

Invasive biota in the deep-sea Mediterranean: an emerging issue in marine conservation and management

B. S. Galil · R. Danovaro · S. B. S. Rothman · R. Gevili · M. Goren

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Abstract Although the ecological importance and impact of non-indigenous species is increasingly recognised and documented in shallow water ecosystems, their presence beyond the shelf has scarcely been documented. A survey of the upper slope biota of the Mediterranean coast of Israel revealed the presence at 200-m depth of individuals of three Erythraean species, the crocodile toothfish *Champsodon*

nudivittis, Golani's round herring *Etrumeus golanii*, and the burrowing goby, *Trypauchen vagina*. In the past decade several Erythraean species, some newly arrived, some well-established, have been collected on the Levantine lower shelf and upper slope. The species invasion revealed that thermal niche estimations based on the species' native environment may have underestimated their ability to tolerate lower temperatures. The results reported here suggest that the wide thermal tolerance of some Erythraean species may facilitate their bathymetric and geographic expansion. Their spread to the depths where the unique, diverse and fragile mesophotic 'animal forests' occur, bodes ill to these beleaguered communities.

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B. S. Galil (✉)
The Steinhardt Museum of Natural History, Tel Aviv University, Tel Aviv 69978, Israel
e-mail: galil@post.tau.ac.il

R. Danovaro
Polytechnic University of Marche, 60121 Ancona, Italy

R. Danovaro
Stazione Zoologica Anton Dohrn, 80121 Naples, Italy

S. B. S. Rothman
School of Zoology, Tel Aviv University, Tel Aviv 69978, Israel

R. Gevili
Ashdod, Israel

M. Goren
The Steinhardt Museum of Natural History, and School of Zoology, Tel Aviv University, Tel Aviv 69978, Israel

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Introduction

In the coastal ecosystems of the Mediterranean Sea, bioinvasions present threats to the local biodiversity comparable to those exerted by climate change, pollution and fisheries (Micheli et al. 2013; EEA 2015; Galil et al. 2018). The number of non-indigenous species (NIS) more than doubled in the past 30 years, and is substantially greater in the Levant than in other basins in the Mediterranean due to the propagule pressure exerted by the Suez Canal, which

serves as the major pathway of introduction. NIS along the Mediterranean coast of Israel, mainly fish, decapod crustaceans and molluscs, have been recorded since the early 20C, and more consistently since the mid-century. The introduction through the Suez Canal, the Erythraean invasion, is causing a dramatic restructuring of biotic communities, altering ecosystem functions and affecting the availability of biological resources and ecosystem services. (Galil 2007a, b, 2008, 2017; Galil et al. 2018; Goren et al. 2016).

Since the Suez Canal is shallow, it has been assumed that the populations of the NIS introduced through the canal into the Mediterranean will be restricted to the upper shelf (<https://www.suezcanal.gov.eg/English/About/SuezCanal/Pages/CanalCharacteristics.aspx>). Indeed, until the 1970s Erythraean biota entering in the Mediterranean was typically confined to habitats shallower than 50 m (Galil and Lewinsohn 1981; Tom and Galil 1991). A survey of bottom communities off Ashdod, at the southern Mediterranean coast of Israel, carried out in 2010–2012 included 16 trawl hauls each along the 100 and 120 m isobaths, as well as 4 hauls at 250 m. The resulting findings have upended this paradigm as Erythraean biota was collected on the deeper portions of the shelf (Table 1). A survey along the 200 m isobath off Ashdod, conducted between October and

