TESTING THE D2C1 GES INDICATOR FOR MARINE NON-INDIGENOUS SPECIES WITH LONG-TERM DATA FROM DANISH SEAS

Scientific Report from DCE – Danish Centre for Environment and Energy no. 546 2023

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Data sheet

Series title and no.:	Scientific Report from DCE – Danish Centre for Environment and Energy No. 546
Category:	Scientific advisory report
Title:	Testing the D2C1 GES indicator for marine non-indigenous species with long-term data from Danish Seas
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Institution:	Aarhus University, Department of Ecoscience, Denmark
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL:	http://dce.au.dk/en
Year of publication:	March 2023
Editing completed:	March
Referee:	Jesper P.A. Christensen
Quality assurance, DCE:	Anja S. Hansen
Linguistic QA:	Sanjina U. Stæhr
External comments:	Miljøministeriet. The comments can be found here: http://dce2.au.dk/pub/komm/SR546_komm.pdf
Financial support:	Danish Ministry of Environment
Please cite as:	Stæhr, P.A.U., Jakobsen, H.H. 2023. Testing the D2C1 GES indicator for marine non-indigenous species with long-term data from Danish Seas. Aarhus University, DCE – Danish Centre for Environment and Energy, 23 pp. Scientific Report No. 546 http://dce2.au.dk/pub/SR546.pdf

Abstract: Using a long-term data set on non-indigenous species (NIS) we tested a proposed Good Ecological Status (GES) indicator (D2C1) for assessing the arrival rate of NIS in Danish Seas. The importance of monitoring effort and human activities influencing the observed changes in NIS introductions are discussed with recommendations on how to account for these effects for future GES assessments of NIS.

Keywords:	Non-indigenous species, NIS, MSFD, Indicator, D2C1, Good ecological State, baseline, Danish seas
Layout:	Peter A.U. Stæhr
Front page photo:	Helle Buur (Hemigrapsus takanoi)
ISBN:	978-87-7156-763-2
ISSN (electronic):	2244-9981
Number of pages:	23
Internet version:	The report is available in electronic format (pdf) at http://dce2.au.dk/pub/SR546.pdf

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Preface

This study was supported by the Danish Ministry of environment as a contribution to ongoing discussions on establishing a robust indicator to assess new introductions of non-indigenous species in the Danish and European Seas.

Sammenfatning

Vi undersøgte anvendeligheden af en foreslået indikator for god økologisk tilstand (Good Ecological Status; GES) i relation til presfaktoren ikke-hjemmehørende arter (non-indigenous species; NIS) som er en deskriptor under havstrategidirektivet. Baseret på observationer af første NIS fund i danske farvande for perioden 1850 til 2020, anvendte vi en statistisk analyse til at definere en referencetilstand for den årlige hastighed (antal nye NIS per år) for introduktion af NIS. Data blev samlet i seks års perioder og de beregnede introduktionsrater blev sammenlignet med rater beregnet ud fra en GES grænseværdi defineret som en 50% reduktion ift. introduktionsraten i en baselineperiode. Vi diskuterer betydningen af moniteringsintensiteten samt menneskelige presfaktorer, herunder skibstrafik og klimaforandringer, for ændringer i spredning og introduktion af NIS. Afslutningsvist kommer vi med forslag til hvordan disse forhold kan inddrages i fastsættelse af GES grænseværdien for NIS indikatoren D2C1.

Summary

We investigated the usefulness of a proposed Good Ecological Status (GES) indicator for assessing the arrival rate of non-indigenous species (NIS), an assessment criterion applied under the Marine Strategy Framework Directive. Based on NIS records in Danish seas from 1850 to 2020, we applied a statistical baseline analysis to define a baseline level for annual NIS introductions (#NIS per year). We aggregated NIS observations into six-year assessment periods and investigated changes (#NIS per six years) compared to a GES threshold of a 50% reduction relative to the identified baseline introduction rate. We discuss the importance of human activities influencing the observed changes in NIS introductions. Finally, we highlight possible ways of accounting for uneven monitoring efforts and pressures associated with different pathways of introduction on setting a GES threshold.

