

Section 4

Chapter 6

Pressures

Subchapter 6A

Invasive species

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Key points

- Globally, the spread of non-indigenous species (NIS) continues, exacerbated by climate change and human activities, negatively affecting some of the most vulnerable marine ecosystems.
- The introduction of NIS continues to negatively impact native species and habitats, affecting global ecological, socioeconomic, cultural and human health outcomes.
- Despite the crucial importance of preventing the introduction of NIS, few mandatory regulations or policies exist globally or regionally.
- A significant gap remains in systematic monitoring and information-sharing about NIS at multiple temporal and spatial scales, which undermines management and response efforts.
- A lack of long-term studies on NIS impacts hinders risk identification and reduces the effectiveness of post-invasion management efforts.

1. Introduction

NIS have been detected in ecosystems worldwide, but the type of species, their diversity and population sizes are affected by biotic and abiotic factors (see figure I). The ongoing accidental or intentional introduction of species significantly affects marine ecosystems, resulting in biotic homogenization and threatening biodiversity, ecosystem services, human health and socioeconomic outcomes (Schwindt and others, 2022; Ojaveer and others, 2023; Roy and others, 2024; Simberloff and others, 2024; Zaiko and others, 2024). Any species may become invasive under favourable conditions (Williamson, 1999; United Nations Environment Programme (UNEP), 2002). The approach adopted in the present subchapter is therefore a precautionary one, under which all NIS are considered while acknowledging that some native species can also become invasive, such as crown-of-thorns starfish (*Acanthaster planci*) (Hoey and others, 2016; Guareschi and others, 2024).

Information on NIS varies, with strong biases in the breadth and depth of taxonomic coverage and expertise towards larger, more conspicuous species and those with economic consequences (Watkins and others, 2021; Schwindt and others, 2022). As noted in the second *World Ocean Assessment*, there is a lack of, and continuing need for, large-scale systematic surveys on NIS. In addition, the context-dependent nature of many NIS makes it difficult to generalize (Carlton and Schwindt, 2024; see figure II and table 1). Although determining which NIS to prioritize for management is challenging, there are an increasing

number of screening and risk assessment tools to support decision-making (Dahlstrom and others, 2011; Kumschick and Richardson, 2013; Srébaliené and others, 2019; Wilcox and others, 2024).

In global policy documents, NIS are clearly identified as a major threat to biodiversity. The targets set out in the Kunming-Montreal Global Biodiversity Framework, developed under the Convention on Biological Diversity, directly address NIS. In particular, target 6 requires States to minimize the impacts of NIS on biodiversity and ecosystem services through preventative measures aimed at reducing the rates of introduction and establishment of NIS by at least 50% by 2030. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has recognized the negative impacts of invasive species around the world (IPBES, 2023). Several important considerations have been highlighted in IPBES assessments, including local extinctions caused by marine species such as *Pterois volitans*, *Caulerpa taxifolia* and *Mytilus galloprovincialis* (Bacher and others, 2023; Schwindt and others, 2024). Given that marine protected areas (MPAs) are one internationally accepted tool to conserve biodiversity, it is surprising that efforts to characterize NIS in MPAs and to better understand their potential impacts have been limited (Soares, 2018; Mendez and Schwindt, 2024). Meanwhile, vectors such as recreational vessels are creating invasion networks by linking MPAs to invasion hotspots (Iacarella and others, 2020), thus compromising conservation objectives.

As a global ecosystem stressor, NIS can belong to any taxa (see Briski and others, 2024; see also chaps. 4 and 5). Some marine plants have been introduced globally, including habitat-altering species belong to the genera *Spartina* and *Phragmites* (see subchap. 4H). Bivalves, such as the Pacific oyster (*Magallana gigas*), have been introduced globally for aquaculture purposes, but often with negative consequences for native biodiversity (Bacher and others, 2023; Di Blasio and others, 2023). White spot syndrome, a viral disease that affects most commercially cultivated marine shrimp species globally (Flegel, 1997; Lotz, 1997), has spread to most shrimp culture countries (Yan and others, 2007). NIS have been shown to benefit from habitats that were already stressed or degraded by other human impacts (see subchaps. 6B–6E). In addition, many NIS have socioeconomic or cultural impacts (Campbell and Hewitt, 2018; Bortolus and Schwindt, 2022; see also sect. 5).

