Impacts of marine invasive alien species on European fisheries and aquaculture - plague or boon?

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Abstract
Many invasive alien species highly impact fisheries and aquaculture in European Seas. Despite the fact that mostly negative impacts are reported in the literature, many alien species can have important positive impacts and can restore or secure ecosystem processes and functions, especially in degraded ecosystems. These negative or positive impacts occur through a variety of mechanisms such as blooms of toxic algae, the degradation of important habitats, predation, competition, fouling shellfish, gear or equipment, damage of catch or fishing gear, entanglement in nets, disease transmission, new commodities, new food source for commercial species, biological control of other invasives, and creation of novel habitats. The balance between positive and negative impacts is difficult to assess, and in many regions alien species are considered as a boon to fisheries and aquaculture. In some regions, climate change has caused the loss of temperature-sensitive species. In such cases, alien species can be beneficial overall by fulfilling the lost ecological roles. Further research is needed to conduct proper impact and risk assessments and address the inherent uncertainty.

1. Introduction

Alien species are taxa that have managed, by human agency, to overcome bio-geographical barriers and get established in new regions beyond their natural distribution (Falk-Peteren *et al*., 2006). In the last decades, introductions of alien species have been accelerated due to the rapid globalization and unprecedented rates of trade, travel, and transport (Essl *et al*., 2015; Seebens *et al*., 2017). This increasing trend of new introductions has been documented in the European Seas (Katsanevakis *et al*., 2013), and in the Mediterranean Sea in particular, the latter mainly due to introductions of Indo-Pacific species arriving through the Suez Canal (Zenetos *et al*., 2012; Tsiamis *et al*., 2018).

Some of the established alien species may have important impacts on biodiversity, human health, infrastructure, and ecosystem services by modifying habitats and community composition, causing local extinctions, and affecting food-web properties, ecosystem processes and functioning (Mazza *et al*., 2014; Katsanevakis *et al*., 2014; Bellard *et al*., 2016). On the other hand, alien species can also have positive impacts, the latter through provision of food and shelter, creation of novel habitats or by securing ecosystem processes and functions (Hobbs *et al*., 2009; Schlaepfer *et al*., 2011; Katsanevakis *et al*., 2014).

The reported socio-economic impacts of alien species often exceed their ecological impacts, perhaps because the former are more readily perceived by humans (Vilà *et al*., 2010). There have been many attempts to assess the socio-economic impacts of alien species based on utilitarian approaches of monetizing their costs (e.g. Zavaleta, 2000) or, recently, by proposing a standardized system for classifying the magnitude of impacts on human well-being (Bacher *et al*., 2018). Nevertheless, most efforts have so far focused on negative impacts - and mostly on the terrestrial environment - ignoring any positive contribution of alien species to ecosystem services. Katsanevakis *et al*. (2014) critically reviewed >2000 articles on impacts of invasive alien species on ecosystem services and biodiversity in the European seas. As seen in the Table 1, both negative and positive impacts must be accounted for.

Table 1. Negative (red) and positive (green) impacts of alien marine species on fisheries and aquaculture in European waters, as reported in the literature. The table includes only species that have been considered as high-impact species. (Cr): cryptogenic species. Modified and updated from Katsanevakis *et al*. (2014).

