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Progress in Mediterranean bioinvasions two years after the Suez Canal enlargement

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The possibility that the recent expansion of the Suez Canal could trigger an entirely new twenty first century wave of invasions was investigated. Results showed that only 19 new alien species were detected after August 2015 (date of the last Suez Canal enlargement). Five of the newcomers have already established viable populations.

Between August 2015 and August 2017 approximately 9,5 new species (mostly fish) entered the Mediterranean annually, 7 of them via the Suez Canal unaided. The next most important pathway is Transport - Stowaway: Shipping, while intentional releases from aquaria appear to play an important role.

Our results confirm previous findings on the decreasing rate of introductions, which is not affected by the recent expansion of the Suez Canal. Conclusively, the rate of bio invasions via the Suez Canal has not "doubled" as anticipated but rather decreased in relation to previous years.

Key words: Alien species, Suez Canal, Internet screening

INTRODUCTION

It has been well documented that the Suez Canal is the main pathway of Marine Alien species (MAS) introductions into the Mediterranean Sea (POR, 1978; GALIL, 2006; RILOV & GALIL, 2009; ZENETOS *et al*., 2012; KATSANEVAKIS *et al.,* 2013; NUNES *et al.,* 2013).

The successive enlargements of the Suez Canal have raised concern over increasing propagule pressure resulting in introductions of additional MAS and associated degradation and loss of native populations, habitats and ecosystem services (THORSON, 1971; GALIL *et al.,* 2017).

The trend in introduction of alien species via the Suez Canal has been increasing over the last decades (ZENETOS *et al*., 2012; GALIL *et al*., 2016). However, a recent study revealed that from 2011 to 2016, the annual rate of MAS introductions in the Mediterranean has decreased regardless of the pathway (ZENETOS *et al*., 2017). GALIL *et al.* (2015) claimed that the recent expansion of the Suez Canal could trigger an entirely new twenty first century wave of invasions through a next-generation Suez Canal.

The aim of the present work is to examine the rate of introductions in relation to the pathway/vector after the latest enlargement of the Suez Canal.

MATERIAL AND METHODS

The Google scholar searches were made, with a combination of the key words: new spe-

Table 1. New MAS reported in the period August 2015 to November 2017. Taxon: F=Fish Mol=Mollusca, Cru=Crustacea, Alg=macroalgae, Cni =Cnidaria, Asc=Ascidiacea, Bry-Bryozoa, Pol=Polychaeta, Dia= Diatoms. In bold, species described from the Mediterranean

