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First insights into marine invasions along the Namibian coast

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Background: Alien species are a growing concern due to harmful impacts on the environment and ecosystem services. However, relatively little information exists about alien marine species in Namibia.

Objectives: To compile the first list of marine alien and cryptogenic species for Namibia.

Methods: A systematic search of the primary literature was combined with searches of historic taxonomic literature, the World Register of Introduced Marine Alien Species (WRiMS), the Global Biodiversity Information Facility (GBIF), the Ocean Biodiversity Information Systems (OBIS), iNaturalist and the grey literature, to identify alien and cryptogenic species that have been reported from Namibia.

Results: A total of 26 alien and 12 cryptogenic species have been documented along the Namibian coast. Most species have a Northern Hemisphere native range and more than half were first recorded pre-2000. The primary likely mechanism of introduction has been shipping [i.e., hull fouling (63% of species), ballast water (20%) and ship boring (7%)] but mariculture (10%) has also played a role. The Ikaras Region supports the most alien (23) and cryptogenic (11) species. This likely reflects the presence of the busy Robert Harbour in Lüderitz, the proximity to the South African west coast, which is known to support >60 alien species and the fact that this region is the most accessible and well studied.

Conclusion: This study provides first insights into marine invasions in Namibia, but dedicated surveys for alien taxa will improve our understanding of the full extent of invasions along the Namibian coast.

Keywords: alien species, bioinvasions, coastal, introductions, Namibia.

Introduction

In recognition of the impacts alien species can have on natural ecosystems (Kumschick et al. 2015; Bailey et al. 2022), the human interests associated with introduced species (Vimercati et al. 2020) and the increase in emerging alien species forecast for the future (Seebens et al. 2021), there is a need to develop effective management strategies to prevent and manage invasions. In response to this need, the Kunming-Montreal Global Biodiversity Framework (GBF) as developed under the Convention on Biological Diversity (CBD), has dedicated Target 6 to addressing biological invasions by reducing the introduction and establishment of alien species by 50% by 2030 (CBD/COP/DEC/15/4). In response to this target, signatories (such as Namibia) are required to track invasions (McGeoch et al. 2023). As lists of alien species provide a measure of the scale of invasions in a country (McGeoch et al. 2010, 2012; Verbrugge et al. 2012), the development of lists is the first step in managing biological invasions (Moshobane et al. 2019). Although lists are not without inaccuracies (Jacobs

et al. 2017) they are still foundational and remain an important regulatory tool (McGeoch et al. 2012).

Despite the notable impacts of invasions in Africa, only a few countries have invested in comprehensive lists of invasive species (Pyšek et al. 2020), with most lists focused on terrestrial systems. South Africa and Angola are the only two African countries to have produced lists of marine alien species. Angola reported 29 alien and seven cryptogenic species (Pestana et al. 2017). In South Africa, currently 95 marine alien species are listed with 56 of these being recognised as invasive (Robinson et al. 2020). In addition, 39 cryptogenic species are known from South Africa (Mead et al. 2011a). Notably, most marine alien species known from South Africa occur on the west coast, in the Southern Benguela region (Robinson et al. 2020).

Although Namibia shares the Southern Benguela with South Africa and Angola, research into alien species in the marine environment has been very limited (Zettler 2021). While there has been reference made to marine alien species occurring along the Namibian coast [e.g., the mussels *Semimytilus patagonicus* Hanley, 1843, previously known as *Semimytilus algosus* (e.g., Ma et al. 2020a, 2020b; Zeeman et al. 2020) and *Mytilus galloprovincialis* Lamarck, 1819 (Assis et al. 2015)], there has been no dedicated research on the topic and no national list exists. This represents a large knowledge gap that needs to be addressed if Namibia is to meet its obligations in terms of GBF Target 6. In this study the primary literature, in combination with global databases [i.e., the Global Biodiversity Information Facility (GBIF), iNaturalist, the Ocean Biodiversity Information System (OBIS), the World Register of Introduced Marine Species (WRiMS)] and grey literature (e.g., theses and museum reports) were used to compile the first comprehensive list of alien and cryptogenic species from along the coastline of Namibia.

Methods

The approach used in this study to develop a comprehensive list of alien and cryptogenic species, was guided by Carlton and Schwindt (2024). Due to the lack of data, viruses, diatoms, dinoflagellates and foraminifera were excluded. In contrast, all macro-algae, macro-invertebrates and fish were included. Habitats that were considered included estuaries and lagoons, salt marshes, intertidal rocky and sandy shores, fouling (intertidal and subtidal – both natural and artificial structures), wood boring, hard bottom subtidal, soft bottom subtidal and mariculture farms.

