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Research Article

# First insights into the scale of invasions in African marine protected areas: leveraging global databases and citizen science data

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## Abstract

Up-to-date information on the distribution of alien species is essential for evidence-based management. However, routine monitoring is resource intensive. This has led to regional biases in the availability of information on invasions, with little understanding of invasions in many developing regions, including Africa. This knowledge gap, particularly problematic for marine protected areas (MPAs), challenges the ability of African states to meet their obligations under the Global Biodiversity Framework (GBF) Target 6. This study drew on freely available global databases (Protected Planet; World Register of Introduced Marine Species; World Register of Marine Species) and citizen science data (iNaturalist) to provide novel insights into marine alien species in African MPAs. A total of 27 species were recorded within 17 MPAs across seven countries. The potential threat posed to these MPAs was assessed using the EICAT and SEICAT impact schemes. Worryingly, species known to have impacts of massive or major magnitude were documented in nine MPAs (Table Mountain National Park, Robben Island, Sixteen Mile Beach, Langebaan Lagoon, Namaqua National Park – all in South Africa); Namibian Islands (Namibia); Ilhas Formosa, Nago and Tchedia (Urok) (Guinea-Bissau); Banc d'Arguin National Park (Mauritania); Massa (Morocco)). When used in conjunction with curated databases, iNaturalist offered cost-effective and verifiable records of some alien species in under-surveyed MPAs. By leveraging data from disparate databases, this study improves our knowledge of the scale of invasions in African MPAs and provides a foundation upon which States can prioritise monitoring within their MPA networks. Ultimately, these data could support the development of targeted routine monitoring programmes which could assist the management of marine invasions and the attainment of GBF Target 6.

**Key words:** Africa, biological invasions, community science, data acquisition, impacts, iNaturalist, management, protected areas

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## Introduction

Biological invasions are a major driver of global environmental change (Ricciardi et al. 2021) and protected areas are not immune to the impacts of invasive alien species (Shackleton et al. 2019, 2020). The Kunming-Montreal Global Biodiversity Framework (GBF), developed under the Convention on Biological Diversity (CBD), proposes 23 targets to support and guide the achievement of the Sustainable Development Goals and the global vision to reduce anthropogenic impacts on biodiversity by 2030 (Robinson et al. 2025). Target 6 aims to reduce the rate of introductions and establishment of known or potentially invasive alien species by at least 50% by 2030 (CBD/COP/DEC/15/4). The aim of this target is to eliminate, minimise, reduce and mitigate the overall impacts of alien species on biodiversity and ecosystem services (CBD/COP/DEC/15/5). The target also requires the eradication or control of alien species in priority sites (e.g. protected areas) as these areas allow for conservation objectives to be met while providing economic, political and social benefits (Busch 2008).

Although the availability of global data on alien species and their distribution has improved greatly over the last few decades (Pyšek et al. 2020), substantial geographical biases still remain, often reflecting the developmental and socioeconomical status of regions (Pyšek et al. 2008, 2020; Nuñez and Pauchard 2010). This can be seen, for example, in the focus of research effort in the Americas and Europe (Hulme et al. 2014). Inconsistencies in the availability of information across continents has also been highlighted. For example, as of 2006, work in South Africa accounted for approximately two-thirds of research effort on biological invasions on the African continent (Pyšek et al. 2008). Dedicated efforts to provide up-to-date alien species lists (e.g. Zengeya and Wilson (2023) for South Africa)) has improved the understanding of alien species in some countries, but many still lag behind. For example, there is a need for comprehensive invasive plant species lists for sub-Saharan Africa (Witt et al. 2018) and no data are available for many regions (Richardson et al. 2022). The same situation exists for other taxa. While the responsibility for the provision of such information usually falls on to researchers, the outputs of such studies are of practical use for managers (Ojaveer et al. 2015). The lack of foundational knowledge within understudied regions has the potential to perpetuate knowledge debt. This challenge is especially prevalent in developing regions where the management of alien taxa is already limited (Kumar Rai and Singh 2020).

Global declines in marine biodiversity and threats posed by anthropogenic actions have led to the increasing implementation of marine protected areas (MPAs) (Ban et al. 2015; Chukwuka et al. 2025). Defined as geographical spaces dedicated to legally manage long-term conservation of ecosystem functions, services and cultural values (Day et al. 2012), MPAs are important marine conservation tools. Given the multitude of threats (including biological invasions) facing marine systems (Evariste et al. 2018; Horwitz et al. 2020; Pyšek et al. 2020; Renchen et al. 2021) and the fact that conservation agencies have limited resources (Delaney et al. 2008; Beric and MacIsaac 2015), managers must prioritise how and where to spend scarce resources. However, despite much effort, current management and conservation efforts are inadequate in most protected areas (Crain et al. 2009; Borja et al. 2016; Chukwuka et al. 2025). Marine protected areas serve a number of economic, ecological and societal aims, all of which are undermined by biological invasions. The need to address alien species and quantify the scale of invasions in MPAs is thus crucial to ensure that MPAs meet their intended purpose.

Monitoring provides critical information on the changing scale of invasions and is crucial for evidence-based management (Lehtiniemi et al. 2020; Loureiro et al. 2021). When collected systematically over space and time, such information supports comprehensive databases that provide temporal and spatial insights into invasions (Delaney et al. 2008). However, monitoring is challenging in marine environments because of to their complex nature (D’Amen and Azzurro 2020). Their underwater landscapes and interconnectedness make invasions in the marine realm difficult to document and manage (Arndt et al. 2018). Additionally, large-scale, long-term monitoring rarely occurs due to resource limitations (Delaney et al. 2008; Beric and MacIsaac 2015). Cost-effective methods of monitoring are needed to bridge the gap between data requirements and scientific understanding (Lehtiniemi et al. 2020; Howard et al. 2022). One way of achieving this is to utilise crowd-sourced data provided by citizen science initiatives (Horwitz et al. 2020; Howard et al. 2022). The advancement of technology and the recent proliferation of online platforms has enhanced the potential for monitoring by using devices and smartphone applications (Daniels et al. 2022; Howard et al. 2022). Applications, such as iNaturalist, enable observers to upload photographic evidence of individual sightings and suggest taxonomic identifications (Pimm et al. 2015; Howard et al. 2022). Records collected by observers have the potential to provide a large volume of data over a wide area. If utilised with due attention to inherent limitations, citizen science offers a complementary source of data to support effective monitoring of alien species (Howard et al. 2022; Potgieter et al. 2024). iNaturalist has facilitated many useful insights within the marine realm, including improved understanding of reef fish species richness (Roberts et al. 2022), biodiversity patterns (Rocha et al. 2024) and invasions (Compagnone et al. 2024).

For African countries to meet their obligations under GBF Target 6, better foundational knowledge on the presence of alien species within MPAs is essential. Underdeveloped regions are already experiencing a high economic burden which is exacerbated by the financial demands associated with managing invasive species (Bradshaw et al. 2024). The monitoring required to provide information for routine management of alien species has the potential to further intensify financial strain, challenging the acquisition of foundational knowledge and the implementation of effective management. Accordingly, this study aimed to: (1) provide insights into the scale of alien species in African MPAs through the use of global databases and citizen science data from iNaturalist; and (2) assess the potential environmental and socio-economic impacts posed by these taxa.

## Methods

Marine protected areas (MPAs) along the African coast were identified using the open-access Protected Planet database (https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas; accessed: 9 January 2024). This database, the most comprehensive and up-to-date source of data on protected areas, collates submissions from government agencies, non-governmental organisations and local communities. Marine Protected Areas were defined using the filters listed in Suppl. material 1. Data, extracted over a single day (9 January 2024), covered all African MPAs declared prior to January 2024.

Records of all species reported as alien [i.e. species whose presence in a region is attributable to human actions enabling crossing of biogeographical barriers *sensu* Richardson et al. (2011)] along the African coast were extracted from the World Register of Introduced Marine Species (WRiMS; Costello et al. (2024); https://www.marinespecies.org/introduced/aphia.php?p=checklist; accessed: 10 September 2024). Data included both occurrence records of alien species as well as records of established populations. This database was selected as it collates data from peer-reviewed articles to provide the most comprehensive and standardised global-scale database of marine introduced organisms (Costello et al. 2021). All species records that were extracted were inspected and a three-step cleaning procedure was applied. As data extracted from WRiMS include both accepted names and synonyms with no option to filter out these redundancies, all taxonomic duplicates were checked and removed to avoid overestimations of the number of alien species. Scientific names were then updated according to the most recent nomenclature collated in the World Register of Marine Species (WoRMS; Ahyong et al. (2024); https://www.marinespecies.org; accessed: 10 September 2024). Since WRiMS contains both marine and estuarine data, all oligohaline species were inspected. Using current literature to investigate salinity tolerances, only species with a tolerance for marine environments were retained.

To ensure that no published records of alien species were inadvertently excluded, a search was conducted on the ISI Web of Science on 10 September 2024. A systematic literature review was conducted using the following search string "marine" AND "alien" OR "invasive" OR "introduced" OR "nonnative" AND "country name". As the terminology used to describe alien species is inconsistent and highly variable in the literature (Lockwood et al. 2013), broad search terms (i.e. "alien", "invasive", "nonnative" and "introduced") were used to capture as much of the relevant literature as possible. As no additional records of marine alien species were detected in the literature search, the dataset extracted from WRiMS was accepted as complete.

