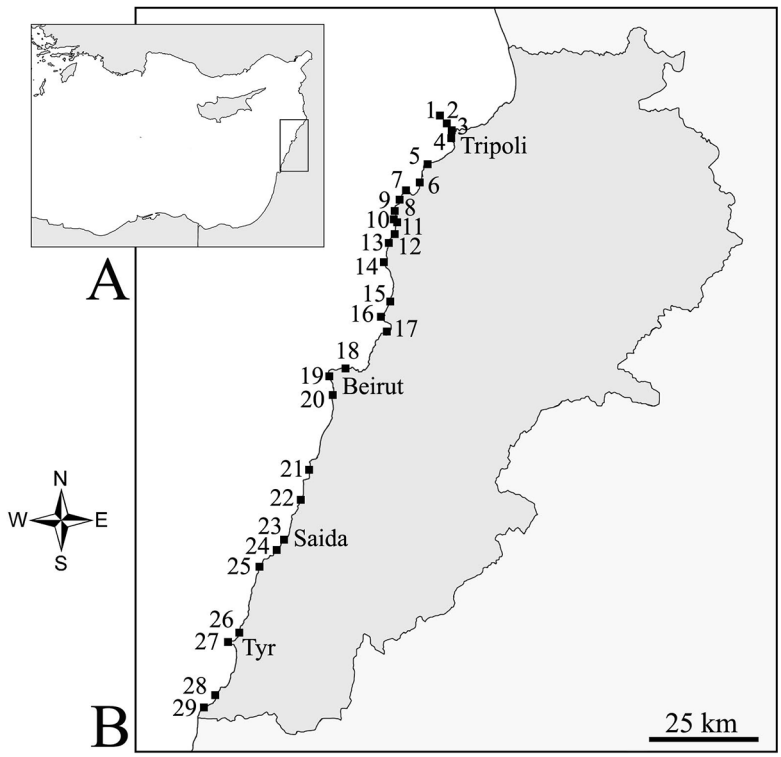

Figure 1. Study area. A. The eastern Mediterranean Sea, with location of Lebanon (rectangle). B. Map of the sampling sites, numbers corresponding to localities reported in Table 1.

Methods

Study Area, Benthic Features, and Sampling.—Lebanon lies at the central/northeastern tip of the Mediterranean Sea between Syria and Israel within the Levant basin (Fig. 1). Its approximate 220 km of coastline has a narrow continental shelf (3–7 km wide) dominated by pebble beaches and rocky coasts, with sandy beaches occupying only 20% of the coast (Badreddine et al. 2018). Several localities, spanning the entire Lebanese coastline, have been sampled by snorkeling and scuba diving at daylight hours by two of the authors (GB and HZ) between 1999 and 2002 within the French-Lebanese joint program "Coopération pour l'Évaluation et le Développement de la Recherche" (CEDRE), aimed to study the coastal environment and the marine biodiversity of the Lebanese coastline (*see* Zibrowius and Bitar 2003). As the final target of the program was mostly qualitative, a high diversity of habitats from the intertidal down to approximately 40 m depth was examined (*see* Online Appendix 1 for details). When directly observed, gastropod samples were collected by hand, and other sampling techniques were used including destructive (scrapings: mesh size 1 mm) and nondestructive (visual census, underwater photographs) approaches. In addition, bioclastic sediments were collected whenever possible in each habitat explored (mesh size 1 mm), with particular attention to caves and harbors. The CEDRE material was later increased by additional samples, photos,

and personal observations (samples from 1988 onwards) donated by colleagues and ourselves, which also allowed us to include two specimens from approximately 100 m depth. Gastropoda were overall found at 29 sites, listed in Table 1 (*see also* Fig. 1).

Bibliographic Data.—An extensive literature survey has been conducted following the same criteria reported by Crocetta et al. (2013a, b, 2014). Indexed papers were reviewed first, followed by nonindexed papers, articles in non–peer reviewed journals, books, congress abstracts, and the "gray literature." The listing of literature records was as exhaustive as possible, regardless of each record referring to an independent finding. Collected data were reanalyzed and taxonomically adjusted to allow for comparisons. In many cases, earlier literature records were found to be reported by subsequent authors with or without explicit reference to the previous papers. As the majority of the material previously recorded from Lebanon has neither been deposited in a museum nor is available for comparison, we trusted records based only on literature unless we found unequivocal evidence that they were wrong (*see* Online Appendices 2–5). Furthermore, the availability of all historical gastropod names based on Lebanese type material was checked as a contribution to Mediterranean taxonomy.

Laboratory Work and Updated Taxonomy and Nomenclature.—Live-collected gastropod samples were first fixed in 2% buffered formaldehyde and subsequently transferred to 100% EtOH. Empty shells were dried. Specimens collected for the present study were curated in the Department of Biology and Biotechnologies "Charles Darwin" ("Sapienza" University of Rome - Italy: BBCD), Museo Nacional de Ciencias Naturales in Madrid, Spain (MNCN), and the Muséum national d'Histoire naturelle (Paris - France: MNHN) (Online Appendix 1). Very eroded shells were discarded to exclude as much as possible contamination from taphocoenotic assemblages. Whenever possible, samples were identified to species level, following taxonomy and nomenclature in the World Register of Marine Species (WoRMS Editorial Board 2019).

Special Emphasis on Alien Species.—Special emphasis was given to alien species, with the following data provided for each taxon: published and unpublished records from the coastal and offshore territorial waters of Lebanon, date of first record, most plausible pathway(s) of introduction in Lebanon, and establishment success. Pathway nomenclature follows the Convention on Biological Diversity (2014). Two categories were encountered: (1) one related to a transport vector, the transport-stowaway (T-S), which typically refers to the movement of living organisms attached to transporting vessels; and (2) one related to the unaided spread (US), which refers to the secondary natural dispersal of alien species from neighboring areas. The establishment success of each species was determined on the basis of published and unpublished data. We considered each species as either casual (C) species recorded only once, the record of which is based on one or very few specimens (here synonymous with nonestablished and/or extinct), or established (E) species recorded in the wild with free living, likely self-maintaining, and/or reproducing populations, as inferred from record dates, total number of records, and number of specimens per record.

Table 1. Sampling localities shown in Figure 1, with coordinates, maximum depths (MD, in meters), and main habitats sampled (*see also* Online Appendix 1).