A systematic literature search was performed to identify peer-reviewed reports of alien marine species in Namibia. This was done using the search string 'marine AND (invasive OR alien OR exotic OR introduced OR non-native OR non-indigenous) AND (Namibia OR South West Africa)' in Google Scholar, Scopus and Web of Science. Note, South West Africa was the name of the country before independence in 1990. All searches were conducted between September and November 2024. This search produced 181 records (once duplicates had been removed). Each record was inspected for relevance and 44 were retained. To retrieve hidden records, historic regional and global taxonomic works were manually searched for reports of species for which Namibian occurrences were disjunct from the rest of the species range. Additionally, grey literature including newspapers, museum reports, MSc and PhD theses and government reports were sourced through online searches and discussions were held with research officials at the Ministry of Fisheries and Marine Resources and academics at regional universities. This process produced 15 records. The World Register of Introduced Marine Species (WRiMS) and iNaturalist was searched for alien species reported in Namibia. Moreover, the global databases Global Biodiversity Information Facility (GBIF) and Ocean Biodiversity Information System (OBIS) were used to search for occurrence records in Namibia of species that have been reported as alien or cryptogenic in neighbouring countries [i.e., South Africa (Mead et al. 2011b; Robinson et al 2020) and Angola (Pestana et al. 2017)]. This was done as species may have been noted in Namibia, but their invasion status may not have been reported, precluding them from being identified during the literature search described above.

Inclusion of the species identified through the above process onto a list of alien and cryptogenic species for Namibia was determined following Marchini et al. (2015). Species names were checked on World Register of Marine Species (WoRMS) for synonyms and nomenclature changes. Finally, species were designated as aliens or cryptogenic (*sensu* Carlton 1996).

For each species on the list, the following information was extracted from the literature: date of collection or publication (used as a proxy for date of introduction); the most likely mechanism of introduction; native range; and the Namibian region from which it was first reported (Figure 1). Native ranges were categorised by marine realms (sensu Spalding et al. 2007). If information on the native range of a species was not included in the original record, this information was sourced from published literature. The origin of cryptogenic species was classified as unknown. Additionally, the establishment status of each species was categorised following Blackburn et al. (2011). If no evidence of establishment was found for a species, establishment status was classified as unknown. Separate Chi-square tests were conducted in R version 4.4.3 (R Core Team 2024) to compare the number of alien and cryptogenic species

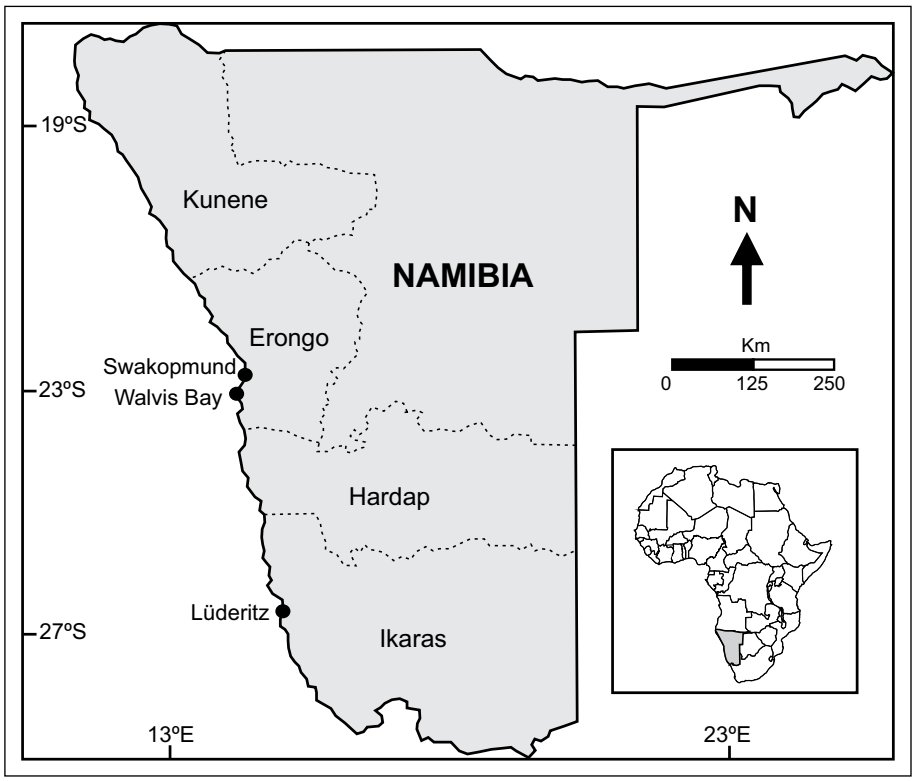

Figure 1. Map showing different coastal regions and towns of Namibia.

across taxa, the realms they originated from, the coastal regions in which they are found and their mechanisms of introduction.