December 2017, collected 8 specimens of the crocodile toothfish *Champsodon nudivittis* (Ogilby, 1895), and a single specimen each of *Etrumeus golanii* Di Battista et al. 2012, and the burrowing goby *Trypauchen vagina* (Bloch and Schneider, 1801). *Champsodon nudivittis* occurs in the Indo-Pacific Ocean over a wide bathymetric range (Nemeth 1994). As its common name—crocodile toothfish—implies, it is carnivorous predator, feeding on shrimp and fish. It was collected at the Dahlak Archipelago, southern Red Sea, at depth of 36 m (Goren et al. 2011), and at the north-eastern Arabian Sea at depths of 282–393 m (Goren et al. 2014), where the water temperature is 13–14 °C (Shankar et al. 2005). Recently reported from the eastern Mediterranean, it was first recorded in Iskenderun Bay, Turkey, in 2008, at 50 m depth (Çiçek and Bilecenoglu 2009), and subsequently in deeper waters (Table 2, Fig. 1). *Etrumeus golanii* was recorded from the upper shelf in the northern Red Sea (Di Battista et al. 2012), and is noted for its protracted spawning season, and high absolute fecundity (3953–12698) (Osman et al. 2011). It was first recorded in the Mediterranean Sea from Israel in 1961, and subsequently spread across the sea to Algeria (Di Battista et al. 2012, Stamouli et al. 2017) The sea surface temperature in the northern Gulf of Aqaba ranges between 21.2 and 27.8 °C (Shaked and Genin 2017) but only 14.5–24.5 °C off Algeria (Manca et al.

Table 1 Erythraean fish recorded in 2010–2011 at depths of 100 and 120 m off Ashdod, Mediterranean coast of Israel

Species	First record in Israel	100 m N specimens	120 m N specimens
<i>Bregmaceros nectabanus</i>	2004	2	1
<i>Champsodon nudivittis</i>	2011	2	1
<i>Cynoglossus sinusarabici</i>	1953	1	1
<i>Equulites klunzingeri</i>	1934	805	271
<i>Etrumeus golanii</i>	1961	8	
<i>Jaydia queketti</i>	2007	6	10
<i>Jaydia smithi</i>	2007	10	5
<i>Nemipterus randalli</i>	2005	2268	1758
<i>Ostorhinchus fasciatus</i>	2008	36	3
<i>Oxyurichthys petersi</i>	1982	–	1
<i>Parexocoetus mento</i>	1935	–	1
<i>Sargocentron rubrum</i>	1947	10	16
<i>Saurida lessepsianus</i>	1952	491	293
<i>Sphyræna pinguis</i>	1931	2	3
<i>Trypauchen vagina</i>	2009	6	3
<i>Upeneus molluccensis</i>	1947	917	660

Table 2 Locations of records of *Etrumeus golanii* Di Battista et al. 2012, *Champsodon nudivittis* (Ogilby, 1895), and *Trypauchen vagina* (Bloch and Schneider, 1801) on the shelf and upper slope in the Mediterranean Sea—locality, depth (m), year of collection, and reference