Impacts of alien species in Europe on fisheries and aquaculture

Species	Impact
Dinophyta (Myzozoa)	
Alexandrium minutum (Cr)	Red
Alexandrium monilatum	Red
Karenia mikimotoi (Cr)	Red
Gymnodinium catenatum (Cr)	Red
Haptophyta	
Phaeocystis pouchetii (Cr)	Red
Ochrophyta	
Coscinodiscus wailesii (Cr)	Red
Fibrocapsa japonica (Cr)	Red
Pseudochattonella verruculosa (Cr)	Red
Macroalgae	
Acrothamnion preissii	Red
Asparagopsis armata	Red
Caulerpa cylindracea	Red
Caulerpa taxifolia	Red
Codium fragile subsp. *fragile*	Red / Green
Gracilaria vermiculophylla	Red / Green
Grateloupia turuturu	Red / Green
Lophocladia lallemandii	Red
Polysiphonia morrowii	Red
Sargassum muticum	Red / Green
Undaria pinnatifida	Red / Green
Womersleyella setacea	Red
Tracheophyta	
Halophila stipulacea	Green
Spartina alterniflora	Red
Spartina anglica	Red
Cnidaria	
Cordylophora caspia	Red
Oculina patagonica	Red
Rhopilema nomadica	Red
Ctenophora	
Beroe ovata	Green
Mnemiopsis leidyi	Red
Polychaeta	
Ficopomatus enigmaticus	Red
Hydroides dianthus	Red
Hydroides elegans	Red
Marenzelleria spp. (neglecta & viridis)	Green
Crustacea	
Acartia (Acanthacartia) tonsa (Cr)	Green
Amphibalanus improvisus (Cr)	Red
Austrominius (Elminius) modestus	Red
Callinectes sapidus	Red / Green
Cercopagis pengoi	Red / Green
Chionoecetes opilio	Green
Eriocheir sinensis	Red / Green
Gammarus tigrinus	Red
Homarus americanus	Red / Green
Marsupenaeus japonicus	Green
Palaemon macrodactylus	Green
Paralithodes camtschaticus	Red / Green
Portunus segnis	Green
Rhithropanopeus harrisii	Red
Mollusca	
Anadara kagoshimensis	Red
Anadara transversa	Red
Arcuatula senhousia	Red
Crassostrea gigas	Red / Green
Crepidula fornicata	Red / Green
Ensis directus	Green
Mercenaria mercenaria	Green
Mya arenaria	Green
Pinctada imbricata radiata	Red / Green
Rapana venosa	Red / Green
Spondylus spinosus	Green
Urosalpinx cinerea	Red
Venerupis philippinarum	Green
Fish	
Liza haematocheila	Red / Green
Fistularia commersonii	Red / Green
Lagocephalus sceleratus	Red
Neogobius melanostomus	Red / Green
Nemipterus randalli	Red / Green
Plotosus lineatus	Red
Saurida undosquamis	Red / Green
Scomberomorus commerson	Green
Siganus luridus	Red / Green
Siganus rivulatus	Red / Green
Upeneus moluccensis	Red / Green
Ascidiacea	
Microcosmus squamiger	Red
Styela clava	Red

2. Review of impacts on fisheries and aquaculture

Food provision is the ecosystem service impacted by the greatest number of alien species both positively and negatively. The indicators most commonly used to assess the impacts of alien species on fisheries and aquaculture included abundance or biomass of commercial marine living resources, sea food quality, catches, landings, number of viable fisheries, and income and jobs from fisheries and aquaculture (Liquete *et al*., 2013).

Alien species can impact fisheries and aquaculture through a variety of mechanisms which are developed below:

- **Algal Blooms**: Many invasive phytoplanktonic species have been reported to cause severe damage to both aquaculture and fisheries because of persistent toxic blooms (Gourguet *et al*., in this volume). Severe economic losses to aquaculture have been caused by the alien dinophyte *Alexandrium minutum* in northern Europe since 1985 (Nehring, 1998). Massive mortalities of fish have been caused by *Karenia mikimotoi* in north-western Europe from 1968 onwards, including farmed finfish and shellfish (Raine *et al*., 2001). The alien dinophyte *Gymnodinium catenatum* is well-established in the Alborán Sea and is associated with frequent toxic events, causing paralytic shellfish poisoning episodes along the west coast of the Iberian Peninsula, leading to the interruption of harvesting of shellfish, with severe economic losses to the sector (Ribeiro *et al*., 2012). The ichthyotoxic flagellate *Pseudochattonella verruculosa* caused the death of hundreds of tonnes of farmed Norwegian salmon in 1998 and 2001 (Edvardsen *et al*., 2007) and massive mortality of wild fish (garfish, herring, sandeel and mackerel) along the west coast of Denmark. During *Coscinodiscus wailesii* blooms, high amounts of mucilage can be produced, often causing extensive clogging of fishing nets, aquaculture cages and other equipment (Boalch and Harbour, 1977; Boalch, 1984). *Phaeocystis pouchetii* has been reported to reduce growth in farmed salmon (Aanesen *et al*., 1998).