Results

Twenty-six alien and 12 cryptogenic species have been reported from Namibia (Table 1). See Supplementary material for details on each species. In total 25 of these species were identified through the primary literature (including historic works), four through the grey literature, and nine by searching for alien and cryptogenic taxa known from neighbouring countries on GBIF and OBIS. While no species were identified solely through iNaturalist, the platform did supply a confirmatory record for the oyster *Magallana gigas* Thunberg, 1793. Notably, the majority (58% of both alien and cryptogenic species) have been recorded more than once, suggesting that many taxa are in fact established.

Taxonomic patterns

The number of alien and cryptogenic species varied significantly among taxonomic groups (alien: $\chi^2 = 54.55$, $p < 0.0001$; cryptogenic: $\chi^2 = 180.6$, $p < 0.0001$; Figure 2). Mollusca and Crustacea were the most dominant groups of alien taxa (6 species), followed by Ascidiacea (4 species). Crustacea accounted for the most cryptogenic taxa (5 species) followed by Cnidaria (3 species).

Spatial patterns

Of the four coastal regions in Namibia, alien and cryptogenic species have been reported from only three regions (Figure 3). The number of alien species reported differed significantly among regions ($\chi^2 = 26.42$, $p < 0.0001$), with the highest number of alien (23) and cryptogenic (11) species reported in the Ikaras region. Furthermore, the same number of alien species (9) have been recorded in the Kunene and Erongo regions. No alien and cryptogenic species have been reported from the Hardap region.

The species reported from Namibia originate from seven biogeographical realms, with the number of species differing significantly among these realms ($\chi^2 = 32.59$,

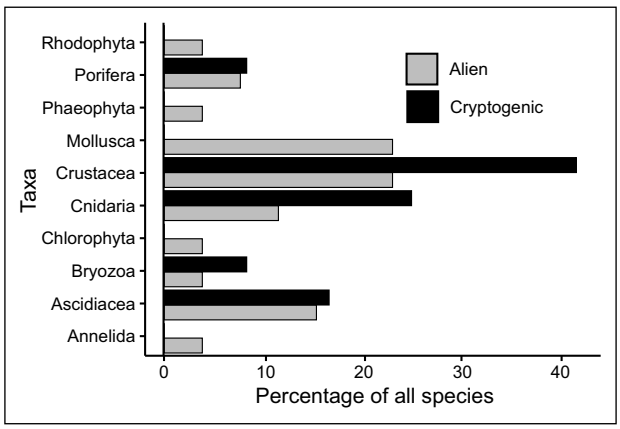

Figure 2. Percentage of Namibian alien and cryptogenic species across major taxonomic groups.

Table 1. Marine alien and cryptogenic species recorded along the Namibian Coasts. [Status: A – Alien; C – Cryptogenic. Date: DOC – Date of collection[#]; DOP – Date of publication[*]. Namibian regions: KU – Kunene; ER – Erongo; KA – Ikaras. Native ranges (following the realms defined by Spalding et al. 2007): TNA – Temperate Northern Atlantic; TNP – Temperate Northern Pacific; CIP – Central Indo-Pacific; WIP – Western Indo-Pacific; TSAM – Temperate Southern America; TSA – Temperate Southern Africa; TEP – Tropical Eastern Pacific; UN – Unknown. Establishment (following the categories of Blackburn et al. 2011): B2 – in cultivation with no measures to prevent dispersal of larvae; B3 – release directly into natural environment for cultivation; C3 – established with selfsustained populations in the wild; E – fully invasive species surviving and reproducing at multiple sites; UN – Unknown. Likely mechanisms of introduction (MI): HF – Hull Fouling; BW – Ballast Water; SB – Ship Borer; M – Mariculture]. Key references are provided for each species