1 Introduction

Marine non-indigenous species (hereafter NIS), also referred to as alien, exotic species, subspecies, or lower taxon, occurring outside their natural range and dispersal potential (Nature & Group, 2000). The need for common approaches to monitor and assess NIS has been identified at the European Union level (Schulz & Della Vedova, 2014). A subset of marine NIS has demonstrated their potential to have adverse effects on native species and reductions in ecosystem integrity, ecosystem services (Rilov & Crooks, 2009; Simberloff et al., 2013; Tsirintanis et al., 2022) and economic losses (Williams et al., 2010), hence considered invasive. Globally, invasive NIS are one of the most critical threats to biodiversity due to habitat loss (Watson et al., 2019). NIS may threaten the balance of the local and regional ecosystem by displacing indigenous species through competition for food, space and resources, predation, or by introducing disease. Yet, the ecosystem impacts are not always only negative (Katsanevakis et al., 2014)

Moreover, the increased globalization with the growing trends in trade, travel and transport have also enhanced those marine invasions through the many pathways, e.g. shipping, navigational canals, aquaculture, and the aquarium trade (Hulme, 2009; Katsanevakis et al., 2014; Katsanevakis et al., 2013; Tsiamis et al., 2018). On a global scale, these human-mediated introductions are responsible for biotic homogenization and preventing the introduction of NIS is currently considered the only feasible management option in the marine environment (Giakoumi et al., 2019).

A recent assessment estimated that 787 NIS have been found in European marine systems alone (Tsiamis et al., 2019), several of which require special attention as they are highly invasive with consequences for marine ecosystem services and biodiversity, often causing adverse effects on environmental quality (Katsanevakis et al., 2014; Ojaveer et al., 2017; Wallentinus & Nyberg, 2007). To address the risks NIS poses in European seas, the Marine Strategy Framework Directive (MSFD) requires EU Member States (MSs) to consider NIS in their marine management strategies. Similarly, within the Regional Sea Conventions (RSCs) of OSPAR, HELCOM and the Mediterranean, there is ongoing work to develop and define indicators to assess NIS introduction and impact.

For both MSFD and RSCs, NIS is treated as a distinct Descriptor (D2): "*Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem*". A primary criterion (D2C1) has been described by the European Commission (Commission, 2017) and defined as: "*The number of non-indigenous species which are newly introduced via human activity into the wild, per assessment period (6 years), in comparison to a reference condition as reported for the initial assessment under Article 8(1) of Directive 2008/56/EC, is minimized and where possible reduced to zero*". In addition, two secondary NIS GES criteria (D2C2 and D2C3) are described. These aim to address the abundance and spatial distribution of established NIS (D2C2) and the impact of invasive NIS (D2C3) on species and habitats (Commission, 2017).

The emphasis within MSFD and RSCs has so far been on gathering updated, and quality-assured NIS lists from the EU member states and contracting parties to describe the status and trends in new NIS arrivals. For OSPAR and

HELCOM, the analysis of temporal trends in new NIS introductions is included in the forthcoming QSR2023 and HOLASIII assessments. In addition, a study is being carried out for the EU implementation of a Good Ecological Status (GES) indicator under the MSFD, which will build upon an updated analysis of NIS observations (Zenetos et al., 2022). However, neither of these organizations tested a threshold for the D2C1 NIS GES indicator. Thus the next step is to fully define and test the D2C1 indicator before incorporating NIS into GES assessments. Development of the NIS indicators to assess spread and impact (D2C2 and D2C3) are also being developed. Still, reports from NIS expert groups at both the MSFD and RSC levels (e.g. Stæhr et al. 2022) highlight significant gaps regarding the lack of standardized data collection, which must be addressed before the development and assessment of the secondary indicators can be made.

Regarding the primary indicator (D2C1), two major challenges have been identified: 1) defining robust and useful baseline periods and 2) setting threshold values or targets for GES (Teixeira et al. 2016). To operationalize an indicator, it is paramount to identify relevant baseline periods which are preferably long (preferably from the 1970s), and that threshold values are adapted to regional conditions. A threshold of zero new NIS introductions per year to achieve good GES, was initially suggested by HELCOM, which aligns well with the ambition of a reduction to zero (Commission, 2017). While easy to apply, a zero-threshold level seems impossible to achieve. A NIS expert group proposed using an alternative D2C1 threshold, which is defined by a relative reduction in new NIS arrivals compared to a baseline period (OSPAR, 2018). A percentage reduction in new NIS for a specific assessment period compared to the average number of previous six-year assessment cycles has accordingly been recommended as a NIS D2C1 indicator (Tsiamis et al., 2021).