No.	Sites	Coordinates		MD	Habitats sampled
		Latitude	Longitude		
1	Ramkine Island	34°29′34″N	35°46′36″E	15	rocky bottom, under stones, photophilous algae, overhang with concretions and corals, shaded wall, tunnel and roof, cave, coarse sand bottom
2	Palms Island	34°28′16″N	35°51′34″E	4	rocky bottom, under stones, photophilous algae
3	Tripoli	34°27′28″N	35°49′34″E	5	rocky bottom, under stones, photophilous algae, harbour
4	Bouhssas	34°25′10″N	35°49′12″E	2	pebbles, muddy bottom, sandy bottom
5	Anfeh	34°21′43″N	35°43′36″E	24	rocky bottom, under stones, photophilous algae, shaded wall, cave, boulders, sandy bottom
6	El Heri	34°18′37″N	35°41′51″E	9	rocky bottom, under stones, photophilous algae, overhang, cave, *Cymodocea* meadow, muddy bottom, sandy bottom
7	Ras El Chakaa	34°18′47″N	35°40′59″E	14	rocky bottom, under stones, photophilous algae, shaded wall, cave, vertical wall with concretions, coarse sand bottom, sandy bottom
8	Chak El Hatab	34°17′36″N	35°40′17″E	18	rocky bottom, under stones, photophilous algae, overhang, cave
9	Selaata	34°17′03″N	35°39′31″E	35	vermetid platform, rocky bottom, under stones, photophilous algae, overhang with concretions, tunnel and roof, cave, cliff
10	Hannouch	34°18′26″N	35°40′35″E	24	rocky bottom, under stones, photophilous algae, overhang with concretions, sandy bottom
11	Batroun	34°15′13″N	35°39′19″E	12	vermetid platform, rocky bottom, under stones, photophilous algae, overhang with calcareous algae, vertical wall with concretions, cave, sandy bottom
12	Kfar Abida	34°14′02″N	35°39′15″E	12	rocky bottom, under stones, photophilous algae, overhang with concretions, tunnel and roof, cave
13	El Barbara	34°11′32″N	35°37′19″E	29	rocky bottom, under stones, photophilous algae, overhang, harbour, sandy bottom
14	Jbail	34°07′18″N	35°38′28″E	16	rocky bottom, under stones, overhang with concretions, cave, shoal, harbour
15	El Bouar	34°02′53″N	35°37′55″E	4	rocky bottom, under stones, photophilous algae, overhang with concretions, boulders
16	Tabarja	34°01′55″N	35°37′26″E	25	rocky bottom, under stones, photophilous algae, coarse sand bottom, sandy bottom
17	Aquamarina	34°00′51″N	35°37′57″E	25	rocky bottom, sciaphilous algae, boulders, artificial slope
18	Beirut	33°54′55″N	35°31′57″E	34	rocky bottom, under stones, photophilous algae, overhang with corals, harbour, boulders, pillars, muddy bottom
19	Raoucheh	33°53′18″N	35°28′01″E	10	rocky bottom, under stones, photophilous algae, cave, boulders, sandy bottom
20	Khaldeh	33°46′44″N	35°28′10″E	18	rocky bottom, under stones, photophilous algae, muddy bottom
21	Saadiyat	33°41′49″N	35°25′54″E	8	rocky bottom, under stones, photophilous algae, overhang with calcareous algae and bryozoans, cave, sandy bottom
22	Rmaileh	33°36′27″N	35°23′30″E	25	sandy bottom
23	Saida	33°34′00″N	35°22′10″E	31	rocky bottom, under stones, photophilous algae, sandy bottom
24	El Zahrani	33°29′46″N	35°20′01″E	24	rocky bottom, under stones, photophilous algae, sandy bottom, detritic sandy bottom
25	Khaizaran	33°26′47″N	35°16′31″E	0	vermetid platform
26	El Kassmieh	33°20′22″N	35°14′19″E	44	rocky bottom, coralligenous, freshwater springs, detritic sandy bottom
27	Tyr	33°15′56″N	35°11′24″E	37	rocky bottom, under stones, photophilous algae, overhang with concretions, shoal, coarse sand between rocks
28	El Bayada	33°09′96″N	35°10′85″E	10	rocky bottom, under stones, photophilous algae, sandy bottom
29	Nakoura	33°06′57″N	35°07′11″E	5	rocky bottom, under stones, photophilous algae, boulders, jetty

Results

Bibliographic Data.—Our bibliographic analysis revealed 1543 literature records from Lebanon, contained in 77 literature sources from 1844 (Philippi 1844) to 2019 (Badreddine et al. 2019). However, 60 sources mentioned fewer than 10 taxa; 37 contained records of single taxa only, and often reiterated records published by previous authors; only 33 sources actively contributed with new records for Lebanon (Online Appendix 1). The majority of these records (1070, approximately 69.5%) appeared in 6 major molluscan checklists of Lebanon, which again were mostly, if not exclusively, based on literature data (Pallary 1919, 1938, Gruvel and Moazzo 1929, Moazzo 1931, Bitar 1996, Bitar and Kouli-Bitar 1998). Emblematic examples of literature records are those of *Alvania dictyophora* and *Alvania hispidula*, both allegedly found only once a century ago, and then repeatedly listed in subsequent reviews from Lebanon with no additional findings (Online Appendix 1).

The literature records cover 237 valid gastropod taxa, consisting of 199 natives, 35 aliens, and 3 cryptogenics (Online Appendix 1, Tables 2–3); such a number also includes 25 misidentified species, whose taxonomic identifications were corrected here (Online Appendix 2, Table 4). Two taxa were ranked as *Incertae sedis*, namely *Vermetus imbricatus* and *Mitrella aradusana*, whose actual identities remain unknown (Online Appendix 3). Finally, besides the misidentifications, the presence in Lebanon of 17 more taxa was rejected and the respective records excluded from our considerations because they were based on incorrect and/or invalid locality data (11 taxa), misreadings (5 taxa), or represented species from other phyla (1 taxon). These include both alien and cryptogenic species, such as *Haliotis rugosa pustulata*, *Aspella anceps*, *Ergalatax contracta*, *Biuve fulvipunctata*, and *Retusa desgenettii*, and native taxa known only from very restricted ranges in the Mediterranean Sea, such as *Gibbula spratti*, *Jujubinus unidentatus*, and *Turritella decipiens* (Online Appendix 4, Table 5).

The 1543 literature records from Lebanon also accounted for 71 nominal gastropod taxa based on type material from Lebanon, including 3 genera, 8 species, and 60 subspecific units. *Nomina nuda* (International Commission on Zoological Nomenclature - ICZN 2012: Art. 12, 13, glossary) are represented by 38 cases, 19 have infrasubspecific rank (ICZN 2012: Art. 10.2, 45.5, 45.6, glossary), and only 13 proved to be available (ICZN 2012: Art. 10, glossary). Among the available taxa, *Patella lusitanica* (var.) *orientalis* is presumably the name to be assigned to the eastern Mediterranean clade of the *Patella rustica* complex, *Vermetus anguliferus* and *Buccinum gaillardoti* are the names to be used for the eastern Mediterranean clades of the *Dendropoma petraeum* and *Aplus dorbignyi* complexes, and *Nassa cuvieri* var. *louisi* is now known as *Tritia louisi*, a valid species. All other names are junior synonyms of valid taxa, except *Vermetus imbricatus* Pallary, 1938, which is a junior primary homonym of *Vermetus imbricatus* Sandberger, 1859 and *Vermetus imbricatus* Dunker, 1860, and thus permanently invalid (ICZN 2012: Art. 57.2) (Online Appendix 5).

Newly Sampled Material.—Sampling along the Lebanese coast yielded 6417 gastropod specimens, of which 2414 were living and 4003 were empty shells. As some specific samples had already been listed in nine recent articles (Online Appendix 1),

Table 2. Native marine gastropods from Lebanon, with literature records (L) and material examined (M). New records marked with an asterisk. *See* full details and species authorities in Online Appendix 1.