Species	Locality	Depth, m	Marked in map as	Collection year	References
<i>Etrumeus golanii</i>	Algeria, Cherchell	30	A 9	2017	Stamouli et al. (2017)
<i>Etrumeus golanii</i>	Cyprus, Larnaca	unavailable	A 2	2012	SMNH-P 15068
<i>Etrumeus golanii</i>	Cyprus, Limassol	50	A 2	1999	Golani (2000)
<i>Etrumeus golanii</i>	Egypt, Alexandria	41–58	A 11	2007	Akel (2009)
<i>Etrumeus golanii</i>	Greece, Crete	59–62	A 7	2005	Kasapidis et al. (2007)
<i>Etrumeus golanii</i>	Greece, Cyclades	110	A 6	2005	Kallianiotis and Lekkas (2005)
<i>Etrumeus golanii</i>	Greece, Rhodes	30–50	A 5	2003–2004	Corsini et al. (2005)
<i>Etrumeus golanii</i>	Israel, Ashdod–Haifa	11–100	A 1	2008–2014	SMNH-P 13575; 13576; 13961; 14152; 14244; 14248; 14327; 14498; 14680; 14759; 14852; 15086; 15230; 15480
<i>Etrumeus golanii</i>	Italy, Lampedusa	65	A 8	2005	Falautano et al. (2006)
<i>Etrumeus golanii</i>	Tunisia, Zarzis, Gulf of Gabes	30	A 10	2014	Boussellaa et al. (2016)
<i>Etrumeus golanii</i>	Turkey, Dikili coast	40–50	A 4	2009	Yarmaz et al. (2010)
<i>Etrumeus golanii</i>	Turkey, Izmir Bay	63	A 3	2015	Akyol and Ulas (2016)
<i>Champsodon nudivittis</i>	Greece, Rhodes	150	B 7	2012	Kalogirou and Corsini-Foka (2012)
<i>Champsodon nudivittis</i>	Israel, Ashdod	100	B 1	2011	Goren et al. (2011)
<i>Champsodon nudivittis</i>	Israel, Ashdod	60–120	B 1	2012–2016	SMNH-P 14329; 14520; 14587; 14593; 15492; 15493; 15494; 15495; 15496; 15845; 15896;
<i>Champsodon nudivittis</i>	Turkey, Antalya Bay	140–150	B 3	2010	Gökoğlu et al. (2011)
<i>Champsodon nudivittis</i>	Turkey, Edremit Bay	60	B 6	2014	Torcu Koç et al. (2015)
<i>Champsodon nudivittis</i>	Turkey, Ekincik Bay	55–72	B 5	2010–2011	Filiz et al. (2014)
<i>Champsodon nudivittis</i>	Turkey, Fethiye Bay	120–190	B 4	2010–2011	Filiz et al. (2014)
<i>Champsodon nudivittis</i>	Turkey, Finike Bay	180	B 4	2011	Erguden and Turan (2011)
<i>Champsodon nudivittis</i>	Turkey, Iskenderun Bay	50	B 2	2008	Çiçek and Bilecenoglu (2009)
<i>Trypauchen vagina</i>	Israel, Atlit and Hadera	90	C 1	2009	Salameh et al. (2010)

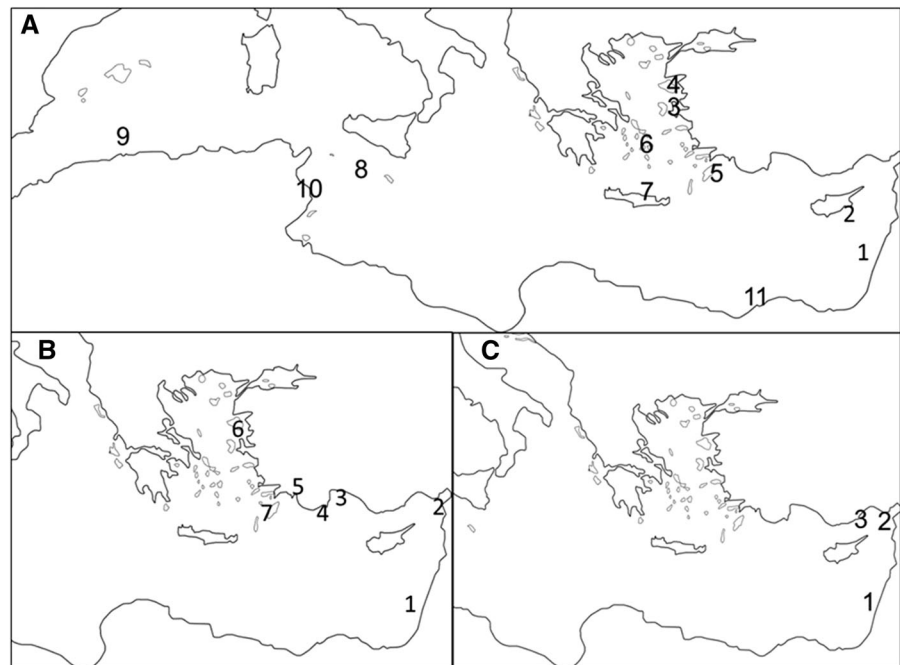
Table 2 continued

Species	Locality	Depth, m	Marked in map as	Collection year	References
<i>Trypauchen vagina</i>	Israel, Ashdod	60–120	C 1	2012–2016	SMNH-P 14566; 14567; 15871; 15897
<i>Trypauchen vagina</i>	Turkey, Iskenderun Bay	20–27	C 2	2010	Akamca et al. (2011)
<i>Trypauchen vagina</i>	Turkey, Mersin	25–30	C 3	2012	Siokou et al. (2013)