Utilising the explore page on iNaturalist (https://www.inaturalist.org; accessed: 18–19 September 2024), searches were made for each species listed as alien in any African country on WRiMS. Records for each species across all quality grades were extracted from iNaturalist for the period 1 April 2008 (the date of establishment of the iNaturalist platform) to 18 September 2024. Information on the species identification (scientific name and associated media), the date of observation, the date in which the observation was uploaded to the platform, the coordinates of the observations and positional accuracy were extracted for each observation. As some species may have a native range in one African country, but be alien in another, the native range of each species was confirmed using the World Register of Marine Species (WoRMS; Ahyong et al. (2024); https://www.marinespecies.org; accessed 20–21 September 2024) and published articles. To interrogate the geographic distribution of iNaturalist observations and ensure that the observations were, in fact, observed within an MPA, the coordinates for each observation were plotted using the Quantum Geographic Information System (QGIS; version 3.22 LTR). Each observation was plotted on to a map of Africa with the MPAs demarcated [MPA shapefiles from Protected Planet (https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas; accessed: 9 January 2024]). All points were visually inspected and any records from outside MPAs were excluded from further analysis. iNaturalist observations occurring within the native range of a species were also excluded.

To address uncertainty in iNaturalist data and improve its accuracy and reliability, confidence for each observation was scored following the protocol proposed by Ackland et al. (2024). This process included three steps: assessing the species, the image and geolocation of each record. Only records receiving medium or high confidence scores were retained for further analysis. A Kendall's rank correlation was used to assess the relationship between the number of records of alien species as detected in African MPAs through time. Effort was quantified as the number of marine alien species records per 100 records within African MPAs. All statistical analyses were conducted in the R statistical environment (version 4.3.2 – "Eye Holes", R Core Team (2023)).

To determine the threat that these species may pose to MPAs, a literature review was carried out using ISI Web of Science to identify all previously published reports of impact for each species at any global location. The search string "scientific name" AND "impact*" OR "effect*", was applied along with each species name and all previous synonyms. Searches were completed between 25 and 27 September 2024. Environmental impact was categorised according to the mechanisms through which they manifest [i.e. (1) competition; (2) predation; (3) hybridisation; (4) disease transmission; (5) parasitism; (6) poisoning/toxicity; (7) bio-fouling; (8) grazing/herbivory/browsing; (9) chemical; (10) physical or (11) structural impact on an ecosystem; and (12) interaction with other alien species] using the Environmental Impact Classification for Alien Taxa scheme (EICAT; Blackburn et al. (2014)). Socio-economic impacts were classified according to the constituents of human well-being they affect [i.e. (1) safety; (2) material and immaterial assets; (3) health; and (4) social, spiritual and cultural relations] using the Socio-economic Impact Classification for Alien Taxa scheme (SEICAT; Bacher et al. (2017)). Lastly, the magnitude of impact (i.e. massive, major, moderate, minor, minimal or data deficient) reported previously in literature was assigned for each species. Classification of magnitude was based on the maximum impact noted for the species, regardless of location, following Kumschick et al. (2017).

## Results

Seventy-nine African marine protected areas (MPAs) were identified across 14 countries (Fig. 1, Suppl. material 2: table S2). A total of 497 marine species were reported as alien in coastal African countries (Suppl. material 2: table S3) on the World Register of Introduced Species (WRiMS), with a total of 440 iNaturalist records for 34 of those species reported from within African MPAs. After excluding records that were not scorable and those with low confidence scores, 307 records (70%) of 27 species were retained for further analysis (Table 1, Suppl. material 2: table S4). Over two-thirds of these observations [211 records (72%)] received a maximum score for image clarity. Examples of such records are provided in Fig. 2.

Of the 27 species recorded on iNaturalist, four were observed within countries with no previous records according to WRiMS. These species included the barnacle *Balanus trigonus* (Mauritania), the bryozoan *Amathia verticillata* (Mauritania and South Africa), the colonial tunicate *Symplegma brakenhielmi* (Senegal) and the crab *Callinectes sapidus* (Guinea-Bissau and Mauritania).

A general trend of increased engagement on iNaturalist was observed, with records of marine alien species in African MPAs increasing significantly over time (Kendall's rank correlation: $\tau = 0.51$, $p < 0.05$; Fig. 3). Records were spread across 17 MPAs from seven countries (Fig. 4). Two MPAs accounted for 85.7% of all records (i.e. Table Mountain National Park MPA (South Africa) and Banc d'Arguin National Park (Mauritania)], with many other MPAs having fewer than five records. Table Mountain National Park MPA had the most records of alien taxa [i.e. 241 records (78.5%)] and the highest number of species detected on iNaturalist (15 species). The MPA with the second highest number of records was Banc d'Arguin National Park in Mauritania (22 records; 7.2%), the second highest number of species (8 species) was also detected in this MPA.

Of the 27 alien species detected in African MPAs, environmental impact had been reported for 23 species and socio-economic impact for 14 species (Suppl.

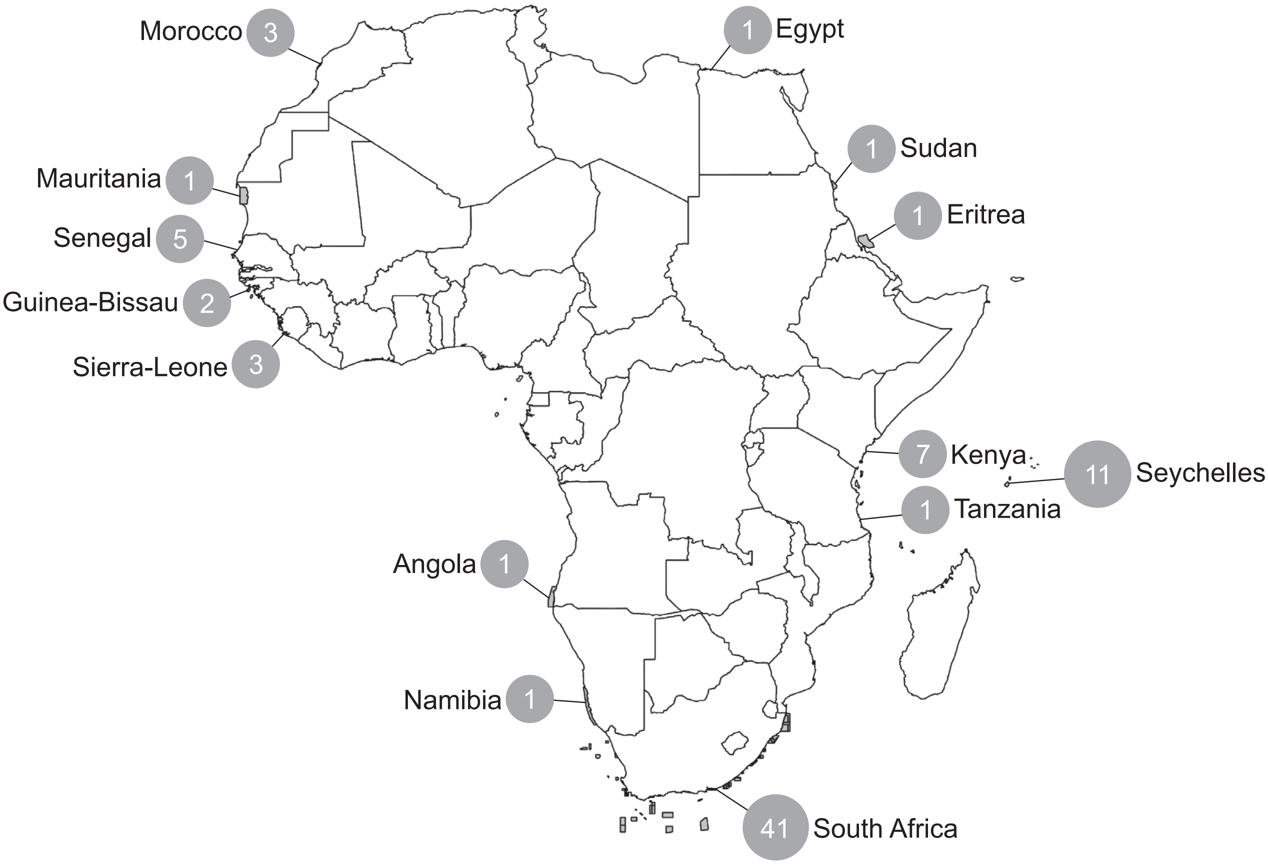


**Figure 1.** Location of the 14 African countries and the number of marine protected areas declared within those countries on the Protected Planet database.

material 2: table S5) and four species were listed as data deficient. Namibian Islands (Namibia) and Langebaan Lagoon (South Africa) were the only MPAs that supported species with massive (i.e. the oyster *Magallana gigas* and the Mediterranean mussel *Mytilus galloprovincialis*) and major impact (i.e. the mussel *Semimytilus patagonicus*, the ascidian *Ciona robusta* and the bryozoan *Amathia verticillata*). Table Mountain National Park MPA in South Africa had the highest number of species with previously documented impacts. This MPA had a single species known for massive impact (i.e. the Mediterranean mussel *Mytilus galloprovincialis*) and three species for which major impact had been reported (i.e. the European green crab *Carcinus maenas*, the mussel *Semimytilus patagonicus* and the ascidian *Ciona robusta*). Banc d'Arguin National Park in Mauritania had the second highest number of species with previously documented impacts. While some species displayed only environmental mechanisms of impact, a general pattern was that species that exerted environmental impact through multiple mechanisms also had many mechanisms of socio-economic impact and ultimately exerted high impacts (Pearson's product-moment correlation: r = 0.79, $p < 0.001$; Fig. 5, Suppl. material 2: table S5). Three species had a high number of environmental and socio-economic mechanisms of impact (i.e. the oyster *Magallana gigas* and the mussels *Mytilus galloprovincialis* and *Semimytilus patagonicus*). The Pacific oyster, *Magallana gigas*, had the highest number of mechanisms through which it has caused environmental and socio-economic impacts. This species was only observed within Namibian Islands MPA in Namibia.

