Updating Marine Non-Indigenous Species Indicators

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Cover image: The clubbed tunicate, *Styela clava*, in Lyttelton Harbour/Whakaraupō [Kimberley Seaward, NIWA]

Contents

Tables

Figures

Executive summary

The Ministry for the Environment and Stats NZ are required to report on the state of the environment using a pressure-state-impact framework under the Environmental Reporting Act 2015 and have asked for a review of the marine non-indigenous species (MNIS) indicator for Environmental Reporting. In 2016, Inglis and Seaward produced a report reviewing potential indicators and suggested three different statistical measures and data that could be used to report on:

1. Time series information on the presence/absence of non-indigenous species (NIS) in Aotearoa New Zealand waters and by region.
2. Range expansion/decrease for the key selected species.
3. Information on the abundance/prevalence and change in abundance/prevalence for key selected species.

Eight key species were originally identified and during subsequent reporting rounds two more species (*Caulerpa brachypus* and *Caulerpa parvifolia* are counted as one because of the difficulty in distinguishing between the two species in the field) were added for reporting on changes in establishment, presence, and spread in Aotearoa New Zealand waters. There are now ten key species:

- Asian bag mussel, Arcuatula senhousia
- Asian paddle crab, Charybdis (Charybdis) japonica
- Australian droplet tunicate, Eudistoma elongatum
- Green tail or 'greasy-back' prawn, Metapenaeus bennettae
- Mediterranean fanworm, Sabella spallanzanii
- Clubbed tunicate, Styela clava
- Fragile clam, Theora lubrica
- Undaria, Undaria pinnatifida
- Indo-Pacific ascidian, Symplegma brakenhielmi
- Sea mustard, Caulerpa brachypus and Caulerpa parvifolia.

This report was requested to review international developments in the construction of indicators since 2016 for reporting on the status of MNIS in Aotearoa New Zealand, detail the methods used to derive them and provide data and metadata to support their reporting in New Zealand. Many global reports and publications aiming to improve global indicators for MNIS have been published in the last seven years, however, all have highlighted the lack of robust, taxonomically reliable data to report on those suggested indicators and few developments have occurred to overcome these hurdles. To maintain consistency with reporting, and provide the most robust data that are comparable on a global scale, it is suggested that the MNIS indicators remain unchanged.

By the end of December 2022, four hundred and twenty nine MNIS have been reported in New Zealand. This includes all taxa recorded on permanent substrata (established) as well as those that have only been recorded on vessel hulls or non-permanent structures such as floating debris (not established).

Twenty two new-to-New Zealand species have been recorded since the last report in 2018 and four of the ten ‘key species’ have expanded their last recorded maximum latitudinal range. The addition of the two species of aquarium weed (*C. brachypus* and *C. parvifolia*) included a small distribution with presence only accounted for in Aotea Great Barrier Island at the time of data extraction, however, it has recently been found in locations throughout the Bay of Islands.

1 Introduction

Robust indicators for measuring the status of marine non-indigenous species (MNIS) are essential for understanding how biological invasions are impacting on national changes in biodiversity. The *Environmental Reporting Act 2015* established a framework for reporting on the condition of New Zealand's environments. The framework requires regular reports on five environmental domains: air, atmosphere and climate, fresh water, land, and marine. Information is required to address three general topics for each domain:

- human activities and natural factors that influence the condition of the environment ('pressures'),
- the biophysical condition of the environment (its 'state'), and
- how changes in the condition of the environment affect New Zealand society and natural resources ('impact').

Information on the state of indigenous biodiversity and ecosystems is also provided within the land, freshwater and marine domains and brought together in the "Environment Aotearoa" reporting series.

Statistical measures are used to report on specific aspects of each environmental domain and to track trends over time. 'Marine pests' have been classified as a national indicator for New Zealand's marine domain and indigenous marine biodiversity. Other non-indigenous species indicators reported on in "Environment Aotearoa" include land pests (occupancy and abundance for ungulates, rabbits, hares, and possums on conservation land), and freshwater pests (numbers and locations of freshwater fish, invertebrate and plant pests of greatest concern for New Zealand's freshwater environments).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) for a dedicated global assessment of invasive alien species and the Convention on Biological Diversity's (CBD's) Aichi Target on Invasive Alien species (specifically Aichi Target 9) stated that "by 2020, invasive alien species and pathways are identified and prioritised, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment". The current percentage of countries currently meeting this target is eleven percent, with over fifty-eight percent recorded as not reporting these data, including New Zealand, although these results cover reporting from all environmental realms including freshwater and terrestrial, not just marine (UN Environment Programme 2020).

The first draft of the Post-2020 Global Biodiversity Framework from a global open working group has included "Target 6. Manage pathways for the introduction of invasive alien species, preventing, or reducing their rate of introduction and establishment by at least 50 percent, and control or eradicate invasive alien species to eliminate or reduce their impacts, focusing on priority species and priority sites" (UN Environment Programme 2021).

Measuring and reporting this information, however, can be extremely difficult. Most countries have limited knowledge of the rates of introduction and establishment to be able to implement the changes needed to assess a fifty percent reduction. Control and eradication are always difficult and expensive, and performing risk assessments requires understanding what the impact of a new non-indigenous species may be. Potential impacts can be governed by many factors in new host locations including, but not limited to; environmental conditions, reproductive abilities, available habitat, and many unknown variables associated with a changing climate. Knowing how a non-indigenous species may behave in a new environment is hard to determine.

Biosecurity New Zealand (Biosecurity NZ) is the government agency with primary operational responsibility for New Zealand's biosecurity system. NIWA is contracted by Biosecurity NZ to manage data on Marine Non-Indigenous Species (MNIS) obtained from Biosecurity NZ's operational marine biosecurity programmes. This arrangement has been in place for 18 years. The centralized and coordinated management of data on MNIS in New Zealand places it in a much stronger position than most other countries to report on national trends.

Two national synthetic reviews, undertaken in 1998 (Cranfield et al. 1998) and 2010 (Kospartov et al. 2010) collated historical data on the MNIS that had been recorded in New Zealand and the timing of their discovery. Between 2001 and 2007, a set of standardised biodiversity surveys (Port Biological Baseline Surveys; PBBS) was undertaken in all New Zealand's international shipping ports and marinas to determine the MNIS present and their relative abundance in each. In total, 43 separate PBBSs were completed throughout New Zealand, including repeat surveys of our 13 major shipping ports. Together, the historical reviews and PBBS provided an effective baseline of data on the MNIS present in New Zealand against which subsequent changes could be measured. Contemporary records of MNIS are collated at a national level on an ongoing basis principally from two sources:

- the Marine Invasives Taxonomic Service (MITS), and
- the National Marine High-Risk Site Surveillance (NMHRSS) programme.

MITS is a taxonomic clearinghouse service, funded by Biosecurity NZ (and its predecessor organisations), which identifies suspect organisms submitted to it from Biosecurity NZ's biosecurity surveillance, research, or response activities, including reports received from other scientists, regional government, industry, or members of the public through its 'Pests and Diseases Hotline'. MITS has been in operation continuously since 2005. The NMHRSS is a standardised national programme of targeted monitoring for MNIS at 12 ports of first entry for international vessels located throughout New Zealand. Surveys of each of the 12 ports are undertaken every 6 months. The NMHRSS has been in operation since 2002.

This combination of baseline data and on-going active and passive surveillance will be used to report on MNIS trends.

2 Indicators for reporting trends in non-indigenous species

In 2016, NIWA developed a set of indicators to report on marine non-indigenous species (MNIS) in New Zealand as part of the joint Environmental Reporting Programme on the state of the environment (Inglis and Seaward 2016). The indicators were to provide:

- time-series information on the presence and/or absence of non-indigenous species in New Zealand waters, and by region,
- estimates of range expansion and/or decrease for key selected species,
- the abundance and/or prevalence and change in abundance and/or prevalence of the key selected species.

The measures used were based on a review of:

- indicators used by other countries and organisations (e.g., UNEP (United Nations Environment Programme), European Environment Agency, etc.) to report on trends in non-indigenous species and their management,
- New Zealand national data holdings on marine non-indigenous species,
- sources of bias in reporting indicators for non-indigenous species, and
- statistical measures for representing the indicators sought by the Ministry for the Environment (Inglis and Seaward 2016).

These were subsequently reviewed and updated by Seaward and Inglis (2018) in consultation with Stats NZ and the Ministry for the Environment, and a reduced set of indicators was used for the "Our Marine Environment 2019" report.

Since the New Zealand indicators were first developed, several other countries and jurisdictions have established reporting indicators for non-indigenous species. This report will review and assess these new developments and their relevance for use in New Zealand, including the suitability of data available in New Zealand and how they perform against the five criteria used by Stats NZ for Tier 1 statistics.

2.1 Updates post–2016 to marine non-indigenous species indicators.

Several reviews have assessed the condition of current Indicators for how adequately they monitor and report on the status of biological invasions. Current inadequacies of these indicators have been highlighted and new frameworks, updates to indicators and ways of measuring progress towards ceasing and mitigating spread of MNIS have been proposed (Wilson et al. 2018; McQuatters-Gollop et al. 2019; McGeoch et al. 2021; Vicente et al. 2022). In some cases, these indicators have been reported on at national and regional scales.

2.1.1 Europe

In the European Union, NIS are treated as a distinct Descriptor (D2) of Good Environmental Status (GES) of the Marine Strategy Framework Directive (MSFD). An EU commission decision was passed in May 2017 "laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment" (EU 2017).

Under Descriptor 2 (*non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems*), specific criteria for calculating indicators for reporting include:

By region or subregion, divided where needed by national boundaries:

- Newly introduced NIS – number of newly introduced non-indigenous species introduced via human activity in the last 6 years (assessment period) and a list of those species.
- Abundance and spatial distribution of established invasive non-indigenous species, particularly those on the list of invasive alien species of Union concern.
- Proportion of the species groups or spatial extent of the broad habitat types that are adversely altered due to non-indigenous species, particularly invasive non-indigenous species.

Units of measurement are specified for the criteria: number of individuals, biomass in tonnes (t), or the extent in square kilometres (km^2) per MNIS (EU 2017).

United Kingdom

The Joint Nature Conservation Committee attempts to update basic indicators for non-indigenous species in Great Britain at least every couple of years (Harrower et al. 2022). These indicators are:

- Species list of all invasive non-native species (marine, terrestrial and freshwater) having negative or strongly negative ecological effect.
- Analytical estimation of Area of Extent (AoE) using area estimates from an alpha hull polygon.

Species with a negative or strongly negative effect were defined as those that posed the greatest threat to native biodiversity, either through the spread of disease, competition for resources, direct consumption, parasitism or hybridisation of native species and a high capacity for spread to natural or semi-natural habitats. However, species lists were not collated based on quantitative assessments of negative ecological effects, but through a rapid assessment relying on expert opinion (Harrower et al. 2022).

An alpha hull, used to describe the area occupied by a non-indigenous species, is generalisation of the convex hull polygon, which is the minimum area bounded by a polygon that includes the limits of the distribution records. An alpha hull is created based on the duality of the Voronoi diagram and Delaunay triangulation of the data points (all points are joined so that no lines intersect between points). Lines are then selectively removed from the triangulation based on the value of a parameter α (Burgman and Fox 2003).

European Environment Agency (EEA)

The European Environment Agency (EEA) officially reported on marine non-indigenous species indicators in February 2023, using the following indicators:

- Introduction rates since the last round of reporting by
  - species group
  - pathway
  - and marine region.
- Number of new MNIS.
- Cumulative number of new MNIS through time.
- Pathways of MNIS introduction (average from 1970 to 2020).

- Transport method of new MNIS in 5-year bins (European Environment Agency 2023).

HELCOM

HELCOM (The Baltic marine Environment Protection Commission – also known as the Helsinki Commission) is an intergovernmental organisation (IGO), which reports from all countries surrounding the Baltic Sea. It defines the regional borders of the Baltic Sea differently in comparison to the EU MSFD.