Taxon	Common name	Status	DOC[#]/DOP[*]	Namibian region	Native range	Establishment	MI	References
PORIFERA								
Halichondria (*Halichondria*) *panicea* Pallas, 1766	Breadcrumb sponge	A	2005[*]	KA	TNA	UN	HF	Samaai & Gibbons (2005)
Hymeniacidon perlevis Montagu, 1814	Crumb of bread sponge	C	1969[#]	KU/ER/KA	UN	C3	HF/BW	Penrith & Kensley (1970a); Kreiner (2014); Kreiner et al. (2019a)
Suberites ficus Johnston, 1842	Sea orange	A	1998[*]	KA	TNA	UN	HF	Samaai & Gibbons (2005)
CNIDARIA								
Hydrozoa								
Amphisbetia operculata Linnaeus, 1758	Wiry hydroid	C	1969[*]	KA	UN	UN	HF	Penrith & Kensley (1970a)
Coryne eximia Allman, 1859	Pink hydroid	A	1975[*]	KA	TNA/TNP	UN	HF	Millard (1975)
Obelia dichotoma Linnaeus, 1758	Sea thread hydroid	C	1969[#]	KU/ER/KA	UN	C3	HF/BW	Penrith & Kensley (1970b); Millard (1975); Kensley & Penrith (1980); Gili et al. (1989)
Obelia geniculata Linnaeus, 1758	Zigzag hydroid	A	1975[*]	KA	TNA	C3	HF/BW	Millard (1975); Gili et al. (1989)
Plumularia setacea Linnaeus, 1758	Plumed hydroid	C	1969[#]	KU/ER/KA	UN	C3	HF/BW	Penrith & Kensley (1970a, 1970b)
Ptychogena crocea Kramp & Damas, 1925	Cross jelly	A	1984[#]	KA	TNA	UN	HF/BW	Gili et al. (1989)
ANNELIDA								
Polychaeta								
Polydora websteri Hartman in Loosanoff & Engle, 1943	Oyster mudworm	A	2011[#]	ER	TNP	C3	M	Williams (2015); Rodewald et al. (2021)

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Taxon	Common name	Status	DOC[#]/DOP[*]	Namibian region	Native range	Establishment	MI	References
ARTHROPODA								
Crustacea								
Cirripedia								
Balanus glandula Darwin, 1854	Pacific barnacle	A	2019[#]	KU/KA	TNP	C3	HF	Bezeng & Van der Bank (2019); Kreiner et al. (2019a)
Balanus trigonus Darwin, 1854	Triangle barnacle	A	1967[*]	KU	CIP/WIP/TEP	UN	SB	Stubbings (1967)
Tanaidacea								
Chondrochelia savignyi Kroyer, 1842	Tanaidacean	C	1969[#]	KA	UN	UN	HF	Penrith & Kensley (1970a)
Amphipoda								
Caprella equilibra Say, 1818	Skeleton shrimp	C	1916[*]	KU/ER/KA	UN	UN	HF/BW	Barnard (1916); Griffiths (1974); Kelp Blue (2024)
Caprella penantis Leach, 1814	Skeleton shrimp	C	1969[#]	KU/ER	UN	C3	HF/BW	Penrith & Kensley (1970b) Kreiner et al. (2019a)
Ischyrocerus anguipes Krøyer, 1838	Amphipod	A	1953[#]	KU/KA	TNA	C3	HF/BW	Schellenberg (1953); Penrith & Kensley (1970a); Kensley & Penrith (1980)
Monocorophium acherusicum A.Costa, 1853	Fat feeler amphipod	A	1969[#]	KA	TNA	UN	HF/BW	Penrith & Kensley (1970a); Griffiths (1974)
Isopoda								
Ligia exotica Roux, 1828	Sea roach	A	1924[*]	KA	WIP	UN	HF/BW	Panning (1924)
Sphaeroma terebrans Spence Bate, 1866	Boring isopod	A	1911[#]	KA	WIP/CIP	UN	SB	Loyola e Silva (1960)
Synidotea hirtipes Milne Edwards, 1840	Isopod	C	1978[*]	KA	UN	C3	HF/BW	Kensley (1978); Chapman & Carlton (1991)

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Taxon	Common name	Status	DOC[#]/DOP[*]	Namibian region	Native range	Establishment	MI	References
ARTHROPODA (continued)								
Synidotea variegata Collinge, 1917	Isopod	C	1991[*]	KA	UN	UN	HF/BW	Chapman & Carlton (1991)
BRYOZOA								
Bugula neritina complex Linnaeus, 1758	Brown hydrozoan	C	2004[*]	ER/KA	UN	UN	HF	Lim (2004)
Electra verticillata Ellis & Solander, 1786	Hairy sea-mat	A	1969[#]	KU/ER	TNA	C3	HF	Penrith & Kensley (1970b); Kensley & Penrith (1980)
MOLLUSCA								
Gastropoda								
Haliotis midae Linnaeus, 1758	South African abalone	A	2002[#]	KA	TSA (SA)	B2	M	Gonçalo Murta & Kibria (2017); Britz et al. (2019)
Littorina saxatilis Olivi, 1792	Rough periwinkle	A	1996[#]	KA	TNA	UN	BW	Mead et al. (2011b)
Bivalvia								
Magallana gigas Thunberg, 1793	Pacific oyster	A	1991[#]	ER/KA	TNP	B2	M	Ruesink et al. (2005); Britz et al. (2019)
Mytilus galloprovincialis Lamarck, 1819	Mediterranean mussel	A	1988[#]	KU/ER/KA	TNA	E	HF/BW	Hockey & Van Erkom Schurink (1992); McQuaid & Phillips (2000); Branch & Steffani (2004); Rius & McQuaid (2009)
Semimytilus patagonicus Hanley, 1843	Bisexual mussel	A	1931[#]	KU/ER/KA	TSAM	E	HF/BW	De Greef et al. (2013); Ma et al. (2020a, 2020b); Zeeman et al. (2018, 2020)
Teredo navalis Linnaeus, 1758	Naval shipworm	A	1911[#]	ER/KA	TNA	C3	SB	Alves (2011); Werz (2009)