**Table 1.** The species detected on iNaturalist within African marine protected areas and the magnitude of their environmental impact (as per Blackburn et al. 2014) and socio-economic impact (as per Bacher et al. 2017). Marine protected area codes are as follows: iSimangaliso (iSi); Aliwal (Ali); Protea Banks (Pro); Amathole (Ama); Addo Elephant (Add); Betty's Bay (Bet); Table Mountain National Park Marine Protected Area (Tmn); Robben Island (Rob); Sixteen Mile Beach (Smb); Langebaan Lagoon (Lan); Namaqua National Park (Nam); Namibian Islands (Nim); Namibe Marine (Nmc); Ihas Formosa, Nago & Tchedia (Iha); Gorée (Gor); Banc d'Arguin National Park (Ban) and Massa (Mas). Numbers (#) assigned to species correspond to the numbers in Figs 4, 5.

| # | Scientific name | Country | Marine protected area | Environmental impact | Socio-economic impact | Impact literature |
|---|---|---|---|---|---|---|
| 1 | *Ectopleura crocea* | South Africa | Tmn | Moderate | Minor | Fitridge and Keough 2013; Yan et al. 2021 |
| 2 | *Obelia dichotoma* | South Africa | Tmn | Moderate | Data deficient | Wyatt et al. 2005 |
| 3 | *Tridentata marginata* | Mauritania | Ban | Data deficient | Data deficient | |
| 4 | *Anisolabis maritima* | South Africa | Tmn | Data deficient | Data deficient | |
| 5 | *Amphibalanus venustus* | South Africa | Ali; Ama | Data deficient | Data deficient | |
| 6 | *Balanus glandula* | South Africa | Ali; Tmn | Moderate | Data deficient | Kado 2003; Vallarino and Elias 2008 |
| 7 | *Balanus trigonus* | Angola | Nmc | Minimal | Minimal | Lozano-Cortès and Zapata 2014; Abelouah et al. 2024 |
| | | Mauritania | Ban | | | |
| 8 | *Megabalanus tintinnabulum* | South Africa | iSi, Tmn | Moderate | Data deficient | Pfaff et al. 2022 |
| 9 | *Callinectes sapidus* | Guinea-Bissau | Iha | Major | Minor | Clavero et al. 2022; Mancinelli et al. 2017 |
| | | Mauritania | Ban | | | |
| | | Morocco | Mas | | | |
| 10 | *Carcinus maenas* | South Africa | Tmn | Major | Minor | Grosholz et al. 2011; Breen and Metaxas 2008 Whitlow 2010; de Rivera et al. 2011; Mabin et al. 2022 |
| 11 | *Amathia verticillata* | Mauritania | Ban | Major | Minor | McCann et al. 2015 |
| | | South Africa | Lan | | | |
| 12 | *Bugula neritina* | South Africa | Bet | Minor | Minor | Yu et al. 2007; Bae et al. 2022 |
| 13 | *Viridentula dentata* | South Africa | iSi; Tmn | Minimal | Data deficient | Micael et al. 2016 |
| 14 | *Watersipora subtorquata* | South Africa | Add; Tmn | Minor | Minor | Sellheim et al. 2010; McKenzie et al. 2011 |
| 15 | *Magallana gigas* | Namibia | Nam | Massive | Major | Troost 2010; Kelly et al. 2008 |
| 16 | *Mytilus galloprovincialis* | Mauritania | Ban | Massive | Major | Branch and Steffani 2004; Steffani and Branch 2005; Alexander et al. 2015 |
| | | Namibia | Nim | | | |
| | | South Africa | Lan; Nam; Rob; Smb; Tmn | | | |
| 17 | *Semimytilus patagonicus* | Namibia | Nam | Major | Major | Skein et al. 2018 |
| | | South Africa | Lan; Tmn | | | |
| 18 | *Siphonaria pectinata* | Mauritania | Ban | Minor | Data deficient | Boukhicha et al. 2015 |
| 19 | *Thecacera pennigera* | South Africa | Tmn | Data deficient | Data deficient | |
| 20 | *Ophiactis savignyi* | Guinea-Bissau | Iha | Minor | Data deficient | Çinar et al. 2019 |
| | | South Africa | Pro | | | |
| 21 | *Botryllus schlosseri* | South Africa | Tmn | Moderate | Data deficient | Wong and Vercaemer 2012 |
| 22 | *Ciona robusta* | South Africa | Lan; Tmn | Major | Minor | Robinson et al. 2017 |
| 23 | *Clavelina lepadiformis* | South Africa | Tmn | Minimal | Data deficient | Casso et al. 2018 |
| 24 | *Diplosoma listerianum* | South Africa | Tmn | Minor | Minimal | Aldred and Clare 2014 |
| 25 | *Symplegma brakenhielmi* | Senegal | Gor | Minor | Minimal | Spyksma et al. 2024 |
| 26 | *Acanthophora spicifera* | Mauritania | Ban | Moderate | Data deficient | Davidson et al. 2015 |
| 27 | *Hypnea musciformis* | Guinea-Bissau | Iha | Moderate | Minimal | Okuhata et al. 2023 |
| | | Mauritania | Ban | | | |
| | | Senegal | Gor | | | |

## Discussion

Invasive species are major drivers of global change (Pyšek et al. 2020) and invasions directly undermine the conservation objectives of protected areas (Ren et al. 2021). It is, therefore, critical to identify the protected areas that are most at risk to invasions and the species that may pose the greatest threat to them (Pyšek et al. 2020). However, the current lack of baseline data on alien species in MPAs hinders this task, since information on the scale of invasions in MPAs is lacking in most

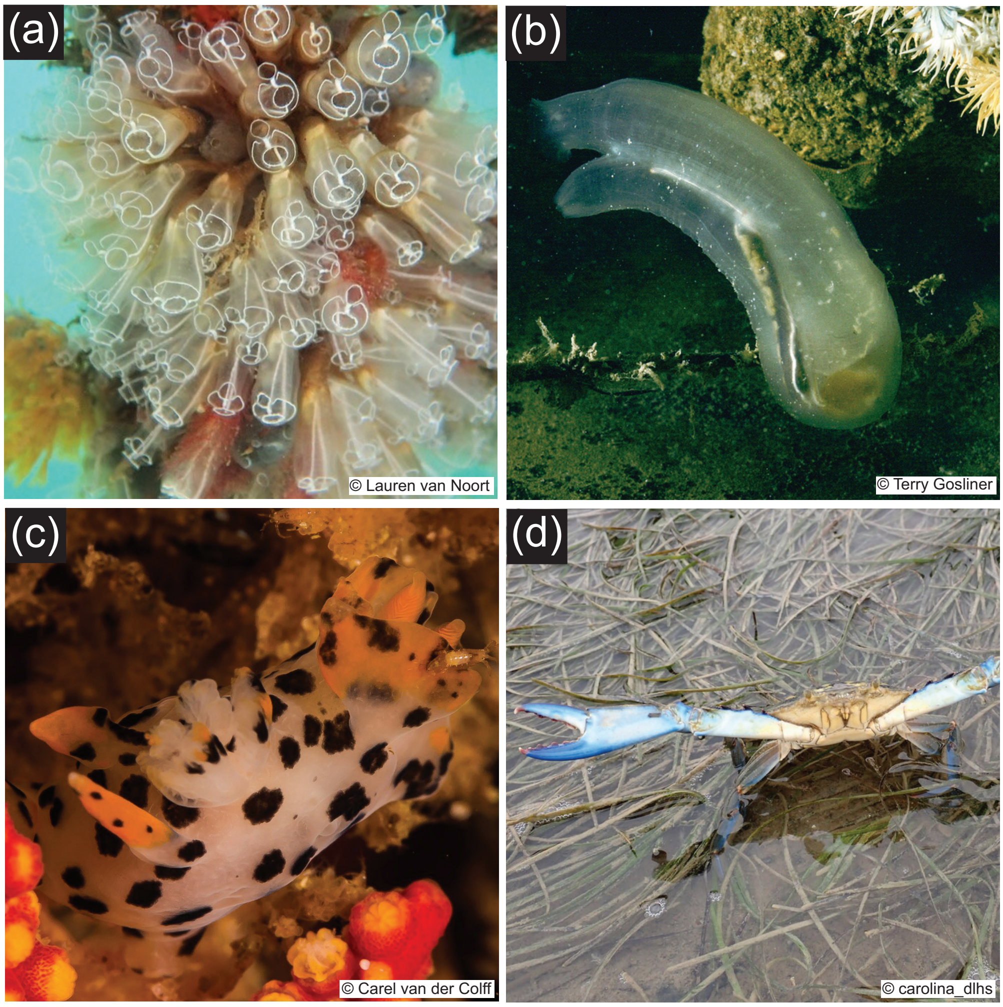


**Figure 2.** iNaturalist records that contributed towards the findings of this study. **a.** *Clavelina lepadiformis* (iNaturalist ID 152956163); **b.** *Ciona robusta* (iNaturalist ID 69033891); **c.** *Thecacera pennigera* (iNaturalist ID 23247918); **d.** *Callinectes sapidus* (iNaturalist ID 174999050).