This study investigates the appropriateness of the proposed indicator for non-indigenous marine species (D2C1) at the country scale (Danish Seas). The analysis has been conducted closely with NIS experts in the JRC group to align our approach and recommendations for testing and setting a threshold at different geographical scales with the work conducted across the EU member states. Specifically, we analyzed a long-term time series (1850-2020) covering the Danish seas to define baseline conditions and compare these with a reduction measure to assess changes in GES status. Our analysis builds upon recent recommendations for the D2C1 definition described by Tsiamis et al. (2021) and investigated by Galanidi and Zenetos (2022).

2 Methods and materials

Following the MSFD timeline, reporting of GES should be done every six years, although assessments can be conducted between years at any point during this period. Data handling and management must be agreed upon as the indicator is developed further. The approach applied in this analysis follows recommendations provided by OSPAR in the most recent CEMP guideline for NIS (OSPAR 2022).

2.1 Data sources for NIS in Danish waters

Our analysis combines historical records from experts and literature with long-term monitoring data (1950 –2021) from fjords, estuaries and coastal and open water sites scattered across the Danish seas. These sampling sites have been regularly monitored since 1989 as part of the Danish National Aquatic Monitoring and Assessment Program (NOVANA, but also referred to as DNAMAP – see Riemann et al. (2016)). The analysis of trends in NIS introductions (D2C1) was based on a nationwide, updated data set of first observations, covering the period 1850 to 2020 (Miljøstyrelsen 2022). This data set on NIS records in Danish waters is updated regularly against NIS listed in the European Alien Species Information Network (EASIN) (Tsiamis et al., 2019) and the AquaNIS (Sergej et al., 2013). This approach ensures that the applied NIS are checked and validated by appointed experts from the EU MSs, with substantial contribution by the ICES Working Group of Introduction and Transfers of Marine Organisms (WGITMO). We are therefore confident that our list is updated with the latest scientific findings about NIS in Europe and their current status. However, we acknowledge that the list is the subject of critique and may have to be updated in the future (Gómez, 2019; Tsiamis et al., 2019).

In preparation for the D2C1 assessment, we applied the OSPAR CEMP (OSPAR Agreement 2018-04) NIS quality assurance/control steps:

1. Check the format of the date of the first observation
2. Check the format of latitude and longitude data
3. Check taxonomic validation against WORMS
4. Assign information on higher taxonomic groups (Primary producers, Invertebrates, Vertebrates)
5. Check cryptogenic status using relevant databases (EASIN and AquaNIS)
6. Remove NIS species recommended not to be included in the NIS assessment.

To align the assessment with the criteria for NIS assessments decided under the MSFD NIS descriptor (D2), we adopted the following criteria for data selection (Table 2.1):

Table 2.1. Species groups to include or exclude in setting the reduction percentage for newly introduced NIS (Tsiamis et al., 2021).

Species group	Exclude from threshold (yes/no/why)
Cryptogenic	yes (high uncertainty)
Cryptogenic expanding	yes (high uncertainty)
Range-expanding	yes (cannot be considered alien)
Partly native	Case-by-case at the subregional level
NIS introduced through natural dispersal	Case-by-case
Debatable/questionable	yes (status may change in the future)
Unicellular marine algae	yes (significant data gaps regarding their origin)
Parasites	Case-by-case at the subregional level, if sufficient information is available
Extinct species	Case-by-case (based on taxon, research effort, regional data, etc.)
Freshwater/Oligohaline species	no (provided they are found in the coastal systems of a country)

For this study, no species on the Danish NIS list are considered partly native. As the information on the dispersal pathways is associated with high uncertainty, we included all NIS deemed to be introduced via natural dispersal. No parasites or extinct species were included in this analysis. For taxonomic referential and coherence, we acknowledge that several records have an approximate geographical reference or an indefinite period for the first record, e.g. before a specific year or in a set of years. Accordingly, these records were assigned to a central geographical point in the referenced area or to the most approximate year of the assessment period.

2.2 Indicator definition

The MSFD aims to implement a program of measures to reduce human pressures on the marine environment and a monitoring program to determine the effectiveness of the measures. The NIS indicator presented within this document takes a pragmatic approach to assess changes in the community of NIS within a given region, exemplified by Danish seas.