Family/Taxon	L	M	Family/Taxon	L	M
Patellidae			Cerithiidae (*continued*)		
Patella caerulea	×	×	*Bittium reticulatum*	×	×
Patella rustica complex	×	×	*Cerithidium submammillatum*	×	×
Patella ulyssiponensis	×	×	*Cerithium alucastrum*	×	
Lottiidae			*Cerithium lividulum*	×	×
Tectura virginea	×	×	*Cerithium renovatum* complex	×	×
Fissurellidae			*Cerithium vulgatum* complex	×	
Diodora gibberula	×	×	Planaxidae		
Diodora graeca	×		*Fossarus ambiguus*	×	×
Diodora italica	×		Potamididae		
*Emarginula huzardii**		×	*Pirenella conica*	×	×
Emarginula octaviana	×		Siliquariidae		
Emarginula sicula	×		*Tenagodus obtusus*	×	×
Fissurella nubecula	×	×	Turritellidae		
Haliotidae			*Turritella turbona*	×	×
Haliotis tuberculata lamellosa	×	×	Triphoridae		
Trochidae			*Marshallora adversa**		×
Clanculus corallinus	×	×	*Metaxia metaxa*	×	×
Clanculus cruciatus	×	×	*Monophorus erythrosoma**		×
Clanculus jussieui	×	×	*Monophorus perversus*	×	×
Gibbula ardens	×	×	Cerithiopsidae		
Gibbula drepanensis	×		*Cerithiopsis barleei**		×
Gibbula fanulum	×		*Cerithiopsis nana**		×
Gibbula guttadauri	×	×	*Cerithiopsis tubercularis* complex	×	
Gibbula leucophaea	×		*Dizoniopsis concatenata**		×
Gibbula magus	×	×	*Dizoniopsis coppolae**		×
Gibbula philberti	×		Epitoniidae		
Gibbula racketti	×		*Epitonium clathrus*	×	×
Gibbula turbinoides	×	×	*Epitonium turtonis*	×	
Jujubinus exasperatus complex	×	×	*Gyroscala lamellosa*	×	
Jujubinus striatus complex	×	×	*Janthina janthina*	×	
Phorcus articulatus	×		*Janthina globosa*	×	
Phorcus mutabilis	×		Eulimidae		
Phorcus richardi	×		*Eulima glabra*	×	
Phorcus turbinatus	×	×	*Melanella boscii*	×	
Steromphala adansonii complex	×	×	*Melanella polita*	×	
Steromphala divaricata	×		*Parvioris ibizenca**		×
Steromphala nebulosa	×	×	Littorinidae		
Steromphala rarilineata complex	×	×	*Echinolittorina punctata*	×	×
Steromphala varia	×	×	*Melarhaphe neritoides*	×	×
Calliostomatidae			Rissoidae		
*Calliostoma laugieri laugieri**		×	*Alvania amatii**		×
Calliostoma zizyphinum	×	×	*Alvania colossophilus**		×
Turbinidae			*Alvania datchaensis*	×	×
Bolma rugosa	×	×	*Alvania dictyophora*	×	
Phasianellidae			*Alvania geryonia*	×	×
Tricolia pullus pullus	×	×	*Alvania hispidula*	×	
Tricolia speciosa	×	×	*Alvania lineata*	×	
Neritidae			*Alvania mamillata*	×	×
Smaragdia viridis	×		*Alvania perversa**		×
Cerithiidae			*Alvania* sp.*		×
Bittium latreillii	×	×	*Crisilla* cf. *semistriata**		×

Table 2. *Continued.*

Family/Taxon	L	M	Family/Taxon	L	M
Rissoidae (*continued*)			Ranellidae		
Pusillina marginata	×	×	*Charonia lampas lampas*	×	
*Pusillina munda**		×	*Charonia variegata*	×	×
*Pusillina philippi**		×	*Monoplex corrugatus*	×	
Pusillina radiata	×	×	Muricidae		
Rissoa lia	×	×	*Bolinus brandaris*	×	
Rissoa monodonta	×		*Coralliophila meyendorffii*	×	×
*Rissoa scurra**		×	*Hexaplex trunculus* complex	×	×
Rissoa similis	×	×	*Muricopsis cristata*	×	×
Rissoa variabilis	×		*Ocenebra edwardsii* complex	×	×
Rissoinidae			*Ocenebra hybrida*	×	
Rissoina bruguieri	×	×	*Ocinebrina aegeensis*	×	×
Barleeiidae			*Stramonita haemastoma*	×	×
Barleeia unifasciata	×		*Typhinellus labiatus*	×	×
Caecidae			Marginellidae		
Caecum auriculatum	×		*Volvarina mitrella*	×	×
*Caecum trachea**		×	Cystiscidae		
Tornidae			*Gibberula miliaria*	×	
*Tornus mienisi**		×	*Gibberula philippii*	×	×
Tornus subcarinatus	×	×	Mitridae		
Truncatellidae			*Episcomitra cornicula*	×	×
Truncatella subcylindrica	×		*Isara cornea*	×	
Vermetidae			Costellariidae		
Dendropoma anguliferum	×	×	*Pusia ebenus*	×	×
Petaloconchus glomeratus	×		*Pusia granum*	×	
Thylacodes arenarius	×	×	*Pusia tricolor*	×	
*Thylaeodus rugulosus**		×	*Vexillum hypatiae*	×	×
Vermetus triquetrus	×		Pisaniidae		
Aporrhaidae			*Aplus gaillardoti*	×	×
Aporrhais pespelecani	×		*Aplus scacchianus*	×	×
Velutinidae			*Enginella leucozona*	×	×
*Lamellaria perspicua**		×	*Pisania striata*	×	×
Triviidae			Buccinidae		
Niveria problematica	×	×	*Chauvetia brunnea*	×	
Cypraeidae			*Euthria cornea*	×	×
Luria lurida lurida	×	×	Colubrariidae		
Naria spurca spurca	×	×	*Cumia reticulata*	×	×
Zonaria pyrum pyrum	×		Nassariidae		
Naticidae			*Tritia circumcincta*	×	×
Euspira intricata	×	×	*Tritia corniculum* complex	×	
Euspira nitida	×	×	*Tritia cuvierii* complex	×	×
Naticarius hebraeus	×		*Tritia gibbosula*	×	
Naticarius stercusmuscarum	×	×	*Tritia grana*	×	
Neverita josephinia	×	×	*Tritia incrassata* complex	×	×
Notocochlis dillwynii	×		*Tritia louisi*	×	
Tectonatica sagraiana	×		*Tritia mutabilis*	×	×
Tonnidae			*Tritia neritea*	×	×
Tonna galea	×	×	*Tritia nitida*	×	
Cassidae			*Tritia pygmaea**		×
Galeodea rugosa	×		*Tritia turulosa*	×	×
Semicassis granulata	×	×	*Tritia unifasciata*	×	×