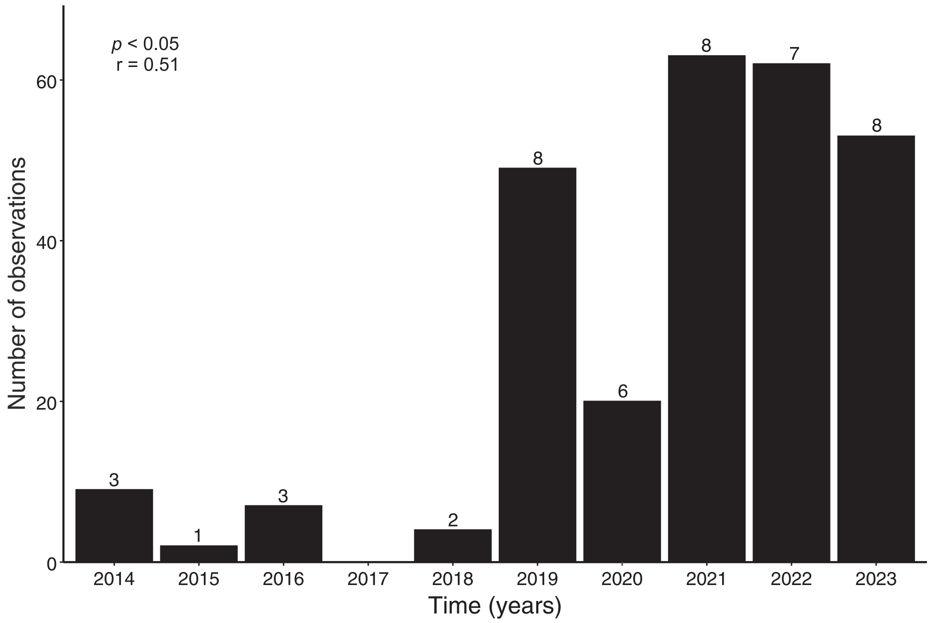


**Figure 3.** The number of alien species with records on iNaturalist in African marine protected areas (MPAs) over time. Numbers above bars indicate the number of alien species records per 100 records within African MPAs.

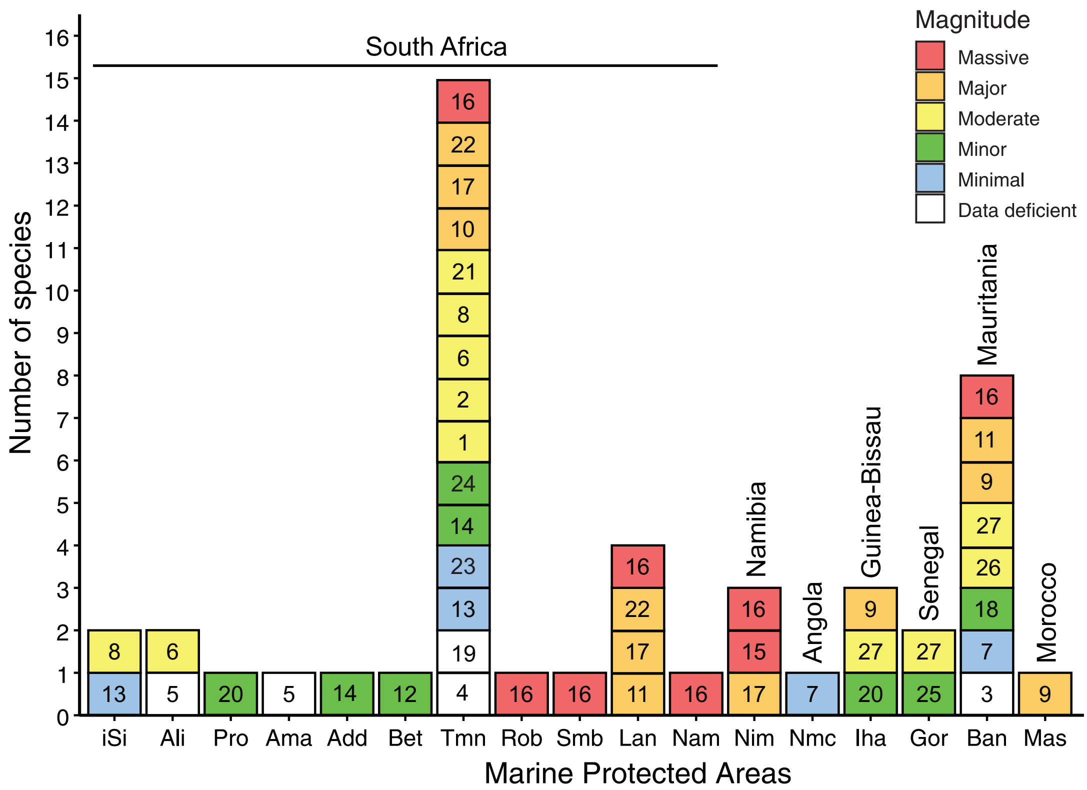


**Figure 4.** The number of marine alien species with records in iNaturalist across marine protected areas (MPAs) and the countries in which they occurred. Species are categorised according to the highest magnitude of impact noted for the species. Species codes (numbers in the boxes) are explained in Table 1. MPA names (below x axis): iSimangaliso (iSi); Aliwal (Ali); Protea Banks (Pro); Amathole (Ama); Addo Elephant (Add); Betty's Bay (Bet); Table Mountain National Park Marine Protected Area (Tmn); Robben Island (Rob); Sixteen Mile Beach (Smb); Langebaan Lagoon (Lan); Namaqua National Park (Nam); Namibian Islands (Nim); Namibe Marine (Nmc); Ihas Formosa, Nago & Tchedia (Iha); Gorée (Gor); Banc d'Arguin National Park (Ban) and Massa (Mas).

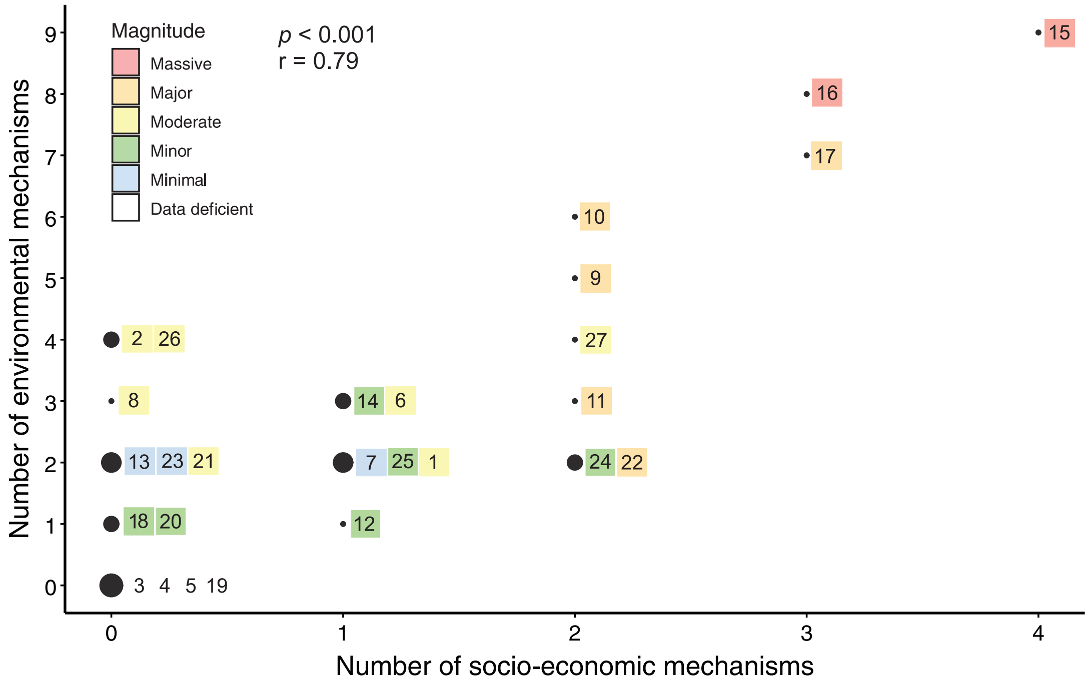


**Figure 5.** The relationship between the environmental and socio-economic mechanisms reported for each species recorded within an African marine protected area. The magnitude of impact for each species is indicated by the colours; the size of the points represents the number of species. The numbers alongside points indicate species as listed in Table 1.

regions. In response to this need, this study drew together existing information to advance our current understanding on the scale of invasions in African MPAs. Four species [the barnacle *Balanus trigonus* (Mauritania), the bryozoan *Amathia verticillata* (Mauritania and South Africa), the colonial tunicate *Symplegma brakenhielmi* (Senegal) and the crab *Callinectes sapidus* (Guinea-Bissau and Mauritania)] were documented in countries for which there were no previous records in WRiMS or in literature. Impacts were identified for all, except four species documented in this study. Two of these species (the bivalves *Mytilus galloprovincialis* and *Magallana gigas*) are known to have massive impact within invaded regions across globe.

Marine protected areas serve diverse ecological and socio-economic goals that aim to protect biodiversity and secure the ecosystem services that flow from intact systems (Sala et al. 2018; Rees et al. 2018; Giakoumi et al. 2019). This alignment with the GBF targets highlights that MPAs are important for achieving these targets. In this study, records of alien taxa were detected within 17 MPAs across seven African countries. The detection of four species in countries from which they have not previously been reported adds valuable information on alien marine species within these regions. However, it is vital for MPA managers to conduct field surveys to ground-truth these records and to determine whether these species are indeed established to provide information for possible management responses. Table Mountain National Park Marine Protected Area (TMNP MPA) in South Africa had the highest number of records and the highest number of alien species of all MPAs. There are several possible reasons for the high level of citizen science engagement in this MPA. Firstly, TMNP MPA is located within the popular tourist city of Cape Town. It is also home to a number of natural attractions, including a breeding colony of African penguins (*Spheniscus demersus*) which received about 800,000 visitors in 2019 (Kock et al. 2022). Secondly, access to most of TMNP MPA is unrestricted, enabling easy access to both locals and visitors. Furthermore, good internet coverage across the MPA facilitates engagement on the iNaturalist platform. Another way in which the uptake of records on to iNaturalist has been accelerated in this MPA is through participation in the 'City Nature Challenge' (https://www.inaturalist.org/projects/city-nature-challenge-2024-city-of-cape-town). This is a global citizen science event that aims to document biodiversity within cities over a designated period. This event is widely advertised within Cape Town, which has a large community of marine users (e.g. SCUBA divers and free-divers). Banc d'Arguin National Park in Mauritania had the second highest number of records and detections of alien species. Unlike the high community engagement with the TMNP MPA, the large number of iNaturalist records from Banc d'Arguin National Park were contributed by a small number of individuals; a single person contributed hundreds of records within this MPA in a single year. The contrasting nature of the iNaturalist users in these two MPAs highlights the importance of a strong community of observers and tourists, but also the role that 'champion' individuals have in driving use of the platform (Howard et al. 2022).