The D2C1 - New Introductions indicator quantifies new NIS records in each assessment area during several assessment periods to provide a status report. It measures the number of NIS identified and reported for the first time in the assessment area (i.e. not previously present) during the assessment period. Relative change in this parameter over subsequent assessment periods facilitates assessment of this pressure on the marine environment, and may be used to evaluate the effectiveness of measures to prevent or reduce the introduction of NIS and their spread across areas.

For criterion D2C1, it was initially suggested to apply a GES value of zero by HELCOM: "The number of newly introduced non-indigenous species, via human activity, is minimized and, where possible, reduced to zero". However, in OSPAR (Stæhr et al. 2022) and recently by the JRC, it has been recommended to use a measure of reduction in NIS introductions relative to a baseline period (Tsiamis et al., 2021), where GES is achieved when the reduction (%) is below a defined threshold.

The percent reduction in new NIS introductions per assessment period (%NIS reduction$_t$) is calculated as:

$$\%NIS\ reduction_t = \frac{Rate\ NIS_t - Rate\ NIS_{baseline}}{Rate\ NIS_{baseline}}\ x\ 100\%$$

Rate NIS_t is the annual rate of NIS introductions over a six-year assessment period. The baseline NIS introduction rate (Rate $NIS_{baseline}$) is determined as the average rate over an extended baseline period with a near-constant annual introduction. To determine the baseline period, we applied the R-program ASCETS[1] to investigate structural time series changes (Östman et al., 2020). Here, we excluded the three most recent six-year periods covering 2003-2020 to enable GES assessment of these periods. Finally, we determine the GES level by comparing the relative change in new NIS arrivals (%NIS $reduction_t$) for each six-year assessment period, with a suggested GES threshold of a 50% reduction as suggested by Tsiamis et al. (2021). The 50% reduction is not based on an evaluation of the reduction needed to avoid negative impact but is suggested as a simple measure to test the threshold approach for a given subregion. To explain the threshold approach, an example with 30 new NIS observed during the last three six-year cycle periods (18 years in total) provides an average of 10 new NIS per six-year cycle. Applying a threshold value of 50% reduction of the average number of new NIS during the selected 6-years cycle periods: 50% of 10 new NIS = 5 new NIS. To summarize, a threshold reduction value of 50% for this example results in a maximum of 5 new NIS introductions in the most recent six-year assessment period. In the following, we assign GES levels as: Good (%NIS $reduction_t \geq 50\%$), and Poor (%NIS $reduction_t < 50\%$), where the 50% threshold level has the unit of #NIS per six-year assessment period.

[1] Analyses of structural changes in ecological time series (ASCETS)

3 Results

3.1 Trends in new NIS arrivals – setting a baseline

New NIS introductions have been reported for Danish marine waters since the 1850ies. Before the onset of regular species monitoring in the early 1980s, records originated from academic surveys only. Later, more than 2/3 of the new recordings were found through the repeated monitoring program, which was not established to identify NIS, but species in general in the soft bottom, hard bottom benthic communities and for pelagic zoo and phytoplankton. The trend in the accumulated number of new NIS (Figure 3.1A) suggests an overall exponential trend in NIS as indicated by the dashed line, with a modelled estimate of initial NIS in 1850 around four and a growth in the annual NIS introduction rate of 1.02 NIS/year. Although the model fits the data well, deviations from the exponential curve were apparent. Accordingly, the observed trend suggests a breakpoint around 1980 with a departure from the exponential model. Applying linear regression models provided an annual NIS introduction rate of 0.36 and 1.72 before and after 1980, supporting that 1980 represents a breakpoint, which corresponds approximately to the onset of the marine species monitoring program (Figure 3.1A).

Looking at the trend in annual number of new NIS observations, an exponential model suggests a gradual increase in the yearly recordings over time (Figure 3.1B). There were several years with no observations before 1980, after which the annual rate of new NIS introductions increased, as indicated by the inserted 18-year running mean (Figure 3.1B). Before 1980, there were an average of 0.35 new NIS observations per year, compared to 1.8 after 1980, and for the past 18 years (2003-2020), the arrival of 2.1 NIS per year is observed (Figure 3.1B). According to a non-parametric Mann-Whitney U-test, the baseline level before 1980 was significantly lower ($p<0.001$) than after 1980 and the 2003-2020 period. Applying the ASCETS program (Östman et al., 2020), we also identified a breakpoint around 1980, which supported using the period after 1980 as suitable for defining a baseline level. To enable comparison with the three latest 6-year assessment periods (2003-2020) applied, we used a baseline period covering the years 1980-2002. To compare with the most recent assessment period (2015-2020), we furthermore used a baseline period covering 1980-2014.