Table 2. *Continued.*

Family/Taxon	L	M	Family/Taxon	L	M
Columbellidae			Ringiculidae		
Columbella rustica	×	×	*Ringicula auriculata*	×	
*Mitrella coccinea**		×	*Ringicula conformis*	×	×
*Mitrella minor**		×	Bullidae		
Mitrella scripta	×		*Bulla striata*	×	×
Fasciolariidae			Haminoeidae		
Aptyxis syracusana	×		*Haminoea hydatis*	×	
Fusinus sp.*		×	Cylichnidae		
Tarantinaea lignaria	×	×	*Cylichna cylindracea*	×	
Conidae			Retusidae		
Conus ventricosus	×	×	*Retusa mammillata*	×	
Horaiclavidae			*Retusa truncatula*	×	
Haedropleura secalina	×	×	Rhizoridae		
Haedropleura septangularis	×		*Volvulella acuminata*	×	
Mitromorphidae			Cavoliniidae		
Mitromorpha columbellaria	×	×	*Clio pyramidata* complex	×	
Mangeliidae			Plakobranchidae		
Bela zonata	×		*Elysia timida*	×	
*Mangelia callosa**		×	Umbraculidae		
Mangelia costulata	×	×	*Umbraculum umbraculum*	×	×
*Mangelia angelinae**		×	Aplysiidae		
Mangelia paciniana	×		*Aplysia depilans*	×	×
Mangelia stosiciana	×	×	*Aplysia fasciata*	×	×
Mangelia taeniata	×		Pleurobranchidae		
Mangelia unifasciata	×		*Berthella aurantiaca*	×	×
Mangelia vauquelini	×	×	*Berthella ocellata*	×	×
Mangelia sp.*		×	Chromodorididae		
*Sorgenfreispira brachystoma**		×	*Felimare picta picta*	×	×
Raphitomidae			*Felimida binza*	×	×
Clathromangelia granum	×		*Felimida luteorosea*	×	×
*Clathromangelia loiselieri**		×	*Felimida purpurea*	×	×
Cirillia linearis	×		Phyllidiidae		
Raphitoma cordieri	×		*Phyllidia flava*	×	×
*Raphitoma farolita**		×	Dendrodorididae		
Raphitoma laviae	×	×	*Dendrodoris grandiflora*	×	×
Raphitoma philberti	×		*Dendrodoris limbata*	×	×
Pyramidellidae			Aeolidiidae		
*Eulimella acicula**		×	*Aeolidiella alderi*	×	×
Euparthenia bulinea	×		*Spurilla neapolitana*	×	
Megastomia conoidea	×	×	Facelinidae		
*Odostomella bicincta**		×	*Cratena peregrina*	×	
*Ondina vitrea**		×	*Dondice banyulensis*	×	×
Ondina sp.*		×	Flabellinidae		
Parthenina monozona	×	×	*Flabellina affinis*	×	
Pyrgiscus rufus	×		Siphonariidae		
Pyrgostylus striatulus	×	×	*Williamia gussoni*	×	×
Turbonilla lactea	×		Ellobiidae		
*Turbonilla pusilla**		×	*Auriculinella bidentata*	×	
Amathinidae			*Myosotella myosotis*	×	
Clathrella clathrata	×		*Ovatella firminii*	×	
Acteonidae			Trimusculidae		
Acteon tornatilis	×		*Trimusculus mammillaris*	×	×

Table 3. Alien and cryptogenic marine gastropods from Lebanon, with literature records (L) and material examined (M), first record dates (FRD), plausible pathway(s) of introduction in Lebanon (P), and establishment success (ES). New entries are marked with a plus+. *See* full details and species authorities in Online Appendix 1. Species for which the first Mediterranean records also included Lebanon are marked with an asterisk, whereas those recorded for the first time in the Mediterranean from Lebanon only are marked with two asterisks.

Family	Taxon	L	M	Status	FRD	P	ES
Nacellidae	*Cellana rota*	×		alien	2012–2013	US	C
Fissurellidae	*Diodora ruppellii*	×	×	alien	2002	US	E
Trochidae	*Pseudominolia nedyma*	×	×	alien	1985–1987	US	C
Trochidae	*Trochus erithreus*	×	×	alien	1985–1987	US	E
Cerithiidae	*Cerithidium perparvulum*+		×	alien	1992	US	E
Cerithiidae	*Cerithium scabridum*	×	×	alien	1929–1930	US	E
Cerithiidae	*Rhinoclavis kochi*	×	×	alien	1985–1987	US	E
Dialidae	*Diala semistriata*	×		alien	1985–1987	US	C
Scaliolidae	*Finella pupoides*	×		alien	1985–1987	US	C
Cerithiopsidae	*Cerithiopsis pulvis*	×	×	alien	1985–1987	US	E
Cerithiopsidae	*Cerithiopsis tenthrenois*+		×	alien	1999	US	C
Eulimidae	*Sticteulima clandestina*+		×	cryptogenic	1999		
Eulimidae	*Sticteulima* sp.+		×	cryptogenic	1999		
Rissoinidae	*Rissoina bertholleti*+		×	alien	1999	US	E
Strombidae	*Conomurex persicus*	×	×	alien	1985–1987	US	E
Cypraeidae	*Purpuradusta gracilis notata*	×	×	alien	1991	US	E
Muricidae	*Ergalatax junionae*	×	×	alien	1999	US	E
Muricidae	*Indothais sacellum***	×	×	alien	2000	T-S, US	E
Muricidae	*Murex forskoehlii forskoehlii*	×	×	alien	1929–1930	US	E
Pisaniidae	*Pollia rubens*** +		×	alien	2000	T-S, US	C
Columbellidae	*Zafra savignyi*	×		alien	1985–1987	US	C
Columbellidae	*Zafra selasphora*+		×	alien	1999	US	E
Fasciolariidae	*Fusinus verrucosus*	×	×	alien	2000	US	E
Pyramidellidae	*Brachystomia* sp.+		×	cryptogenic	2000		
Pyramidellidae	*Cingulina isseli*	×	×	alien	1985–1987	US	E
Pyramidellidae	*Megastomia* sp.+		×	cryptogenic	1999		
Pyramidellidae	*Oscilla jocosa*+		×	alien	1999	US	C
Pyramidellidae	*Pyrgulina fischeri*	×		alien	before 1996	US	C
Pyramidellidae	*Pyrgulina maiae*	×	×	alien	1985–1987	US	E
Pyramidellidae	*Syrnola fasciata*	×		alien	1985–1987	US	C
Amathinidae	*Amathina tricarinata**	×	×	alien	2000	T-S, US	C
Mnestiidae	*Mnestia girardi*	×		alien	1985–1987	US	C
Tornatinidae	*Acteocina mucronata**	×	×	alien	1986	US	C
Retusidae	*Pyrunculus fourierii***	×	×	alien	1985–1987	US	C
Plakobranchidae	*Elysia grandifolia* complex	×	×	alien	2002	US	E
Aplysiidae	*Aplysia dactylomela*	×	×	cryptogenic	2009		
Aplysiidae	*Bursatella leachii*	×	×	cryptogenic	1999		
Aplysiidae	*Syphonota geographica*	×	×	alien	2003	US	C
Pleurobranchidae	*Berthellina citrina*	×		alien	2016	US	C
Pleurobranchidae	*Pleurobranchus forskalii*	×	×	alien	2003	US	C
Discodorididae	*Tayuva lilacina* complex	×	×	cryptogenic	2000		
Chromodorididae	*Goniobranchus annulatus***	×	×	alien	2000	T-S, US	E
Chromodorididae	*Hypselodoris infucata*	×	×	alien	1999	US	E
Polyceridae	*Plocamopherus ocellatus*	×	×	alien	2000	US	E
Tethydidae	*Melibe viridis*	×		alien	2015	US	C
Facelinidae	*Caloria indica*	×		alien	2016	US	C
Flabellinidae	*Coryphellina rubrolineata*	×	×	alien	2003	US	E
Siphonariidae	*Siphonaria crenata*	×		alien	1967	US	C

Table 4. Species recorded from Lebanon but excluded as based on misidentifications. Records subsequently assigned to the misidentified taxa. *See* full details and species authorities in Online Appendices 1 and 2. Fossil taxa are marked with a dagger †.