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Taxon	Common name	Status	DOC[#]/DOP[*]	Namibian region	Native range	Establishment	MI	References
CHORDATA								
Ascidiacea								
Ascidia sydneiensis Stimpson, 1855	Grey sea squirt	A	1969[#]	KA	WIP	UN	HF	Penrith & Kensley (1970a)
Asterocarpa humilis Heller, 1878	Compass sea squirt	A	1914[*]	KA	TNA	UN	HF	Michaelsen (1914)
Ciona robusta Hoshino & Tokioka, 1967	Sea vase	A	2010[#]	KU/ER/KA	TNP	C3	HF	Branch et al. (2022)
Corella eumyota Traustedt, 1882	Orange-tipped sea squirt	C	1915[*]	KA	UN	C3	HF	Michaelsen (1915); Turon (1988); Moniot et al. (2001)
Diplosoma listerianum complex Milne Edwards, 1841	Jelly crust tunicate	A	1914*	KA	TNA	C3	HF	Michaelsen (1914)
Polysyncraton bilobatum Lafargue, 1968	Yellow didemnid	C	1988[*]	KA	UN	C3	HF	Turon (1988); Rocha et al. (2012)
CHLOROPHYTA								
Cladophora prolifera (Roth) Kützing, 1843	Fine green algae	A	2010[#]	KU/ER/KA	TNA	C3	HF	Branch et al. (2022)
OCHROPHYTA								
Macrocystis pyrifera (Linnaeus) C.Agardh, 1820	Giant kelp	A	2022[#]	KA	TNP	B3	M	Hooft (2023)
RHODOPHYTA								
Caulacanthus ustulatus (Turner) Kützing, 1843	Red turf algae	A	2014[*]	KU/ER/KA	TNP	C3	HF	Kreiner (2014); Kreiner et al (2019a, 2019b, 2019c)

$p < 0.0001$). Most alien species are native to the Temperate Northern Atlantic realm (13 species), followed by the Temperate Northern Pacific (6 species) and Western Indo-Pacific (4 species) realms (Figure 4). The native range of 12 species is unknown, resulting in their classification as cryptogenic.

Likely mechanisms of introduction

Species were found to have been introduced to Namibia via four likely mechanisms, with numbers varying significantly among these for alien species ($\chi^2 = 80.72$, $p < 0.0001$; Figure 5). Most introductions were associated with shipping (hull fouling (63%), ballast water (20%) and ship borers (7%)), followed by mariculture (10%).

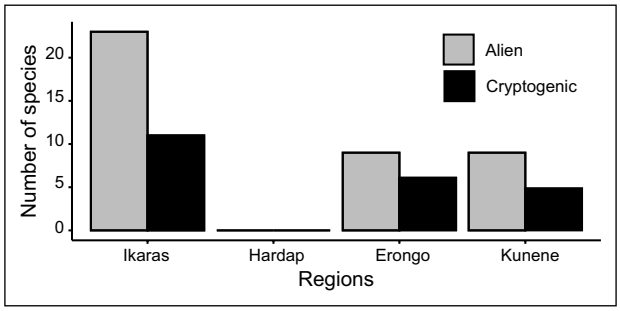

Figure 3. Bar graph showing regional distribution of alien and cryptogenic species along the coastline of Namibia. Note the regions are listed from south to north.

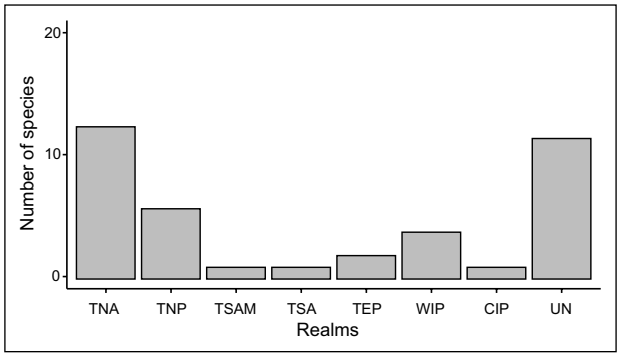

Figure 4. The number of alien and cryptogenic species and the realms. TNA - Temperate Northern Atlantic; TNP – Temperate Northern Pacific; TSAM – Temperate Southern America; TSA – Temperate Southern Africa; TEP – Temperate Eastern Pacific; CIP – Central Indo-Pacific; WIP – Western Indo-Pacific; UN – Unknown native range (all cryptogenic species).

