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Data towards assessing non-indigenous species introductions in the Black Sea

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A R T I C L E I N F O

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A B S T R A C T

The Marine Strategy Framework Directive (MSFD, 2008/56/EC) sets the foundation for community actions in the field of marine environmental protection and a robust and collaborative assessment of the implementation of measures by Member States (MS) of the European Union. In particular, the Commission Decision (EU) 2017/848 lays down criteria and methodological standards on good environmental status (GES) for assessing non-indigenous species (NIS) pressure in marine waters. One of these criteria (i.e. D2C1) aims to minimise and where possible reduce to zero, the number of NIS newly introduced into Europe's marine waters. To this end, the need for up-to-date data on newly introduced NIS is paramount to enable a quantitative assessment of D2C1. This paper provides a summary of the latest developments on the methodologies for assessing D2C1 and their application on the Black Sea dataset. The analysis identifies common practices and needs; strengthening NIS monitoring would improve the confidence of NIS assessment and allow for investigation of changes in NIS spread, ecological impact and effectiveness of management action. Additional efforts should also be made to ensure access to the monitoring results.

1. Introduction

The Marine Strategy Framework Directive (MSFD, 2008/56/EC, [3]), in force since 2008, requires Member States (MS) to achieve good environmental status (GES) in their marine waters. The determination of GES is based in criteria and methodological standards laid down by the Commission Decision (EU) 2017/848 [5], hereafter GES Decision). The objectives set by the Commission Decision (2017/848) [5] on Descriptor 2 Criterion 1 (D2C1), aim at minimising and where possible reduce to zero the number of non-indigenous species (NIS) into European marine waters over a six-year assessment period. Achieving GES relies on several factors, including the availability and quality of data, specific targets, and collaborative efforts among Member States. As a result, there are currently different approaches to assess D2C1 [23]; MS have worked on establishing threshold values that provide a quantitative assessment of D2C1, building upon standards stemming from Regional Seas Conventions (RSCs) [11,17,6], with the objective of developing comparable and scientifically-sound threshold values [9]. A threshold value for D2C1, allowing managers for an assessment of GES for the criterion, rely on high quality data on NIS introductions and involves two key steps: first the identification of the baseline data in relation to which the threshold value is set and second setting the threshold value itself. Thus, the implementation of thresholds required exchange of information on practices, monitoring outcomes and harmonization of NIS data [24] with the aim of ensuring comparable assessments across marine regions.

This study presents an update of the NIS baseline data for the Black Sea marine region, and the application of different RSCs indicators to

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evaluate D2C1 for GES in this marine region. The aim of this communication is to support future development by identifying common practices and existing challenges.

2. Assessment of newly introduced NIS

2.1. Data

Time series data on NIS new introductions is key for a quantitative assessment of D2C1 [24]. Existing approaches to the assessment of GES for D2C1 are so far depending on regional characteristics and data availability. MS through their national experts coordinate the collection of NIS data at national scale (e.g., [10,13,16,18]). It includes species name, authorship, year of first introduction, bibliographic reference of the observation, pathways of introduction, national, subregion and marine region of occurrence. These datasets are eventually compiled in inventories at regional scale through coordination by the RSCs. For instance, in the Mediterranean Sea under the Barcelona Convention, national datasets were compiled regionally and made available through the Specially Protected Areas Regional Activity Centre (SPA-RAC) MAMIAS (Marine Mediterranean Invasive Alien Species) database, which also includes neighbouring countries (i.e. Turkey, Syria, Lebanon, Israel, Egypt, Libya, Tunisia, Algeria, Morocco, Albania, Montenegro) [8]. In the Baltic Sea, under the Baltic Marine Environment Protection Commission (HELCOM), data is available through the HELCOM Biodiversity database which specifically for NIS collects observation from AquaNIS (Information system on aquatic non-indigenous and cryptogenic species) and includes nine contracting parties (i.e. Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden). In the North-East Atlantic, OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) region, NIS data are provided by the OSPAR contracting parties and originates from a range of national monitoring approaches, combined with documented reports by national experts [17]. National and regional NIS inventories for the MSFD are then coordinated by the Joint Research Centre (JRC) of the European Commission [24].