TAXON	Species	Source	country	publication year online/in press	coll Year	time lapse	Date
Alg	*Avrainvillea amadelpha* (Montagne) A. Gepp & ES Gepp	Verlaque et al., 2017	Tunisia	2017	2015	2	26.07.2015
Alg	*Cutleria multifida* (Turner) Greville	Kawai et al., 2016	Italy	2016	1960s	>50	
Alg	*Monosporus indicus* Børgesen	Hoffman & Wynne, 2016	Israel	2016	2015	1	Dec 2015
Asc	*Polyclinum constellatum* Savigny, 1816	Halim & Abdel Messeih, 2016	Egypt	1994/2016	1994	0	
Bry	***Calyptotheca alexandriensis***	Abdelsalam et al., 2017	Egypt	2017	2015	2	Dec 2015
Bry	*Conopeum ponticum* Hayward, 2001	Sokolover et al., 2016	Israel	2016	2010	6	
Cni	*Aequorea vitrina* Gosse, 1853	Yilmaz et al., 2017	Turkey	2017	2015	2	24.6.2015
Cni	*Cotylorhiza erythraea* Stiasny, 1920	Galil et al., 2016	Israel	2016	2003	13	
Cru	*Arcania brevifron* s Chen, 1989	Galil et al., 2017	Israel	2017	2016	1	
Cru	*Calcinus latens* (Randall, 1840)	Ounifi-Amor et al, 2016	Tunisia	2015	2015	0	<May 2015
Cru	*Grandidierella bonnieroides* Stephensen, 1947	Lo Brutto et al., 2016	Israel	2016	2014	2	
Cru	*Halimede ochtodes* (Herbst, 1783)	Moussa et al., 2016	Egypt	2015	2013	2	
Cru	*Ianiropsis serricaudis* Gurjanova, 1936	Marchini et al., 2016	Italy	2016	2012	4	
Cru	*Pleopis schmackeri* (Poppe, 1889)	Terbıyık Kurt & Polat, in press	Turkey	2017	2012	5	
Cru	*Sicyonia lancifer* (Olivier, 1811)	Patania & Mutlu, 2016	Turkey	2016	2014	2	
Cru	*Stenothoe georgiana* Bynum & Fox, 1977	Fernandez-González & Sanchez-Jerez, 2017	Spain	2016	2010	6	
Dia	*Chaetoceros pseudosymmetricus* Nielsen, 1931	Čalić et al., 2017	Croatia	2017	2015	2	13.12.2015
F	*Abudefduf hoefleri* (Steindachner, 1881)	Vella et al., 2016	Malta	2016	2014	2	
F	*Argyrops filamentosus* (Valenciennes, 1830)	Gürlek et al., 2016	Turkey	2016	2015	1	28.10.2015
F	***Arnoglossus nigrofilamentosus***	Fricke et al., in press	Israel	2017	2017	0	05.05.2017
F	*Bathygobius cyclopterus* (Cuvier & Valenciennes 1837)	Akel in Stamouli et al., in press	Egypt	2017	2017	0	10.08.2017
F	*Cephalopholis hemistiktos* (Rüppell, 1830)	Evans & Schembri, 2017a	Malta	2017	2009	8	
F	*Cephalopholis nigri* (Günther, 1859)	Vella et al., 2016	Malta	2016	2016	0	July, 2016
F	*Chlorurus rhakoura* Randall & Anderson, 1997	Insacco & Zava, 2017	Italy	2017	2017	0	18.2.2017
F	*Diplogrammus randalli* Fricke, 1983	Seyhan et al., 2017	Turkey	2016	2016	0	26.8.2016
F	***Encrasicholina gloria***	Hata & Motomura, 2016	Israel	2016	2009	7	
F	*Encrasicholina punctifer* Fowler, 1938	Çiftçi et al., 2017	Turkey	2016	2014	2	
F	*Epinephelus areolatus* (Forsskål, 1775)	Rothman et al., 2016	Israel	2015	2015	0	**30.08.2015**
F	*Fistularia petimba* Lacepède, 1803	Stern et al., in press	Israel	2017	2016	1	11.12.2016
F	*Himantura leoparda* Manjaji-Matsumoto & Last, 2008	Yucel et al., 2017	Turkey	2016	2016	0	24.1.2016
F	*Leiognathus berbis* (Valenciennes, 1835)	Alshawy et al., 2016	Syria	2016	2016	0	15.5.2016
F	*Lutjanus sebae* (Cuvier, 1816)	Zenetos et al., 2016	Greece	2016	2010	6	
F	*Paracanthurus hepatus* (Linnaeus, 1766)	Marcelli et al., 2017	Israel	2016	2015	1	02.09.2015
F	*Zebrasoma xanthurum* (Blyth, 1852)	Guidetti et al., 2016	Italy	2015	2015	0	03.08.2015
Mol	*Crithe cossinea* T. Cossignani, 1997	Aslan & Ovalis, 2017	Turkey	2017	2014	3	
Mol	*Goniobranchus obsoletus* (Rüppell & Leuckart, 1830)	Halevy et al., 2015	Israel	2015	2015	0	24.05.2015
Mol	*Isognomon legumen* (Gmelin, 1791)	Mienis et al., 2016	Israel	2016	2015	1	12.11.2015
Mol	*Lottia sp.*	Scuderi & Eernisse, 2016	Italy	2016	2015	1	Jan. 2015
Mol	*Morula aspera* (Lamarck, 1816)	Ounifi-Amor et al., 2016	Tunisia	2015	2012	3	
Mol	*Phidiana militaris* (Alder & Hancock, 1864)	Rothman et al., 2017	Israel	2017	2016	1	05.10.2016
Mol	*Sclerodoris apiculata* (Alder & Hancock, 1864)	Mienis & Rittner, 2015	Israel	2015	1986	29	
Mol	*Varicopeza pauxilla* (A. Adams, 1855)	Öztürk et al., 2017	Turkey	2017	2016	1	18.08.2016
Mol	*Viriola* sp. [cf. *corrugata* (Hinds, 1843)]	Micali et al., 2017	Greece	2017	2016	1	Sept. 2016
Pol	*Iphione muricata* (Lamarck, 1818)	Goren et al., 2017	Israel	2016	2015	1	May 2015

cies, first record, marineintroduced species, alien species, Mediterranean, Suez Canal, Lessepsian. In addition, taxonomic studies were screened for mentions of new MAS. Cryptogenic species and questionable cases were not considered. As the exact publication date is not always clear, the literature addressing new marine alien species in the Mediterranean was searched for the period 2015-2017. Publications in press were also considered while literature published either online or in a published issue prior to August 15, 2015 were not taken into account. The year of first detection was retrieved from each publication. However, the exact date was extracted only for the species detected in the period August 2015 to August 2017.