MNIS indicators in HELCOM's 2018 core indicator report (Lehtiniemi et al. 2018) included:

- Number of new MNIS per 10-year time bin for the region.
- Number of MNIS and cryptogenic species for each HELCOM country within 5 specific time periods from 1900–2015.

OSPAR

Two conventions, the Oslo convention (1972) and the Paris Convention (1974) were unified in 1992 to become the OSPAR convention and includes 15 governments and the EU who cooperate to protect the marine environment of the North-East Atlantic.

OSPAR provides assessments and quality status reports (QSR). Only one indicator was reported on for their QSR 2023 report on Trends in New Records of Non-indigenous species introduced by human activities:

- New records of MNIS introductions.

This was the only indicator reported on because it was considered the only reliable data available (Staehr et al. 2023).

2.1.2 Canada

In 2015, Canada's federal, provincial, and territorial governments released the 2020 Biodiversity Goals and Targets for Canada. Target 11 specified by 2020, pathways of invasive alien species introductions are identified, and risk-based intervention or management plans are in place for priority pathways and species. Three indicators for all non-indigenous species (not just marine species) were identified.

- Number of known newly established invasive alien species in Canada, by Federal Regulatory status.
- Percent of federally regulated foreign invasive alien species not established in Canada.
- Number of intervention or management plans in place.

The indicator used for the Summary of Canada's 6th National Report in 2019 has not been updated since 2015. Their target is recorded as being met as they have not recorded any new invasive alien species becoming established in Canada from 2012 to 2015. Information on interventions or management plans in place has not been updated since 2018. No other Canadian regions have produced new reports (Government of Canada 2015).

2.1.3 Australia

Australia's *State of Environment 2021: Coasts* report contains limited information on aquatic invasive species (Clark et al. 2021). It includes an approximate total number of MNIS recorded nationally and brief information about some well-known invasive species in Australia.

The main indicator for reporting MNIS includes several maps of Australia displaying responses to surveys from local government areas (LGA) and their assessment of the status, trend, and management of effectiveness of coastal environment components and pressures that occurred within their LGA. There are 537 LGAs in Australia, the majority of which would not be recognised as 'coastal'. However, 34 LGAs responded with assessments and of those, only 6 reported any response, which ranged from very low to very high "biological pressure" from aquatic invasive species in their local coastal environment (Clark et al. 2021). What constitutes 'high pressure' in the context of aquatic invasive species, however, was unclear.

New South Wales

The biodiversity indicator programme in New South Wales reports on the status of biodiversity and integrity under their *Biodiversity Conservation Act 2016.* The overarching monitoring framework, or method, which outlines how indicators are related and derived, is presented in Measuring Biodiversity and Ecological Integrity in New South Wales: Method for the Biodiversity Indicator Program (OEH and CSIRO 2019).

NSW metrics were developed to report on two dimensions of MNIS pressures on native biodiversity and ecosystem quality; exposure (presence, size, and extent of MNIS pressure) and impact (consequences of MNIS pressures, i.e., changes to ecosystems as a direct result of MNIS, specifically those to native species and ecological communities) (Froese et al. 2021). The indicator metrics chosen, and the data or essential variables selected to report on these metrics can be found in Figure 2-1.

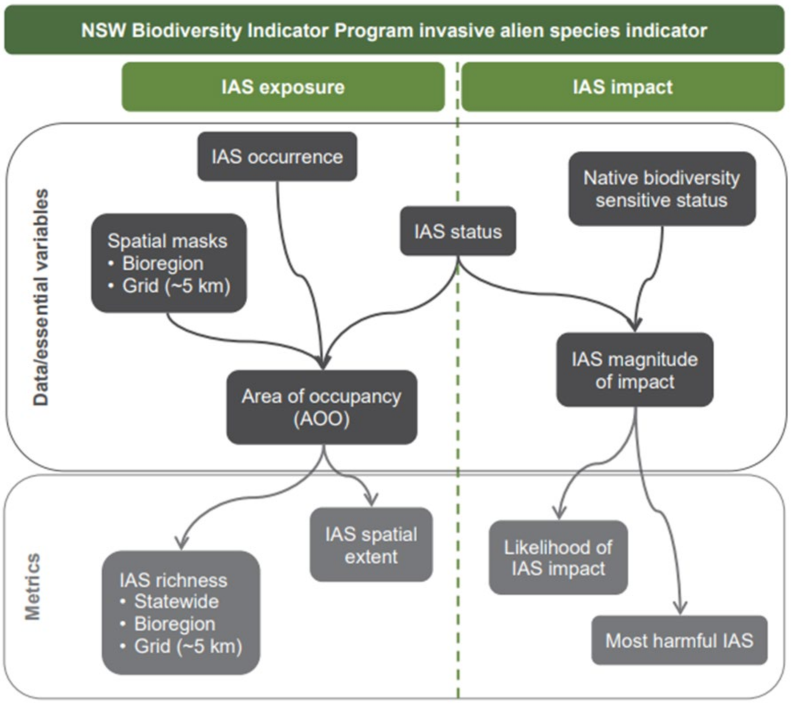

Figure 2-1: Schematic design of the invasive species indicator method. Taken from (Froese et al. 2021). The figure shows data inputs, derived essential variables and metrics implemented in the first assessment to measure each of the two implemented dimensions of IAS pressure: IAS exposure and IAS impact.

2.1.4 Other published indicators and their suggestions for future development

A review by Essl and colleagues (2020) identified that the years following the 2020 global biodiversity framework were critical for developing global biodiversity policy agendas (Essl et al. 2020).

They suggested that the following indicators and information were necessary for monitoring NIS effects on biodiversity change through time.

- Trends in the number of IAS introduction rates
- Time series of IAS numbers for various taxonomic groups and regions
- Trends in the impact of IAS on extinction risk
- Database of all successful eradications
- Legislation, policy and regulations for prevention and control of invasive alien species
- Trends in the numbers and impacts of invasive alien species in countries using the IUCN endorsed EICAT (environmental impact classification of alien taxa).

Although there have been advances in the collation and dissemination of data on NIS there is still a paucity of basic information such as the rate of new species arrivals, the impacts they cause and general knowledge around their occurrences (McGeoch et al. 2021). Three indicators deemed policy-relevant to capture the key dimensions of species invasions and address this lack in basic information for MNIS assessment and reporting were:

1. *Rate of Invasive Alien Species Spread*, which provides modelled rates of ongoing introductions of species based on invasion discovery and reporting, based on the Maximum Likelihood (ML) estimation method proposed by Solow and Costello (2004).
2. *Impact Risk*, which estimates invasive alien species impacts on the environment in space and time and provides a basis for nationally targeted prioritisation of where best to invest in management efforts.
3. *Status Information on invasive alien species*, which tracks improvement in the essential dimensions of information needed to guide relevant policy and data collection and in support of assessing invasive alien species spread and impact (McGeoch et al. 2021).

The most comprehensive framework of NIS indicators was proposed by Wilson et al. (2018) at the country level with direct reference to South Africa (Wilson et al. 2018). They proposed 20 indicators that fell into four higher level categories.

- Rate of introduction of new unregulated species.
- Number of invasive species that have major impacts.
- Extent of area that suffers major impacts from invasions.
- Level of success in managing invasions.

The proposed indicators were:

1. Introduction pathway prominence
2. Introduction rates
3. Within-country pathway prominence
4. Within-country dispersal rates
5. Number and status of alien species
6. Extent of alien species
7. Abundance of alien species
8.Impact of alien species
9. Alien species richness
10. Relative invasive abundance
11. Impact of invasions
12. Quality of regulatory framework
13. Money spent
14. Planning coverage
15. Pathways treated
16. Species treated
17. Sites treated
18. Effectiveness of pathway treatments
19. Effectiveness of species treatments
20. Effectiveness of site treatments

The European Commission's Joint Research Centre (JRC) aim is to facilitate existing alien species information from a variety of sources within the EU, such as the EU funded project Delivering Alien Species Inventories for Europe (DAISIE), European Alien Species Information Network (EASIN) and the information system on Aquatic Non-Indigenous and Cryptogenic Species (AquaNIS) (Zenetos et al. 2022). They have reported on the required indicators from all reporting EU countries on:

- Number of NIS detected by year and region.
- Cumulative numbers of NIS detected by region and year from 1970.
- Annual rates of NIS introductions (6-year average) at different geographic levels (with a linear regression for all European Seas).

One of the indicators they see as lacking from the trends analyses from all countries is a threshold value for NIS. The Commission Decision (EU) 2017/848 (EU 2017) specifies that:

"Threshold values are intended to contribute to MS' (each EU Member State's) determination of a set of characteristics for GES (Good Environmental Status) and inform their assessment of the extent to which GES is being achieved" and that "threshold values should be set in relation to a reference condition".

Zenetos et al. (2022) suggest that thresholds have not been set at a suitable level yet and neither have more specific recommendations for the time frame or reporting cycles that will define whether rates of introduction have decreased.

Following the GES Decision for MFSD Descriptor 2, thresholds of the three descriptors (Section 2.1.1) were considered (Tsiamis et al. 2021; Vasilakopoulos et al. 2022). A six year cycle period of reporting is included in the D2C1 *(number of newly introduced non-indigenous species introduced via human activity in the last 6 years, and a list of those species*), however, calculating the exact value of percentage reduction was recommended to be decided at the regional/subregional scale because of different levels of pathway pressure and levels of monitoring coverage (Tsiamis et al. 2021). It was decided that no thresholds were needed for spatial coverage and abundance measures (Criterion D2C2), but threshold values were flagged as important for Criterion D2C3 (*Proportion of the species groups or spatial extent of the broad habitat types that are adversely altered due to NIS, particularly invasive NIS*), however suitable data were lacking and no threshold values were determined (Vasilakopoulos et al. 2022).

Latombe et al. (2017) have developed a vision for global monitoring of biological invasions. The concept of Essential Biodiversity Variables (EBV's) is used to identify a minimum suite of variables they deem essential for monitoring biological invasions at a global scale. They detail the stages of development of national observation and monitoring systems for NIS and how to increase the spatial and temporal resolution of collected data. They identified three main EBV's, the data or observation required to fulfil each variable, how they should be collated and examples of derived supplementary variables and indicators, see table Table A-1 in Latombe et al. (2017) for more detailed information about each of the three indicators:

- Species occurrence.
- Species alien status.
- Alien species impact.

3 Indicator limitations

3.1 Out of scope

All indicators implemented or suggested by other countries and regions fall into some form of the pressure-state-response model (McGeoch et al. 2010). The Ministry for the Environment and Stats NZ are required to report on the state of the environment using a pressure-state-impact framework. However, pathway analysis and response are not included in this review as response activities, including pathway analysis, legislation, and policy adoption are managed by Biosecurity NZ. The data for these activities are not readily available but are held by Biosecurity NZ.

3.2 Sampling bias

Bias and uncertainty in reporting patterns of invasion were examined in the initial reviews of indicators for MNIS in New Zealand (Inglis and Seaward 2016). We know there are limitations with the collection of observation records, and each method has its own intrinsic set of biases. A key distinction can be made between 'passive' surveillance (sometimes referred to as 'general' surveillance) where information on NIS in an area is gathered from many different available sources, and 'specific' (or 'targeted') surveys, which are purposefully designed to provide information on NIS in an area (McMaugh 2005; FAO 2018). Passive surveillance collates data from a range of *ad hoc* sources including reviews of published and unpublished literature, aggregations of existing regional data or other distributed sources, museums, herbarium specimens, solicited and un-solicited observations made by the public or "citizen science", and records from general scientific surveys not necessarily concerned with NIS. Targeted surveys have the prescribed objective of cataloguing the presence, distribution, or abundance of NIS (Inglis and Seaward 2016). Most countries developing indicators of MNIS rely solely on passive sources of data to compile their indicators. New Zealand's indicators are able to utilise data from both coordinated passive surveillance, through MITS, and a regular national targeted survey programme, the NMHRSS.