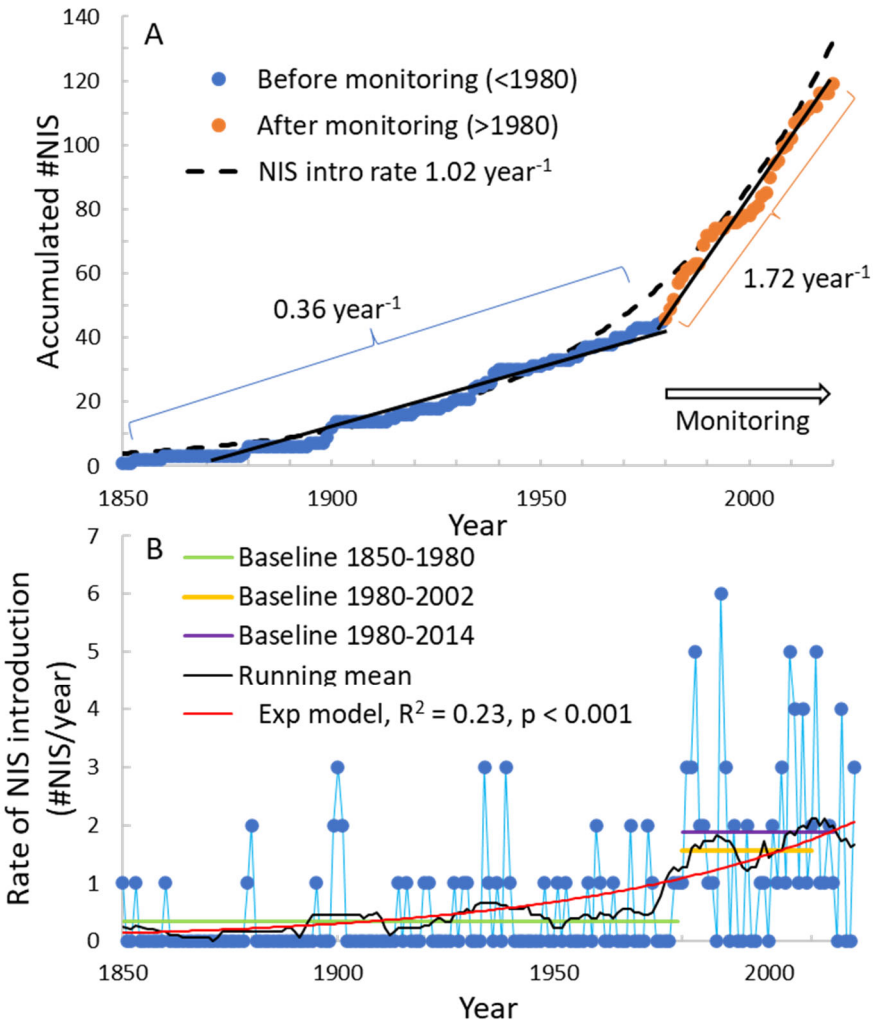
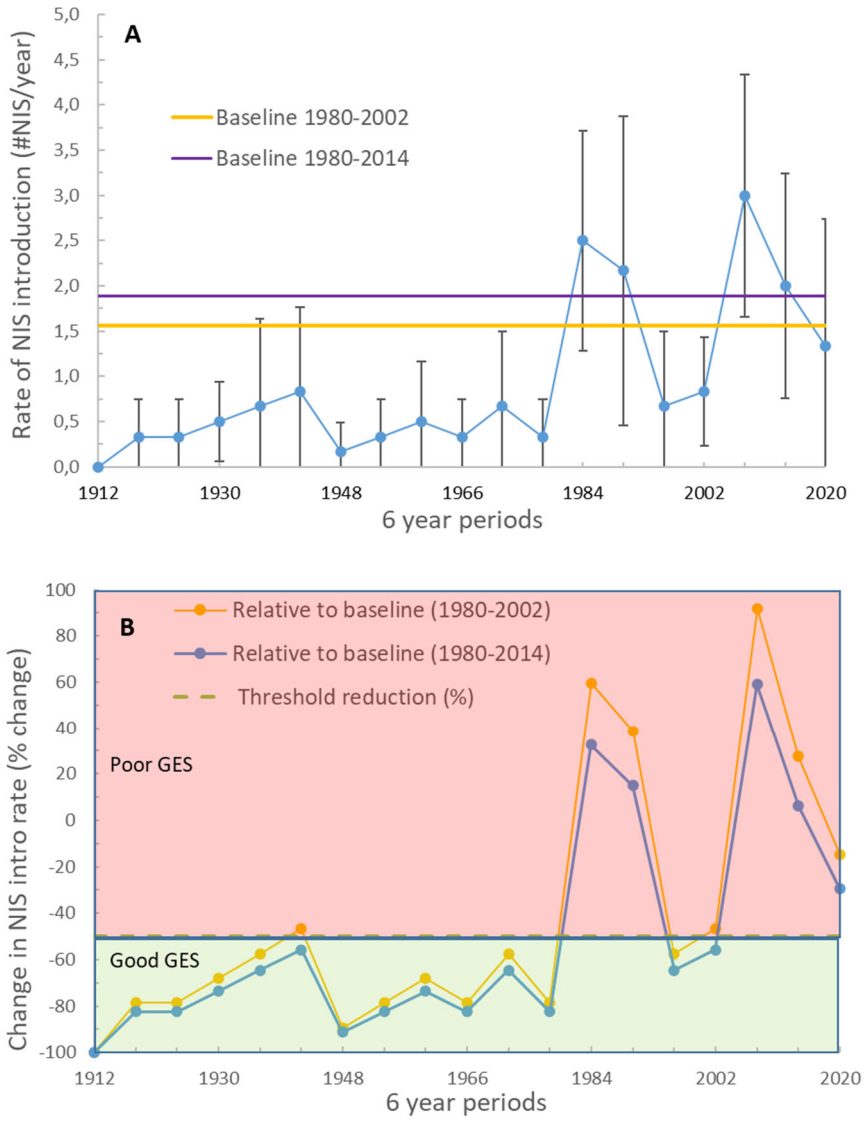