2. Changes since the second *World Ocean Assessment*

Globally, significant gaps remain in the detection and reporting of, and response to, NIS, thereby limiting the understanding of the associated ecological, economic and cultural impacts, which in turn limits the ability to predict the impacts of NIS in new locations (Schwindt and others, 2022). The continued introduction and spread of NIS compromise the achievement of up to 11 of the 17 Sustainable Development Goals and other global conservation efforts. Although vectors and pathways have only been partially characterized globally, commercial shipping, the Suez Canal and other artificial waterways, aquaculture, recreational boats and aquarium releases are responsible for the introduction and spread of most NIS (Bailey and others, 2020; Seebens and others, 2021; Menezes and others, 2022; Guerra-García and others, 2023; Aylagas and others, 2024). Marine debris and litter is an emerging vector globally (Therriault and others, 2018; Audrézet and others, 2021; Galil, 2023), and unprecedented pathways between Antarctica and other continents have been observed (Dawson and others, 2024).

Biogeographical barriers can limit the natural spread of NIS, depending on their permeability; the strength and location of such barriers, however, is being affected by climate change (Krumhansl and others, 2023).

Climate change also results in more frequent and intense marine heatwaves, which facilitates the spread and impacts of NIS. In the Mediterranean region, New Zealand and temperate regions of Australia, the nearshore ecosystem has proved to be highly vulnerable to recurrent heat-induced mass mortality events over the past four decades (Thomsen and others, 2019; Verdura and others, 2019, Tait and others, 2021; Wernberg, 2021; Bell and others, 2023). That scenario is likely to be repeated in multiple ocean basins. While most research has documented NIS impacts on ecological and, to a lesser extent, socioeconomic endpoints, there is growing recognition of cultural impacts of NIS in some ocean basins. An exhaustive analysis of NIS impacts is beyond the scope of the present subchapter, but figure II and table 1 show examples of the types of impacts that certain NIS can have.

3. Region-specific changes

Arctic Ocean

There continue to be significant knowledge gaps for the Arctic Ocean, with no new reports since the publication of the second *World Ocean Assessment*. Some studies have shown, however, that NIS from polar and subpolar environments could establish in the Arctic Ocean, especially under multiple climate change scenarios and projections of increased vessel traffic (Goldsmid and others, 2020). For example, the red king crab (*Paralithodes camtschaticus*) originally introduced to the Barents Sea to establish a fishery has now spread to Norway, causing significant ecological and economic impacts (Sundet and Hoel, 2016).

North Atlantic Ocean, Baltic Sea, Black Sea, Mediterranean Sea and North Sea

By July 2023, 1,671 NIS and cryptogenic marine and oligohaline species had been reported in European seas (Katsanevakis and others, 2023), and that figure is likely a significant undercount. By December 2020, 1,006 NIS (excluding cryptogenic and data-deficient species) had been reported in Mediterranean waters alone, half of which were Erythraean species introduced through the Suez Canal (Galanidi and others, 2023), which suggests that such invasions will continue. The number of NIS in the Black Sea is unclear, but recent accounts have identified 81, in addition to 113 cryptogenic, cryptogenic-expanding and data-deficient species (Öztürk, 2021; Băncilă and others, 2022; Shalovenkov, 2022). The number of NIS newly introduced into the Baltic Sea was higher during the most recent Baltic Marine Environment Protection Commission (HELCOM) assessment period (13 NIS in the period 2016–2021, compared with 12 in the period 2011–2016; HELCOM, 2023). Meanwhile, the number of NIS newly introduced each year into the Greater North Sea has varied from three to five over the period 2018–2021, in a reversal of the long-term increasing trend (International Council for the Exploration of the Sea (ICES), 2022). The rate of introduction of new NIS has decreased in regions II (Greater North Sea), III (Celtic Seas) and IV (Bay of Biscay and Iberian Coast) of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Commission) (Stæhr and others, 2022).