For the analysis of the annual rate of introductions attributed to the Suez Canal (Lessepsian immigrants), the pan-European inventory of MAS provided by the European Alien Species Information Network (EASIN; http://easin.jrc.ec.europa.eu/) and updated up to March 2017 (EASIN Catalogue version 5.6) was used. The pathway/vector of introduction was assigned for the species observed/collected after January 2015 following the CBD classification (ANONYMOUS, 2014).

RESULTS

Screening of the internet search results led to 44 new alien species reported in the period August 2015 to October 2017 (Table 1). These belong to: Fish (17 species); Mollusca (9), Crustacea (8), macroalgae (3), Cnidaria (2), Ascidiacea (1), Bryozoa (2), Polychaeta (1), Diatoms (1). Twenty six of these were detected in the period January 2015 to August 2017, of which 19 species appear to have been detected after August 15, 2015 (Table 2).

The countries of first records are in decreasing order Israel (15 species), Turkey (9), Italy (5), Egypt (4), Malta (3), Tunisia (3), Greece (2), Spain (1), Croatia (1), Syria (1).

The time lapse between finding and publication is on average 2.76 years exempting records of species hitherto considered as native such as the macroalgae *Cutleria multifida* or overlooked

Table 2. MAS detected in the period 2015-2017. In bold the species after 15.08.2015. ES=Establishment success: cas=casual, est=established, unk=unknown

Species	ES	observation/ collection date	Potential pathway
Lottia sp.	est?	Jan. to Aug. 2015	TRANSPORT- STOWAWAY: Ship/boat hull fouling
Aequorea vitrina	cas	24.06.2015	TRANSPORT- STOWAWAY: Ship/ballasts
Calcinus latens	cas	<May 2015	CORRIDORS-Suez canal
Goniobranchus obsoletus	est	24.05.2015	CORRIDORS-Suez canal
Iphione muricata	unk	May 2015	CORRIDORS-Suez canal
Avrainvillea amadelpha	est	26.07.2015	TRANSPORT- STOWAWAY: other
Zebrasoma xanthurum	cas	03.08.2015	RELEASE IN NATURE: Other intentional release
Epinephelus areolatus	cas	30.08.2015	CORRIDORS-Suez canal
Paracanthurus hepatus	cas	02.09.2015	RELEASE IN NATURE: Other intentional release
Argyrops filamentosus	cas	28.10.2015	CORRIDORS-Suez canal
Isognomon legumen	est	12.11.2015	CORRIDORS-Suez canal
Chaetoceros pseudosymmetricus	unk	13.12.2015	TRANSPORT- STOWAWAY: Ship/ballasts
Monosporus indicus	est	Dec. 2015	TRANSPORT- STOWAWAY: Ship/boat hull fouling
Calyptotheca alexandriensis	est	Dec. 2015	CORRIDORS-Suez canal
Himantura leoparda	cas	24.01.2016	CORRIDORS-Suez canal
Cephalopholis nigri	cas	July 2016	RELEASE IN NATURE: Other intentional release
Leiognathus berbis	cas	15.05.2016	CORRIDORS-Suez canal
Diplogrammus randalli	cas	26.08.2016	CORRIDORS-Suez canal
***Viriola* sp. [cf. *corrugata*]**	cas	Sept. 2016	CORRIDORS-Suez canal
Varicopeza pauxilla	cas	18.08.2016	CORRIDORS-Suez canal
Phidiana militaris	cas	05.10.2016	CORRIDORS-Suez canal
Arcania brevifrons	unk	11.12.2016	CORRIDORS-Suez canal
Fistularia petimba	est	11.12.2016	CORRIDORS-Suez canal
Chlorurus rhakoura	cas	18.02.2017	TRANSPORT- STOWAWAY: Shipping
Arnoglossus nigrofilamentosus	cas	05.05.2017	CORRIDORS-Suez canal
Bathygobius cyclopterus	cas	10.08.2017	CORRIDORS-Suez canal

because of their similarity to natives. The period between detection and publication drops to 0.73 year for species observed in the 2015-2017 period.

Based on the results of Table 2, the 19 species reported in the 2 years period correspond to a rate of 9.5 new species per year, regardless of the pathway of introduction. Suez Canal is suspected responsible for seven per year, while shipping and Aquarium trade appear to be responsible for the introduction of the rest.