Figure 3.1. Long-term trends in new NIS arrivals in Danish marine waters derived from academic surveys and regular monitoring of marine species.
A) Trends in the accumulated #NIS records appear exponential, but with marked differences before and after the onset of regular monitoring around 1980.
B) Trends in the annual records of new NIS introductions. The baseline level, defined for both the 1980-2002 and the 1980-2014 period, were both significantly higher than the yearly mean rate (in green) prior to 1980. The solid black line in B represents a running mean of 3 assessment periods (18 years), and the red line represents an exponential model.

3.2 Quantifying the D2C1 GES indicator

To investigate the proposed D2C1 GES indicator, we compared trends in 6-year assessment periods with baseline levels for 1980-2002 and 1980-2014, respectively (Figure 3.2A). According to the 95% confidence levels, the NIS baseline introduction rate for the 1980-2002 period (1.57 NIS per year) was not significantly different from 2003-2020. Similarly, the baseline level for 1980-2014 (1.89 NIS per year) was not significantly different from the rate of NIS introductions during 2015-2020 (1.33 NIS per year) (Figure 3.2A). Before 1980, the introduction rates were lower than both baseline levels. After 1980, the introduction rates were much higher but also more variable, with several assessment periods above the baseline. To finally assess the GES level, the difference (as a per cent) of the NIS introduction rate (avg #NIS/year) was compared to the baseline NIS introduction levels and a suggested GES threshold of a 50% reduction (Figure 3.2B).

Figure 3.2.
A) Trends in NIS introduction rate for 6-year assessment periods (average ± 95% CL) compared with a baseline level for the 1980-2002 and 1980-2014 periods.
B) Trends in relative difference (%change) in NIS introduction rate compared with the baseline level.



Comparing the averages ± 95% CL of six-year assessment periods with both baseline levels (Figure 3.2A) show that until the early 1980s, the annual rate of NIS introductions fell below both applied baseline levels. After this, rates increased significantly above the baseline levels for most periods (except from 1990 to 2002). Using the 50% reduction threshold criteria provides a good GES before 1984, after which all assessment periods (except for the 1991-2002 period) fell into the poor GES status (Figure 3.2B). It's also interesting that the transition from good to poor GES (before and after 1984) was associated with much higher variability in the rate of NIS introduction.