- **Degradation of important habitats:** Alien species may have an indirect negative impact on fisheries by impacting essential habitats for fish stocks, which provide food, refuge and nursery grounds. The alien herbivore fishes *Siganus luridus* and *Siganus rivulatus* have caused, through overgrazing, the gradual transformation of the eastern Mediterranean sublittoral ecosystem from one dominated by lush and diverse brown algal forests – essential habitat for many commercial species – to one dominated by bare rock or algal turf (Sala *et al*., 2011, Verges *et al*, 2014). Alien macroalgae such as *Acrothamnion preissii*, *Caulerpa cylindracea, C. taxifolia, Codium fragile subsp. fragile, Gracilaria vermiculophylla, Lophocladia lallemandii, Sargassum muticum, and Womersleyella setacea*, and also encrusting alien animals such as the coral *Oculina patagonica* may cause the degradation of essential habitats for fish.

- **Direct predation or competition**: One of the most marked examples of how biological invasions can impact fisheries due to predation is the invasion of the carnivorous ctenophore *Mnemiopsis leidyi* in the Black and Caspian Seas, which caused dramatic reductions in zooplankton, ichthyoplankton, and zooplanktivorous fish populations in the 1980s and early 1990s (Shiganova, 1998; Shiganova *et al*., 2001b; Leppäkoski *et al*., 2009). This species, probably in combination with other stress factors (Niermann, 2004), affected stocks of many small pelagic fish, causing an estimated annual financial loss in the fisheries sector of approximately 200 million USD in the Black Sea and 30-40 million USD in the Sea of Azov (GESAMP, 1997). Another predatory alien species in the Black Sea, the gastropod *Rapana venosa*, is responsible for the depletion of large stocks of commercial bivalves (esp. *Mytilus galloprovincialis* and *Ostrea edulis*) and the associated communities in the Black Sea since the 1950s

(Zolotarev, 1996; Salomidi *et al*., 2012). Decline of commercial stocks due to direct predation or competition for resources (food or space) is the presumed mechanism of negative impact in the cases of many other alien species, such as the decapods *Homarus americanus* and *Paralithodes camtschaticus*, the fishes *Fistularia commersonii*, *Neogobius melastomus, Saurida lessepsianus, Liza haematocheila, Siganus luridus* and *S. rivulatus*, the bivalves *Crassostrea gigas* and *Pictada imbricata radiata*, and the gastropod *Urosalpinx cinerea*. However, these associations and impacts are difficult to prove empirically and will require more research to assess measurable effects.

- Fouling shellfish, gear and equipment: Some alien macroalgae (e.g. *Codium fragile subsp. fragile, Gracilaria vermiculophylla, Grateloupia turuturu, Sargassum muticum, Undaria pinnatifida*) can have a negative economic impact on aquaculture and fisheries by fouling fishing gear, shellfish facilities and shellfish beds, smothering mussels and scallops, clogging scallop dredges, and interfering with harvesting. The cladoceran *Cercopagis pengoi* attaches to fishing gear and clogs nets and trawls, potentially causing problems and substantial economic losses for fishermen and fish farms. Many fouling species such as the polychaetes *Ficopomatus enigmaticus*, *Hydroides dianthus* and *Hydroides elegans*, the barnacles *Amphibalanus improvisus* and *Austrominius modestus*, the gastropod *Crepidula fornicata*, the ascidians *Microcosmus squamiger*, and *Styela clava*, and the hydrozoan *Cordylophora caspia* may compete for space with cultured bivalves causing a reduction of production, bring additional costs for sorting and cleaning fouled shells before marketing, and lead to extra costs for maintenance of fishing gear or aquaculture equipment.

- Damage of catch and fishing gear, entanglement in nets: The invasive silver-cheeked toadfish *Lagocephalus sceleratus* has been reported to attack the catch of nets or longlines and cause extensive damage to the fishing gear, causing substantial economic losses to coastal small-scale fisheries (Ünal and Göncüoğlu - Bodur, in this volume). Fishers often have to change their fishing practices (gear, depth, time, etc) to avoid encounters with the species (Katsanevakis *et al*., 2009). The entanglement of some species (e.g. *Eriocheir sinensis, Gammarus tigrinus, Plotosus lineatus*) in fish and shrimp nets may increase handling times, injure fishers and damage the nets or the target species. Coastal trawling and purse-seine fishing are often disrupted in Israel due to massive swarms of the jellyfish *Rhopilema nomadica*, which damage the catch, clog and tear nets, impair hauling equipment, sting fishers and make it difficult to sort the catch (Rilov and Galil, 2009; Angel *et al*., 2016).