Literature record	Excluded species	Corrected identification
Patellidae		
Patella depressa	*Patella depressa*	*Patella ulyssiponensis*
Trochidae		
Gibbula tumida	*Gibbula tumida*	*Gibbula racketti*
Monodonta marmorata	?	*Phorcus turbinatus*
Turritellidae		
Turritella triplicata	*Turritella triplicata* †	*Turritella turbona*
Turritella communis	*Turritella communis*	*Turritella turbona*
Eulimidae		
Eulima polita	*Melanella polita*	*Melanella boscii*
Eulima polita var. *brevis*	*Melanella polita*	*Melanella boscii*
Rissoidae		
Rissoa subcrenulata	*Alvania subcrenulata*	*Alvania amatii*
Alvania subcrenulata	*Alvania subcrenulata*	*Alvania amatii*
Rissoa aspera var. *minor*	*Alvania aspera*	*Alvania datchaensis*
Alvania aspera	*Alvania aspera*	*Alvania datchaensis*
Rissoa cimex var. *minor*	*Alvania cimex*	*Alvania mamillata*
Rissoa cimex	*Alvania cimex*	*Alvania mamillata*
Alvania cimex	*Alvania cimex*	*Alvania mamillata*
Rissoa montagui var. *minor*	*Alvania discors*	*Alvania* sp.
Rissoa montagui var. *fulva*	*Alvania discors*	*Alvania* sp.
Rissoa montagui var. *flavescens-fasciata*	*Alvania discors*	*Alvania* sp.
Rissoa montagui	*Alvania discors*	*Alvania* sp.
Alvania discors	*Alvania discors*	*Alvania* sp.
Vermetidae		
Vermetus cristatus	*Dendropoma cristatum*	*Dendropoma anguliferum*
Dendropoma petraeum	*Dendropoma cristatum*	*Dendropoma anguliferum*
Strombidae		
Strombus decorus	*Conomurex decorus*	*Conomurex persicus*
Triviidae		
Trivia pulex var. *minor*	*Trivia mediterranea*	*Niveria problematica*
Trivia pulex	*Trivia mediterranea*	*Niveria problematica*
Muricidae		
Ergalatax obscura	*Ergalatax martensi*	*Ergalatax junionae*
Murex tribulus	*Murex tribulus*	*Murex forskoehlii forskoehlii*
Ocinebrina corallina	*Ocinebrina corallina*	*Ocinebrina aegeensis*
Ocinebrina aciculata	*Ocinebrina aciculata*	*Ocinebrina aegeensis*
Pisaniidae		
Buccinum orbignyi	*Aplus dorbignyi*	*Aplus gaillardoti*
Pisania orbignyi	*Aplus dorbignyi*	*Aplus gaillardoti*
Pisania d'Orbignyi	*Aplus dorbignyi*	*Aplus gaillardoti*
Pisania d'orbignyi sous-var. *angusta*	*Aplus dorbignyi*	*Aplus gaillardoti*
Cantharus d'orbigny	*Aplus dorbignyi*	*Aplus gaillardoti*
Pollia dorbignyi	*Aplus dorbignyi*	*Aplus gaillardoti*
Nassariidae		
Nassa reticulata	*Tritia reticulata*	*Tritia nitida*
Nassarius reticulatus	*Tritia reticulata*	*Tritia nitida*
Hinia angulate	*Tritia angulata* †	*Tritia pygmaea*
Mitromorphidae		
Mitrolumna olivoïdea	*Mitromorpha olivoidea*	*Mitromorpha columbellaria*
Mitromorpha olivoidea	*Mitromorpha olivoidea*	*Mitromorpha columbellaria*
Mangeliidae		
Mangelia attenuata	*Mangelia attenuata*	*Mangelia costulata*
Raphitomidae		
Cordieria reticulata	*Raphitoma echinata*	*Raphitoma cordieri*
Raphitoma echinata	*Raphitoma echinata*	*Raphitoma cordieri*
Philbertia bicolor	*Raphitoma bicolor*	*Raphitoma laviae*
Raphitoma purpurea	*Raphitoma purpurea*	*Raphitoma laviae*

Table 5. Species recorded from Lebanon but excluded and not subsequently reported in our list. Rationale for rejection: I - incorrect and/or invalid locality data; M - misreading; O - records based on species from other phyla. *See* full details and species authorities in Online Appendix 4.

Literature record	Accepted taxon	Status	Rejection
Haliotidae			
Haliotis pustulata	*Haliotis rugosa pustulata*	alien	I
Haliotis pustulata cruenta	*Haliotis rugosa pustulata*	alien	I
Trochidae			
Gibbula spratti	*Gibbula spratti*	native	I
Calliostoma unidentatum	*Jujubinus unidentatus*	native	I
Jujubinus unidentatus	*Jujubinus unidentatus*	native	I
Gibbula latior var. *albida*	*Steromphala umbilicaris*	native	I
Turritellidae			
Turritella decipiens	*Turritella decipiens*	native	I
Vermetus lumbricalis	*Vermicularia lumbricalis*	?	I
Caecidae			
Caecum orientale	*Caecum clarkii sensu auctores*	native	M
Caecum clarkii	*Caecum clarkii sensu auctores*	native	M
Vermetidae			
Vermetus semisurrectus (originally *Vermetus intestinum*)	*Thylaeodus semisurrectus*	native	O
Cassidae			
Cassis saburon	*Semicassis saburon*	native	M
Phalium saburon	*Semicassis saburon*	native	M
Muricidae			
Aspella anceps	*Aspella anceps*	cryptogenic	I
Ergalatax contracta	*Ergalatax contracta*	alien	I
Pisaniidae			
Pisania scabra	*Aplus scaber*	native	I
Pollia scabra	*Aplus scaber*	native	I
Buccinidae			
Donavania granulata	*Chauvetia ventrosa*	native	I
Cancellariidae			
Cancellaria cancellata	*Bivetiella cancellata*	native	M
Raphitomidae			
Philbertia syriaca	*Raphitoma syriaca*	native	M
Aglajidae			
Chelidonura fulvipunctata	*Biuve fulvipunctata*	alien	I
Retusidae			
Retusa desgenettii	*Retusa desgenettii*	alien	M

only 2064 specimens and 3921 shells constitute previously unpublished material. The most abundant taxon, in terms of total number of live-collected specimens, was the alien *Cerithium scabridum*, with 958 individuals. Other species abundantly represented in our samples were taxa known to aggregate in colonies, such as the natives *Dendropoma anguliferum* and *Pirenella conica* and the aliens *Elysia grandifolia* (complex) and *Ergalatax junionae*, all accounting for more than 100 specimens each. When analyzing empty shells, the native *Bittium latreillii* and the alien *Cerithium scabridum* accounted for 950 and 911 individuals, respectively. Additional species accounting for more than 100 shells were the native *Alvania mamillata* and the alien *Conomurex persicus*. The most commonly collected species (including both specimens