4 Discussion

Setting a baseline level for the rate of new NIS introductions in Danish seas depends on which period baseline is being applied, as rates vary several-fold over time. Thus, the length and period of the time series for defining the reference conditions require careful consideration, as the baseline level is used for calculating the percentage reduction in the NIS introduction rate. Research has shown that longer-term time series is more appropriate for evaluating the effectiveness of mitigation decisions (Butchart et al., 2010; Galanidi & Zenetos, 2022). In this study, we identified two baseline periods (1850-1980 and 1980-2002) to assess the D2C1 indicator for the three most recent 6-year assessment periods (2003-08, 2009-14 and 2015-2020). Baseline periods were identified from an analysis of trends in the accumulated NIS numbers and annual records of new NIS. The observed breakpoint in new NIS arrivals around 1980 coincided approximately with the onset of the national marine species monitoring program. This suggests that repeated sampling may raise the likelihood of observing new NIS. Such a dependency is observed for NIS and marine species in general because rare species, such as newly introduced NIS require many samples to be detected (Staehr et al., 2020). This highlights the importance of significant reporting lags between the first observation of a species and when it becomes regularly observed, as recently documented by Zenetos and co-workers (Zenetos et al., 2019). In addition to an increased sampling effort, the intensification of globalization and thus increased shipping occurred since the 1980ies (Robbins et al., 2022). As shipping is considered a primary vector of NIS introductions to European waters (Tsiamis et al., 2018), it seems likely that the rate of ship-related introductions increased significantly around 1980, adding to the sudden increase in NIS observations hereafter as observed for the North-East Atlantic in general (Stæhr et al. 2022).

When setting the GES threshold value, this should ideally reflect a level by which there is no negative impact on the ecological status. However, as very little is currently known about the impact of NIS and acknowledging that the impact and distribution of a given NIS can vary a lot between regions, it is currently not possible to set a threshold based on zero impact. As an alternative, it has been suggested that the regional monitoring effort (spatial coverage and frequency of sampling) should influence the regional GES threshold (Zenetos et al., 2022). As the chance of observing new NIS increases with monitoring efforts, this effect should be acknowledged when setting a GES threshold value. Consequently, if a country has a high monitoring effort, then the threshold should be lowered (e.g. 40% rather than 50%); otherwise, there is economic potential for rewarding a reduction in monitoring. When setting a GES threshold, it should also be acknowledged that human activities (such as shipping) and differences in environmental conditions (e.g. salinity, temperature, sediments, hydrodynamics) affect the introduction potential and establishment success of NIS. Differences in these conditions among countries and regions may cause significant spatial and temporal differences in the rate of NIS introduction. It has therefore been suggested that the threshold level should be adjusted according to the pathway pressure of NIS introductions, such that regions/countries with many pathways (higher pressure), having a higher chance of NIS introductions, are provided with a lower GES threshold (Zenetos et al., 2022). Here it can be argued that a regional threshold set as a percentage reduction compared to a regional baseline level already considers

that regional differences related to pathways are present in the rate of NIS introductions.

While the effect of increased NIS monitoring efforts has likely affected the rate of new NIS observations, the onset of the 1980ies also marks a period with a tremendous increase in global trading, raising the likelihood of new NIS introductions via shipping (Robbins et al., 2022) which is reflected in the importance of shipping as a pathway for NIS introductions in the NE Atlantic (Stæhr et al. 2022). Furthermore, several NIS were deliberately introduced via aquaculture (e.g. pacific oyster and associated flora and fauna) during the 1980ies, and the introduction of NIS from neighbouring seas (secondary spread) has likely also influenced the rate of new NIS arrivals (Stæhr et al. 2022). On top of this, increasing seawater temperatures with climate change are likely to have facilitated the expansion of warmer adapted NIS species through secondary spread from southern Europe to the colder northern regions such as Danish seas (Pinsky et al., 2013; Poloczanska et al., 2016). NIS are often introduced through many pathways, with the likely effect of climate change further facilitating spread via secondary introductions (Katsanevakis et al., 2013).