- Disease transmission: Alien species can transmit diseases, causing increased mortality in native populations of commercially important species or in holding facilities. For example, the alien crab *Rhithropanopeus harrisii* was identified as a carrier of the white spot syndrome, a viral infection causing a highly lethal and contagious disease in commercially harvested and aquacultured penaeid shrimp (Payen and Bonami, 1979), and the alien American lobster *Homarus americanus* transmitted *gaffkaemia* to native European lobsters, a bacterial disease caused by *Aerococcus viridans var. homari* (Stebbing *et al*., 2012).

- New commodities: Many of the species that have caused the decline of native commercial species are fished or farmed and can have at the same time substantial a positive impact on food provision. For example, *Rapana venosa* (which has caused the decline of bivalve fisheries in the Black Sea) is edible and has supported very profitable fisheries (Sahin *et al*., 2009). The following alien species are edible and are important, some on a large-scale and others locally, for fisheries or aquaculture in their introduced range (see Kaiser and Kourantidou, in this volume): the fishes *Liza haematocheila*, *Saurida lessepsianus*, *Scomberomorus commerson, Upeneus moluccensis, Nemipterus randalli, Siganus luridus, S. rivulatus,* the mollusks *Ensis directus, Mercenaria mercenaria, Mya arenaria, Venerupis* *philippinarum, Sepia pharaonis* and *Crepidula fornicata*, the decapods *Chionoecetes opilio, Marsupenaeus japonicus, Palaemon macrodactylus, Paralithodes camtschaticus*, and *Portunus segnis*, and the brown alga *Undaria pinnatifida*. For example, *V. philippinarum* is one of the most important species in shellfish farming with a production accounting for >20% of the global shellfish market; Italy is the largest European producer with a production worth over 100 million euros (Otero *et al*., 2013).

- New food source for fish: Many alien species provide important food sources for commercial fish populations or contribute indirectly to such populations through more complicated trophic web interactions. For example the polychaetes *Marenzelleria neglecta* and *Marenzelleria viridis* are a significant food source for demersal fish such as plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*) in the Baltic Sea (Winkler and Debus, 1997). The copepod *Acartia tonsa* constitutes significant prey for pelagic fish, and has been used to produce live feed for aquacultured species (Sørensen *et al*., 2007), such as turbot reared in the Black Sea. The invasive cladoceran *Cercopagis pengoi* is a very important food source for many fishes in the Baltic Sea, such as small herring, stickleback, smelt, and bleak (Ojaveer *et al*., 2004; Kotta *et al*., 2006).

- Biological control: Species that control species having a negative impact on fisheries or aquaculture are actually having a positive impact on food provision. A marked example is the establishment of the ctenophore *Beroe ovata* in the Black Sea. *B. ovata* is a predator of *M. leidyi* and has been reported to cause its decline in the Black Sea, and consequently a partial recovery of the planktonic food web structure and pelagic fish populations that had collapsed (Shiganova *et al*., 2001a; Finenko *et al*., 2003).

- Novel habitats: Katsanevakis *et al*. (2014) reported 49 invasive species in Europe to be ecosystem engineers that fundamentally modify, create or define habitats by altering their physical or chemical properties (Wallentinus and Nyberg, 2007; Berke, 2010). The novel habitats created by some of these ecosystem engineers differ in composition and structure from past and present native habitats, and result in different species interactions and functions. Some of these novel habitats created by reef-builders, tube-builders, macroalgae, and seagrasses can increase the spatial complexity of benthic habitats, offer novel microhabitats, and provide nursery grounds, shelter for macro- and microfauna, and strongholds for a diverse community of algae and invertebrates, potentially supporting stocks of commercial species.