South Atlantic Ocean and wider Caribbean

National scale reassessments have not been conducted since the publication of the second *World Ocean Assessment*, but high-profile species such as the sun coral (*Tubastraea* spp.) continue to spread (Dutra and others, 2023). At least 10 NIS that had been reported previously in the South-West Atlantic are now widely distributed, the ranges of another 24 are expanding (Schwindt and others, 2020; Teixeira and Creed, 2020), and several others are expected to spread (Schwindt and others, 2022; Soares and others, 2022). In

Argentina and Uruguay, six NIS hotspots have been identified, mostly associated with ports and cities (Reyna and others, 2023).

In the South-East Atlantic, almost 100 NIS have been detected from South African coastlines (Robinson and others, 2020). Although there are efforts to establish routine monitoring programmes (Loureiro and others, 2021), detections of new incursions remain largely coincidental. In South Africa, the failure of the first attempt to eradicate the European green crab (*Carcinus maenas*) has reinforced the need for preventative management (Mabin and others, 2020).

In the wider Caribbean, one recent assessment reported 33 NIS (Alidoost Salimi and others, 2021), which is likely an underestimate. In this vast region, lionfish (*Pterois* spp.) are probably the most widespread and studied NIS, with ecological, economic and human health impacts (Côté and others, 2013).

Indian Ocean, Arabian Sea, Bay of Bengal, Red Sea, Gulf of Aden and Persian Gulf

The Red Sea is a major shipping route, making it vulnerable to the introduction of NIS. The status of NIS in the region is uncertain, however, due to a lack of monitoring efforts and baseline biodiversity information. Clarke and others (2020) identified 35 NIS in the Persian Gulf and the Gulf of Oman, and additional efforts are required to confirm the invasive status of other species. Fernández and others (2022) conducted an environmental DNA study in the Gulf of Aqaba and found that more than 36% of exact sequence variants detected were non-native. Aylagas and others (2024) and Shchepanik (2022), using molecular methods, identified 16 NIS newly introduced into the Red Sea, including Ascidiaceans, Bryozoans and Crustaceans, as well as the barramundi (*Lates calcarifer*), a species introduced for aquaculture.

North Pacific Ocean

Although large-scale studies of NIS in the North Pacific have not been updated, several of the 747 reported in the second *World Ocean Assessment* continue to spread within the basin, and the increasing trend in invasions continues (Bailey and others, 2020). Lyons and others (2020), using habitat suitability modelling, identified the southern Salish Sea as an invasion hotspot, along with parts of the outer coasts of Washington and Oregon, and found that existing hotspots were predicted to shift or expand and new ones were likely to appear in a future climate scenario. Species such as the European green crab (*Carcinus maenas*) continue to spread towards the North Pole along the west coast of North America, with significant impacts on eelgrass (Howard and others, 2019) and other native species (Grosholz and others, 2000). In China, the introduction of *Spartina* to prevent coastal erosion resulted in extensive spread, with dense stands drastically altering the nearshore environment (Chung, 2006; Zhang and others, 2017). China implemented a diverse series of policies, regulations, and ecological restoration projects that have effectively controlled the spread of *Spartina alterniflora* (Li and others, 2022; Luo and Ma, 2025). By October 2023, this annual effort had cleared approximately 300 km² (Dong and others, 2024).

South Pacific Ocean

Large-scale surveys and surveillance continue to be conducted in Australia and New Zealand, with increasing baseline evaluations elsewhere in the South Pacific. There are also continued efforts to develop tools to aid vector management and surveillance in the South Pacific (Secretariat for the Pacific Regional Environment Programme (SPREP), 2022). Nevertheless, NIS continue to spread (Lane and others, 2022). Some declared pests, including *Undaria*, *Asterias* and *Sabella*, are being managed in Australia, but early

detection and rapid response tools generally are lacking. The recent arrival and rapid spread of two habitat-forming subtropical algae in New Zealand, *Caulerpa brachypus* and *Caulerpa parvifolia*, caused national concern about impacts on native habitats, recreational and commercial fisheries and the spiritual and cultural resources of the Māori, the Indigenous People of New Zealand (Evans, 2022). NIS impact studies have included an examination of the likelihood of ecosystem impacts due to key invaders (Soliman and Inglis, 2018; Atalah and others, 2019; Tait and others, 2020, 2023(a)), and the impacts on social and cultural values (Campbell and Hewitt, 2018; Manaaki te Awanui and National Institute of Water and Atmospheric Research (NIWA), 2021; Campbell and others, 2024).