Given that the importance of pathways (e.g. ballast water, hull fouling, aquaculture) of introduction is likely to differ between different taxonomic groups (e.g. macroalgae, phytoplankton, zooplankton, benthic invertebrates and fish), it could be considered to establish different baselines and GES levels for these. The pressure of different pathways would need to be calculated quantitatively from the information collected through surveillance systems at borders, ports, and other regulations (i.e., ballast water). For the Danish NIS recordings, limited information is currently available on pathways of introductions. Recent studies highlight that multiple introduction pathways can be relevant (Rius et al., 2015), making it difficult to effectively assess the effectiveness of measures to reduce the rate of NIS introductions. Many conditions, therefore, are likely to have influenced the increase in NIS numbers in Danish Seas, making it challenging to apply information on pathway pressure for setting a NIS D2C1 GES threshold. This underlines the importance of improved information on pathways of NIS introductions into Danish seas, established using common practices (e.g. Katsanevakis et al. 2013). A quality-assured assessment of NIS introduction pathways would enable setting GES thresholds for e.g. primary introductions and for certain taxonomic groups.

The applied approach in this study to determine GES is based on a simple analysis of raw numbers of new NIS per year, which is the type of data generally available within most European countries. However, this approach does not account for the monitoring effort and reporting (e.g., reporting lags). As a result, raw time series of NIS detection can give a misleading picture of the number of new NIS introductions and preventive efforts. Advanced statistical models have been suggested to help reduce the bias related to changes in monitoring efforts and reporting time lags (McGeoch et al., 2021). Regardless, a process whereby baselines for the region and/or Contracting Party are maintained and updated needs to be agreed, as this will help decrease the time lag between reports and data availability. We, therefore, support any developments to standardize and centralize databases and data management at the EU level. Defining a GES threshold value for NIS introductions in a given region should include careful consideration by a forum of scientists, alongside managers and policymakers, to provide a realistic threshold in the context of

specific conservation goals and management objectives (Galanidi and Zenetos 2022).

Finally, as an alternative to the baseline-based reduction threshold tested in this study, a fixed threshold of zero new NIS per assessment period has been applied within HELCOM being presented in the upcoming HOLAS3 assessment for NIS. The zero-threshold application, which only considers primary NIS introductions, has been highlighted as having advantages with regards to 1) communicating with managers, 2) it addresses only primary introductions, which in theory can be managed, and 3) it is a precautionary approach which is needed given the uncertainties associated with current lack of a harmonized and standardized monitoring program for NIS. However, on the negative side, it seems highly unrealistic that any country would ever achieve good GES with such a threshold, given that the continued discussions among NIS experts and stakeholders involved in NIS monitoring and management have resulted in a recommendation that a reduction threshold set against a baseline level should be adopted for D2C1 assessment (Tsiamis et al., 2019).

5 Conclusions

A simple approach taken in this study was to define a baseline period from analysis of trends in introductions and then compare rates over six-year assessment periods to a GES threshold, set as a fixed percentage reduction defined from the chosen baseline period. For simplicity, we applied a 50% reduction target using two categories of GES (Good vs Poor) commonly applied in the MSFD. Our approach can easily be applied to other regions and subregions, which as a minimum, have NIS records covering the last ca. 18 years. While the 50% threshold approach is relatively easy to apply, future work at the EU and Regional Sea Conventions levels should investigate and recommend ways of adjusting the threshold level with information on monitoring efforts and, if possible, pathway pressures. Also, it would be relevant to examine the importance of global warming on NIS introductions associated with different pathways.

6 Acknowledgements

This work was supported by the Danish Environmental Protection Agency to provide adequate advice on assessments of indicators related to non-indigenous marine species within OSPAR (QSR2023), HELCOM (HOLASIII) and as part of the GES assessment under the Marine Strategy Framework Directive (MSFD). We would like to thank Ana-Cristina Cardoso and Chiara Magliozzi from the Joint Research Centre, Ispara, for their valuable discussions and input to the analysis and report.

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Using a long-term data set on non-indigenous species (NIS) we tested a proposed Good Ecological Status (GES) indicator (D2C1) for assessing the arrival rate of NIS in Danish Seas. The importance of monitoring effort and human activities influencing the observed changes in NIS introductions are discussed with recommendations on how to account for these effects for future GES assessments of NIS.

ISBN: 978-87-7156-763-2
ISSN: 2244-9981