3. The balance between negative and positive impacts

In general, invasive alien species do not have only positive or only negative impacts on biodiversity or ecosystem services but they have a mixture of both, with differing impacts on different services or ecological features (Katsanevakis *et al*., 2014). With the exception of some invasive species that have clearly only negative effects, such as microalgae causing toxic blooms (see Table 1), in many cases it is quite difficult to assess the overall balance of the effect on food provision, which may vary depending on several factors. Many alien species (especially fish, crustaceans and mollusks) are edible and are of high value for fisheries or aquaculture but they may cause the decline of native commercial species through a variety of mechanisms. For example, in the Levantine Sea, the world's most invaded marine region because of the opening of the Suez Canal, the catch of commercial fisheries is now dominated by alien species (Edelist *et al*., 2013) (Fig. 1), many of which are considered by local fishermen as an important gain for Levantine fisheries (Galil, 2007).

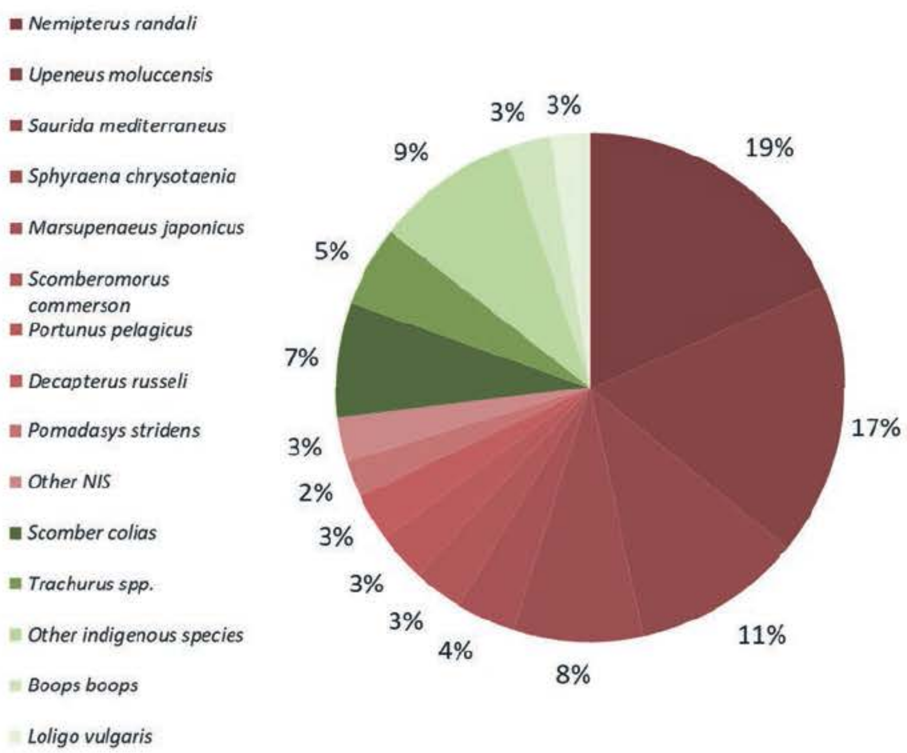

Figure 1. Catch composition in 78 commercial trawl hauls conducted between May and December of 2017 along the Israeli coast between Ashdod and Hadera in depths of 30-60m. Red shades refer to non-indigenous species, while green shades refer to indigenous species. Source: Edelist (2018).

A good example reported by Galil (2007) is the case of the alien penaeid prawns in the Mediterranean. Eight species, in particular the highly prized *Marsupenaeus japonicus*, compose most of the prawn catches off the Mediterranean coast of Egypt and Israel. They are considered by fishermen as a boon as they bring in a substantial part of trawl catches and income. Nevertheless, this comes along with the decline of the native species *Melicertus kerathurus*, which, probably due to competition with the new invaders, has nearly disappeared from its previous fishing grounds.

The complexity of species interactions and the variety of impacts make risk assessments and management decisions challenging, especially in view of often-conflicting stakeholders' perceptions (e.g. Kaiser and Kourantidou, in this volume). Although the positive impacts of alien species are under-reported due to a common perception bias against alien species, i.e. a 'native good – alien bad' perception (Goodenough, 2010), they are now receiving increasing consideration as providers of ecosystem services or even as having conservation benefits (Schlaepfer *et al.*, 2011, 2012; Thomsen *et al.*, 2014; Giakoumi *et al.*, 2016).