DISCUSSION

Most of the internet search results addressed local or review studies. Some new records referred to new species for science described from the Mediterranean i.e. the fish *Diplecogaster umutturali* Bilecenoğlu *et al*, 2017 in Turkey; some to Atlantic species extending their distribution range i.e the sea star *Luidia atlantidea* Madsen, 1950 in Spain reported by GALLARDO-ROLDAN *et al*. (2015); while a lot more included species whose alien or native status is debatable and should be provisionally classified as cryptogenics i.e. the sea star *Coronaster briareus* (Verrill, 1882) in Malta (EVANS *et al*., 2017) and many others.

Two fish species reported as aliens in the study period were excluded as misidentifications: P*omacanthus asfur* (Forsskål, 1775) reported by DEIDUN & BONNICI in KARACHLE *et al*., 2016, refuted by EVANS & SCHEMBRI (2017b), as misidentification of *Pomacanthus imperator* (Bloch, 1787), and/or questionable cases such as the fish *Plectorhinchus gaterinus* (Forsskål, 1775) reported by CORSINI-FOKA & SARLIS (2016) with reservation.

Among the 44 validated newly reported species as MAS are three species described in the Mediterranean. These are:

1. The bryozoan *Calyptotheca alexandriensis*whosecolonies began to appear in the Eastern Harbour of Alexandria, Egypt in December 2015. The species was identified as belonging to the predominantly Indo-Pacific cheilostome genus *Calyptotheca* Harmer, 1957 and described as a new species (ABDEL-SALAM, TAYLOR, & DORGHAM, 2017).
2. The fish *Encrasicholina gloria* was described from the Persian Gulf (Khasab, Oman), the Red Sea (Egypt and Saudi Arabia) and the eastern Mediterranean (Israel) (HATA & MOTOMURA, 2016). The distribution of specimens in the Mediterranean is considered to represent a Lessepsian migration.
3. The fish *Arnoglossus nigrofilamentosus* was described from four specimens collected in the southeastern Mediterranean near Tel-Aviv, Israel (FRICKE *et al*., 2017). Though the species has not yet been observed in the northern Red Sea, it probably originates from the Gulf of Suez, so this finding represents a probable new case of Lessepsian migration.

The reports of most MAS detected after August 2015 are based on casual records, while the following five species are established, as follows:

1. *Calyptotheca alexandriensis*: The bryozoan exhibits intensive growth sporadically on different hard substrata, including rocks, submerged concrete walls, ropes, ships' hulls, and metal pipes supporting marina piers in Alexandria (ABDELSALAM *et al*., 2017)
2. *Isognomon legumen*: the first record of this mollusk in Israel was based on an empty shell (MIENIS *et al*., 2016). However subsequent findings in Greece MICALI *et al*. (2017); ANGELIDIS in LIPEJ *et al*. (2017) as *Malleus regula* (Forsskål in Niebuhr, 1775) confirm its establishment success in the eastern Mediterranean (CROCETTA *et al*., 2017).
3. *Monosporus indicus*: this epiphytic red alga has established healthy populations in the warm Levant Mediterranean Sea of Israel (HOFFMAN & WYNNE, 2016).
4. *Avrainvillea amadelpha*: This alga was common and was growing gregariously in colonies, between 20-22 m depth, in sunny places (sub-horizontal substrates), in *Cymodocea nodosa* (Ucria) Ascherson meadows, *Posidonia oceanica* beds, on dead mattes of *P. oceanica* meadows and coarse sand bottoms (VERLAQUE *et al*., 2017).

5. *Fistularia petimba*: following the first finding in of this cornet fish in December 2011, off the coast of Ashdod, five additional juvenile specimens of *F. petimba* were caught on November 26, 2017, in the southern coast of Israel, from a shallow depth of 20m. This finding confirms the establishment of this species along the Israeli Mediterranean coast (STERN *et al*., 2017).

Unknown remains the establishment success of three species namely the diatom *Chaetoceros pseudosymmetricus,* the polychate *Iphione muricata* and the decapod *Arcania brevifrons*.

The diatom, *C. pseudosymmetricus* is a very rare species, reported only from the Indian Ocean. It is still unknown whether the record of C. *pseudosymmetricus* is a temporary appearance in the Adriatic or will adapt and become a common taxon of the Mediterranean phytoplankton communities. It might have being overlooked or misidentified in the past. Its record in the Adriatic (Croatia) is also the first occurrence in European seas (ČALIĆ *et al*., 2017).

The presence of *I. muricata* in two different locations and in two consecutive years may indicate a stable self-sustaining population along the Israeli coast (GOREN *et al*., 2017). Although the record of *Arcania brevifrons* is very recent and it is based on two specimens only, the presence of an ovigerous female may indicate the existence of an established population (GALIL *et al*., 2017).