Southern Ocean

There are also significant knowledge gaps with respect to NIS in the Southern Ocean. A horizon scanning exercise identified the risk of introduction of invertebrate species into the Antarctic Peninsula owing to ballast water and hull fouling (Hughes and others, 2020). Unless appropriate biosecurity measures are implemented, the rate of invasions in this region is likely to increase (McCarthy and others, 2022).

4. Key remaining knowledge and capacity gaps and new gaps

Critical data gaps and a lack of standardization and of frameworks for facilitating comparisons make large-scale assessments such as the *World Ocean Assessment* challenging (Carlton and Schwindt, 2024). Efforts need to be made to ensure that NIS records are freely accessible to the global community by removing access and language barriers. Knowledge brokers could fulfil the role of bridging such gaps by connecting data holders to managers.

NIS are a major threat to biodiversity. Nevertheless, distinctions are not made between native and non-native species in most biodiversity studies, and such studies are incomplete for most of the world's oceans. While some global registers, including the World Register of Marine Species (WoRMS) and the Ocean Biodiversity Information System, are attempting to track NIS separately, significant gaps remain. New molecular methods are improving the understanding of biodiversity in general (Adams and others, 2023) and of NIS broadly (Zhan and others, 2014; Westfall and others, 2020; Lavrador and others, 2024), but a lack of verified DNA barcodes and standard protocols for using them for surveillance has only confounded the problem (Couton and others, 2022; Zaiko and others, 2022; Bowers and others, 2021). In this context, and as the homogenization of the world's oceans accelerates, it will be increasingly difficult to ensure that NIS are correctly identified.

Prevention is key to limiting the impacts of NIS, but prevention strategies are limited. Efforts to prioritize continuous monitoring and early detection are also needed. Global efforts have been undertaken to reduce the risk of introduction of NIS under the International Convention for the Control and Management of Ships' Ballast Water and Sediments (Ballast Water Management Convention) and biofouling management guidelines, while regional efforts have included the application of the ICES Code of Practice to reduce risk of introduction of NIS from aquaculture activities. Nevertheless, many vectors and pathways remain unregulated, and the effectiveness of those regulations that do exist is uncertain (Outinen and others, 2024). There are also regional efforts to reduce the risk to the North-East Atlantic and the Baltic Sea through the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) and the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention), in addition to several national efforts (Castro and others, 2018). However, this

fragmented and patchwork research and policy environment, which differs across regions and countries, only hinders the ability to identify and respond to NIS risks. One holistic, interdisciplinary approach that has been proposed is the “One Biosecurity” model (Hulme, 2020, 2021; Hulme and others, 2023; Bray and others, 2024), which is aimed at reducing risks across ecosystem components by reducing redundancy and increasing collaboration. Such an approach, if applied broadly, would help managers to identify NIS that need to be prioritized for early detection, control or management, all of which require context-specific approaches to ensure the effectiveness of the measures implemented.

In most global ocean basins, the bulk of the attention and research effort is focused on a few high-risk or high-profile NIS (Watkins and others, 2021, Ojaveer and others, 2023), which limits the comprehensive identification of NIS impacts across a number of categories, including socioeconomic and cultural impacts, and the understanding of how NIS are being redistributed by human activities. This ultimately compromises the ability to determine the achievement of the Sustainable Development Goals. In addition, most studies have been conducted in coastal waters, with limited attention paid to the deep sea, areas beyond national jurisdiction and polar regions. Baseline information for such areas, which are logistically much more difficult to access, is virtually non-existent despite the known presence of NIS and an increase in human activities. NIS are implicated in all marine-based industries (e.g., fishing, aquaculture, transport, energy and mining), and those industries are growing faster than other global industries, which compromises the achievement of a sustainable blue economy. Thus, prevention and mitigation must be increasingly considered as these industries develop to ensure the negative consequences of NIS are fully addressed (Carvalho and others, 2023; Aylagas and others, 2024).