4. Invasive species and climate change

Climate change is estimated to substantially affect fisheries and aquaculture production in various ways, with important variation of yield impacts among countries, and not all impacts necessarily being adverse (Barange *et al.*, 2014). What is supported by new evidence and models is that climate change will cause a redistribution of benefits and losses at multiple scales and across marine and coastal socio-ecological systems, because of species shifts and ecosystem modifications and changes in primary productivity (Weatherdon *et al.*, 2016).

Climate change directly influences the likelihood of alien species managing to get established in a new territory and is thus assisting or driving the expansion of species towards previously uninhabitable regions (Walther *et al*., 2009). In many regions, the loss of temperature-sensitive species might compromise food provision, especially in land-locked seas such as the Mediterranean or the Black Sea, in which species shifting their range from southern latitudes cannot fill the gap. In such cases, alien species are more likely than native species to persist, and could be beneficial overall by fulfilling the lost ecological roles and providing a novel exploitable source for fisheries. Some alien species that are currently considered as pests with mainly negative impacts might in the climate-modified future become acceptable or even desired species as they will assure ecological functions and the provision of ecosystem services (Walther *et al*., 2009). In the Levantine Sea, multi-species collapses of native shallow reef species have been, at least partially, attributed to climate change (see Box 1 adapted from Rilov, 2016). In one case, that of the sea urchin *Paracentrotus lividus*, it was experimentally demonstrated that its decline was related to the fast ocean warming (Yeruham *et al*., 2015). In that region, where alien fish dominate today in the shallow shelf communities and in the commercial catches (Edelist *et al*., 2013; Rilov *et al*., 2017), it is quite probable that food provision and the income of the fishers would have seriously declined if there were no alien species.

Box1

In the past three decades, temperatures on the Israeli coast have increased by 2-3°C. In the 1960-70s, peak summer temperatures were around 29°C and today they are 31-32 °C (Fig.2). Comparing historical taxonomic descriptions and anecdotal data of shallow reef species in the region with data from extensive ecological surveys between 2009-2016, showed that dozens of species (mostly molluscs but also sea urchins; Fig 2) that were described as abundant or very abundant in the past are now absent or very rare (Rilov, 2016). It was speculated that the warming might have reduced the fitness of temperature sensitive species and, at least partially, caused this decline. This was experimentally proven for sea urchins, that die when temperatures cross 30.5 °C (Yeruham *et al*, 2015), which occurred on the Israeli coast every summer for the past two decades (Fig 2). But, the reefs are not empty. Instead of the absent native molluscs, the reefs are totally dominated by alien molluscs (Fig. 2). It is quite reasonable to believe that many of them serve ecological functions that are similar to that of the missing natives. If so, and if indeed the natives' decline was driven by warming, then these aliens are critical for compensating for the loss of functions due to climate change. The collapse of the grazing urchins was "overcompensated" by the invasive rabbitfish that totally decimate native macrophytes (e.g., *Cystoseira* species) which are important habitat for many benthic species. *Cystoseira*, also show sensitivity to warm temperatures (Guy Haim, Rilov *et al*., unpublished data) which means that its populations are affected by both intensive overgrazing and warming.