3.3 Terminology

Terminology is also important. Often, inconsistent definitions are used that can lead to quite different reporting of statistics. The term 'invasive' has been used by several of the national and regional reports but a definition is often not given. Even the EU Commission Decision on methodological standards (2017) defines "invasive non-indigenous species" as meaning "invasive alien species" within the meaning of Article 3(2) of Regulation (EU) No 1143/2014 of the European Parliament and of the Council. This article states that:

> *"An invasive alien species should be considered to be of Union concern if the damage that it causes in affected Member States is so significant that it justifies the adoption of dedicated measures applicable across the Union, including in the Member States that are not yet affected or are even unlikely to be affected"*[1]

However, what these damages may be and how they are perceived from country to country across the EU will vary. As mentioned in Inglis and Seaward (2016), Richardson et al. (2000) argued that the term 'invasive' should be used without any inference of harmful effects but should apply to the subset of non-indigenous species that produce large numbers of offspring and thus have the potential to spread over a considerable area. To navigate this linguistic taxonomy, McGeoch et al. (2012) proposed three non-exclusive criteria to define IAS for inclusion in national lists.

[1] (Official Journal of the European Union 2014).

1. The species has a demonstrated impact anywhere outside its indigenous range.
2. The species is widespread, abundant, fast spreading or has a high population growth rate anywhere outside its indigenous range.
3. The species is widespread, abundant, fast spreading or has a high population growth rate in the reporting country.

For marine systems, the distinction between what is indigenous to a biogeographic region and what is not can also be problematic. Patterns of marine biogeography and biodiversity are complex and still poorly understood (Warwick 1996). Significant gaps in global marine taxonomy and biogeography make it difficult to determine the true natural range and origin of many species reliably. Even within relatively well-studied coastal assemblages, up to 30% of species can be considered 'cryptogenic' (i.e., not demonstrably native, or non-indigenous; Carlton (1996)). Thus, determining trends in the numbers of non-indigenous species in space or time requires application of consistent schema for deciding upon provenance (e.g., Chapman and Carlton 1991, Cranfield et al. 1998).

4 Data sources and their updates since previous review

The main sources of New Zealand data used for this review remains unchanged (Inglis and Seaward 2016). Data are derived from four sources:

1. Port Biological Baseline surveys (PBBS)
2. National Marine High Risk Site Surveillance (NMHRSS)
3. Marine Invasives Taxonomic Service (MITS)
4. Other verified information.

A brief account of these sources is found in Section 1 (Introduction), and descriptions of the data, locations sampled, purpose of collection, and sampling methods have been described in earlier reports as well as multiple other sources (Seaward et al. 2015; Inglis and Seaward 2016; Seaward and Inglis 2018; Woods et al. 2022). However, since 2016 there has been an increase of approximately 64,000 native and non-indigenous marine taxa records available in the marine biosecurity database to analyse (Seaward et al. 2015; Marine Biosecurity Porthole 2023).

4.1 Addition of Napier Port and Ahuriri Inner Harbour to NMHRSS

In November 2021, the Port of Napier and Ahuriri Inner Harbour were added to the NMHRSS programme as the twelfth high risk monitoring site (Woods et al. 2021). This was based on a re-analysis of the risk of exposure of New Zealand's ports and harbours of first entry to MNIS through discharge of ballast water and carriage of vessel biofouling by international vessels[2]. Separate predictive models were constructed using historical data (2000–07) of ballast water discharge to New Zealand ports and historical (2004–07) biofouling data on vessels entering New Zealand ports. These predictive models where then used to estimate the total volume of ballast water discharged and biomass of biofouling vectored by recent (2015–17) vessel arrivals to New Zealand using K-Nearest Neighbours (KNN) and random forest algorithms for ballast water and biofouling (Hatami et al. 2022). The analyses identified Napier Port as a site that has a high relative likelihood of MNIS exposure from both vessel ballast water discharge and biofouling but was not part of the current NMHRSS programme (Woods et al. 2021; Hatami et al. 2022).

4.2 National review of NIS algae in NZ

The first person to compile a list of non-indigenous macroalgae present in New Zealand and those species that had "possibly naturalised" was Adams (1983). She also discussed potential pathways of introduction and vectors contributing to their arrival. In the 40 years since that review many additional species of non-indigenous macroalgae have been recorded in New Zealand. Nelson et al. (2021) assembled an updated list that now includes 61 macroalgal taxa that are considered to be introduced. The status of several taxa that were considered to be endemic in New Zealand have changed to non-indigenous and one species of *Agarophyton* was reclassified as native. This species of *Agarophyton* was originally recorded from Manukau Harbour and was morphologically similar to the invasive species *Agarophyton chilense* (C.J.Bird, McLachlan et E.C.Oliveira) Gurgel, J.N.Norris et Fredericq, 2018[3] (formerly *Gracilaria chilensis*). It is no longer considered to be non-indigenous following reassessment using molecular phylogeny (ITS restriction fragment length polymorphism; Candia et al. 1999 from Nelson et al. 2021).

The number of non-indigenous macroalgae present in New Zealand has increased by 30% since the last review was completed in 2019. The knowledge of this increase has come from the NMHRSS programme and specific investigations to inform taxonomy. All historical macroalgal records present in the marine

[2] The report did not consider risks associated with entry into New Zealand of private recreational craft or other non-shipping pathways.
[3] (Bird et al. 2011)

biosecurity database (which includes NMHRSS data), which underpins the marine biosecurity porthole (marinebiosecurity.org.nz) and is the source of data for this review, have been updated to reflect changes published in Nelson et al. (2021) (Appendix B).

4.3 National review of non-indigenous ascidians in NZ

A review of historical taxonomic determinations through morphology as well as routine molecular bar-coding of non-indigenous ascidians in New Zealand is in progress (Mike Page pers. comm.). Although many species have been collected and identified through the NMHRSS programme, there has been no national review or synthesis of information since 2010 (Kospartov et al. 2010). Although this review has not been completed, progress so far has been transferred to historical records in the marine biosecurity database (Appendix B).

4.4 Other updates

Since reported in 2018, there have been two additions of MNIS to the porthole database that have historical presence in New Zealand (Marine Biosecurity Porthole 2023). One is the freshwater weed *Lagarosiphon major,* first discovered in New Zealand in the 1950's. Although freshwater, this weed was recorded during an NMHRSS survey in brackish water and as other brackish plant species such as the cordgrass *Spartina* have been included in previous reports, it was decided to retain this record (Appendix B). The second is the Gastropod nudibranch *Polycera fujitai* which was first detected in New Zealand in 1996, but we were only alerted to its presence in New Zealand and non-indigenous status with the discovery of new specimens in Nelson, a significant range extension from its original identification in Waitematā Harbour (Appendix B).

Two other status changes have occurred to taxonomic records that were not included in the reviews mentioned previously. The amphipod *Leucothoe nagatai* was first recorded in New Zealand by Thomas et al. (2021) after re-examination of museum specimens using morphological and molecular analysis using both COI mitochondrial and 18S ribosomal DNA to compare with examples around the world. This species was found with specimens of the cryptogenic cosmopolitan species of ascidian *Styela plicata* from samples taken in 2015, although there is no material lodged in New Zealand institutions (Appendix B). The other is the nudibranch *Thecacera pennigera,* which was recorded in the 2010 MNIS inventory as Cryptogenic (Kospartov et al. 2010). Following recent detections since 2020 and confirmation of specimens by expert nudibranch taxonomist Richard Willan, the status of this species has been updated to non-indigenous (Appendix B).

5 Key species

The '*Marine non-indigenous species'* indicator which this project contributes to, is used to measure the '*Pests, diseases, and exotic species'* topic within New Zealand's Environmental Reporting Series. It aligns with the national '*Land pests'* indicator (Ministry for the Environment and Statistics New Zealand 2015). Eight marine species were nominated as 'Key Species' in 2016 to encompass a range of life habits, taxonomic and trophic groups that occur in a variety of different environments. The eight species also represent a broad time scale of introductions to New Zealand, from relatively recent incursions (e.g., *Sabella spallanzanii* (Gmelin, 1791) and *Metapenaeus bennettae,* Racek and Dall, 1965) to species that have been present in New Zealand for more than 40 years (e.g., *Theora lubrica* Gould, 1861). Each has been chosen because it fits at least one of the three criteria proffered by McGeoch et al. (2012) to classify a NIS as 'Invasive' (see Terminology 3.3 above).

Inglis and Seaward (2016) nominated eight key marine species that were intended to measure threats from MNIS to New Zealand's cultural and natural heritage, and to economic activities such as commercial and recreational fishing, shellfish harvesting, and aquaculture (Ministry for the Environment & Statistics New Zealand 2015). These were:

- Asian bag mussel, *Arcuatula senhousia* (Benson, 1842);
- Asian paddle crab, *Charybdis (Charybdis) japonica* (A. Milne-Edwards, 1861);
- Australian droplet tunicate, *Eudistoma elongatum* (Herdman, 1886);
- Greentail or 'greasy-back' prawn, *Metapenaeus bennettae* Racek and Dall, 1965;
- Mediterranean fanworm, *Sabella spallanzanii* (Gmelin, 1791);
- Clubbed tunicate, *Styela clava* Herdman, 1881;
- Fragile clam, *Theora lubrica* Gould, 1861;
- Undaria, *Undaria pinnatifida* (Harvey) Suringar, 1873.

5.1 New additions to 'key species' since 2016

The change in establishment, presence, and spread of the key species mentioned above, with three new additions since 2016, have been requested using the latest data available. A new colonial ascidian, *Symplegma brakenhielmi* (Michaelsen, 1904), first described in New Zealand in early 2015, was added to the list of key species for 2018 (Seaward and Inglis 2018). *S. brakenhielmi* is a colourful, very distinctive, encrusting ascidian that grows to approximately 100 mm in diameter (Page 2015). It has an extensive pan-tropical distribution that includes Bermuda, USA, Puerto Rico, Australia, Ghana, Hawaii, New Caledonia, and Israel. *S. brakenhielmi* was first detected from Marsden Cove marina in Whāngārei Harbour in February 2015 and was subsequently found in Waitematā Harbour in 2017. It appears to have a fast rate of growth and spread, but with marked seasonality.

The green alga or sea mustard *Caulerpa brachypus* (Caulerpaceae, Chlorophyta) is a widespread tropical and subtropical species native to the Indo-Pacific. It has been reported from Africa to the Philippines and Australia, in Brazil, the Caribbean Sea and Florida (D'Archino et al. 2021a). It was first recorded in New Zealand around Aotea Great Barrier Island through the online reporting app iNaturalist (inaturalist.nz) in late June 2021. Citizen scientists referred the record through to NIWA experts for identification. Samples were collected and the results of DNA sequencing confirmed the species as non-indigenous *Caulerpa brachypus* Harvey (1860) in July 2021 (D'Archino et al. 2021a).

During subsequent delimiting surveys for *Caulerpa brachypus* on Aotea, a second, morphologically similar non-indigenous alga, *Caulerpa parvifolia*, was also discovered. The two species are indistinguishable in the field. A slight difference in morphology was noted during laboratory preservation of *C. brachypus* and subsequent *tuf*A molecular analysis confirmed the presence of *C. parvifolia* (D'Archino et al. 2021b).

The species of the genus *Caulerpa* are well known globally to cause negative impacts on the diversity of native macrofauna, invertebrates and fishes, seagrass and other encrusting and foliose species. They can propagate from asexual fragments and can grow rapidly on many different substrata (D'Archino et al. 2021a, 2021b).

A summary of invasive criteria, trophic functional group, habit and type of organism for the selected 'key species' are provided in Table 5-1 from Inglis and Seaward (2016), with the addition of the new species of ascidian, *S. brakenhielmi,* and both green algae species *C. brachypus* and *C. parvifolia* considered together because of their morphological and environmental similarities.

5.2 Assessment of current relevance of 'key species' for reporting

5.2.1 Relevance for national reporting and importance on a global scale

Not only do the ten taxa chosen to be *key species* fulfil the criteria set out by McGeoch (2012), which classify them as invasive, their presence in New Zealand, their reputation worldwide as top invading species, and the inclusion of the original eight key species in globally reported aquatic trends for New Zealand accepted through peer review, make them appropriate key species to report on (Bailey et al. 2020).