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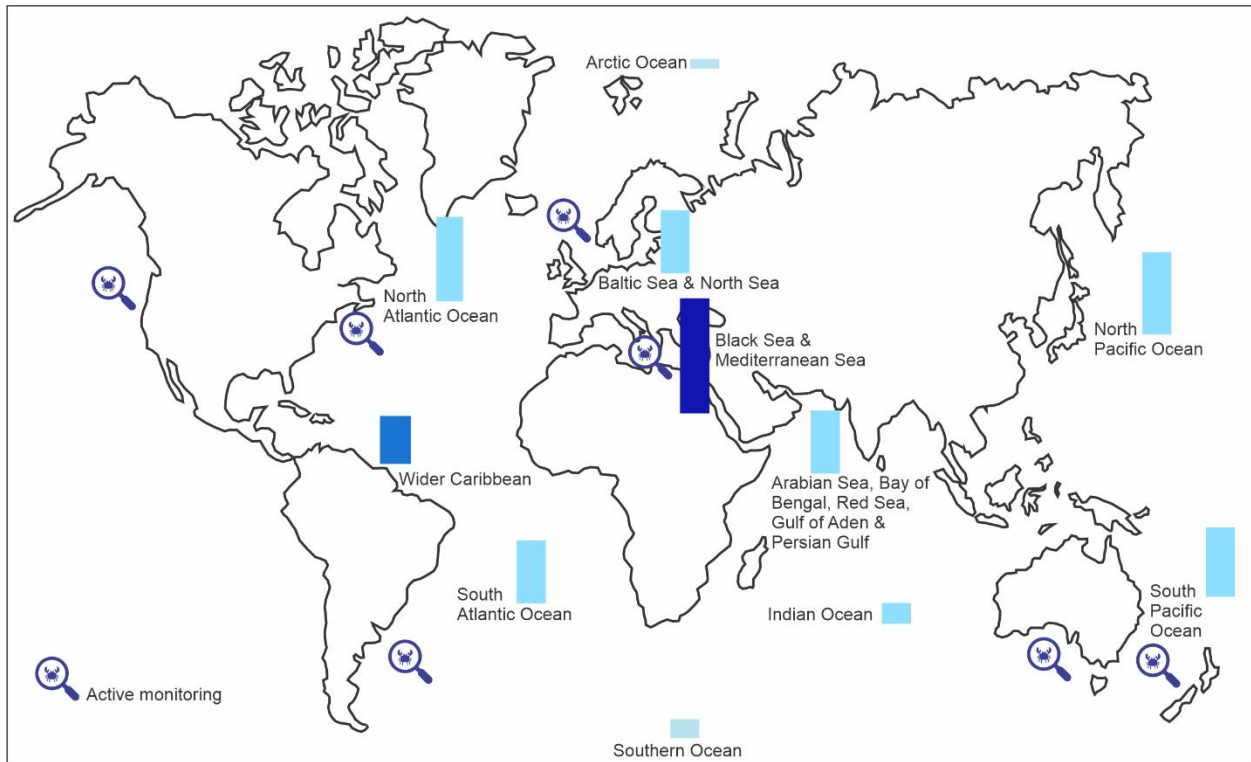
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Figure I