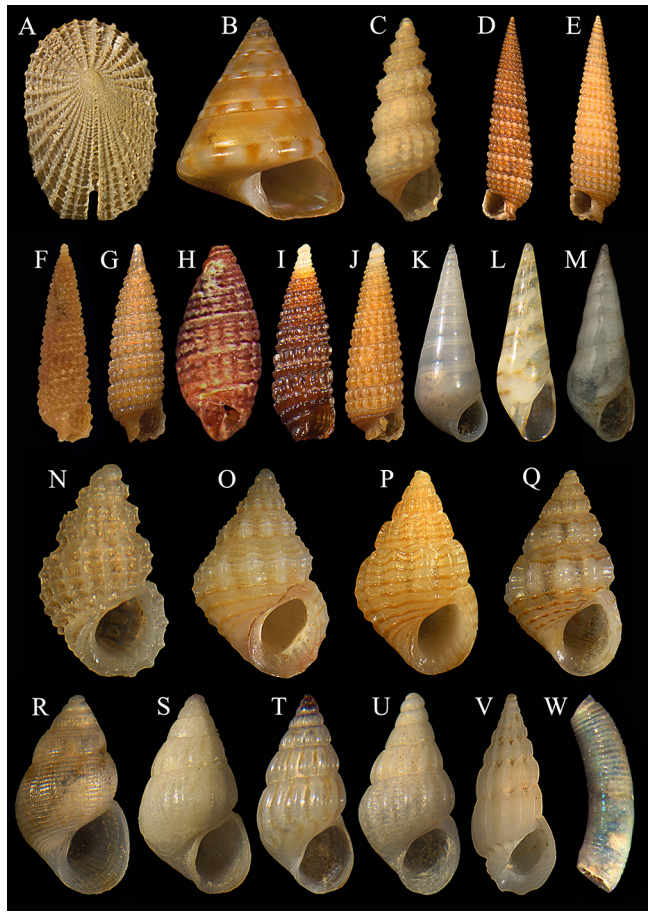

Figure 2. Marine gastropods newly recorded from Lebanon (authorities in Online Appendix 1). Specimens/shells not to scale, sizes reported as total height. A. *Emarginula huzardii* - 7.8 mm. B. *Calliostoma laugieri laugieri* - 6.65 mm. C. *Cerithidium perparvulum* - 2.65 mm. D. *Marshallora adversa* - 7.15 mm. E. *Monophorus erythrosoma* - 5.9 mm. F. *Cerithiopsis barleei* - 5.6 mm. G. *Cerithiopsis nana* - 3.05 mm. H. *Cerithiopsis tenthrenois* - 2.1 mm. I. *Dizoniopsis concatenata* - 4.1 mm. J. *Dizoniopsis coppolae* - 3.85 mm. K. *Parvioris ibizenca* - 3.9 mm. L. *Sticteulima clandestina* - 2.6 mm. M. *Sticteulima* sp. - 3.5 mm. N. *Alvania amatii* - 2.2 mm. O. *Alvania colossophilus* - 3.9 mm. P. *Alvania perversa* - 3.55 mm. Q. *Alvania* sp. - 4.15 mm. R. *Crisilla* cf. *semistriata* - 2.45 mm. S. *Pusillina munda* - 3 mm. T. *Pusillina philippi* - 2.55 mm. U. *Rissoa scurra* - 2.4 mm. V. *Rissoina bertholleti* - 5.9 mm. W. *Caecum trachea* - 2.1 mm.

and shells) were the native *Columbella rustica* and the alien *C. scabridum*, found in 17 and 16 sampling sites, respectively (Online Appendix 1).

The newly sampled material comprised 188 taxa, consisting of 151 natives, 30 aliens, and 7 cryptogenics. Only 181 taxa were identified to species level (but some belong to species complexes), whereas 7 (4 putative natives and 3 putative cryptogenics) remained at genus level (Online Appendix 1, Tables 2–3). These may represent undescribed taxa, presumably eastern Mediterranean endemics, but the lack of fresh/living and/or conspicuous material prevented us from describing them formally here. Furthermore, 46 taxa (39 of which were identified to species level) were never inventoried as part of the Lebanese fauna (Online Appendix 1, Tables

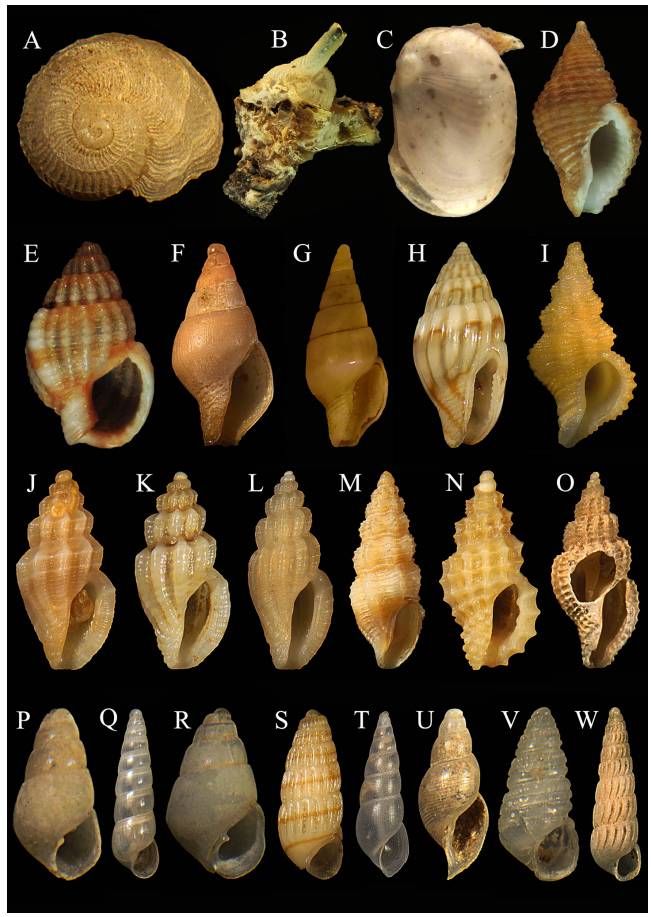

Figure 3. Marine gastropods newly recorded from Lebanon (authorities in Online Appendix 1). Specimens/shells not to scale, sizes reported as total height. A. *Tornus mienisi* - 2.3 mm. B. *Thylaeodus rugulosus* - 11 mm. C. *Lamellaria perspicua* - 5.35 mm. D. *Pollia rubens* - 19.9 mm. E. *Tritia pygmaea* - 6.9 mm. F. *Mitrella coccinea* - 5.8 mm. G. *Mitrella minor* - 7.1 mm. H. *Zafra selasphora* - 3.85 mm. I. *Fusinus* sp. - 8.5 mm. J. *Mangelia callosa* - 4.35 mm. K. *Mangelia angelinae* - 3.85 mm. L. *Mangelia* sp. - 5.65 mm. M. *Sorgenfreispira brachystoma* - 6 mm. N. *Clathromangelia loiselieri* - 4 mm. O. *Raphitoma farolita* - 6.95 mm. P. *Brachystomia* sp. - 1.7 mm. Q. *Eulimella acicula* - 2.8 mm. R. *Megastomia* sp. - 1.8 mm. S. *Odostomella bicincta* - 2.65 mm. T. *Ondina vitrea* - 5.4 mm. U. *Ondina* sp. - 2.25. V. *Oscilla jocosa* - 2.15 mm. W. *Turbonilla pusilla* - 3.6 mm.