Impacts have only been studied for a small proportion of known marine alien species (Watkins et al. 2021). This is evident in large research biases towards particular invaders and the potential and actual impacts for numerous marine alien species remain unknown (Ojaveer et al. 2015; Watkins et al. 2021). In addition, complex or indirect impacts are difficult to detect (Davidson and Hewitt 2014) and there may also be a delay in the manifestation of impact due to lags in the invasion process (Crooks 2005; Iacarella et al. 2015). Nonetheless, some information on impact was available for all, but four species detected in this study. The magnitude of these reported impacts ranged from minimal to massive. Three bivalves (i.e. the Pacific oyster, *M. gigas* and the mussels, *M. galloprovincialis* and *Semimytilus patagonicus*) had the highest number of mechanisms of environmental and socio-economic impact and were classified as having either massive or major impact, highlighting the threat that they may pose within MPAs. Oysters and mussels are commercially important bivalves (Wijsman et al. 2019) and are imported for mariculture all around the world. Escapes from mariculture farms pose a biosecurity risk (Harikrishnan et al. 2024) with impacts including biofouling (Lins et al. 2021; Parisi et al. 2022), habitat alteration (Linares et al. 2022), hybridisation (Brannock and Hilbish 2010), competition with native species (Oyarzún et al. 2024) and losses in material and immaterial assets (Veiga et al. 2020). As a result, escapes can result in irreversible impacts on aquatic ecosystems (Thorvaldsen et al. 2015; Kang et al. 2022). Therefore, the identification of high-impact species, such as these bivalves in MPAs, is important as managers are then able to prioritise the allocation of resources and make strategic decisions on how to address such introductions. Prevention is the most cost-effective way to manage marine invasions (Ojaveer et al. 2015; Tsiamis et al. 2020; Simberloff 2021). Therefore, as nations expand MPA networks in response to GBF Target 3, spatial planning must address the link between invasions and mariculture (Hulme et al. 2025).

The high levels of engagement with iNaturalist in the TMNP MPA and the resulting high number of detections of alien species highlights the need to increase participation on this platform in other MPAs, if the full value of the platform is to be realised. There are a number of ways in which the use of iNaturalist can be encouraged. Events such as iNaturalist "BioBlitzes" are very useful; these aim to assess the biodiversity present within a specific geographic area over a short period of time (Meeus et al. 2023). They have engaged a large number of people worldwide in gathering and sharing information on biodiversity in both natural and urban areas (Postles and Bartlett 2018). Such events have played important roles in monitoring alien species by providing up-to-date, accurate and complete occurrence data. For example, the Texas Invasive Species BioBlitz was used to reassess previously invaded sites for alien plant species (Meeus et al. 2023). The engagement of the public and coordinated knowledge sharing is critical to boosting iNaturalist use. For example, iNaturalist has been successfully integrated into school-based initiatives (Echeverria et al. 2021) which promotes the importance of collecting biodiversity data amongst the youth.

Despite the utility of the method used in this study, limitations associated with global databases must be noted. Firstly, some species are not conducive to this form of supplemental monitoring as they are too small to record on images by amateur observers (e.g. microscopic dinoflagellates and protists) (Ackland et al. 2024). The general lack of interest in non-charismatic species (see Munzi et al. (2023)) also affects their representation in non-specialist surveys. Furthermore, although WRiMS is the most comprehensive global database currently available (Costello et al. 2021), it is a work in progress and requires continual updating. The fact that this study found no additional records during a thorough literature search shows that the database accurately reflects the current state of knowledge, at least for some regions. However, it is recommended that, where possible, management agencies should supplement these data with multifaceted studies that develop comprehensive alien species lists (Carlton and Schwindt 2024) and insights from locals and stakeholders to capture indigenous knowledge (Azzurro et al. 2019; Henke et al. 2025). Nonetheless, the methodology proposed in this paper provides a strong foundation upon which traditional survey methods can build. The method used in this study would be most beneficial for countries that are starting to create inventories of alien species [e.g. Algeria (Grimes et al. 2018) and Morocco (Mghili et al. 2024)]. In a broader context, the method proposed in this study could also be implemented to monitor areas surrounding suspected points of introduction (e.g. commercial harbours and ports) and buffer zones around protected areas to identify species that may not yet have reached the area of concern.

## Conclusions

Through the use of global databases and citizen science data from iNaturalist, this study provided novel insights on the presence of alien species in African MPAs in a cost-effective manner. The study also assessed the environmental and socio-economic impacts associated with taxa recorded in these MPAs. Together, these insights provide information that is critical for management agencies to make strategic decisions about introductions in these understudied areas of conservation importance. Moreover, these data advances regional knowledge of marine invasions and provide a foundation upon which States can begin to build their response to GBF target 6.

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## Additional information

### Conflict of interest

The authors have declared that no competing interests exist.

### Ethical statement

No ethical statement was reported.

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### Author contributions

All authors conceptualised the paper. SJA undertook the data analyses. All authors contributed to the written manuscript and approved the submission thereof.

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## Data availability

The dataset and the description thereof will be available from Zenodo (https://doi.org/10.5281/zenodo.14840792). All other associated data are provided in the Supplementary Information.

## References

Abelouah MR, Ben-Haddad M, Hajji S, Nouj N, Ouheddou M, Mghili B, De-la-Torre GE, Costa LL, Banni M, Alla AA (2024) Exploring marine biofouling on anthropogenic litter in the Atlantic coastline of Morocco. Marine Pollution Bulletin 199: 115938. https://doi.org/10.1016/j.marpolbul.2023.115938

Ackland SJ, Richardson DM, Robinson TB (2024) A method for conveying confidence in iNaturalist observations: A case study using non-native marine species. Ecology and Evolution 14: e70376. https://doi.org/10.1002/ece3.70376

Ahyong S, Boyko CB, Bernot J, et al. (2024) World Register of Marine Species. https://www.marinespecies.org [at VLIZ. Accessed 2024-09-17]

Aldred N, Clare AS (2014) Mini-review: Impact and dynamics of surface fouling by solitary and compound ascidians. The Journal of Bioadhesion and Biofilm Research 30: 259–270. https://doi.org/10.1080/08927014.2013.866653

Alexander ME, Adams R, Dick JTA, Robinson TB (2015) Forecasting invasions: Resource use by mussels informs invasion patterns along the South African coast. Marine Biology 162: 2493–2500. https://doi.org/10.1007/s00227-015-2742-5

Arndt E, Marchetti MP, Schembri PJ (2018) Ecological impact of alien marine fishes: Insights from freshwater systems based on a comparative review. Hydrobiologia 817: 457–474. https://doi.org/10.1007/s10750-018-3511-5

Azzurro E, Bolognini L, Dragičević B, Drakulović D, Dulčić J, Fanelli E, Grati F, Kolitari J, Lipej L, Magaletti E, Marković O, Matić-Skoko S, Mavrič B, Milone N, Joksimović A, Tomanić J, Scarpato A, Tutman P, Vrdoljak D, Zappacosta F (2019) Detecting the occurrence of indigenous and non-indigenous megafauna through fishermen knowledge: A complementary tool to coastal and port surveys. Marine Pollution Bulletin 147: 229–236. https://doi.org/10.1016/j.marpolbul.2018.01.016

Bacher S, Blackburn TM, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou AF, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Roy HE, Saul W-C, Scalera R, Vilà M, Wilson JRU, Kumschick S (2017) Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution 9: 159–168. https://doi.org/10.1111/2041-210X.12844

Bae S, Lee YJ, Kim MK, Kwak Y, Choi C-H, DG Kim (2022) Antifouling effects of superhydrophobic coating on sessile marine invertebrates. International Journal of Environmental Research and Public Health 19: 7973. https://doi.org/10.3390/ijerph19137973

Ban NC, Evans LS, Nenadovic M, Schoon M (2015) Interplay of multiple goods, ecosystem services, and property rights in large social-ecological marine protected areas. Ecology and Society 20: 2. https://doi.org/10.5751/ES-07857-200402

Beric B, MacIsaac HJ (2015) Determinants of rapid response success for alien invasive species in aquatic ecosystems. Biological Invasions 17: 3327–3335. https://doi.org/10.1007/s10530-015-0959-3

Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Marková Z, Mrugała A, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, JR Wilson U, Winter M, Genovesi P, Bacher S (2014) A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology 12: e1001850. https://doi.org/10.1371/journal.pbio.1001850

Borja A, Elliott M, Andersen JH, Torsten Berg, Carstensen J, Halpern BS, Heiskanen A-S, Korpinen S, Lowndes JSS, Martin G, Rodriguez-Ezpeleta N (2016) Overview of integrative assessment of marine systems: The ecosystem approach in practice. Frontiers in Marine Science 3: 20. https://doi.org/10.3389/fmars.2016.00020

Boukhicha J, Ben Hassine OK, Tlig-Zouari S (2015) On the establishment of the non-native false limpet *Siphonaria pectinata* in Tunisia: Distribution, population structure and environmental relationships. Cahiers de Biologie Marine 56: 55–64. https://doi.org/10.5555/20153055547