Marine non-indigenous species across the various ocean basins

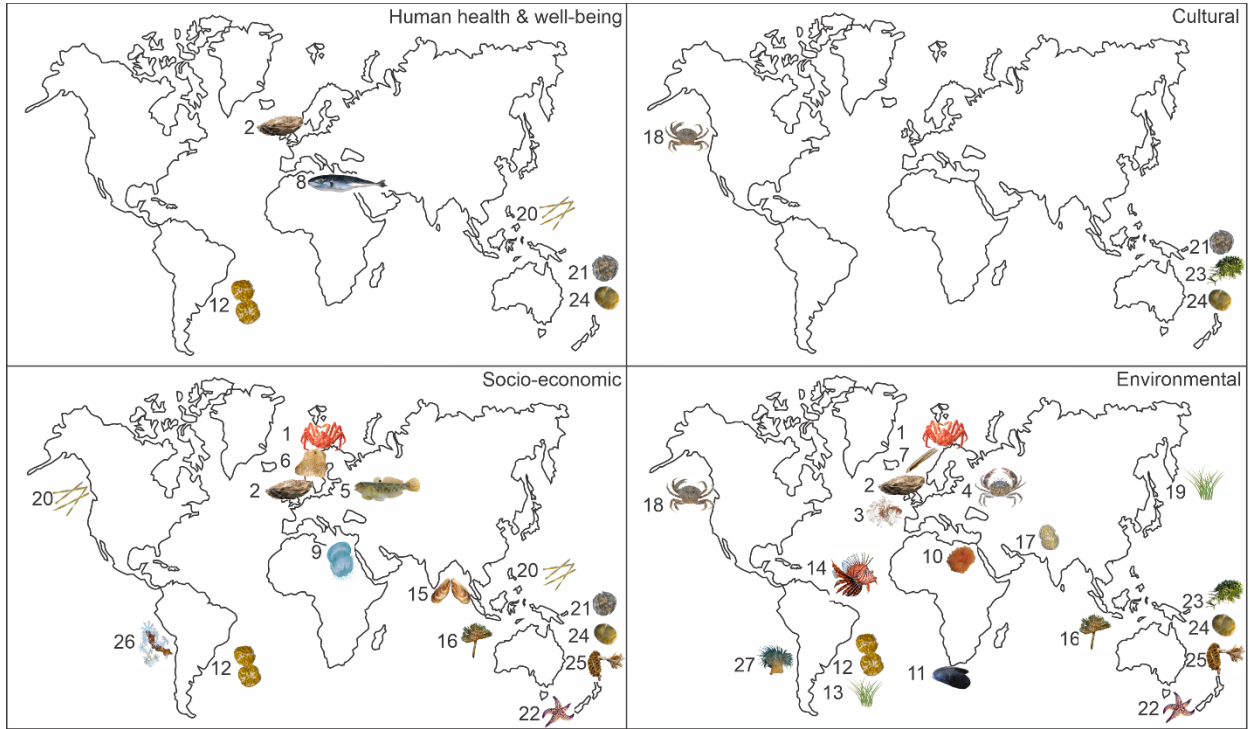


Source: Prepared by the writing team.

Note: The height of the bars reflects the relative abundance of documented alien taxa, while darker colours indicate a greater increase since the publication of the second *World Ocean Assessment*. Regions that have active monitoring programmes are indicated.

Figure II

Species that have affected human health and well-being, socioeconomic and cultural assets and the marine environment



Source: Prepared by the writing team.

Table 1

Non-indigenous species that have had demonstrable impacts in ocean basins

#	Species	Type of impact	Description	References
Arctic				
1	Red king crab <i>Paralithodes camtschaticus</i>	Socioeconomic; environmental	Despite being fished commercially in some areas, causes losses to fisheries in other areas; reduces biodiversity	Sundet and Hoel, 2016; Falk-Petersen and others, 2011
North Atlantic Ocean				
2	Pacific oyster <i>Magallana gigas</i> (previously known as <i>Crassostrea gigas</i>)	Human health and well-being; socioeconomic; environmental	Carries disease-causing viruses; is extensively farmed; alters habitat structure, phytoplankton communities and food webs; reduces biodiversity	Ueki and others, 2021; Des and others, 2022; Troost, 2010
3	Red seaweed <i>Dasysiphonia japonica</i>	Environmental	Reduces seaweed diversity	Newton and others, 2013
Baltic Sea				
4	Mud crab <i>Rhithropanopeus harrisi</i>	Environmental	Has caused a regime shift through consumption of native species	Kotta and others, 2018
5	Round goby <i>Neogobius melanostomus</i>	Socioeconomic	Negatively affects commercial species, but is also fished commercially	Ustups and others, 2016
North Sea				
6	Carpet sea squirt <i>Didemnum vexillum</i>	Socioeconomic	Threatens shellfish aquaculture	Gittenberger, 2010