NIS data at European scale can be accessed through the JRC Data Catalogue and the European Alien Information Network (EASIN), which are linked to published scientific and policy work of MS NIS experts in 2019 and 2021 [22,24] and following updates [27,7,8]. This set of NIS data constitutes the baseline reference for the assessment of D2C1 and its GES determination.

2.2. Existing approaches

The assessment of MS reports on MSFD obligations for the period from 2012 to 2017 revealed inconsistencies in setting threshold values for D2C1 in the Baltic Sea and NE Atlantic countries, while Black Sea and Mediterranean Sea countries did not report any threshold values [23]. GES for D2C1 was indicated as achieved by 7 out of 19 reporting MS (i.e. Annex 2 [23].

Since the last reporting, MS NIS experts and RSCs have worked to provide an update of new NIS records across marine regions, discussed about methodological approaches to fulfil the D2C1 MSFD obligations [15,24], and work towards setting threshold values.

Time series analysis was proposed to identify the trends in new NIS introductions in the Mediterranean Sea and North-East Atlantic, by the indicators “IMAP Common Indicator 6 related to non-indigenous species” (UNEP/MED WG.502/16 Rev.1; UNEP/MED WG.520/Inf.3) and “Trends in New Records of Non-indigenous Species Introduced by Human Activities” (OSPAR, [20]. These indicators have not yet a numerical threshold defined (e.g. [20]. Whereas, in the Baltic Sea, the indicator on "Trends in arrival of new non-indigenous species" is used to aim for zero anthropogenic-mediated introductions of NIS [12]. According to HELCOM [12], the threshold value for distinguishing between good and not-good status is defined as ’no new introductions of NIS per assessment unit through human activities during a six-year assessment period.’ HELCOM has acknowledged that due to scarce monitoring resources and inconsistencies in the availability of information and knowledge across the sub-basins of the Baltic Sea [12], the indicator concerns only new species to the entire Baltic Sea, and not secondarily spread species into new areas within the Baltic Sea.

At the Black Sea scale, there is currently no established methodology or agreed-upon thresholds for D2C1. Recent discussions at EU scale during the 30th and 31st meeting of the MSFD Common Implementation Strategy Working Group on GES[1] have raised the possibility of testing a methodological protocol for determining GES under D2C1- “Percentage reduction by manageable pathways” [14].

As part of this effort, the update of the baseline NIS data in the Black Sea offers an opportunity to progress on the threshold settings, highlighting the priorities of MS and identifying areas of concern.

2.3. NIS data in the Black Sea

A review of NIS data published in [24] was carried out for the Black Sea by NIS experts between December 2023 and January 2024 and is available through the JRC Data Catalogue and EASIN services (e.g. EASIN -Lit). This review included scientific publications, monitoring programmes, and citizen science, as well as grey literature (e.g., technical reports, conference proceedings, and Ph.D. and M.Sc. theses).

In addition to Bulgaria and Romania, data from the non-EU countries Ukraine, Türkiye, and Georgia were considered for a more encompassing picture of NIS introductions in the Black Sea. The inclusion of species not currently found in MS national waters, while acknowledging the interconnectedness of the marine areas, will inform the MS to consider a risk-based approach and the precautionary principle outlined in the GES Decision (preamble 13).

The Black Sea dataset consists of 258 new human mediated NIS introductions from 1892 to 2023, including 180 non-indigenous, 46 cryptogenic and 31 questionable species. Two species have respectively data deficient and range-expanding statuses (Table A.1 in Annex). The majority of species belong to the Animalia and Chromista Kingdoms, respectively 54 % and 36 % of the total number of species. Plantae and Fungi accounted for the 7 % and 3 % of the species respectively. Microalgae represented the majority of records within the Chromista Kingdom (88 %).

A primary pathway of introduction was assigned to 80 % of records (20 % ‘unknown’ pathways, Fig. 1) according to the main categories of the Convention of Biological Diversity [2].