Bradshaw CJA, Hulme PE, Hudgins EJ, Leung B, Kourantidou M, Courtois P, Turbelin AJ, McDermott SM, Lee K, Ahmed DA, Latombe G, Bang A, Bodey TW, Haubrock PJ, Saltré F, Courchamp F (2024) Damage costs from invasive species exceed management expenditure in nations experiencing lower economic activity. Ecological Economics 220: 108166. https://doi.org/10.1016/j.ecolecon.2024.108166

Branch GM, Steffani NC (2004) Can we predict the effects of alien species? A case-history of the invasion of South Africa by *Mytilus galloprovincialis* (Lamarck). Journal of Experimental Marine Biology and Ecology 300: 189–215. https://doi.org/10.1016/j.jembe.2003.12.007

Brannock PM, Hilbish TJ (2010) Hybridization results in high levels of sterility and restricted introgression between invasive and endemic marine blue mussels. Marine Ecology Progress Series 406: 161–171. https://doi.org/10.3354/meps08522

Breen E, Metaxas A (2008) A comparison of predation rates by non-indigenous and indigenous crabs (juvenile *Carcinus maenas*, juvenile *Cancer irroratus*, and adult *Dyspanopeus sayi*) in laboratory and field experiments. Estuaries and Coasts 31: 728–737. https://doi.org/10.1007/s12237-008-9068-1

Busch J (2008) Gains from configuration: The transboundary protected area as a conservation tool. Ecological Economics 67: 394–404. https://doi.org/10.1016/j.ecolecon.2007.12.012

Carlton JT, Schwindt E (2024) The assessment of marine bioinvasion diversity and history. Biological Invasions 26: 237–298. https://doi.org/10.1007/s10530-023-03172-7

Casso M, Navarro M, Ordóñez V, Fernández-Tejedor M, Pascual M, Turon X (2018) Seasonal patterns of settlement and growth of introduced and native ascidians in bivalve cultures in the Ebro Delta (NE Iberian Peninsula). Regional Studies in Marine Science 23: 12–22. https://doi.org/10.1016/j.rsma.2017.11.002

Chukwuka AV, Adegboyegun AD, Adeogun AO (2025) Marine protected areas of Africa: Current challenges and future opportunities in conservation. Aquatic Sciences 87: 61. https://doi.org/10.1007/s00027-025-01188-w

Çinar ME, Bakir K, Doğan A, Açik S, Kurt G, Katağan T, Öztürk B, Dağli E, Özcan T, Kirkim F (2019) Macro-benthic invertebrates associated with the black sponge *Sarcotragus foetidus* (Porifera) in the Levantine and Aegean Seas, with special emphasis on alien species. Estuarine, Coastal and Shelf Science 227: 106306. https://doi.org/10.1016/j.ecss.2019.106306

Clavero M, Franch N, Bernardo-Madrid R, Clavero M, Franch N, Bernardo-Madrid R, López V, Abelló P, Queral JM, Mancinelli G (2022) Severe, rapid and widespread impacts of an Atlantic blue crab invasion. Marine Pollution Bulletin 176: 113479. https://doi.org/10.1016/j.marpolbul.2022.113479

Compagnone F, Varricchione M, Stanisci A, Matteucci G, Carranza ML (2024) Exploring the contribution of a generalist citizen science project for alien species detection and monitoring in coastal areas. A case study on the Adriatic of Central Italy. Diversity 16: 746. https://doi.org/10.3390/d16120746

Costello MJ, Dekeyzer S, Galil BS (2021) Introducing the World Register of Introduced Marine Species (WRiMS). Management of Biological Invasions 12: 792–811. https://doi.org/10.3391/mbi.2021.12.4.02

Costello MJ, Ahyong S, Bieler R, et al. (2024) World Register of Introduced Marine Species (WRiMS). https://www.marinespecies.org/introduced [Accessed on 2024-09-17]

Crain CM, Halpern BS, Beck MW, Kappel CV (2009) Understanding and managing human threats to the coastal marine environment. Annals of the New York Academy of Sciences 1162: 39–62. https://doi.org/10.1111/j.1749-6632.2009.04496.x

Crooks JA (2005) Lag times and exotic species: The ecology and management of biological invasions in slow-motion. Ecoscience 12: 316–329. https://doi.org/10.2980/i1195-6860-12-3-316.1

D'Amen M, Azzurro E (2020) Lessepsian fish invasion in Mediterranean marine protected areas: A risk assessment under climate change scenarios. ICES Journal of Marine Science 77: 388–397. https://doi.org/10.1093/icesjms/fsz207

Daniels SR, Barnes A, Peer N, Egan VT, Taylor R, Taylor RW, van der Colff D (2022) iNaturalist is useful at enhancing biodiversity studies as evident from southern African freshwater crabs (Decapoda: Brachyura: Potamonautidae). Journal of Crustacean Biology 42: 1–12. https://doi.org/10.1093/jcbiol/ruac042

Davidson AD, Hewitt CL (2014) How often are invasion-induced ecological impacts missed? Biological Invasions 16: 1165–1173. https://doi.org/10.1007/s10530-013-0570-4

Davidson AD, Campbell ML, Hewitt CL, Schaffelke B (2015) Assessing the impacts of nonindigenous marine macroalgae: An update of current knowledge. Botanica Marina 58: 55–79. https://doi.org/10.1515/bot-2014-0079

Day J, Dudley N, Hockings M, et al. (2012) Guidelines for applying the IUCN protected area management categories to marine protected areas. Gland, Switzerland IUCN. https://iucn.org/content/guidelines-applying-iucn-protected-area-management-categories-marine-protected-areas

de Rivera CE, Grosholz ED, Ruiz GM (2011) Multiple and long-term effects of an introduced predatory crab. Marine Ecology Progress Series 429: 145–155. https://doi.org/10.3354/meps09101

Delaney DG, Sperling CD, Adams CS, Leung B (2008) Marine invasive species: Validation of citizen science and implications for national monitoring networks. Biological Invasions 10: 117–128. https://doi.org/10.1007/s10530-007-9114-0

Echeverria A, Ariz I, Moreno J, Peralta J, Gonzalez EM (2021) Learning plant biodiversity in nature: The use of the citizen-science platform iNaturalist as a collaborative tool in secondary education. Sustainability 13: 735. https://doi.org/10.3390/su13020735

Evariste FF, Jean SD, Victor K, Claudia M (2018) Assessing climate change vulnerability and local adaptation strategies in adjacent communities of the Kribi-Campo coastal ecosystems, South Cameroon. Urban Climate 24: 1037–1051. https://doi.org/10.1016/j.uclim.2017.12.007

Fitridge I, Keough MJ (2013) Ruinous resident: The hydroid *Ectopleura crocea* negatively affects suspended culture of the mussel *Mytilus galloprovincialis.* Biofouling 29: 119–131. https://doi.org/10.1080/08927014.2012.752465

Giakoumi S, Pey A, Di Franco A, Francour P, Kizilkaya Z, Arda Y, Raybaud V, Guidetti P (2019) Exploring the relationships between marine protected areas and invasive fish in the world's most invaded sea. Ecological Applications 29: e01809. https://doi.org/10.1002/eap.1809

Grimes S, Benabdi M, Babali N, Refes W, Boudjellal-Kaidi N, Seridi H (2018) Biodiversity changes along the Algerian coast (Southwest Mediterranean basin): from 1834 to 2017: a first assessment of introduced species. Mediterranean Marine Science 19: 156–179. https://doi.org/10.12681/mms.13824

Grosholz E, Lovell S, Besedin E, Katz M (2011) Modelling the impacts of the European green grab on commercial shellfisheries. Ecological Applications 21: 915–924. https://doi.org/10.1890/09-1657.1

Harikrishnan M, Syanya FJ, Khanna ARN, Mumina P, Mathia WM. (2024) Ecological implications of unintentional aquaculture escapees: An overview of risks, remediation strategies and knowledge gaps in the aquaculture sector of India and riparian East African countries. Marine and Fishery Sciences 37: 1–35. https://doi.org/10.47193/mafis.3742024010709

Henke T, Bárðarson H, Thorlacius M, Ólafsdóttir GA (2025) Have you seen this fish? Important contribution of stakeholder observations in documenting the distribution and spread of an alien fish species in Iceland. NeoBiota 97: 67–90. https://doi.org/10.3897/neobiota.97.132365

Horwitz R, Norin T, Watson S, JC Pistevos A, Beldade R, Hacquart S, J-P Gattuso, Rodolfo-Metalpa R, Vidal-Dupiol J, Killen SS, Mills SC (2020) Near-future ocean warming and acidification alter foraging behaviour, locomotion, and metabolic rate in a keystone marine mollusc. Scientific Reports 10: 5461. https://doi.org/10.1038/s41598-020-62304-4

Howard L, van Rees CB, Dahlquist Z, Luikart G, Hand BK (2022) A review of invasive species reporting apps for citizen science and opportunities for innovation. NeoBiota 71: 165–188. https://doi.org/10.3897/neobiota.71.79597

Hulme PE, Pyšek P, Pergl J, Jarošík V, Schaffner U, Vilà M (2014) Greater focus needed on alien plant impacts in protected areas. Conservation Letters 7: 459–466. https://doi.org/10.1111/conl.12061

Hulme PE, Lieurance D, Richardson DM, Robinson TB (2025) Multiple targets of the Global Biodiversity Framework must be addressed to manage invasive alien species in protected areas. NeoBiota 99: 149–170. https://doi.org/10.3897/neobiota.99.152680

Iacarella JC, Mankiewicz PS, Ricciardi A (2015) Negative competitive effects of invasive plants change with time since invasion. Ecosphere 6: 1–14. https://doi.org/10.1890/ES15-00147.1

Kado R (2003) Invasion of Japanese shores by the NE Pacific barnacle *Balanus glandula* and its ecological and biogeographical impact. Marine Ecology Progress Series 249: 199–206. https://doi.org/10.3354/meps249199

Kang B, Vitule JRS, Li S, Shuai F, Huang L, Huang X, Fang J, Shi X, Zhu Y, Xu D, Yan Y, Lou F (2022) Introduction of non-native fish for aquaculture in China: A systematic review. Reviews in Aquaculture 15: 676–703. https://doi.org/10.1111/raq.12751

Kelly JR, Proctor H, Volpe JP (2008) Intertidal community structure differs significantly between substrates dominated by native eelgrass (*Zostera marina* L.) and adjacent to the introduced oyster *Crassostrea gigas* (Thunberg) in British Columbia, Canada. Hydrobiologia 596: 57–66. https://doi.org/10.1007/s10750-007-9057-6

Kock AA, Stanbridge D, Brink R, et al. (2022) Table Mountain National Park Marine Protected Area - State of Knowledge. Internal Report, South African National Parks, Scientific Services, Pretoria, 47 pp.