Each record marked with numeral as in Fig. 1

SMNH Steinhardt Museum of Natural History

Fig. 1 Occurrence of three Erythraean non-indigenous species in the Mediterranean Sea. **a** *Etrumeus golanii* Di Battista et al. 2012, **b** *Champsodon nudivittis* (Ogilby, 1895), **c** *Trypauchen vagina* (Bloch and Schneider, 1801). Details presented in Table 2



2004). (Table 2, Fig. 1). *Trypauchen vagina* occurs in the Indo-west Pacific Ocean in shallow estuarine and coastal areas (Murdy 2006). It too displays high batch fecundity (4000–12,750 eggs/female/spawning) (Dinh 2018). It was collected in muddy coastal waters in the Persian Gulf at depths of 10–20 m (Murdy 2006; Alavi-Yeganeh et al. 2015) where sea surface temperatures ranged between 20 and 32 °C (Al Azhar et al. 2016) as compared to 17.5–28.5 °C in Iskenderun Bay, Turkey (Gucel and Sakalli 2018). Off

the Israeli coast specimens were collected at greater depths (Table 2, Fig. 1).

What may have caused thermophilic NIS, some newly arrived, some established for decades, to spread to the lower shelf and upper slope?

The successive enlargements of the Suez Canal conducted from 1996 to 2015 have increased its depth from

21 to 24 m and its cross sectional area from 3850 to 5200 m² (<https://www.suezcanal.gov.eg/English/About/SuezCanal/Pages/CanalCharacteristics.aspx>). The increased volume of water in conjunction with higher through-current velocities have likely increased propagule pressure—increasing the delivery of Erythraean species, including epipelagic larvae/juveniles of deeper living fish. Both the Red Sea and the Mediterranean Sea are characterized by high deep-water Temperatures. Sea water temperatures measured on the southern Israeli upper shelf from 2014 to 2017 span a range from 18 °C in February to 31 °C in August. Vertical temperature profiles show a typical seasonal pattern with winter thermal mixing creating fairly constant high temperature, 17.5 °C, as deep as 260 m in 2015, 150 m in 2016, and nearly 200 m in 2017 (Herut and Rahav 2017). Both Levantine surface (0–50 m) and intermediate (150–350 m) water masses (LSW, LIW) along the Mediterranean coast of Israel have displayed long-term increase in temperature of $+0.12 \pm 0.07$ and $+0.03 \pm 0.02$ °C year⁻¹, respectively (Ozer et al. 2017). As cold temperatures are considered to limit the geographic distribution of marine thermophilic poikilotherm organisms (Hutchins 1947), a wider thermal niche confers advantages to NIS, as they are likelier to colonize, establish viable populations, and spread in novel habitats. The potential distribution of NIS is commonly predicted using the environmental niche model, which considers a known distribution of a species and then defines a potential and realized niche of a species correlating the available information with the environmental variables of a wider area (Monahan 2009). The invasion of Erythraean species of the Levantine basin, and particularly their recently observed intrusion into the lower continental shelf and upper slope revealed that thermal niche estimations assuming niche conservatism and based on the species' native environment may underestimate their capacity to tolerate lower temperatures. It seems that the climatic niche of some Erythraean species is wider than accounted for, or has altered during the invasion, and is likely to facilitate bathymetric range expansion, as well as higher invasion risk into a wider geographic range.

Why does it matter?