More than half of these species (64 %) were introduced in the Black Sea by ‘transport-stowaway’, which is the main primary pathway across countries. Other pathways, such as ‘transport -contaminant’, ‘escape’, ‘release’, and ‘corridor’ account each for less than 4 % of records.

In the following sections, the dataset is analysed using four different indicators or approaches that are currently employed by RSCs in assessing newly introduced NIS and that are a basis for setting threshold values.

2.4. Application of the OSPAR approach to the Black Sea

OSPAR NIS indicator examines the number of new NIS introductions into OSPAR Regions (i.e. I- Arctic region, II- Greater North Sea, and IV- Bay of Biscay and Iberian Coast) per six-year period (i.e. 2003–2008, 2009–2014, 2015–2020), showing trends of introduction over time [20]. The indicator excludes cryptogenic, phytoplankton and parasitic species from the analysis due to the high uncertainty on their alien status. It uses linear regression models, to provide the absolute changes in number of new NIS, and the annual average rate of new NIS

[1] https://circabc.europa.eu/ui/group/326ae5ac-0419–4167-83ca-e3c2105 34a69/library/7e5728d5-dc95-468a-a510-fc67a9a4e19e/details

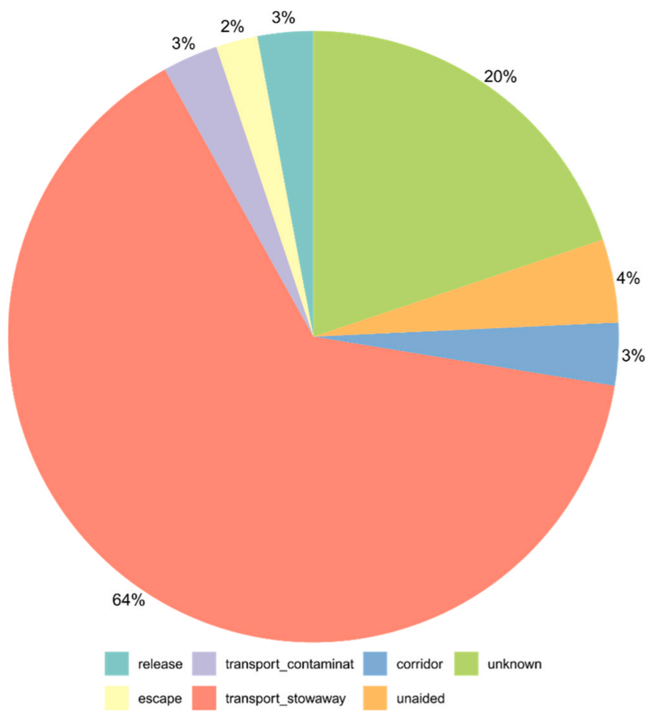

Fig. 1. Pathways of introduction of species in the Black Sea dataset, according to the CBD categories.

introductions per six-year reporting period. No threshold value has been defined to evaluate whether the OSPAR Regions are in GES based on the indicator results.

To this end, the Black Sea dataset was filtered to remove phytoplankton, cryptogenic and parasitic species, resulting in 132 NIS. The 6-year assessment periods were identified as: 'before the MSFD', i.e. 2004–2009, 'first reporting', (i.e. 2010–2015), and 'second reporting', (i.e. 2016–2021) (Fig. 2).

The rate of introduction was calculated across periods from linear regression models using the function *lm* from R programming language [19], R version 4.0.3 (2020–10–10)) (Fig. 3).

The cumulative number of NIS is increasing over time and so the number of new NIS records per year (Fig. 3). However, the variability in the rates of introduction between periods reflects differences in monitoring intensity and limitations of the collected data (Fig. 3). This observation is underscored by the total number of NIS records in between the 'first reporting' and 'before the MSFD' periods (Fig. 2).