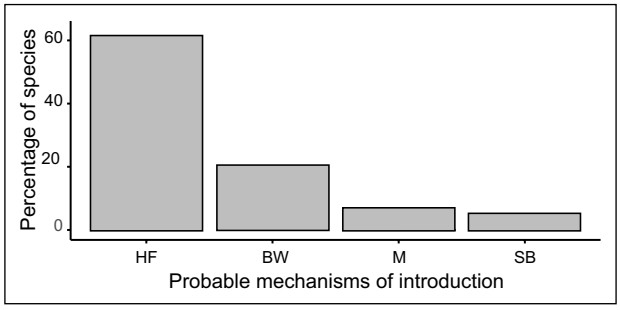

Figure 5. The percentage of alien species introduced via various likely mechanisms of introduction. HF – Hull fouling; BW – Ballast water; M – Mariculture; SB – Ship borer.

Temporal patterns

The first cryptogenic species noted in Namibian waters, the orange-tipped sea squirt, *Corella eumyota* Traustedt, 1882, was reported in 1915 (Figure 6). The mangrove-boring isopod, *Sphaeroma terebrans* Spence Bate, 1866 and the naval shipworm *Teredo navalis* Linnaeus, 1758, were the first alien species documented and were reported in 1911. The detection of species remained low until the late 1960s. From the 1990s, the rate of alien species detection increased, but detection of cryptogenic species slowed with no new species being reported in more than 20 years.

Taxa not included in the list

During the construction of the list of alien and cryptogenic species, an additional thirteen species were uncovered in the literature but were excluded from the list due to unclear taxonomy, doubtful records and lack of evidence of living populations.

Alien species that were excluded due to ambiguous taxonomy included the amphipods *Jassa falcata* Montagu, 1808 (Barnard 1916; Kensley & Penrith 1970) and *Jassa marmorata* Holmes, 1905 (Barnard 1916), both of which have been reported from Swakopmund. However, as the taxonomy of this genus has since been revised by Conlan et al. (2021) and the Namibian records could not be allocated to a species with certainty (i.e., no specimens have been preserved), these records were excluded. The polychaete *Boccardia polybranchia* Haswell, 1885, although reported by Augener (1918) and Day (1967), was excluded due to confusion regarding the nomenclature and identification of this species

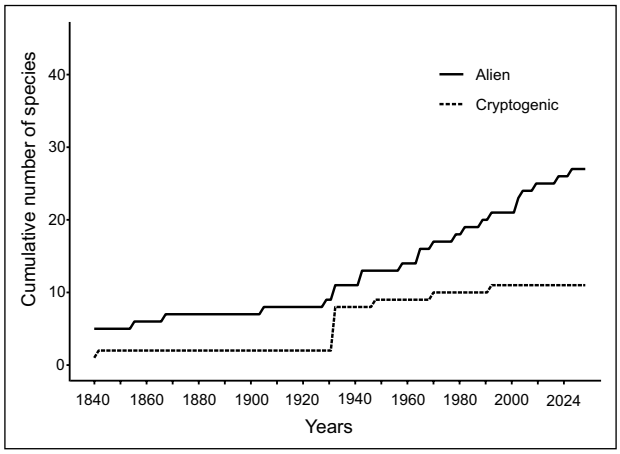

Figure 6. Cumulative number of alien and cryptogenic species, recorded along the Namibian coast.

(Simon et al. 2022). The syllids *Erinaceusyllis erinaceus* Claparède, 1863, *Syllis vittata* Grube, 1840, *S. gracilis* Grube, 1840 and *S. armillaris* O.F.Müller, 1776, have also been reported from Namibia (Day 1967) but the taxonomy of these worms is doubtful (Simon et al. 2022) and so they too have been excluded. The decapod, *Alpheus macrocheles* Hailstone, 1835, the orange European snapping prawn, has been reported from the Kunene region (Macpherson 1991). As *A. macrocheles* is a species complex (Soledade et al. 2019), the Namibian records have been excluded until the identity of the Namibian specimens can be confirmed. The green algae, *Codium fragile* subsp. *fragile* (Suringar) Hariot, 1889, [previously known as *Codium fragile fragile* invasive *tomentosoides* (van Goor) P.C.Silva 1955] has not been included on the list as there has been much confusion about the identity of the *Codium fragile* strains found in southern Africa (Mead et al. 2011b). For this species to be included on the Namibian list genetic samples are needed to confirm its presence in Namibia.