2–3, Figs. 2–3), among which the majority were native species (36, 32 of which were identified to species level). Among them, *Alvania amatii*, *Alvania* sp., and *Tritia pygmaea* had presumably already been found, but were misidentified (Online Appendices 1–2). Among the new records, *Mitrella coccinea* was never recorded from the entire easternmost Mediterranean Sea, while *Mangelia angelinae* was already known from the northern coast of Cyprus only. However, absence of records from other countries may be due to the fact that it was only recently reinstated as a valid species (Amati et al. 2017). Besides few easy-to-identify taxa (e.g., *Emarginula huzardii*, *Calliostoma laugieri laugieri*, *Tritia pygmaea*), the majority of the new records belong to the families Rissoidae (7 taxa), Pyramidellidae (5 taxa), and

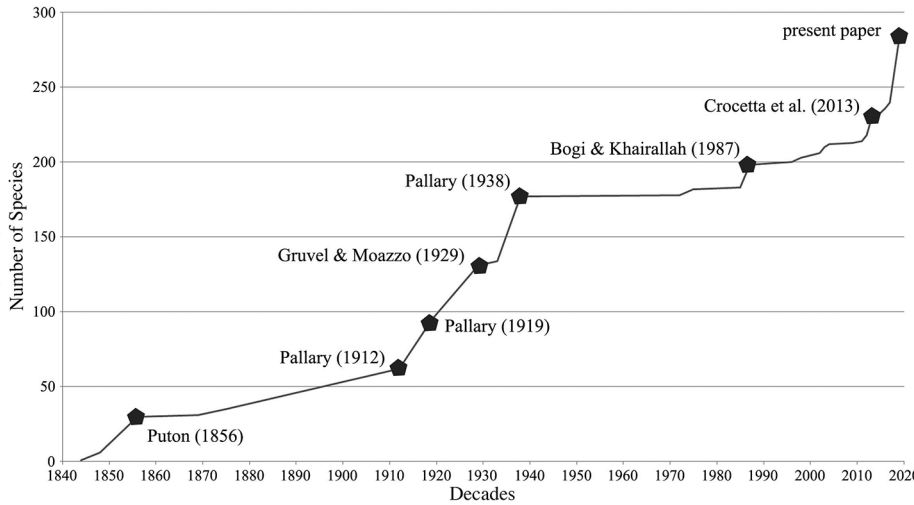

Figure 4. Cumulative increase with time of the number of marine gastropods known from Lebanon, with main contributing articles highlighted. References in Online Appendices 1–5.

Cerithiopsidae and Mangeliidae (4 taxa each), whose correct identification often requires specialist knowledge. Only six alien species were found in our samples and previously unrecorded from Lebanon, followed by four cryptogenics. Among the aliens, *Pollia rubens* had not yet been recorded as newcomer from the Indo-Pacific region (Online Appendix 1).

The Lebanese Gastropod Biota.—When analyzing the pattern of species recorded from Lebanon from 1844 to 2019 (based on publishing dates), a strong chronological inhomogeneity was noted, with contributions that significantly concentrate in three main periods only: (1) 1840–1880, with explorations mostly held by Puton, de Folin, and Périer; (2) 1910–1940, mostly by Gruvel, Moazzo, and Pallary; and (3) 1980–present, with a strong impulse by the CEDRE project (1999–2003) (full references in Online Appendices). On the contrary, comparatively few or no taxonomic studies at all were carried out locally in 1880–1910 and 1950–1980 (Fig. 4). Those three periods (1–3) yielded 35, 142, and 101 taxa, respectively (full references in Online Appendix 1), all together accounting for approximately 98% of the total number of gastropod taxa known from Lebanon. The checklist of 283 gastropod taxa recorded in Lebanon, updated in 2019 and including bibliographic records and original data from field sampling, is given in Table 2 (235 native species, of which 231 identified to species level: approximately 83%) and Table 3 (41 alien, approximately 14.5%; and 7 cryptogenic, of which 3 identified to species level, approximately 2.5%). The majority of the 231 native species have an Atlantic-Mediterranean native distribution (165, approximately 71.5%). They are followed by Mediterranean endemics (58, 25%), of which approximately 20 have ranges restricted to the eastern Mediterranean Sea (e.g., taxa of the rissoid genus *Alvania*, namely *Alvania amatii*, *Alvania colossophilus*, *Alvania datchaensis*, *Alvania dictyophora*, *Alvania perversa*). The remaining eight taxa comprise four species (approximately 1.7%) with a distribution ranging from the Atlantic Ocean to the Indo-Pacific

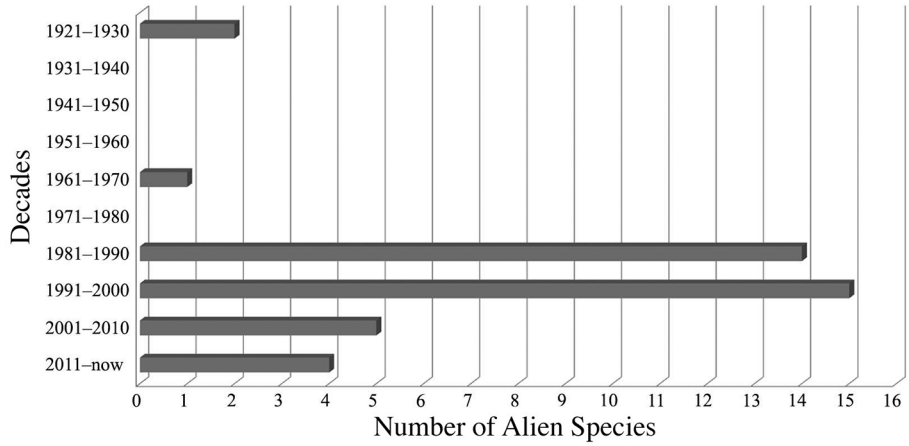

Figure 5. Rate of sighting/collection of marine alien gastropods from Lebanon as number of species per 10-yr periods.

region (*Gyroscala lamellosa*, *Tonna galea*, *Charonia lampas*, and *Umbraculum umbraculum*), three pelagic species (approximately 1.3%) with a cosmopolitan distribution (*Janthina janthina*, *Janthina globosa*, and specimens belonging to the *Clio pyramidata* complex), and a single species (approximately 0.5%) occurring in the Mediterranean Sea and the Indo-Pacific region (*Pirenella conica*). Finally, seven gastropod taxa reported from Lebanon are protected under the Bern and Barcelona conventions, namely the *Dendropoma petraeum* complex (here *Dendropoma anguliferum*), *Luria lurida*, *Naria spurca*, *Zonaria pyrum*, *Tonna galea*, *Charonia lampas*, and *Charonia variegata*. Nearly all 41 alien species are widespread in the Indo-Pacific realm, often including the Red Sea. The sole exception is the circumtropical sea slug *Syphonota geographica*, which occurs also in the Atlantic Ocean. This situation is also largely reflected in the analysis of the most probable pathways of arrival in Lebanon, suggesting that unaided spread accounts for approximately 95% of the Lebanese introductions, followed by approximately 5% of transport-stowaway. The majority of these alien species were already known from other Mediterranean countries, especially from Israel. The exceptions are *Indothais sacellum*, *Pollia rubens*, *Pyrunculus fourierii*, and *Goniobranchus annulatus*, four species first formally found in Lebanon as Mediterranean invaders, and *Amathina tricarinata* and *Acteocina mucronata*, sampled roughly at the same time along the coast of several countries, including Lebanon. Of the 41 alien gastropod taxa inventoried here, 21 species were considered as established in Lebanon, while 20 were considered as casual. The rate (per 10-yr intervals) at which alien marine gastropods were found in Lebanon (based on precise recording dates) is shown in Figure 5. Except for three taxa, they were collected during the last of the three above defined periods (1980–present).