7	Atlantic jackknife clam <i>Ensis directus</i>	Environmental	Alters food webs as it becomes a dominant food source	Tulp and others, 2010
Mediterranean Sea				
8	Silver-cheeked toadfish <i>Lagocephalus sceleratus</i>	Human health and well-being	Causes poisoning and human fatalities	Ulman and others, 2024
9	Nomad jellyfish <i>Rhophilema nomadica</i>	Socioeconomic	Negatively affects commercial fisheries	Ghermandi and others, 2015
10	Epiphytic algae <i>Lophocladia lallemandii</i>	Environmental	Smothers native seagrasses	El Zrelli and others, 2021
South Atlantic Ocean				
11	Mediterranean mussel <i>Mytilus galloprovincialis</i>	Environmental	Changes rocky shore communities and outcompetes native mussels	Sadchatheswaran and others, 2015
12	Dinoflagellate <i>Alexandrium</i> sp.	Human health and well-being; socioeconomic; environmental	Causes poisoning when consumed, resulting in losses for artisanal fisheries; has even caused the death of whales	Gayoso and others, 2006
13	Smooth cordgrass <i>Spartina alterniflora</i>	Environmental	Alters ecosystem functioning	Bortolus and others, 2015
Wider Caribbean				
14	Lionfish <i>Pterois</i> spp.	Environmental	Consumes native fish	Côté and others, 2013
Indian Ocean				
15	Black-striped mussel <i>Mytilopsis sallei</i>	Socioeconomic	Clogs water intakes, fouls ships and maritime infrastructure	Rao and others, 1989; Tan and Morton, 2006

16	Mediterranean fanworm <i>Sabella spallanzanii</i>	Socioeconomic; environmental	Fouls mussel farms; alters recruitment of native sessile communities	Hewitt, 2003; Halloway and Keough, 2002
Persian Gulf				
17	Dinoflagellate <i>Heterocapsa circularisquama</i>	Environmental	Has caused mass mortality of bivalves	Saburova and others, 2022
North Pacific				
18	European green crab <i>Carcinus maenas</i>	Environmental; cultural	Eats native species, competes with native crabs and degrades eelgrass habitats	Howard and others, 2019; Barclay and others, 2024; Fisher and others, 2024
19	Smooth cordgrass <i>Spartina alterniflora</i>	Environmental	Alters physical, biological and biochemical processes	Lee and others, 2024
20	Diatoms of the genus <i>Pseudo-nitzschia</i>	Human health and well-being; socioeconomic	Their blooms cause poisoning and fishery closures	Kim and others, 2018; Perry and others, 2023
South Pacific				
21	Dinoflagellate <i>Alexandrium catenella</i>	Human health and well-being; socioeconomic; cultural	Causes shellfish poisoning, which forces commercial and recreational fisheries to close	Trainer and others, 2020
22	Northern Pacific seastar <i>Asterias amurensis</i>	Socioeconomic; environmental	Predates upon native and commercially important species	Ross and others, 2002; 2003
23	Green algae <i>Caulerpa</i> spp.	Cultural; environmental	Overgrows benthic habitats and smothers culturally important seagrass	Scott, 2021; Gribben and others, 2013
24	Dinoflagellate <i>Karenia mikimotoi</i>	Human health and well-being; socioeconomic;	Causes poisoning and skin irritation in people; kills native	Li and others, 2019

		cultural; environmental	species; prevents collection of marine resources by communities and negatively affects fisheries	
25	Wakame <i>Undaria pinnatifida</i>	Socioeconomic; Environmental	Fouls aquaculture infrastructure and outcompetes native kelp	Carnell and Keough, 2014; Watts and others, 2015
26	Snowflake coral <i>Carijoa riisei</i>	Environmental	Displaces native corals	Sanchez and Ballesteros, 2014
27	Plumose anemone <i>Metridium senile</i>	Socioeconomic	Overgrows aquaculture infrastructure	Häussermann and others, 2022

Source: Prepared by the writing team.