Doubtful records included the syllid *Brania pusilla* Dujardin, 1851 that was noted by Augener (1918). This identification was however considered doubtful by Day (1967), as this species has a discontinuous distribution in the North and South Atlantic oceans and the Pacific Ocean. Following Day (1967) this record was excluded from the current list. The polychaete *Anoplosyllis sexoculata* Hartmann-Schröder, 1962, was reported by San Martín and Hutchings (2006) but has a disjunct distribution, which could indicate anthropogenic-mediated movement or that the species has been misidentified in part of its distribution (Sedick 2018). The ascidian, *Styela clava* Herdman, 1881, has been reported from Namibia by Primo and Vázquez (2004), however, this paper reported on deep sea records of ascidians. As *S. clava* is a shallow water species, these reports are considered unlikely to be accurate and the species has not been included in the list. Additionally, species that were intercepted on incoming ships, but never reported from habitats within Namibia were not included in the list. Examples of such taxa include the barnacle *Megabalanus tintinnabulum* Darwin, 1854, and the amphipod *Ericthonius brasiliensi* Dana, 1853 (Zettler 2021).

Species for which there is a lack of evidence of living individuals (e.g., the bivalves *Ostrea edulis* Linnaeus, 1758, and *Concholepas concholepas* Bruguière, 1789) were excluded from the list. The European oysters are no longer grown in Swakopmund and no wild populations have been found. The Chilean abalone *C. concholepas* was reported by Kensley (1985) as present in coastal deposits along the Namibian coast. It was suggested that the fossil records present in South Africa and Namibia may have originated from drifting individuals (Castilla & Guiñez 2000; Cárdenas et al. 2008). This species was thus excluded from the list, as there is no evidence of extant individuals (Kensley 1985).

Discussion

No national list of marine alien species exists for Namibia, a situation that undermines the country's ability to meet its international obligations with respect to managing biological invasions. In response to this need, this study conducted a systematic literature search, which included historic taxonomic works, contemporary research papers and a variety of databases. Using these diverse sources, this paper compiled Namibia's first comprehensive list of marine alien and cryptogenic species. In total 26 alien and 12 cryptogenic species have been reported from Namibia. The majority of these species originated from the northern hemisphere and were introduced via shipping.

As is typical in many regions (Mead et al. 2011a; Bailey et al. 2020), crustaceans were the dominant taxonomic group supporting 11 species (6 alien, 5 cryptogenic) from five orders. In the Namibian context, the reason for this pattern is likely that many early seminal surveys of the coast were conducted by crustacean experts (e.g., Stubbings 1961; Stubbings 1967; Kensley 1978). This highlights the value of taxonomy in invasion biology (Douglas et al. 2009) and underscores the need to foster the development of African taxonomists (Griffiths et al. 2010). The lack of reports of alien species from some groups (e.g., anthozoans and echinoderms) may reflect an absence of introductions, but as these taxa remain largely unconsidered in Namibia, dedicated surveys are needed to assess both native and alien diversity of such understudied groups. This problem has been highlighted in other understudied regions (Carlton et al. 2019).

The main likely mechanism of introduction for most species to Namibia has been shipping (i.e., hull fouling and ballast water). This is a pattern observed worldwide (Bailey et al. 2020; Schwindt et al. 2020) and highlights the importance of shipping as a pathway for the introduction of marine alien species. The historical threat from shipping is likely to continue as maritime transport plays an important role in economic development, especially in developing nations such as Namibia. Namibia has two ports, Robert Harbour in Lüderitz and the Port of Walvis Bay. Shipping routes connect the two ports with its neighbouring countries Angola (Lobito Harbour) and South Africa (Table Bay Harbour), providing a continuous exchange of cargo between the countries (Finke et al. 2020). Furthermore, well-established shipping routes exist between Namibia, Europe and Asia, providing a direct connection between these regions (Finke et al. 2020). About 2 250 ships report at the Port of Walvis Bay annually, to offload general cargo and containers coming from China and Europe (Namport 2018). Additionally, passenger vessels that use the Port of Walvis Bay as a stopover have become popular in recent years (Namport 2024). As such, the continual flow of maritime traffic offers an ever-present source of new introductions into Namibian waters. Although

Namibia signed the international Ballast Water Management Convention in 2020, it has not yet developed national legislation to guide the implementation of this convention at a domestic level. Similar to many countries, Namibia does not have legislation addressing ship fouling. At present the International Maritime Organisation (IMO) GloFouling Partnership Project is in the process of building capacity in developing countries (like Namibia), to support the implementation of the IMO Biofouling Guidelines, but there is currently no international agreement regulating hull fouling as a mode of introduction of alien species. The IMO Biofouling Guidelines could underpin Namibia's response to the threat of fouling introductions, although these guidelines remain voluntary until written into domestic law. The current absence of regulations regarding ballast water and hull fouling is a major challenge that hinders Namibia's responsibilities in terms of the Kunming-Montreal Global Biodiversity Framework (GBF).