Little has changed in the literature regarding the use of key species as indicators for reporting on the status of MNIS since their initial selection in 2016 (Inglis and Seaward 2016). They are still relevant species that encompass a range of life habits, taxonomic and trophic groups and include species that have large temporal ranges in invasion histories in New Zealand (*Theora lubrica* over 40 years, *C. brachypus* and *C. parvifolia* 2 years).

As the records in the data set, evaluated as part of this review, are all collected under the supervision of at least one of seven highly skilled field team leaders with a minimum of parataxonomic training and having attended an average of eighty eight surveys each, the reliability of their ability to identify the presence and absence of the key species, as well as recognise anything unusual that needs to be sent to taxonomic experts for confirmation is high (Woods 2023).

Table 5-1: Summaries of the nine key marine non-indigenous species proposed for indicators of trends in geographic range and abundance.

Common name	Species	Type of organism	Trophic functional group	Habit	Date of discovery in New Zealand	Meets criteria [4] for an IAS?
Asian bag mussel	*Arcuatula senhousia*	Bivalve mollusc	Macro-planktivore	Sedentary in intertidal and subtidal sediments	1978	1, 2, 3
Asian paddle crab	*Charybdis (Charybdis) japonica*	Swimming crab	Predator / omnivorous consumer	Mobile in subtidal estuarine environments (rocky reefs and soft sediments)	2000	1, 3
Australian droplet tunicate	*Eudistoma elongatum*	Colonial ascidian	Macro-planktivore	Sedentary attached to rocks, seagrass, mangroves, and artificial substrata	2005	1, 3
Green tail or 'Greasy-back' prawn	*Metapenaeus bennettae*	Decapod prawn	Deposit feeder	Mobile in subtidal estuarine sediments	2009	3
Mediterranean fanworm	*Sabella spallanzanii*	Polychaete worm	Macro-planktivore	Sedentary attached to artificial substrata and shells or rocks in soft sediments	2008	1, 2, 3
Clubbed tunicate	*Styela clava*	Solitary ascidian	Macro-planktivore	Sedentary attached to rocks, shells, or artificial substrata	2004	1, 2, 3
Fragile clam	*Theora lubrica*	Bivalve mollusc	Deposit feeder	Mobile within muddy subtidal sediments	1971	2, 3
Wakame / Undaria	*Undaria pinnatifida*	Brown alga (kelp)	Primary producer	Sedentary on rocky reefs and hard shorelines	1987	1, 2, 3
Indo-Pacific ascidian	*Symplegma brakenhielmi*	Colonial ascidian	Macro-planktivore	Sedentary attached to rocks, seagrass, mangroves, and artificial substrata	2015	2, 3
Sea mustard species	*Caulerpa brachypus & Caulerpa parvifolia*	Green algae	Primary producer	Sedentary in subtidal sediments, seagrass, and rocky reefs	2021	1, 2, 3

[4] Criteria proposed by McGeoch et al. (2012)

6 Evaluation of indicators

As required by the Environmental Reporting Act (2015), and based on three of the DPSIR (Driver, Pressure, State, Impact, Response) environmental indicators used by The European Environment Agency, 'pressure', 'state', and 'impact' are used to report on the state of the environment in New Zealand (Smeets and Weterings 1999). Pressures cause changes to the state of the environment and these changes have impacts. Several publications relating to MNIS do not include 'state' as one of the suggested indicators in reporting. Instead, they describe the 'state' of the environment as the biological contamination level of an ecosystem and when referring to MNIS, 'state' often goes hand in hand with 'impact' (McGeoch et al. 2010, 2012, 2021; McGeoch and Latombe 2016; Latombe et al. 2017; Vicente et al. 2022).

In this report we assess 'pressures' as those related to introduction rates on an ecosystem or indicators relating to propagule pressure. 'State' includes those metrics which account for growth in the coverage and spatiotemporally explicit occurrences on MNIS in New Zealand, such as range dynamics, and effects of sampling through time. 'Impacts' will consider the assessment of realised impacts and the types of impacts known to affect biodiversity.

6.1 Pressure

Several 'pressure' indicators suggested to be appropriate for MNIS indicator reporting in New Zealand were previously assessed by Inglis and Seaward (2016) using the five criteria used by the Ministry for the Environment and Stats NZ to evaluate the fitness-for-purpose of statistics for environmental reporting. The criteria are as follows:

- *Relevance* - the degree to which the data meets user needs in coverage, content, and detail.
- *Accuracy* - the degree to which the information precisely describes the phenomena it was designed to measure.
- *Timeliness* - The degree to which data produced are up to date, published frequently and delivered to schedule.
- *Coherence/consistency* - the degree to which data can be successfully brought together within a broad analytical framework and over time.
- *Interpretability* the availability of supplementary data and metadata necessary to interpret and use the indicator effectively.

Identifying the need for robust indicators and assessing the literature published since the initial review has revealed what recommended MNIS indicators should be (Section 2.1), but since that initial review was conducted, very few of the proposed indicators are new and were not already assessed by Inglis and Seaward (2016) (See the summary in Table D-1). Recently published literature describing indicators were very descriptive of the general lack of data availability, reliable taxonomic identifications, and consistency of monitoring in both space and time, but very few metrics have been offered as a new way to report on pressures facing marine ecosystems from MNIS.

'Pressure' indicators already reviewed and reported on in the initial review include:

- Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
- The numbers of NIS summarised by local government agency coastal area, and total search effort in each coastal area.

As can be seen in Table D-1, all indicators published since 2016 have an equivalent indicator that was already assessed using the five criteria to evaluate statistics for environmental reporting, as part of the initial review (Inglis and Seaward 2016).

One metric, mentioned in the initial review (Inglis and Seaward 2016) as an approach developed to account for variability in sample effort in the historical discovery record, is the use of a statistical maximum-likelihood estimator (MLE) to model the average rate of introduction of NIS (Solow and Costello 2004). This approach recognises that the rate of discovery of NIS is a function of the rate at which new species are introduced into the country and the process that leads to their discovery. Because NIS are often not discovered in the same year that they are introduced, but generally sometime later, and because sample effort can vary greatly among years, the raw cumulative discovery record can provide a mispleading picture of the temporal pattern of introductions (Solow and Costello 2004; Inglis and Seaward 2016). The (MLE) was not evaluated previously using New Zealand data but was recently recommended by McGeoch et al. (2021) for their *Rate of Invasive Alien Species Spread* indicators.

We fit the MLE model described in Solow and Costello (2004) to the time series of first records of MNIS detected in New Zealand. Applying the MLE requires specification of the parametric forms of the mean introduction rate (μ_t) and probability (π_{st}) that a species introduced in year s is detected in year t.

The model finds the maximum-likelihood estimates (MLE) of five parameters used in two dependent functions (Equation 6-1 (ii)). The parameter β_1 is the mean annual change in the rate of new species introductions and equation (Equation 6-1(i)) was used to visualise the underlying introduction rates (Solow and Costello 2004).

Equation 6-1.

$$(i) \qquad \mu_t = \exp(\beta_0 + \beta_1)$$

$$(ii) \qquad \Pi_{st} = \frac{\exp\left([\gamma_0 + \gamma_1 t + \gamma_2 \exp(t-s)]\right.}{1 + \exp\left[\gamma_0 + \gamma_1 t + \gamma_2 \exp(t-s)\right]}$$

The maximum likelihood (ML) estimates of the parameters for the full model are.

β_0 = 0.0973 β_1 = 0.034 Υ_0 = 29.748

Υ_1 = 0.113 Υ_2 =-0116

The maximized value of the log likelihood is −278.02. The corresponding estimate of the cumulative mean discovery rate is plotted in Figure 6-1. Under this fitted model, the estimated mean introduction rate, which is the most important metric, rises from approximately 1.14 introductions per year in 1950 at an annual rate of 1.1% to approximately 12.69 introductions per year in 2022.

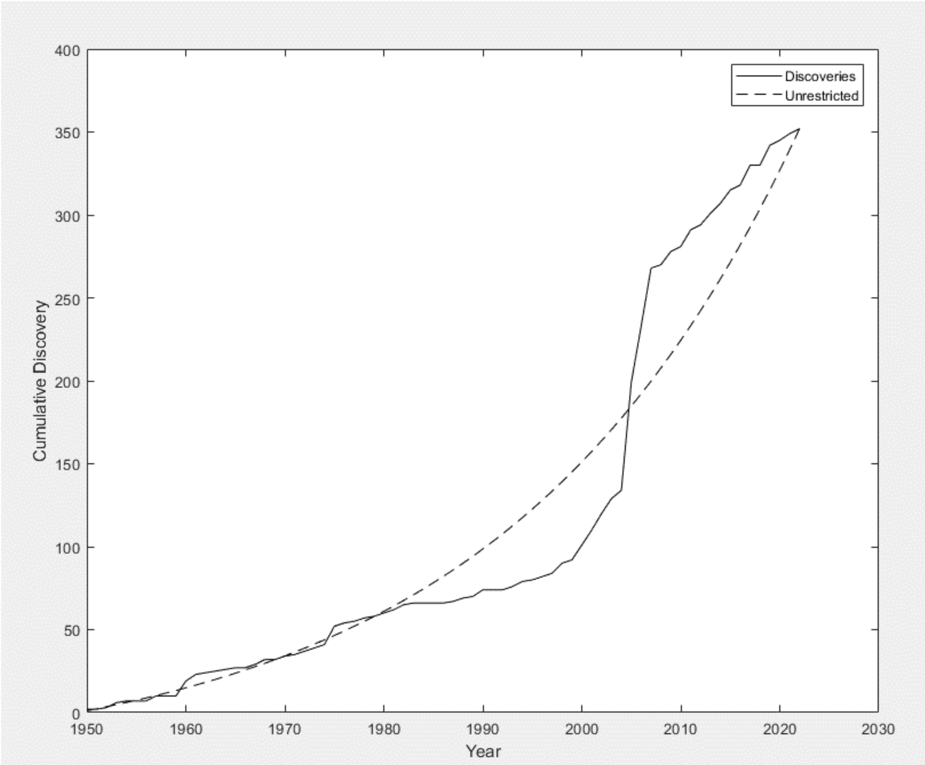

Figure 6-1: Rates of MNIS introduction and detection using a Maximum Likelihood (ML) estimate model. The cumulative record of discoveries of MNIS in New Zealand between 1950 and 2022 (solid line) and the probability of discovery of a species in year t (dashed line).

Although the model is easy to process using MatLab code provided by Solow and Costello (2004), it requires some simplifying assumptions about the parametric form of the number of species introduced per year and how the discovery process can be described probabilistically. This can make it difficult for those without a statistical background to understand and interpret the estimates. Costello et al. (2007) have since described a modified form of this procedure that also uses historical trade data as a co-variate to model the rate of introduction (μ).

To maintain consistency with past and other global reporting we recommended that the original statistic of the raw cumulative total number of non-indigenous species be retained. This metric can be compiled relatively easily from the already specified information sources and, notwithstanding the inherent variability in discovery, it can be interpreted relatively simply.

The recommended statistics for reporting on ‘pressure’ indicators remained unchanged.

- Time series information on the presence/absence of non-indigenous species (NIS) in New Zealand waters
  - *the total number of documented non-indigenous marine species in 2009* and
  - *the annual (post 2009) number of non-indigenous species that are new-to- New Zealand*.

6.1.1 Pressure indicators for 2023

Based on data collected until the end of December 2022 from all sources mentioned in Section 4, there has been a total of 429 MNIS recorded in New Zealand waters. Of those species recorded, 266 have been found to be established and 163 are not known to be established or have only been recorded from vessel hulls but not on permanent substrata in New Zealand waters (Figure 6-2). This is an increase of 74 species from

2009 but this number incorporates reviews of the biosecurity status of some historical specimens that have been catalogued and stored for reassessment, since first reported in 2009.