Our critical reappraisal of literature records revealed that 167 taxa were reported before 1950 and 234 after 1950. Only two alien species, *Cerithium scabridum* and *Murex forskoehlii forskoehlii*, were first recorded by early authors, whereas all other alien and cryptogenic species reported so far from Lebanon were first recorded by modern authors. A high number of taxa (118) are present in the literature of both periods; among the species recorded before 1950, 49 were not found in subsequent

reports, and among those reported after 1950, 116 had not been recorded earlier. Among the species absent from the recent samples, some fall into one of the following categories: species generally rare or more commonly found in waters deeper than the maximum depth of 50 m sampled in "modern" times (e.g., *Cerithium alucastrum*, *Galeodea rugosa*, *Monoplex corrugatus*); pelagic taxa, presumably washed ashore and collected amid beached material, a sampling methodology that was not used here (e.g., *Janthina janthina*, *Janthina globosa*, *Clio pyramidata* complex); records of minute species that may have been based on misidentifications (e.g., *Eulima glabra*, *Alvania hispidula*, *Mangelia paciniana*, *Raphitoma cordieri*, *Pyrgiscus rufus*). However, some widespread, conspicuous, and/or unmistakable taxa are strangely not represented in recent literature and in our samples, e.g., the two common macrogastropods *Bolinus brandaris* and *Aptyxis syracusana,* and the two microgastropods *Smaragdia viridis* and the Mediterranean endemic *Rissoa variabilis*.

Discussion

The most recent checklist of marine Mollusca in Lebanon in 1998 reported a total of 298 species, 196 of which were gastropods (Bitar and Kouli-Bitar 1998), just 1 yr before the start of the CEDRE program. Although our critical revision of the past literature, including the 1998 checklist, resulted in the deletions of several species reported for Lebanon, the present study raises the known number of gastropods to 283 taxa. This brings into question the extremely low diversity that is commonly assumed for the central/northeastern tip of the Mediterranean Sea (*see* Morri et al. 2009, Crocetta et al. 2013a). Notwithstanding recent efforts, the figures reported here almost certainly underestimate true gastropod richness of this region. In fact, the total number of gastropods documented from Lebanon is not only a very small fraction (18%) of the approximately 1550 taxa listed in the most recent reviews of the Mediterranean molluscan biota (Coll et al. 2010, Sabelli and Taviani 2014), but is also quite distant from the few reliable figures available from other eastern Mediterranean countries, i.e., 483 gastropod species in Cyprus (Öztürk et al. 2004), 783 in Greece (Delamotte and Vardala-Theodorou 2007), 476 in Israel (Barash and Danin 1992), and a very recent checklist of 706 taxa in Turkey (Öztürk et al. 2014). If for Greece and Turkey the considerably higher figures can be ascribed to the larger geographic extension of those countries, each encompassing more biogeographical units, the gastropod diversity reported from Cyprus and Israel is about 1.7 times higher than that of Lebanon. With limited exceptions (such as the CEDRE program), poor sampling effort is probably the reason for this gap. Considering that the core of molluscan diversity is largely composed of poorly-known and inconspicuous species, limited fieldwork, along with the taxonomic impediments, are the most likely reasons why so many new records are presented in this study.

The 283 gastropod taxa listed here comprise 235 native, 41 alien, and 7 cryptogenic species. Analysis of the alien species revealed that most species, except two, were late arrivals (1980–present) to Lebanese waters and revealed that all recorded aliens are of Indo-Pacific origin, the majority of them having presumably arrived through unaided spread from the nearby Israeli coast—also considering the proximity to the Suez Canal and the absence of shellfish farming. These findings agree with the majority of previous studies carried out in the Mediterranean Sea, showing a major increase of alien invasion over the last few decades along with a clear east–west

pattern, with the easternmost Mediterranean Sea hosting the vast majority of species arriving via the Suez Canal and the westernmost areas typically receiving species introduced via other pathways (aquaculture, shipping, etc.) (e.g., Galil et al. 2018). Such a high proportion of alien and cryptogenic species (approximately 17%) supports the notion that the Mediterranean Sea is one of the most invaded marine ecosystems of the world, hosting nearly 1000 alien taxa, of which approximately 200 are mollusks (Zenetos et al. 2017, Galil et al. 2018). This has prompted some authors to propose a separate and man-made biogeographic province for the Levant Sea (e.g., Por 1981, Goren et al. 2010).

The invasion of alien species, coupled with the recent increase of Mediterranean water temperatures, has already caused substantial reshufflings of local communities, mostly through species replacement. Although this phenomenon has already been well documented in commercial taxonomic groups such as fishes (e.g., Goren and Galil 2005, Edelist et al. 2013, Arndt et al. 2018), reports on nonharvested marine organisms remained rare until very recently. Concerning mollusks, most authors discussed the decline or disappearance of habitat-forming native bivalve species in favor of their alien counterparts (Mienis 2003, Crocetta et al. 2013a, Safriel 2013, Rilov 2016). Few observations focused on gastropods, only reporting partial outcompetition of the natives *Cerithium lividulum*, *Cerithium vulgatum*, and *Patella caerulea* by the aliens *Cerithium scabridum*, *Rhinoclavis kochi*, and *Cellana rota*, respectively (Mienis 2002, 2003, Safriel 2013), and a marked decline of the native and endangered *Dendropoma anguliferum* (Galil 2013, Rilov 2016, Badreddine et al. 2019). Recently, Rilov (2016) highlighted dramatic changes in the entire biota along the Israeli coast during the 2009–2015 period, including population collapses of several formerly abundant species. These include 38 mollusk species, notably the large-sized muricid *Stramonita haemastoma*. Comparing results from different studies and periods is always a challenging task, and differences in sampling methods and localities between early and modern authors may have also played a role in the differences observed in Lebanon and in other Mediterranean countries. However, if on the one hand we have found in Lebanon some of the species missing in Rilov's (2016) samples, although in low numbers and at least approximately 20 yrs ago, the absence of specimens of the *C. vulgatum* complex both in Israel and Lebanon is remarkable. The same holds for two other previously common gastropods, *Diodora graeca* and *Diodora italica*, and for several topshells (Trochidae). We may also add to the species listed by Rilov (2016) *Bolinus brandaris* and *Aptyxis syracusana*, not found in Lebanon after 1950 and possibly out-competed by the two similar alien taxa, *Murex forskoehlii forskoehlii* and *Fusinus verrucosus*, now widespread in Lebanon. Finally, Rilov (2016) essentially investigated large-sized organisms, whereas the present study also surveyed microgastropods. Among them, *Smaragdia viridis* and *Rissoa variabilis* are common and are both grazers associated with marine algae and/or seagrasses in the infralittoral zone (Steneck and Watling 1982, Rueda et al. 2009). Despite their relatively small size, the peculiar morphology and color pattern make them unmistakable, thus excluding that records of these taxa before 1950 were based on misidentifications. Nevertheless, they were not found again by other investigators, nor by us despite the large amount of suitable material analyzed here. Their local decline, if not complete disappearance, confirms the general issues highlighted by Rilov (2016) and may suggest an alarming loss, such as that experienced by native infralittoral algae and plants (e.g., Sala et al. 2011, Vergés et al. 2014).

Limited data on the biodiversity and community structure of particular habitats and geographic zones hamper conservation actions and legal protection of critical species and habitats. Adequate knowledge of species diversity, including information on local distributions and population dynamics, is a prerequisite for establishing priorities and effective conservation strategies, and for understanding and monitoring the effects of alien invasions and climate changes. Additional field and laboratory research is therefore still necessary to increase our knowledge on both taxonomic composition and species distributions in Lebanon and elsewhere in the easternmost Mediterranean Sea. Efforts should focus on very small fauna, poorly sampled (e.g., coralligenous, soft substrates) and deep-water habitats, and on both long and short temporal processes occurring locally. This suggests that, despite the modern advances of marine biology–related disciplines, the descriptive stage is still far from complete, even in "popular" groups such as mollusks and in widely studied biogeographic areas such as the Mediterranean basin.

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