Kumar Rai P, Singh JS (2020) Invasive alien plant species: Their impact on environment, ecosystem services and human health. Ecological Indicators 111: 106020. https://doi.org/10.1016/j.ecolind.2019.106020

Kumschick S, Measey JG, Vimercati G, de Villiers FA, Mokhatla MM, Davies SJ, Thorp CJ, Rebelo AD, Blackburn TM, Kraus F (2017) How repeatable is the environmental impact classification of alien taxa (EICAT)? Comparing independent global impact assessments of amphibians. Ecology and Evolution 7: 2661–2670. https://doi.org/10.1002/ece3.2877

Lehtiniemi M, Outinen O, Puntila-Dodd R (2020) Citizen science provides added value in the monitoring for coastal non-indigenous species. Journal of Environmental Management 267: 110608. https://doi.org/10.1016/j.jenvman.2020.110608

Linares MS, Macedo DR, Marques JC, Callisto M (2022) Anthropogenically physically changed habitats enable an easier propagation of invasive bivalve in neotropical headwater streams. Biological Invasions 24: 3855–3863. https://doi.org/10.1007/s10530-022-02886-4

Lins DM, Zbawicka M, Wenne R, Poćwierz-Kotus A, JMolina RA, Alves LP, Rocha RM (2021) Ecology and genetics of *Mytilus galloprovincialis*: A threat to bivalve aquaculture in southern Brazil. Aquaculture (Amsterdam, Netherlands) 540: 736753. https://doi.org/10.1016/j.aquaculture.2021.736753

Lockwood JL, Hoopes MF, Marchetti MP (2013) Invasion ecology (2nd edn.) Wiley-Blackwell, Oxford.

Loureiro TG, Peters K, Robinson TB (2021) Dropping plates to pick up aliens: Towards a standardised approach for monitoring alien fouling species. African Journal of Marine Science 43: 483–497. https://doi.org/10.2989/1814232X.2021.1989488

Lozano-Cortés DF, Zapata FA (2014) Invertebrate colonization on artificial substrates in a coral reef at Gorgona Island, Colombian Pacific Ocean. Revista de Biología Tropical 62: 161–168. https://doi.org/10.15517/rbt.v62i0.16273

Mabin CA, Robinson TB, Wilson JRU, Hirsch H, Castillo ML, Jooste M, Roux JJL (2022) Molecular insights into the invasion dynamics of *Carcinus* crabs in South Africa. Biological Invasions 24: 3597–3613. https://doi.org/10.1007/s10530-022-02865-9

Mancinelli G, Chainho P, Cilenti L, Falco S, Kapiris K, Katselis G, Ribeiro F (2017) The Atlantic blue crab *Callinectes sapidus* in southern European coastal waters: Distribution, impact and prospective invasion management strategies. Marine Pollution Bulletin 119: 5–11. https://doi.org/10.1016/j.marpolbul.2017.02.050

McCann L, Keith I, Carlton JT, Ruiz GM, Dawson TP, Collins K (2015) First record of the non-native bryozoan *Amathia* (= *Zoobotryon*) *verticillata* (delle Chiaje, 1822) (Ctenostomata) in the Galápagos Islands. BioInvasions Records 4: 255–260. https://doi.org/10.3391/bir.2015.4.4.04

McKenzie LA, Brooks R, Johnston EL (2011) Heritable pollution tolerance in a marine invader. Environmental Research 111: 926–932. https://doi.org/10.1016/j.envres.2010.12.007

Meeus S, Silva-Rocha I, Adriaens T, Brown PMJ, Chartosia N, Claramunt-López B, Martinou AF, MJPocock O, Preda C, Roy HE, Tricarico E, Groom QJ (2023) More than a bit of fun: The multiple outcomes of a bioblitz. Bioscience 73: 168–181. https://doi.org/10.1093/biosci/biac100

Mghili B, Lamine I, Laamraoui MR, Aksissou M, Galanidi M (2024) Updating the national list of marine alien species in Morocco. Mediterranean Marine Science 25: 231–249. https://doi.org/10.12681/mms.35846

Micael J, Jardim N, Núñez C, Occhipinti-Ambrogi A, Costa AC (2016) Some Bryozoa species recently introduced into the Azores: Reproductive strategies as a proxy for future spread. Helgoland Marine Research 70: 7. https://doi.org/10.1186/s10152-016-0458-7

Munzi S, Isocrono D, Ravera S (2023) Can we trust iNaturalist in lichenology? Evaluating the effectiveness and reliability of artificial intelligence in lichen identification. Lichenologist 55: 193–201. https://doi.org/10.1017/S0024282923000403

Nuñez MA, Pauchard A (2010) Biological invasions in developing and developed countries: Does one model fit all? Biological Invasions 12: 707–714. https://doi.org/10.1007/s10530-009-9517-1

Ojaveer H, Galil BS, Campbell ML, Carlton JT, Canning-Clode J, Cook EJ, Davidson AD, Hewitt CL, Jelmert A, Marchini A, McKenzie CH, Minchin D, Occhipinti-Ambrogi A, Olenin S, Ruiz G (2015) Classification of non-indigenous species based on their impacts: Considerations for application in marine management. PLoS Biology 13: e1002130. https://doi.org/10.1371/journal.pbio.1002130

Okuhata BK, Delevaux JMS, Richards Donà A, Smith CM, Gibson VL, Dulai H, El-Kadi AI, Stamoulis K, Burnett KM, Wada CA, Bremer LL (2023) Effects of multiple drivers of environmental change on native and invasive macroalgae in nearshore groundwater dependent ecosystems. Water Resources Research 59: e2023WR034593. https://doi.org/10.1029/2023WR034593

Oyarzún PA, Toro JE, Nuñez JJ, et al. (2024) The Mediterranean mussel *Mytilus galloprovincialis* (Mollusca: Bivalvia) in Chile: distribution and genetic structure of a recently introduced invasive marine species. Animals 14: 823. https://doi.org/10.3390/ani14060823

Parisi C, Sandonnini J, Coppola MR, Madonna A, Abdel-Gawad FK, Sivieri EM, Guerriero G (2022) Biocide vs. eco-friendly antifoulants: Role of the antioxidative defence and settlement in *Mytilus galloprovincialis.* Journal of Marine Science and Engineering 10: 792. https://doi.org/10.3390/jmse10060792

Pfaff MC, Biccard A, Mvula PE, Olbers J, Mushanganyisi K, Macdonald A, Samaai T (2022) Giants and titans: First records of the invasive acorn barnacles *Megabalanus tintinnabulum* (Linnaeus, 1758) and *Megabalanus coccopoma* (Darwin, 1854) on intertidal rocky shores of South. BioInvasions Records 11: 721–737. https://doi.org/10.3391/bir.2022.11.3.14

Pimm SL, Alibhai S, Bergl R, Dehgan A, Giri C, Jewell Z, Joppa L, Kays R, Loarie S (2015) Emerging technologies to conserve biodiversity. Trends in Ecology & Evolution 30: 685–696. https://doi.org/10.1016/j.tree.2015.08.008

Postles M, Bartlett M (2018) The rise of bioblitz: Evaluating a popular event format for public engagement and wildlife recording in the United Kingdom. Applied Environmental Education and Communication 17: 365–379. https://doi.org/10.1080/1533015X.2018.1427010

Potgieter LJ, ter Huurne MB, Richardson DM (2024) Community science can inform invasive species management: Melaleuca (Myrtaceae) in South Africa. Ecological Solutions and Evidence 5: e12391. https://besjournals.onlinelibrary.wiley.com/doi/10.1002/2688-8319.12391

Pyšek P, Richardson DM, Pergl J, Jarošík V, Sixtová Z, Weber E (2008) Geographical and taxonomic biases in invasion ecology. Trends in Ecology & Evolution 23: 237–244. https://doi.org/10.1016/j.tree.2008.02.002

Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT, Dawson W, Essl F, Foxcroft LC, Genovesi P, Jeschke JM, Kühn I, Liebhold AM, Mandrak NE, Meyerson LA, Pauchard A, Pergl J, Roy HE, Seebens H, van Kleunen M, Vilà M, Wingfield MJ, Richardson DM (2020) Scientists' warning on invasive alien species. Biological Reviews of the Cambridge Philosophical Society 95: 1511–1534. https://doi.org/10.1111/brv.12627