Since last reported in 2018, there has been an increase of twenty-two (established and not established) MNIS in New Zealand (Table 6-1). This increase includes the addition of two species that were likely present in New Zealand previously, but their taxonomic classification and distribution has only recently been established (Mike Page pers. comm.).

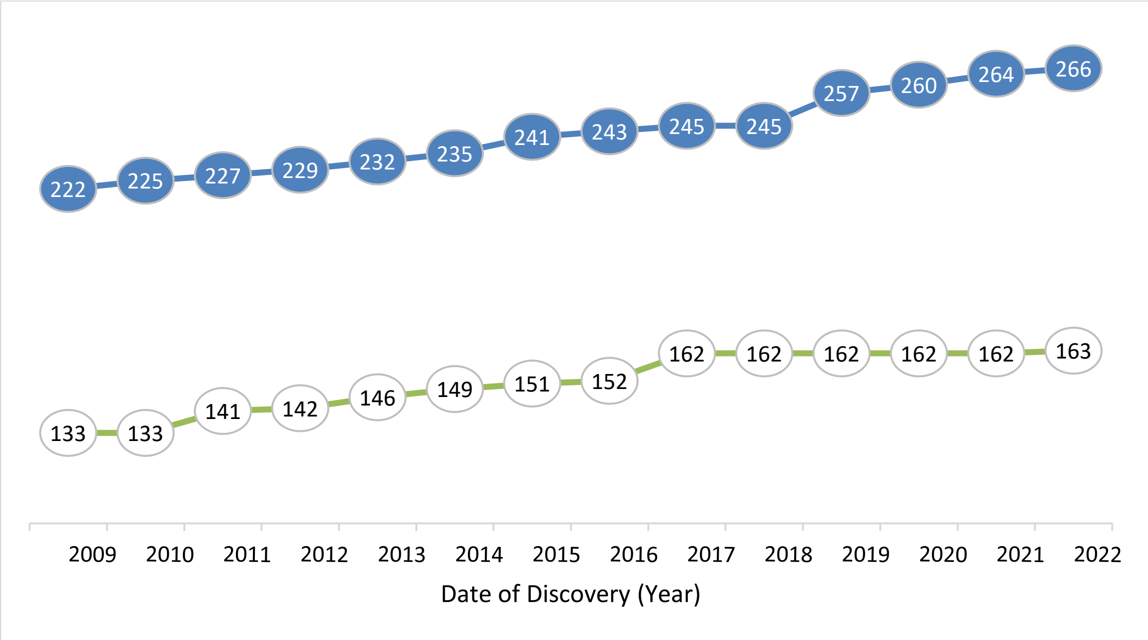

Figure 6-2: Time series of MNIS discovered in New Zealand since 2009. Blue symbols = cumulative number of species established in New Zealand, White symbols = species not known to be established in New Zealand.

6.2 State

'State' indicators assessed in Inglis and Seaward (2016) cover measures of range size, expansion, and contraction of key species, as well as measures of abundance and prevalence and the way they can change.

Similarly, to the 'pressure' indicators mentioned previously, environmental reporting and literature that has been published since 2016 have not revealed any indicators that are new or will represent the MNIS data available in New Zealand, in a new light (Table 6-2).

The recommended statistics for reporting on 'state indicators' remained unchanged.

- Range expansion/decrease for the key selected species
  - the maximum latitudinal extent.
- Information on the abundance/prevalence and change in abundance/prevalence for the ten key selected species.
  - the number and distribution of geographic units from which a species has been recorded within a fixed grid ('occupancy').

6.2.1 State indicators for 2023

As can be seen in Figure 6-3, five species have had no expansion to their maximum latitudinal extent since last reported in 2018. Initially when data were extracted for the locations of the two species of *Caulerpa,* their presence was confined to Aotea Great Barrier Island. However, at the time of writing, this species has since been found on mainland New Zealand in several sites in the Bay of Islands.

The twelfth site of Napier Port and Ahuriri Inner harbour was added to the NMHRSS locations surveyed in 2021. A 100 m x 100 m grid was added to the national grid for this location to keep it consistent with the data being recorded as part of this programme. Search effort, both unique occupied grid cells per annum (Table 6-4), and cumulative number of 100 m x 100 m grid cells searched is included (Table E-1).

However, it is important to note that annualising this measure can appear to create a decline in survey effort on particular years. As the NMHRSS surveys are run in summer and winter, summer can include months from November to March for the NMHRSS programme and the timing of these surveys do not always follow the same order. As the purpose of the surveys is to detect new to New Zealand incursions, not always sampling at the same time of year potentially increases the probability of detecting something new.

To maintain consistency with previous reporting we have included the grid-based indicators of change in cell occupancy per annum and the cumulative number of unique cells of the Mediterranean fanworm *Sabella spallanzanii* Table 6-3. We can see that 2020 was a particularly significant year in the spread and occupancy of *S. spallanzanii* in both Lyttelton and the Waitemata and the total number of grid cells occupied nationwide increased to 370.

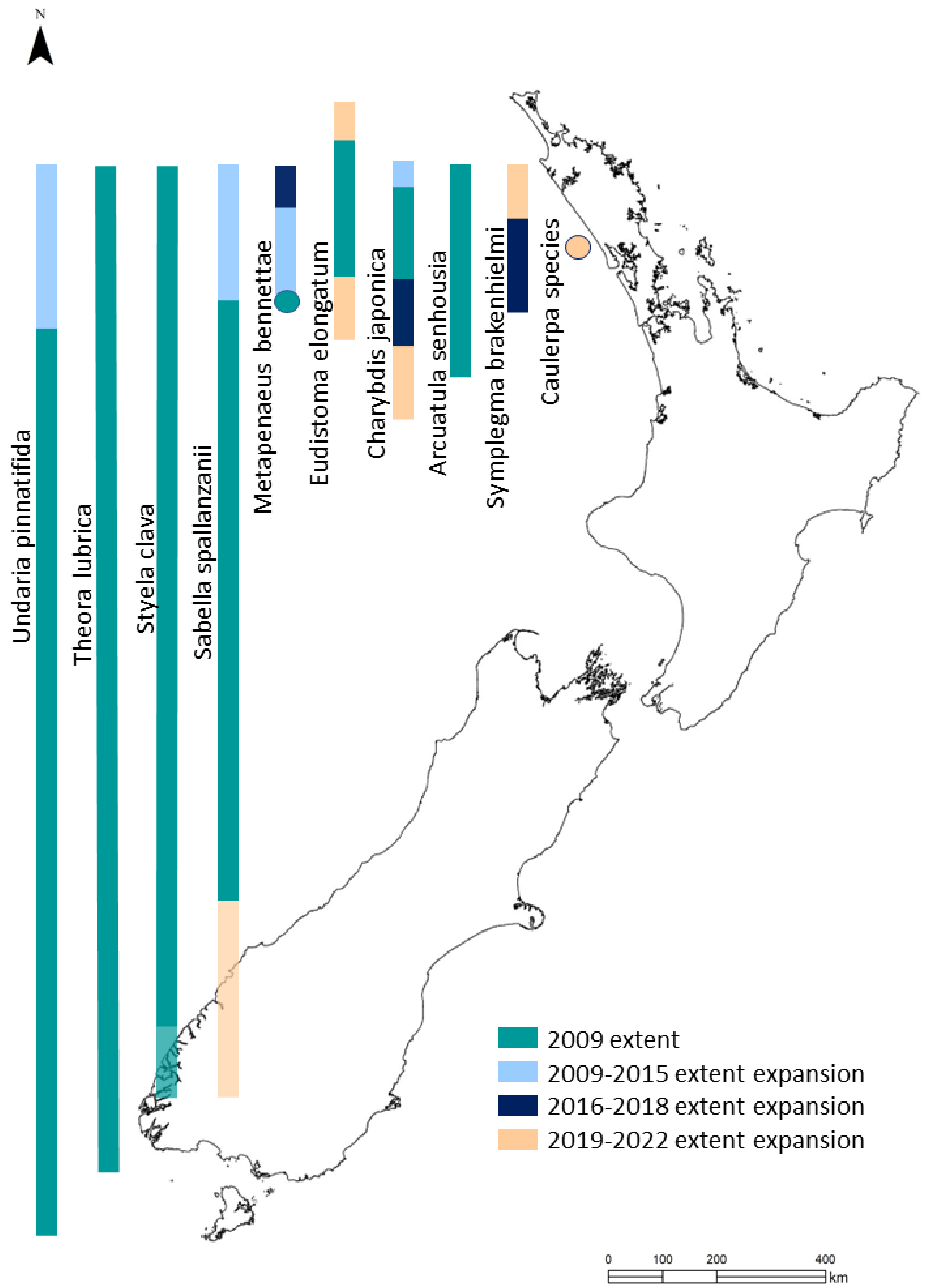

Figure 6-3: Maximum latitudinal extent or range expansion/ decrease for each of the ten key MNIS species.

Table 6-1: New marine non-indigenous species detected since the last report in 2018.

Source of record	taxon_name	Phylum	Class	Order	Family	Year
MESN 118	*Baseodiscus delineatus*	Nermertea	Pilidiophora	Heteronemertea	Valenciniidae	2019
MESN 102	*Bonnemaisonia hamifera*	Rhodophyta	Florideophyceae	Bonnemaisoniales	Bonnemaisoniaceae	2019
MESN 123	*Caulerpa brachypus*	Chlorophyta	Ulvophyceae	Caulerpales	Caulerpaceae	2021
MESN 124	*Caulerpa parvifolia*	Chlorophyta	Ulvophyceae	Caulerpales	Caulerpaceae	2021
MESN 126	*Chaetodon auriga*	Chordata	Actinopterygii	Perciformes	Chaetodontidae	2022
Mike Page pers comm	*Ciona robusta*	Chordata	Ascidiacea	Phlebobranchia	Cionidae	Unknown
MESN 121	*Clathrina* cf. *procumbens*	Porifera	Calcarea	Clathrinida	Clathrinidae	2019
MESN 104	*Clavelina oblonga*	Chordata	Ascidiacea	Aplousobranchia	Clavelinidae	2019
MESN 127	*Didemnum patulum*	Chordata	Ascidiacea	Aplousobranchia	Didemnidae	2022
NMHRSS	*Fushitsunagia catenata*	Rhodophyta	Florideophyceae	Rhodymeniales	Lomentariaceae	2019
MESN 116	*Goniodoris meracula*	Mollusca	Gastropoda	Nudibranchia	Goniodorididae	2020
MESN 103	*Hirayamaia mortoni*	Arthropoda	Malacostraca	Amphipoda	Corophiidae	2017
NMHRSS	*Lissoclinum perforatum*	Chordata	Ascidiacea	Aplousobranchia	Didemnidae	2020
MESN 105	*Melibe australis*	Mollusca	Gastropoda	Nudibranchia	Tethydidae	2019
MESN 125	*Mugilogobius platynotus*	Chordata	Actinopteri	Gobiiformes	Gobiidae	2021
NMHRSS	*Pachymeniopsis lanceolata*	Rhodophyta	Florideophyceae	Halymeniales	Halymeniaceae	2019
MESN 101	*Parablennius intermedius*	Chordata	Actinopterygii	Perciformes	Blenniidae	2019
NMHRSS	*Parablennius tasmanianus*	Chordata	Actinopterygii	Perciformes	Blenniidae	2021
MESN 110	*Paraheteropia ijimai*	Porifera	Calcarea	Leucosolenida	Heteropiidae	2019
Mike Page pers comm	*Perophora annectens*	Chordata	Ascidiacea	Phlebobranchia	Perophoridae	Unknown
NMHRSS	*Symplegma rubra*	Chordata	Ascidiacea	Stolidobranchia	Styelidae	2022
MESN 117	*Ulva tanneri*	Chlorophyta	Ulvophyceae	Ulvales	Ulvaceae	2019

Table 6-2: New 'state' indicators published post-2016, and equivalent indicators already reviewed as part of the initial review.