Antipatharians, ceriantharians, zoantharians, gorgonians and pennatulaceans have been documented on the

shelf and upper slope of the Aegean and Levant seas (mainly < 250 m depth) (Zibrowius 1979a, b; Chintiroglou et al. 1989; Vafidis et al. 1994, 1997; Vafidis and Koukouras 1998 [2002]; Vafidis 2009; Abdelsalam 2014). Recently, a dense population of *Dendrophyllia ramea* (Linnaeus, 1758) has been described in the Levant from eastern Cyprus and Lebanon. The Cypriot population of *D. ramea* was recorded on soft substrate at depths between 125 and 155 m, whereas the deepest record has been documented in Lebanese waters, at 172 m depth (Jimenez et al. 2016; Orejas et al. 2017; OCEANA, 2016). These large arborescent anthozoans form patchy 'meadows' which attract highly diverse mesophotic assemblages (Cerrano et al. 2010; Zeppilli et al. 2016). These mesophotic assemblages are vulnerable to injury from bottom contact fisheries (Pusceddu et al. 2014), together with pollution, offshore extraction and infrastructure, and climate change (Aguilar et al. 2017; Danovaro et al. 2017b). Yet, so far no mention has been made on the direct impact of bioinvasions, which has been considered a priority issue in the coastal Mediterranean environment (Coll et al. 2010). The occurrence of carnivorous and highly fecund NIS at these depths does not bode well. Examination of the ecological impacts of some conspicuous NIS in the Mediterranean Sea underscores their role, among multiple anthropogenic stressors, in altering the littoral and sublittoral communities. Local population losses and niche contraction of native species augur reduction of genetic diversity, loss of functions, processes, and habitat structure, and increase the risk of local extirpations (Galil 2007a). Should a similar process occur in deeper waters, the indigenous biodiversity and sustainability of the unique mesophotic assemblages may be put under severe strain.

The first step for management of deep-living NIS

The first step in addressing NIS in deep-sea habitats is to study their presence, distribution, ecology, pathway, and to assess the threats they present, and concentrate efforts where NIS can be linked with a specific pathway. The Marine Strategy Framework Directive (European Commission 2008, 2010) aimed to achieve or maintain Good Environmental Status (GES) in the marine environment by the year 2020 using a set of environmental targets and associated indicators,

including biodiversity, the number of newly introduced NIS, abundance and spatial distribution of established NIS, and spatial extent adversely altered habitat (European Commission 2017b). However, impacts for the vast majority of marine NIS remain unknown and have not been quantitatively or experimentally studied over large temporal and spatial scales (Ruiz et al. 2011), and their connections with other drivers of change affecting the marine environment are largely unknown (Stachowicz et al. 2002; Rahel and Olden 2008) to satisfy the criteria for ‘adversely altered habitat’. This is far more so for deep-sea ecosystems. Unless impacts are conspicuous, induce direct economic cost, or impinge on human welfare, they fail to arouse public awareness or scientific analysis. It is unlikely that bioinvasion impacts on mesophotic habitats and biodiversity could be discerned unless targeted monitoring and quantification of the presence and abundance of NIS takes place in the most vulnerable areas. The latest assessment of the Member States’ monitoring programmes under the MSFD reveals that only 5% of the programmes are related to NIS, and these “will require a clear acceleration to ensure proper coverage given the MSFD Deadlines for the update of marine strategies by 2018, and achieving Good Environmental Status by 2020” (European Commission 2017a). Crucially, none of the NIS monitoring programmes targeted lower shelf and upper slope habitats, though deep sea communities are in urgent need of conservation (Danovaro et al. 2017a; Guidetti and Danovaro 2018).

Targeted pilot surveys of sensitive, spatially confined slope habitats (e.g. mesophotic ‘animal forests’, cold seeps) within zones noted for populations of deep-living NIS, will support the need expressed in Commission Decision 2017/848 and will provide new elements to integrate monitoring for descriptors “except where sampling needs to focus on main vectors and risk areas for new introductions.” These pilot surveys may serve as a step towards monitoring deep dwelling bioinvasions and their harm to sensitive slope habitats and help establish appropriate protocols to support baselines, targets, and their spatial variability in defining GES for Descriptor 2 in mesophotic habitats.

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