R Core Team (2023) R: A language and environmental for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Rees SE, Pittman SJ, Foster N, Langmead O, Griffiths C, Fletcher S, Johnson DE, Attrill M (2018) Bridging the divide: Social-ecological coherence in marine protected area network design. Aquatic Conservation 28: 754–763. https://doi.org/10.1002/aqc.2885

Ren J, Chen J, Xu C, et al. (2021) An invasive species erodes the performance of coastal wetland protected areas. Science Advances 7: eabi8943. https://doi.org/10.1126.sciadv.abi8943

Renchen GF, Butler CB, Matthews TR (2021) Marine debris knows no boundaries: Characteristics of debris accumulation in marine protected areas of the Florida Keys. Marine Pollution Bulletin 173: 112957. https://doi.org/10.1016/j.marpolbul.2021.112957

Ricciardi A, Iacarella JC, Aldridge DC, Blackburn TM, Carlton JT, Catford JA, J Dick TA, Hulme PE, Jeschke JM, Liebhold AM, Lockwood JL, MacIsaac HJ, Meyerson LA, Pyšek P, Richardson DM, Ruiz GM, Simberloff D, Vilà M, Wardle DA (2021) Four priority areas to advance invasion science in the face of rapid environmental change. Environmental Reviews 29: 119–141. https://doi.org/10.1139/er-2020-0088

Richardson DM, Pyšek P, Carlton JT (2011) A compendium of essential concepts and terminology in invasion ecology. In: Richardson DM (Ed.) Fifty years of invasion ecology. The legacy of Charles Elton. Wiley-Blackwell, Oxford, 409–420. https://doi.org/10.1002/9781444329988.ch30

Richardson DM, Witt ABR, Pergl J, Dawson W, Essl F, Kreft H, van Kleunen M, Weigelt P, Winter M, Pyšek P (2022) Plant invasions in Africa. In: Clements DR, Upadhyaya MK, Joshi S, Shrestha A (Eds) Global plant invasions. Springer International Publishing, Cham, 225–252. https://doi.org/10.1007/978-3-030-89684-3_11

Roberts CJ, Vergés A, Callaghan CT, Poore AGB (2022) Many cameras make light work: Opportunistic photographs of rare species in iNaturalist complement structured surveys of reef fish to better understand species richness. Biodiversity and Conservation 31: 1407–1425. https://doi.org/10.1007/s10531-022-02398-6

Robinson TB, Havenga B, Van Der Merwe M, Jackson S (2017) Mind the gap - context dependency in invasive species impacts: A case study of the ascidian *Ciona robusta.* NeoBiota 32: 127–141. https://doi.org/10.3897/neobiota.32.9373

Robinson TB, Hulme PE, Lieurance D, Richardson DM (2025) Managing invasions in protected areas: Seeking new strategies to achieve global targets. Biological Invasions 27: 118. https://link.springer.com/article/10.1007/s10530-025-03581-w

Rocha RM, Azevedo F, Oliveira U, Cardoso MNM, Clerier PHB, Fortes RR, Lopes-Filho EAP, Lorini ML, Miranda LS, Moura RB, Senna AR, Silva FM, Stampar SN, Venekey V (2024) West

Atlantic coastal marine biodiversity: The contribution of the platform iNaturalist. Aquatic Ecology 58: 57–71. https://doi.org/10.1007/s10452-023-10062-6

Sala E, Lubchenco J, Grorud-Colvert K, Novelli C, Roberts C, Sumaila UR (2018) Assessing real progress towards effective ocean protection. Marine Policy 91: 11–13. https://doi.org/10.1016/j.marpol.2018.02.004

Sellheim K, Stachowicz JJ, Coates R (2010) Effects of a nonnative habitat-forming species on mobile and sessile epifaunal communities. Marine Ecology Progress Series 398: 69–80. https://doi.org/10.3354/meps08341

Shackleton RT, Shackleton CM, Kull CA (2019) The role of invasive alien species in shaping local livelihoods and human well-being: A review. Environmental Management 229: 145–157. https://doi.org/10.1016/j.jenvman.2018.05.007

Shackleton RT, Foxcroft LC, Pyšek P, Wood LE, Richardson DM (2020) Assessing biological invasions in protected areas after 30 years: Revisiting nature reserves targeted by the 1980s SCOPE programme. Biological Conservation 243: 108424. https://doi.org/10.1016/j.biocon.2020.108424

Simberloff D (2021) Maintenance management and eradication of established aquatic invaders. Hydrobiologia 848: 2399–2420. https://doi.org/10.1007/s10750-020-04352-5

Skein L, Robinson TB, Alexander ME (2018) Impacts of mussel invasions on the prey preference of two native predators. Behavioural Ecology 29: 353–359. https://doi.org/10.1093/beheco/arx172

Spyksma AJP, Miller KI, Shears NT (2024) Marine heatwave promotes population expansion of the invasive ascidian *Symplegma brakemhielmi*. Biological Invasions 26: 1987–1995. https://doi.org/10.1007/s10530-024-03296-4

Steffani CN, Branch GM (2005) Mechanisms and consequences of competition between an alien mussel, *Mytilus galloprovincialis*, and an indigenous limpet, *Scutellastra argenvillei*. Journal of Experimental Marine Biology and Ecology 317: 127–142. https://doi.org/10.1016/j.jembe.2004.11.022

Thorvaldsen T, Holmen IM, Moe HK (2015) The escape of fish from Norwegian fish farms: Causes, risks and the influence of organisational aspects. Marine Policy 55: 33–38. https://doi.org/10.1016/j.marpol.2015.01.008

Troost K (2010) Causes and effects of a highly successful marine invasion: Case-study of the introduced Pacific oyster *Crassostrea gigas* in continental NW European estuaries. Journal of Sea Research 64: 145–165. https://doi.org/10.1016/j.seares.2010.02.004

Tsiamis K, Azzurro E, Bariche M, Çinar ME, Crocetta F, Clerck OD, Galil B, Gómez F, Hoffman R, Jensen KR, Kamburska L, Langeneck J, Langer MR, Ya'arit Levitt-Barmats, Lezzi M, Marchini A, Occhipinti-Ambrogi A, Ojaveer H, Piraino S, Shenkar N, Yankova M, Zenetos A, Žuljević A, Cardoso AC (2020) Prioritizing marine invasive alien species in the European Union through horizon scanning. Aquatic Conservation 30: 794–845. https://doi.org/10.1002/aqc.3267

Vallarino EA, Elias R (2008) The dynamics of an introduced: *Balanus glandula* population in the Southwestern Atlantic rocky shores. The consequences on the intertidal community. Marine Ecology (Berlin) 18: 319–335. https://doi.org/10.1111/j.1439-0485.1997.tb00445.x

Veiga P, Ramos-Oliveira C, Sampaio L, Rubal M (2020) The role of urbanisation in affecting *Mytilus galloprovincialis*. PLoS One 15: e0232797. https://doi.org/10.1371/journal.pone.0232797

Watkins HV, Yan HF, Dunic JC, Côté IM (2021) Research biases create overrepresented "poster children" of marine invasion ecology. Conservation Letters 14: e12802. https://doi.org/10.1111.12802

Whitlow WL (2010) Changes in survivorship, behaviour, and morphology in native soft-shell clams induced by invasive green crab predators. Marine Ecology (Berlin) 31: 418–430. https://doi.org/10.1111/j.1439-0485.2009.00350.x

Wijsman JWM, Troost K, Fang J Roncarati (2019) Global production of marine bivalves. Trends and challenges. In: Smaal AC, Ferreira JG, Grant J, et al. (Eds) Goods and Services of Marine Bivalves. Springer, Cham, 7–26. https://doi.org/10.1007/978-3-319-96776-9_2

Witt A, Beale T, Van Wilgen BW (2018) An assessment of the distribution and potential ecological impacts of invasive alien plant species in eastern Africa. Transactions of the Royal Society of South Africa 73: 217–236. https://doi.org/10.1080/0035919X.2018.1529003

Wong MC, Vercaemer B (2012) Effects of invasive colonial tunicates and a native sponge on the growth, survival, and light attenuation of eelgrass (*Zostera marina*). Aquatic Invasions 7: 315–326. https://doi.org/10.3391/ai.2012.7.3.003

Wyatt ASJ, Hewitt CL, Walker DI, Ward TJ (2005) Marine introductions in the Shark Bay World Heritage Property, Western Australia: A preliminary assessment. Diversity & Distributions 11: 33–44. https://doi.org/10.1111/j.1366-9516.2005.00109.x

Yan T, Lin M, Cao W, Han S, Song X (2021) Fouling characteristics of cnidarians (Hydrozoa and Anthozoa) along the coast of China. Journal of Oceanology and Limnology 39: 2220–2236. https://doi.org/10.1007/s00343-021-0242-7

Yu X, Yan Y, Gu J (2007) Attachment of the biofouling bryozoan *Bugula neritina* larvae affected by inorganic and organic chemical cues. International Biodeterioration & Biodegradation 60: 81–89. https://doi.org/10.1016/j.ibiod.2006.12.993

Zengeya TA, Wilson JR [Eds] (2023) The status of biological invasions and their management in South Africa in 2022. Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch, South African National Biodiversity Institute.

## Supplementary material 1

### Filters used to identify marine protected areas along the coast of Africa on the Protected Planet database

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Data type: docx



Link: https://doi.org/10.3897/neobiota.102.149275.suppl1

## Supplementary material 2

### Supplementary information

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Data type: xlsx

Explanation note: **table S2.** Marine protected areas identified from the Protected Planet database and the countries in which they have been declared. **table S3.** Marine alien species as identified on WRiMs and the countries in which they have been reported. **table S4.** Species reported within African marine protected areas on iNaturalist. **table S5.** The assessment of the magnitude of impact of species according to the EICAT (Blackburn et al. 2014) and SEICAT (Bacher et al. 2017) schemes.



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