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016
MSFD directive	(EU 2017)	State	Abundance and spatial distribution of established invasive non-indigenous species, particularly those on the list of invasive alien species of Union concern.	Geographic cumulative point occurrence through time
Australia State of Environment Reporting	(Clark et al. 2021)	State	Biological pressure from aquatic invasive species at local government area scale	The numbers of NIS summarised by regional council coastal area, and total search effort in each coastal area.
New South Wales	(Froese et al. 2021)	State	Invasive alien species spatial extent, area of occupancy	The cumulative number of map grid cells in which the species is detected.
Journal article	(Wilson et al. 2018)	State	Extent of area that suffers major impacts from invasions.	The proportion of grid cells surveyed in which a species is detected.
Journal article	(Wilson et al. 2018)	State	Within-country dispersal rates	Annual measures, total cumulative change from date of first record, maximum distance from first record, latitudinal extent, mean distance from first record, marginal mean distance from first record and longitudinal extent.
Journal article	(Wilson et al. 2018)	State	Extent of alien species	Annual measures, total cumulative change from date of first record, maximum distance from first record, latitudinal extent, mean distance from first record, marginal mean distance from first record and longitudinal extent.
Journal article	(Wilson et al. 2018)	State	Abundance of alien species	The cumulative number of sites in which a species is detected.
Journal article	(Wilson et al. 2018)	State	Relative invasive abundance	The cumulative number of map grid cells in which the species is detected.

Table 6-3: Changes in the occupancy of the Mediterranean fanworm, *Sabella spallanzanii* in the Marine High Risk Surveillance Sites (MHRSS) (2009-2022). (a) The number of 100 m x 100 m grid cells in which the fanworm was detected per annum, (b) the cumulative number of unique grid cells in which the fanworm was detected.

	(a) No. 100 x 100 m grid cells per year														(b) Cumulative no. 100 x 100 m grid cells													
NMHRSS site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Opua	0	0	0	0	0	0	0	0	0	1	20	16	17	7	0	0	0	0	0	0	0	0	0	1	21	23	25	26
Whangarei	0	0	0	4	12	26	10	15	24	18	35	51	40	21	0	0	0	4	15	29	30	38	47	58	73	91	102	105
Waitemata	1	37	123	204	89	174	233	54	197	166	191	287	128	188	1	38	153	309	364	456	561	593	658	700	746	836	869	922
Tauranga	0	0	0	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	3	3	6	6	6	6	6	6	6
Napier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Plymouth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wellington	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Picton	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	2
Nelson	0	0	0	0	1	0	1	1	2	0	1	0	0	0	0	0	0	0	1	1	1	2	4	4	4	4	4	4
Lyttelton	1	5	2	1	3	0	1	1	0	1	1	15	22	19	1	6	8	8	10	10	10	10	10	10	10	20	28	32
Otago	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	2	2	3
Bluff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. NMHRSS sites	2	2	2	3	4	4	5	6	4	4	6	5	4	5	2	2	2	3	4	6	6	7	7	8	9	9	9	9
No. infested grid cells	2	42	125	209	105	204	246	75	224	186	249	370	207	236	2	44	161	321	390	500	606	651	728	782	864	985	1039	1101

Table 6-4: Annual survey effort in each of the Marine High Risk Surveillance Sites (NMHSS). Number of 100 m x 100 m grid cells sampled per annum.

	No. 100 x 100 m grid cells per year													
NMHRSS site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Opua	143	226	278	297	289	179	293	301	369	312	282	186	298	297
Whangarei	444	330	185	322	318	438	182	318	442	178	306	436	316	184
Waitemata	712	765	754	1022	420	737	1005	375	738	714	727	1013	431	706
Tauranga	317	316	340	333	441	207	335	449	186	425	335	193	325	424
Napier	0	0	0	0	0	0	0	0	0	0	0	0	101	121
New Plymouth	95	120	166	116	113	126	118	128	114	129	99	122	135	134
Wellington	292	304	291	172	297	375	291	181	384	287	174	277	370	182
Picton	203	170	118	186	160	122	146	160	162	169	159	160	197	128
Nelson	256	259	159	334	250	166	271	279	259	250	339	231	175	337
Lyttelton	179	308	404	192	317	393	289	318	188	385	175	360	291	284
Otago	335	352	463	213	341	316	426	319	331	185	325	322	312	321
Bluff	177	296	254	393	168	265	241	241	240	262	336	146	239	255
No. NMHRSS sites	11	11	11	11	11	11	11	11	11	11	11	11	12	12
No. infested grid cells	3153	3446	3412	3580	3114	3324	3597	3069	3413	3296	3257	3446	3190	3373

6.3 Impact

Information on socio-cultural, economic, and environmental impacts of NIS have been highlighted as basic information that is important but severely lacking globally (Parker et al. 1999; McGeoch et al. 2010, 2021; Galil et al. 2011; Blackburn et al. 2014; Katsanevakis et al. 2014; Bailey et al. 2020; Latombe et al. 2022)

In some situations, the economic impacts of NIS have been forecast by combining outputs from an infestation model and an ecosystem energy budget model. For example, the cumulative economic impacts of two MNIS (*Styela clava* and *Sabella spallanzanii*) were simulated for the export markets of green-lipped mussel (*Perna canaliculus*) in Aotearoa New Zealand. Direct impacts on producers for both species were estimated to be $26.4 million over a 24 year period (Soliman and Inglis 2018). However, these impacts were only assessed for two species on one economic industry and comparable data are not available for all MNIS recorded in NZ.

Most attempts to categorise impact use a standardised, often qualitative, classification system. One example is the Environmental Impact Classification for Alien Taxa (EICAT) developed by the IUCN (IUCN 2020). EICAT is the IUCN global standard for measuring the severity of environmental impacts caused by taxa living outside their natural range. There are eight categories for defining impact caused by species of concern. The categories are designed so that each subsequent step through the categories reflects an increase in an order of magnitude of a particular impact (Figure 6-4). There are twelve impact mechanisms that describe the ways in which species may cause negative impacts (see Appendix F, (IUCN 2020)). However, assigning an impact category requires all taxa or species to be evaluated against every mechanism and criterion to determine the appropriate EICAT category. Data must be applied using evidence based information, however, large numbers of species lack sufficient information to be classified into an impact category. As a result, when these schemas are used many species end up being classified as "data deficient" or "not evaluated".

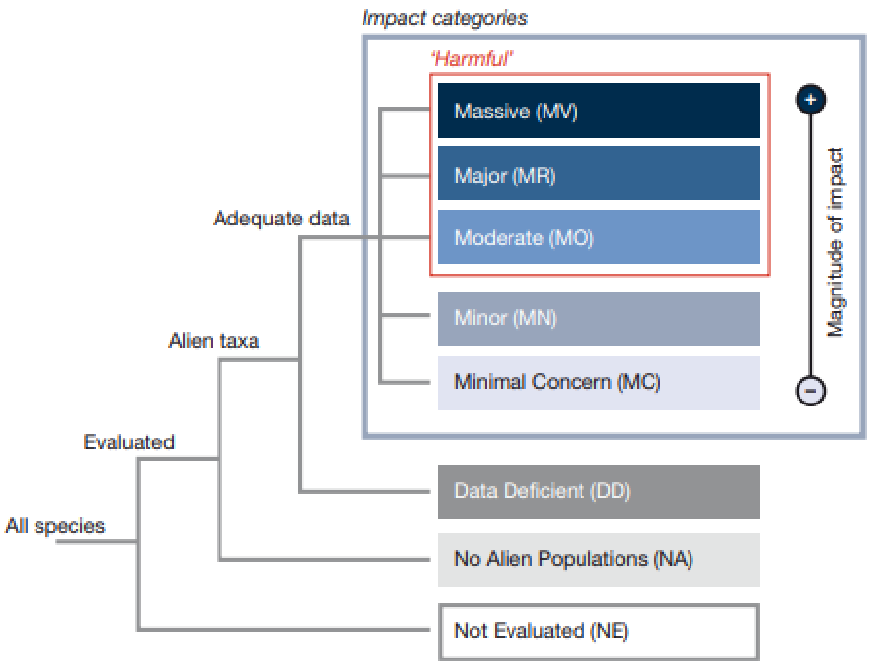

Figure 6-4: Different EICAT categories and the relationship between them taken from IUCN (2020).

As discussed by Inglis and Seaward (2016), there are a range of ecosystem components that could be affected by MNIS and often data or relevant studies are lacking to evaluate them. A single, simple metric would not encompass the range of impacts and values that could be affected to report on this indicator accurately.

One way of providing a metric of impact is to consider the generalised impact of an invade to be a simple geometric function of its range, abundance and per unit impact (the GIRAE model, Parker et al. (1999)).

Equation 6-2.

$$Generalised\ Impact\ =\ Range\ Size\ x\ Abundance\ x\ per-unit\ effect^{5}\ (GIRAE)$$

One limitation of this method, however, is an uneven sampling effort in space and time or among taxonomic groups can result in misleading patterns of occurrence. Absence in an area that has not been intensively surveyed may reflect a lack of survey effort for that taxon rather than true absence of the species (Hassall and Thompson 2010; Wolmarans et al. 2010). A consequence is that the perceived pattern of distribution and any changes through time will be affected by the distribution of observations and the spatial scales at which those observations are made (Wiens 1989; Gaston 1999).

Another limitation in calculating GIRAE is that abundance data are time consuming to collect and rarely available for multiple species (Gaston et al. 2000). However, abundance-occupancy (A-O) relationships are thought to be one of the most general patterns in ecology and were theorised by Darwin (Darwin 1859; Gaston et al. 2000). A-O relationships assume that the abundance and distribution of a species will have a positive relationship and that a species with a declining population will occupy fewer sites, and visa-versa (Gaston et al. 2000; Ten Caten et al. 2022). The resource availability hypothesis predicts that if a resource is widespread and is more locally abundant, the species that use this resource will achieve higher occupancy and abundance. Additionally, if species with broader niches can tolerate more diverse environmental conditions and use variable resources, they will also achieve higher abundance and occupancy. Sampling protocols can affect these A-O relationships but data from standardised surveys with specific methods and a consistent temporal element could provide a robust indicator of abundance.

Calculating the per-unit effect of a NIS is the hardest metric to estimate in the GIRAE calculation because it requires understanding of the functional relationship between the species and affected resources. Moreover, the impacts of NIS are highly context dependent, determined by the local values at risk, the behaviour of the species in a novel ecosystem and the management measures that are (or are not) implemented to mitigate any effects (Latombe et al. 2022). As a result, calculating generalised impacts often requires large amounts of information on each species that is not readily available, but may be possible in the future if there is further development of impact indicators (Table 6-5).

There are no recommended statistics for reporting on 'impact' indicators because suitable data are not currently available.

[5] The impact caused by a single individual, unit of biomass or unit of invaded area depending on how abundance was characterised (Parker et al. 1999; Latombe et al. 2022).

Table 6-5: New 'impact' indicators published post-2016, and equivalent indicators already reviewed as part of the initial review.

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016
MSFD directive	(EU 2017)	Impact	Proportion of the species groups or spatial extent of the broad habitat types that are adversely altered due to non-indigenous species, particularly invasive non-indigenous species.	The proportion of grid cells surveyed in which a species is detected.
New South Wales	(Froese et al. 2021)	Impact	Likelihood of invasive alien species impact	No equivalent indicator: data on realised impacts are not available.
New South Wales	(Froese et al. 2021)	Impact	Most harmful invasive alien species	No equivalent indicator: data on realised impacts are not available.
Journal article	(Essl et al. 2020).	Impact	Trends in the impact of IAS on extinction risk	No equivalent indicator: Difficult to quantify as no data on extinctions from MNIS is available.
Journal article	(Essl et al. 2020).	Impact	Trends in the numbers and impacts of invasive alien species in countries using the IUCN endorsed EICAT (environmental impact classification of alien taxa).	No equivalent indicator: data on realised impacts are not available.
Journal article	(McGeoch et al. 2021).	Impact	Impact Risk, that estimates invasive alien species impacts on the environment in space and time and provides a basis for nationally targeted prioritisation of where best to invest in management efforts.	No equivalent indicator: data on realised impacts are not available.
Journal article	(Wilson et al. 2018)	Impact	Number of invasive species that have major impacts.	No equivalent indicator: data on realised impacts are not available.
Journal article	(Wilson et al. 2018)	Impact	Impact of alien species	No equivalent indicator: data on realised impacts are not available.
Journal article	(Wilson et al. 2018)	Impact	Impact of invasions	No equivalent indicator: data on realised impacts are not available.
Journal article	(Latombe et al. 2017).	Impact	Alien species impact.	No equivalent indicator: data on realised impacts are not available.