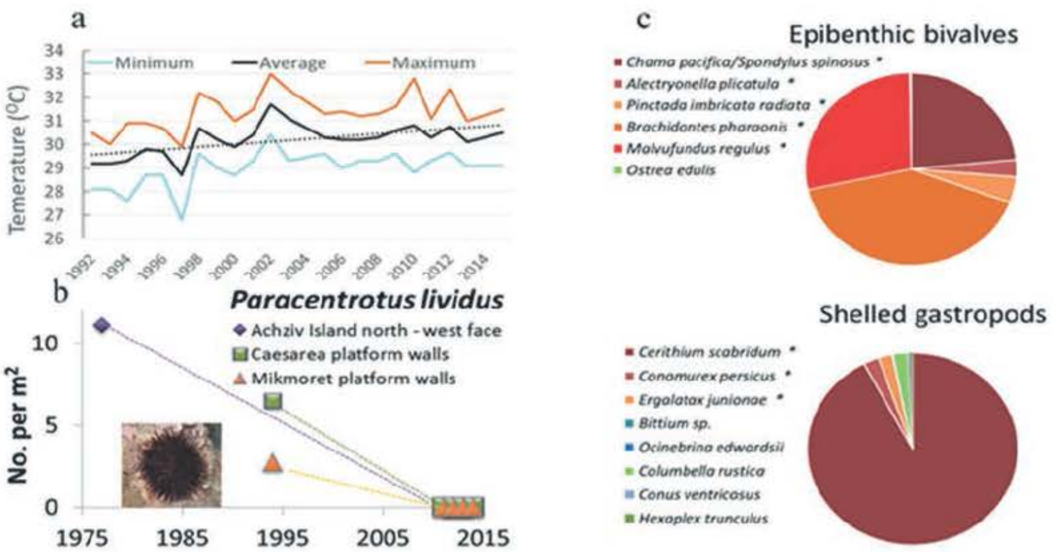

Figure. 2. a. Sea surface temperatures measured from a buoy 2 km offshore in south Israel. b. anecdotal (early years) and survey data (later years) showing the decline of the sea urchin *Paracentrotus lividus* in a site in north Israel that has been a marine reserve for two decades. c. the relative abundance of epi-benthic molluscs species on shallow reefs on the Israeli coast.
* denotes alien species. Figure modified from Rilov, 2016.

5. Needs for further research

Although many impact and risk assessments of biological invasions have been conducted with various protocols (Essl *et al*., 2011; Gallardo *et al*., 2016), our knowledge base is still far from being sufficient for proper and efficient management decisions. In particular, the assessments of impacts on ecosystem services and socio-economic activities, and the effect of climate change on such impacts constitute major gaps in the knowledge required for conducting risk assessments (Roy *et al*., 2018). Some negative or positive impacts on fisheries and aquaculture are directly observable (e.g. algal toxic blooms, fouling of equipment and gear, damage of catch and gear, entanglement in nets, new commodities) but others, in particular those that are related to changes in trophic webs, habitat modification or effects on wider ecological processes and functions need deeper investigation and targeted research. At present, they are mostly based on assumptions and expert judgment but not on targeted research testing the impact. The complexity of species interactions and the variety of both negative and positive impacts linked to alien species often make such research extremely difficult.

Climate change effects as well as cumulative effects of human pressures that act jointly with the effects of biological invasions further complicate impact and risk assessments as it is difficult to separate the different drivers and identify the real causes of observed impacts. For example, simple correlations between the decline of a native population and the increase of an alien population have often been used as evidence of alien species negative impacts (Katsanevakis *et al*., 2014). However, such non-experimental-based correlations do not offer strong evidence for causality, as there are many other alternative hypotheses. Other biotic or abiotic factors (e.g. temperature rise) or cumulative impacts of human pressures (e.g. pollution, overfishing, habitat destruction) could also correlate with the declining native population and thus provide other possible causal explanations. Disentangling cause-effect pathways is inherently difficult and would probably necessitate a combination of experimental and modelling approaches. The development of a variety of ecosystem modelling techniques, such as dynamic ecological models, may offer extremely useful tools for our understanding of interactions among native and alien species to better understand processes and predict the future dynamics of marine systems (Wonham and Lewis, 2009). This would greatly advance impact and risk assessments of biological invasions on food provision services of marine ecosystems. Such modeling attempts have been recently conducted for the Israeli trawl catch data with interesting insights, for example on the possible competition between invasives and natives based on biological trait analysis and on the effect of warming on natives and alien fish (Belmaker *et al*., 2013; Givan *et al*., 2017; Rijn *et al*., 2017; Arndt *et al*., 2018).

The quality of impact assessments can be jeopardized by uncertainty and its insufficient treatment (Stelzemüller *et al*., 2018). Assessments of the impacts of alien species on marine ecosystems and ecosystem services suffer from uncertainties related to insufficient data, type of responses of ecosystems to invasive species, type of multiple species effects (additive or with synergistic or antagonistic interactions), and resolution of spatial data (Katsanevakis *et al*., 2016). Additional research effort is needed to develop proper tools that will allow addressing uncertainty in impact and risk assessments in an adequate and transparent way (Katsanevakis and Moustakas, 2018).

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