The rate of MAS introductions in the Mediterranean has been reported to range between 34 species per year i.e.1 new species every 1.5 weeks: (ZENETOS, 2010) to 26 (1 new species every 2 weeks: (ZENETOS *et al*., 2012)). However, in these calculations cryptogenic species were also included as well as some questionable cases. According to the latest review, which considers strictly alien species, the rate of introductions has dropped from 17 species per year in the 2001-2010 period to 11 species per year in the period 2010-2016 (ZENETOS *et al*., 2017). When only the immigrants via the Suez Canal are considered the annual rate appears to be slightly decreasing (Figure 1). The present work documents that this decreasing/ steady trend in the worst case continues irrespectively of the Suez Canal enlargement. In fact only 7 species per year seem to enter via the Suez Canal after the latest enlargement (Table 2), a figure less than in previous decades. This figure will substantially increase as new records will be published in the following months/years that may have been detected during the study period, although the time lapse between detection and publication of an alien species has dropped significantly over the last decade (results not shown here).

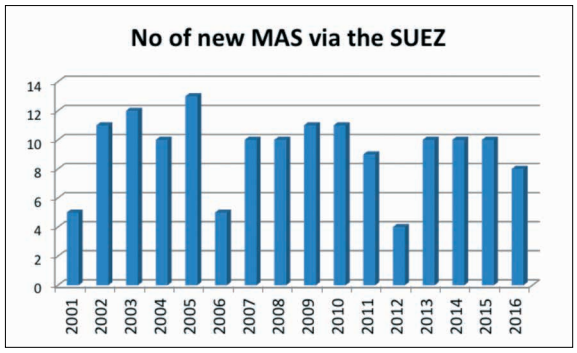

Fig. 1. Trend in annual rate of MAS potentially introduced via the Suez Canal (source: HCMR/EEA offline database)

Exceptionally long time lapse has been documented in some species such as the macroalgae *Cutleria multifida,* which, were considered as native, until recently when molecular phylogenetic studies confirmed their origin (KAWAI *et al*., 2016) or species whose morphology was similar with native species e.g *Cotylorhiza erythraea* Stiasny, 1920 (GALIL *et al*., 2016). Other reason for delayed reporting could be: a) records in gray literature such as the case of the ascidian *Polyclinum constellatum* Savigny, 1816 which was published in 2016 (HALIM & ABDEL MESSEIH, 2016) although its finding was recorded as early as 1994 (ABDEL MESSEIH,1994) and b) misidentification e.g. the identification of the sea slug *Sclerodoris apiculata* (Alder & Hancock, 1864) was based on two photographs taken 29 years ago and misidentified as the native *Atagema rugosa* Pruvot-Fol, 1951. Yet, the time lapse has minimized the last years due to the scientific interest on the topic, the collaboration of citizen scientists with scientists and a whole range of scientific journals that welcome such biodiversity observations.

Summarizing, the enlargement of the Suez Canal has not led to a wave of new bio invasions as anticipated (GALIL *et al*., 2015). Conversely, a slight decrease in relation to previous years was observed. Bearing in mind the time lapse between detection and publication (0.73 year) this finding should be carefully considered.

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Napredovanje bioloških invazija u Sredozemlju u razdoblju od dvije godine nakon proširenja Sueskog kanala

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SAŽETAK

Istraživana je mogućnost prema kojoj je nedavno proširenje Sueskog kanala izazvalo potpuno novi val bioloških invazije u 21. stoljeću. Rezultati su pokazali da je nakon kolovoza 2015. utvrđeno samo 19 novih nezavičajnih vrsta (datum zadnjeg proširenja Sueskog kanala). Od novih pridošlica, njih 5 je već uspostavilo održive populacije.

Od kolovoza 2015. do kolovoza 2017. otprilike 9,5 novih vrsta (uglavnom riba) ušlo je u Sredozemno more na godišnjoj razini, od kojih je 7 vrsta ušlo nepotpomognuto kroz Sueski kanal. Slijedeći najvažniji put bio je putem morskog prometa – kao „slijepi putnici“, a čini se da i namjerna ispuštanja iz akvarija imaju važnu ulogu.

Naši rezultati potvrđuju prethodna otkrića o smanjenju stope invazije, što nije pod utjecajem nedavnog širenja Sueskog kanala. Konačno, stopa biološke invazije preko Sueskog kanala nije se "udvostručila" kao što se očekivalo, već se smanjivala u odnosu na prethodne godine.

Ključne riječi: nezavičajne vrste, Sueski kanal**,** pregledavanje Interneta