7 Summary and recommendations

A review of the 'marine non-indigenous species' indicators first recommended by Inglis and Seaward (2016) has shown that although many new indicators for non-indigenous species have been proposed internationally in reports and literature, few have actually been calculated at a national or regional level because of the lack of reliable data to populate them.

Data from New Zealand, however, sets the standard. The National Marine High Risk Site Surveillance programme has been in place for over twenty years and the data captured from that programme and the Port Biological Baseline Surveys, as its baseline for assessing change in the marine environment, has provided us with a reliable way to consistently report on the status of MNIS in New Zealand. It is for this reason that we have recommended that the indicators remain unchanged and have reported on them in a similar manner to previous environmental reports.

The three specific indicators and statistics to quantify them for reporting on the national '*MNIS'* indicator are:

1. Time series information on the presence/absence of non-indigenous species (NIS) in New Zealand waters
    - the total number of documented non-indigenous marine species in 2009 and
    - the annual (post 2009) number of non-indigenous species that are new-to- New Zealand.
2. Range expansion/decrease for the key selected species
    - the maximum latitudinal extent.
3. Information on the abundance/prevalence and change in abundance/prevalence for the ten key selected species.
    - the number and distribution of geographic units from which a species has been recorded within a fixed grid ('occupancy').

As identified in 2016, specific indicators 1 and 2 should be quantified using data combined from the PBBS, NMHRSS, MITS and the synthetic reviews described in Section 4 of this report. Specific indicator 3 should be quantified using data only from the NMHRSS.

Ten MNIS have been identified as 'key species' for specific indicators 2 and 3:

- Asian bag mussel, *Arcuatula senhousia*
- Asian paddle crab, *Charybdis japonica*
- Australian droplet tunicate, *Eudistoma elongatum*
- Green tail or 'Greasy-back' prawn, *Metapenaeus bennettae*
- Mediterranean fanworm, *Sabella spallanzanii*
- Clubbed tunicate, *Styela clava*
- Fragile clam, *Theora lubrica*

- Wakame / Undaria, *Undaria pinnatifida*
- Indo-Pacific ascidian, *Symplegma brakenhielmi*
- Sea mustard species, *Caulerpa brachypus* & *Caulerpa parvifolia*

Information on all forms of MNIS impacts is one of the indicators that is lacking from this review. A standardised approach for quantifying impacts, perhaps using the GIRAE model mentioned in Section 6.3, could be a way forward in filling this gap in available data.

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9 Glossary of abbreviations and terms

AquaNIS	Information system on Aquatic Non-Indigenous and Cryptogenic Species
CBD	International Convention on Biological Diversity
Cryptogenic	Species that are not demonstrably indigenous or non-indigenous within a biogeographic region
DAISIE	Delivering Alien Species Inventories for Europe
EASIN	European Alien Species Information Network
EICAT	Environmental Impact Classification for Alien Taxa
Established	A non-indigenous species that has formed a self-sustaining population(s). Synonymous with ‘naturalised’.
IAS	Invasive Alien Species
Indigenous	Species that occurred within a biogeographic region historically and were not introduced by human activities. Synonymous with 'native'.
IUCN	International Union for Conservation of Nature
MITS	Marine Invasives Taxonomic Service
MNIS	Marine non-indigenous species
MPI	Ministry for Primary Industries
New to New Zealand	Species that have not previously been recorded from New Zealand waters
NMHRSS	National Marine High Risk Site Surveillance
Non-indigenous (NIS)	Species that are known or suspected to have been introduced as a result of human activities. Synonymous with ‘alien’, ‘adventive’, ‘exotic’, ‘introduced’ and ‘non-native’.
Not established	A non-indigenous species that has been reported only from a vessel or other transient structure or which was introduced but failed to form self-sustaining populations.
PBBS	Port Biological Baseline Survey(s)
GIRAE	Generalised impact model, where: Generalised Impact = Range Size x Abundance x per-unit effect

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Appendix A Essential variables for invasion monitoring

Table A-1: The three essential variables for a global observation and monitoring system for biological invasions, taken from Latombe et al. (2017).

Origin	Essential variable	Observations on which it is based	Collated as	Examples for derived supplementary variables and indicators
In-situ data	1. Alien species occurrence (McGeoch and Latombe 2016)	Taxonomically verified species presence or absence records at a locality with geographic co-ordinate or in a prescribed area, management or geopolitical unit or site.	A matrix of alien species occurrences (presence and where possible absence) by particular locations	Requiring Essential Variables 1 and 2: Alien species area of occupancy Alien species inventories for countries and sites Number of alien species per site, area, or geopolitical unit
Ex-situ information	2. Species alien status (McGeoch et al. 2012)	Knowledge of the historical geographic range of the species that is commonly available in flora and fauna volumes, its historical absence from the introduced range, or genotypic difference from local populations	Categorical Alien/Native for each species record from which the introduced range of the species can be extracted	Trends in numbers of alien species Propagule pressure or invasion rate Status of species along the introduction–naturalization–invasion continuum (Blackburn et al. 2011) An alert system for new incursions Model-based predictions of which species are candidates for future incursion
	3. Alien species impact (Blackburn et al. 2014)	An objective, transparent and repeatable system for classifying alien taxa in terms of the current and maximum realized impact globally of their detrimental effect on any recipient ecosystem	Alien taxa categorized into one of five 'impact' categories by applying the standardized classification system (Hawkins et al. 2015)	Number and identity of species in each impact category at a site or in an area of interest Trends in alien species with the most severe impacts Lists of priority species for policy and management

Appendix B Updates to existing taxonomy since 2018

Table B-1: Updates to taxon names and status of marine non-indigenous species present in New Zealand since last reported in 2018.

Source of record	Taxon name	Phylum	Class	Order	Family	Year	Update
MESN 119	*Botrylloides diegensis*	Chordata	Ascidiacea	Stolidobranchia	Styelidae	Pre-1900	Status change
NMHRSS	*Botrylloides giganteus*	Chordata	Ascidiacea	Stolidobranchia	Styelidae	2005	Name change
Te Papa	*Cladophora vagabunda*	Chlorophyta	Ulvophyceae	Cladophorales	Cladophoraceae	1980	Name change
PBBS	*Cladostephus hirsutus*	Ochrophyta	Phaeophyceae	Sphacelariales	Cladostephaceae	1929	Name change
Cranfield et al (1998)	*Dactylosiphon bullosus*	Ochrophyta	Phaeophyceae	Scytosiphonales	Scytosiphonaceae	1982	Name change
Cranfield et al (1998)	*Diplosoma listerianum*	Chordata	Ascidiacea	Aplousobranchia	Didemnidae	1994	Status change
Cranfield et al (1998)	*Hydroclathrus tilesii*	Ochrophyta	Phaeophyceae	Ectocarpales	Scytosiphonceae	1974	Name change
Nelson et al. 2021	*Hypnea cervicornis*	Rhodophyta	Florideophyceae	Gigartinales	Hypnaceae	2001	Name change
Nelson et al. 2021	*Hypnea corona*	Rhodophyta	Florideophyceae	Gigartinales	Hypnaceae	2010	Name change
NMHRSS	*Lagarosiphon major*	Spermatophyta	Monocotyledonae	Hydrocharitales	Hydrocharitaceae	1950	Record addition
MESN 129	*Leucothoe nagatai*	Arthropoda	Malacostraca	Amphipoda	Leucothoidae	2015	Status change
Miller (2001)	*Polycera fujitai*	Mollusca	Gastropoda	Nudibranchia	Polyceridae	1996	Record addition
Cranfield et al (1998)	*Polysiphonia sertularioides*	Rhodophyta	Florideophyceae	Ceramiales	Rhodomelaceae	1938	Name change
Nelson et al. 2021	*Schizymenia dubyi*	Rhodophyta	Florideophyceae	Nemastomatales	Schizymeniaceae	Unknown	Name change
Golder	*Solieria* sp. A (WELT A020843)	Rhodophyta	Florideophyceae	Gigartinales	Solieriacae	2006	Name change
Cranfield et al (1998)	*Thecacera pennigera*	Mollusca	Gastropoda	Nudibranchia	Polyceridae	1973	Status change
(Heesch et al. 2007)	*Ulva intestinalis*	Chlorophyta	Ulvophyceae	Ulvales	Ulvaceae	2005	Name change
NMHRSS	*Ulva stenophylloides*	Chlorophyta	Ulvophyceae	Ulvales	Ulvaceae	2009	Name change

Appendix C Descriptions of original key species

The Asian bag mussel (also commonly known as the 'Asian date mussel'), *Arcuatula senhousia*, became established in the Auckland region in the 1970s (Willan 1985). Native to the north-west Pacific, it has also spread to many locations around the world, including North America, the Mediterranean, Australia and north-east Atlantic (Bachelet et al. 2009). *A. senhousia* is a small (<35 mm length), thin-shelled mussel that lives on hard and soft intertidal and shallow subtidal substrata in estuaries. It is a habitat-modifier. Juveniles settle from the plankton in very dense patches (tens of thousands per square metre), often over large areas, and secrete fibrous byssal threads that attach to sediment particles and other mussels forming a kind of mat around them. The mats modify water flow and sedimentation near the seafloor and can change areas of sandy sediments into sticky muds altering their suitability for other species (Crooks 1996; Crooks and Khim 1999; Hayward et al. 2008). *A. senhousia* matures quickly (< 9 months) and has a relatively short (~2 yr.) adult life span.

The Asian paddle crab, *Charybdis japonica*, is a large (carapace width up to 12 cm), aggressive swimming crab that was first recorded in the Auckland region in 2000 (Smith et al. 2003). Native to the north-west Pacific, *C. japonica* has also been recorded in South Australia, Western Australia and in the Mediterranean, but it does not appear to have established self-sustaining populations in those regions (Froglia 2012; Hourston et al. 2015). *C. japonica* is a habitat generalist that occurs in soft sediment and subtidal rocky areas of estuaries and shallow coastal embayment's (Gust and Inglis 2006; Kolpakov and Kolpakov 2011). Adults prey on large burrowing urchins, crabs, bivalves, gastropods, and small fishes (Jiang et al. 1998; Sudo et al. 2008; Townsend et al. 2015). Studies have shown that its aggressive nature allows it to outcompete the native New Zealand paddle crab, *Ovalipes catharus*, for food (Fowler and McLay 2013). In its native range, *C. japonica* is known to carry diseases that affect crab, lobster, shrimp, and prawn fisheries.

The Australian droplet tunicate, *Eudistoma elongatum*, was first reported on oyster farms in Houhora Harbour, Northland, in early 2005 (Smith et al. 2007). Native to the northern New South Wales and central Queensland coasts, it does not appear to have been introduced anywhere else in the world. *E. elongatum* is a colonial ascidian ('sea squirt') that forms long (up to 30 cm length), white cylindrical tubes that grow in large numbers on wharves, pontoons, buoys and boats, aquaculture structures and in sand, mud, rock, or seagrass habitats. It can smother beaches, rocks and tide-pools and is a nuisance fouling species in shellfish aquaculture (Morrisey et al. 2009).

The greentail (or 'greasy back') prawn, *Metapenaeus bennettae*, is native to the eastern coast of Australia, from eastern Victoria to central Queensland, where it is the subject of small commercial and recreational fisheries (Rowling et al. 2010). It was first recorded from Waitemata Harbour in 2009 (Morrisey et al. 2010). It does not appear to have been introduced elsewhere in the world. Adult *M. bennettae* occur in soft sediment habitats in coastal lakes, lagoons, and shallow coastal waters, while juveniles can be found in upstream freshwater environments (Rowling et al. 2010). Adults grow to a maximum size of ~13 cm length. Unlike other prawns, *M. bennettae* is able to complete its lifecycle in shallow coastal estuaries.