Mariculture has been recognized as an important pathway of species introductions (Katsanevakis et al. 2018). This can occur via the movement of target species that are introduced to culture, as well as the movement of associated species that are unintentionally translocated with the target species as contaminants (Ruesink et al. 2005; Wonham & Carlton 2005). In Namibia the Pacific oyster (*Magallana gigas*), Cape abalone (*Haliotis midae*) and giant kelp (*Macrocystis pyrifera*) have been intentionally introduced and cultivated near the harbour towns Walvis Bay and Lüderitz. Globally the oyster trade has been responsible for the distribution of many unwanted species (Ruesink et al. 2005), one such group associated with oyster culture are polydorid worms (Rodewald et al. 2021). These worms have been associated with both ecological and socio-economic damage (Shinn et al. 2015; Rodewald et al. 2021). *Polydora websteri,* which is recognised as a pest of commercial mariculture worldwide (Clements et al. 2017) has been introduced to Namibia (Rodewald et al. 2021). Various studies have provided evidence of the invasive potential of *P. websteri* and its ability to cause significant losses to culture operations (Martinelli et al. 2020; Rodewald et al. 2021). Although mariculture can be a source of introductions, culture operations can also be vulnerable to impacts by alien species. For example, the widely invasive colonial ascidian *Didemnum vexillum* Kott, 2002, is known to cause economic losses by overgrowing cultured bivalves, (Valentine et al. 2007). Thus, imports for mariculture need to be tightly regulated to both protect the mariculture industry and the socio-economic benefits that it brings, and to protect natural habitats that surround farms.

Spatial analysis revealed that most alien and cryptogenic species have been reported from the Ikaras region, in the south of Namibia. The presence of the Robert Harbour in Lüderitz and the proximity of Ikaras region to the very invaded South African west coast may explain this spatial pattern. Additionally, this region is also the best studied region due to its accessibility. In the same way that some species may have spread north from South Africa to Namibia, the barnacle *Balanus trigonus* and hydroid *Electra verticillata* may have spread south from Angola. This is evidenced by them being known from Angola (Pestana et al. 2017) and only reported from the Kunene region in northern Namibia. Notably, no species are known from the Hardap region. This could reflect the fact that (1) none are present, a possibility as it is a very exposed region that is dominated by sandy shores, or that (2) few studies have been conducted because the terrestrial access to this coast is both very remote and controlled via a protected area with limited access.

Namibia shows a general trend of increased number of alien species through time. This is seen in many places (Bailey et al. 2020) and it is likely that this trend will continue (Seebens et al. 2021). Dedicated field surveys for alien species in Namibia will thus serve many purposes including detecting new introductions but also confirmation of status of previously reported species (i.e., detection of species that have potentially died out or tracking of spread). If standardised and conducted repeatedly, such surveys can also help to track trends and impacts associated with invasions (Loureiro et al. 2021). The results of this study suggest that surveys should target areas linked to shipping and mariculture, but surveys of the open coast should not be neglected. Such surveys would be aided by a watch list, as such lists are known to make surveys more effective and cost-efficient (Minchin et al. 2016).

Conclusion

This study has produced the first national list of alien marine species for Namibia and thus provides a foundation against which the country can track trends in marine species introductions and demonstrate their contributions to GBF Target 6. This process has highlighted the value of targeted taxonomic surveys to documenting invasions and the importance of developing Namibian taxonomic expertise in the marine realm. Part of this process should include fostering relationships with international taxon experts, so that future field surveys can provide learning opportunities for local taxonomists while concurrently providing accurate accounts of the species encountered. Ultimately this will build capacity in Namibia and strengthen the country's ability to address the threat of marine invasions.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

All authors conceptualised the study. CD (Stellenbosch University) collected the data and wrote the first draft. TBR and CAS (Stellenbosch University) provided supervision and contributed to the writing and editing of the manuscript. All authors have read and agreed to the submission of the manuscript.

Ethical considerations

No permits were required for this study.

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Data availability

The dataset associated with this study is available from Zenodo (https://doi.org/10.5281/zenodo.17153880).

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Supplementary material

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Details of the taxa reported as alien and cryptogenic from Namibia.