The Mediterranean fanworm, *Sabella spallanzanii*, is a very large, fast-growing polychaete worm that builds long, flexible tubes up to 1 m in length on wharves, pontoons, aquaculture structures, boat hulls and hard surfaces in soft sediments. It settles gregariously in large clusters, with densities of up to 1000 individuals per square metre. It is a highly efficient filter-feeder that strains plankton from the water and deposits large quantities of organic material (packaged as pseudo faeces) onto seafloor sediments. The physical presence of large numbers of its tall tubes can also change the nature of benthic habitats. *S. spallanzanii* is native to the Mediterranean and the eastern Atlantic coast of Europe and North Africa (Read et al. 2011). It has been introduced to southern Australia, where it occurs from Western Australia to New South Wales (Knight-Jones and Perkins 1998).

The clubbed tunicate, *Styela clava*, is a solitary ascidian ('sea squirt') that attaches to ropes, wharves, pontoons, aquaculture structures, boats, and hard natural substrata such as rocks, seaweed, and shellfish. It was first recorded in Auckland in 2005, but studies suggest that it may have been present in New Zealand since at least 2002 (Hayward and Morley 2009). It is native to the north-west Pacific but has also been introduced to the Atlantic Coast of Europe (including the United Kingdom), the Mediterranean, Baltic Sea, Pacific and Atlantic coasts of North America, and southern Australia (Davis and Davis 2009). *S. clava* grows rapidly, reaching densities of up to 500-1500 individuals per square metre, is a nuisance fouling organism in shellfish aquaculture and can compete for space and food with native and aquaculture species (e.g., mussels, oysters).

Theora lubrica is a small (~16 mm length), thin-shelled bivalve that is a dominant species in fine, muddy seafloor sediments in eutrophic bays, where it can reach densities in the thousands per square metre (Ranasinghe et al. 2005)It is a deposit feeder that consumes predominantly benthic microalgae (mainly diatoms) and particulate organic matter on the sediment surface (Yokoyama and Ishihi 2003). *T. lubrica* is known to be tolerant of highly contaminated and organically enriched sediments and through its constant burrowing and movement may affect the cycling of nutrients by liberating nitrogenous compounds from bottom sediments. It is native to east Asia, from Japan to Singapore and Indonesia, but has been introduced to a wide range of countries including the Pacific and Atlantic coasts of North America, Europe, the Mediterranean, Australia, and New Zealand (Adarraga and Martínez 2011). It has been present in New Zealand since, at least, the early 1970s (Auckland Institute and Museum. Conchology Section 1994).

The Asian kelp or 'wakame', *Undaria pinnatifida*, is a fast growing brown alga that is native to temperate regions of Japan, China, and Korea. It was first reported from New Zealand in 1987 (Hay and Luckens 1987) and has also been introduced to Argentina, Australia, Britain, France, Italy, the Netherlands, Spain, Mexico, and California (Meretta et al. 2012). *U. pinnatifida* grows on rocky reefs in sheltered and semi-exposed coastal areas and on wharves, pontoons, buoys, and boat hulls. It is also a nuisance fouling species on shellfish aquaculture equipment and stock.

Appendix D 'Pressure' indicators published post–2016

Table D-1: New 'pressure' indicators published post-2016, and equivalent indicators already assessed as part of the initial review.

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016[6]
MSFD directive	(EU 2017)	Pressure	Newly introduced NIS – number newly introduced non-indigenous species introduced via human activity in the last 6 years (assessment period) and a list of those species.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
United Kingdom	(Harrower et al. 2022)	Pressure	Species list of all invasive non-native species (marine, terrestrial and freshwater) having negative or strongly negative ecological effect.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
United Kingdom	(Harrower et al. 2022)	Pressure	Analytical estimation of Area of Extent (AoE) using area estimates from an alpha hull polygon.	Range size – Comparison of different distance based metrics to measure changes in the geographic range of a species.
EEA	European Environment Agency 2023	Pressure	Introduction rates since last round of reporting by species group, pathway, and marine region	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
EEA	European Environment Agency 2023	Pressure	Number of new MNIS	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
EEA	European Environment Agency 2023	Pressure	Cumulative number of new MNIS through time	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
HELCOM	(Lehtiniemi et al. 2018)	Pressure	Number of new MNIS per 10-year time bin for the region.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.

[6] (Inglis and Seaward 2016)

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016[6]
HELCOM	(Lehtiniemi et al. 2018)	Pressure	Number of MNIS and cryptogenic species for each HELCOM country for 5 specific time periods from 1900–2015.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
OSPAR	(Staehr et al. 2023)	Pressure	New records of MNIS introductions	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Government of Canada	(Government of Canada 2015).	Pressure	Number of known newly established invasive alien species in Canada, by Federal Regulatory status.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Government of Canada	(Government of Canada 2015).	Pressure	Percent of federally regulated foreign invasive alien species not established in Canada.	No comparative indicator, only one marine notifiable organism under the Biosecurity Act 2016 is present in New Zealand
New South Wales	(Froese et al. 2021)	Pressure	Invasive alien species richness, state-wide, by bioregion and 5 km grid	The numbers of NIS summarised by regional council coastal area, and total search effort in each coastal area.
Journal article	(Essl et al. 2020).	Pressure	Trends in the number of IAS introduction rates	The numbers of NIS summarised by regional council coastal area, and total search effort in each coastal area.
Journal article	(Essl et al. 2020).	Pressure	Time series of IAS numbers for various taxonomic groups and regions	The numbers of NIS summarised by regional council coastal area, and total search effort in each coastal area.
Journal article	(McGeoch et al. 2021).	Pressure	Rate of Invasive Alien Species Spread, which provides modelled rates of ongoing introductions of species based on invasion discovery and reporting.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(McGeoch et al. 2021).	Pressure	Status Information on invasive alien species, that tracks improvement in the essential dimensions of information needed to guide relevant policy and data collection and in support of assessing invasive alien species spread and impact	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016[6]
Journal article	(Wilson et al. 2018)	Pressure	Rate of introduction of new unregulated species.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Wilson et al. 2018)	Pressure	Introduction rates	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Wilson et al. 2018)	Pressure	Number and status of alien species	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Wilson et al. 2018)	Pressure	Alien species richness	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Zenetos et al. 2022).	Pressure	Number of NIS Detected by year and region.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Zenetos et al. 2022).	Pressure	Cumulative numbers of NIS detected by region and year from 1970.	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Zenetos et al. 2022).	Pressure	Annual rates of NIS introductions (6-year average) at different geographic levels (with a linear regression for all European Seas).	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.
Journal article	(Latombe et al. 2017).	Pressure	Species occurrence	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016[6]
Journal article	(Latombe et al. 2017).	Pressure	Species alien status	Times series of the discovery record of non-indigenous marine species in New Zealand by both decade and by year as both cumulative records and introductions per year.

Table D-2: Indicators that fall under the 'Driver' and 'Response' framework that are out of scope for this review.

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016
EEA	European Environment Agency 2023	Driver	Pathways of MNIS introduction (average from 1970 to 2020)	Pathway analysis outside of scope of report
EEA	European Environment Agency 2023	Driver	Transport method of new MNIS in 5 year bins	Pathway analysis outside of scope of report
Government of Canada	(Government of Canada 2015).	Response	Number of intervention or management plans in place.	Response reporting outside scope of report
Journal article	(Essl et al. 2020).	Response	Database of all successful eradications	Response reporting outside scope of report
Journal article	(Essl et al. 2020).	Response	Legislation, policy and regulations for prevention and control of invasive alien species	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Response	Level of success in managing invasions.	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Driver	Introduction pathway prominence	Pathway analysis outside of scope of report
Journal article	(Wilson et al. 2018)	Driver	Within-country pathway prominence	Pathway analysis outside of scope of report
Journal article	(Wilson et al. 2018)	Response	Quality of regulatory framework	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Response	Money spent	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Response	Planning coverage	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Driver	Pathways treated	Pathway analysis outside of scope of report
Journal article	(Wilson et al. 2018)	Response	Species treated	Response reporting outside scope of report

Source	Reference	Category	Proposed indicator	Equivalent indicator reviewed in 2016
Journal article	(Wilson et al. 2018)	Response	Sites treated	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Response	Effectiveness of pathway treatments	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Response	Effectiveness of species treatments	Response reporting outside scope of report
Journal article	(Wilson et al. 2018)	Response	Effectiveness of site treatments	Response reporting outside scope of report

Appendix E NMHRSS search effort

Table E-1: Annual survey effort in each of the National Marine High Risk Site Surveillance Sites (NMHRSS). Cumulative number of unique 100 m x 100 m grid cells sampled per annum.

Cumulative no. 100 x 100 m grid cells													
2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
143	298	412	622	727	759	814	862	900	929	946	952	968	981
444	659	758	900	1028	1192	1245	1349	1498	1544	1622	1735	1777	1817
712	1269	1691	2186	2331	2585	2924	3026	3244	3445	3634	3835	3854	3988
317	528	680	807	932	969	1030	1111	1139	1206	1237	1253	1277	1312
0	0	0	0	0	0	0	0	0	0	0	0	101	133
95	146	195	206	213	222	229	240	244	254	256	260	272	280
292	474	593	647	736	839	900	927	999	1030	1050	1075	1087	1099
203	262	276	309	321	325	331	337	353	363	368	372	381	386
256	383	425	525	561	578	614	634	656	676	689	717	719	738
179	424	665	737	858	1017	1116	1225	1280	1398	1439	1537	1576	1641
335	602	873	954	1070	1159	1274	1348	1417	1451	1503	1545	1564	1594
177	401	531	653	678	724	751	781	810	845	872	876	888	893
11	11	11	11	11	11	11	11	11	11	11	11	12	12
3153	5446	7099	8546	9455	10369	11228	11840	12540	13141	13616	14157	14464	14862

Appendix F Twelve impact mechanisms

There are twelve impact mechanisms and for each mechanism there are five criteria against which a species should be evaluated. See IUCN (2020) for a full the full descriptions of criteria and mechanisms.

1. Competition – the alien taxon competes with native taxa for resources (e.g., food, water, space), leading to deleterious impact on native taxa.
2. Predation – the alien taxon predates on native taxa, leading to deleterious impact on native taxa.
3. Hybridisation – the alien taxon hybridises with native taxa, leading to deleterious impact on native taxa.
4. Transmission of disease – the alien taxon transmits diseases to native taxa, leading to deleterious impact on native taxa.
5. Parasitism – the alien taxon parasitises native taxa, leading to deleterious impact on native taxa.
6. Poisoning/toxicity – the alien taxon is toxic, or allergenic by ingestion, inhalation, or contact, or allelopathic to plants, leading to deleterious impact on native taxa.
7. Bio-fouling or other direct physical disturbance – the accumulation of individuals of the alien taxon on the surface of a native taxon (i.e., biofouling), or other direct physical disturbances not involved in a trophic interaction (e.g., trampling, rubbing, etc.) leads to deleterious impact on native taxa.
8. Grazing/herbivory/browsing – grazing, herbivory or browsing by the alien taxon leads to deleterious impact on native taxa.
9. Chemical impact on ecosystem – the alien taxon causes changes to the chemical characteristics of the native environment (e.g., pH; nutrient and/or water cycling), leading to deleterious impact on native taxa.
10. Physical impact on ecosystem – the alien taxon causes changes to the physical characteristics of the native environment (e.g., disturbance or light regimes), leading to deleterious impact on native taxa.
11. Structural impact on ecosystem – the alien taxon causes changes to the habitat structure (e.g., changes in architecture or complexity), leading to deleterious impact on native taxa.
12. Indirect impacts through interactions with other species – the alien taxon interacts with other native or alien taxa (e.g., through any mechanism, including pollination, seed dispersal, apparent competition, mesopredator release), facilitating indirect deleterious impact on native taxa.