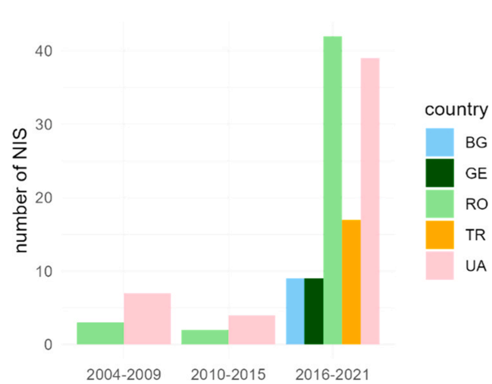

Fig. 2. Number of new NIS records in each country (BG: Bulgaria, GE: Georgia, RO: Romania, TR: Türkiye, UA: Ukraine) of the Black Sea dataset and period assessed.

2.5. Application of the UNEP/MED approach to the Black Sea

IMAP Common Indicator 6 on NIS examines new NIS trends across marine subregions using regression analysis on baseline data (UNEP/MED WG.520/Inf.3). It recommends either simple linear regression analysis or generalized linear and additive models. The indicator is calculated excluding cryptogenic, questionable, range-expanding species and with case-by-case evaluations on phytoplankton, parasitic, freshwater, etc. species from the analysis (Table 3, UNEP/MED WG.520/Inf.3). The outcome of the indicator is a rate of new NIS introductions. No threshold value has been defined to evaluate whether the Mediterranean subregions are in GES based on the indicator results.

To this end, leveraging on previous research in the Mediterranean Sea [9], the Black Sea dataset was analysed using a breakpoint analysis using the R package *strucchange* in R Project for Statistical Computing [25]. This method analyses the dynamic of NIS introductions over time, detecting structural changes in the timeseries [25,26]. The output is one or multiple breakpoints and corresponding break dates, with a reference value associated to the period identified by the breakpoint(s) (Zeileis 2003).

The Black Sea dataset was filtered to keep only species with 'non-indigenous' status from 1970 when more reliable NIS detections are available [24]. Given the long expertise in the Black Sea on unicellular marine algae (phytoplankton), these species were included in the analysis. A total of 112 records of NIS introductions were analysed in 47 years. The first and last periods for the analysis were set to 1970–2015 excluding years overlapping with the upcoming MSFD assessment (i.e. 2016–2021) [9].

The trimming parameter was set to 0.1, so to ensure 10 % of data at each end before conducting the breakpoint analysis [26]. Two breakpoints were detected for the region in 1993 and 2003 (Fig. 4). The mean value of the last reference period (i.e. 2003 onwards) could be used for setting GES threshold (Table 1).

2.6. Application of the HELCOM approach to the Black Sea

HELCOM Indicator calculates the number of new species introduced to the whole Baltic Sea over a six-year period [12]. A threshold value of zero new NIS has been defined to evaluate whether the Baltic Sea is in GES based on the indicator result.

The Black Sea dataset was filtered to include non-indigenous and cryptogenic species only, resulting in 226 species. The 6- year assessment periods were identified as: 'before the MSFD', (i.e. 2004–2009), 'first reporting', (i.e. 2010–2015), and 'second reporting', (i.e. 2016–2021), for the whole Black Sea region (Fig. 5).

Eleven new species have appeared for the first time in the Black Sea during the assessment period 2016–2021 (Fig. 5). Since the threshold value between GES and not good environmental status is zero new introductions of NIS per assessment unit through human activities during a six-year assessment period, the indicator trends in arrival of new non-indigenous species does not reach GES in the Black Sea.

2.7. Application of the 'percentage reduction by manageable pathways' approach to the Black Sea

In this approach, the threshold value, which expresses the maximum allowable number of new NIS introductions in the assessment area, is obtained by applying a percentage of reduction to the segment yearly mean in the reference period of the time series analysis (e.g. UNEP/MED), based on the number of NIS introduced via manageable pathways [14]. Manageable pathways include the CBD categories (Table A.1 in Annex) release, escape, transport contaminant, and transport stowaway, for which measures on pathways of introduction are addressed by MS in the MSFD implementation.

For the Black Sea dataset, the approach is applied after the reference period is identified from the breakpoint analysis (Table 1). At this stage,

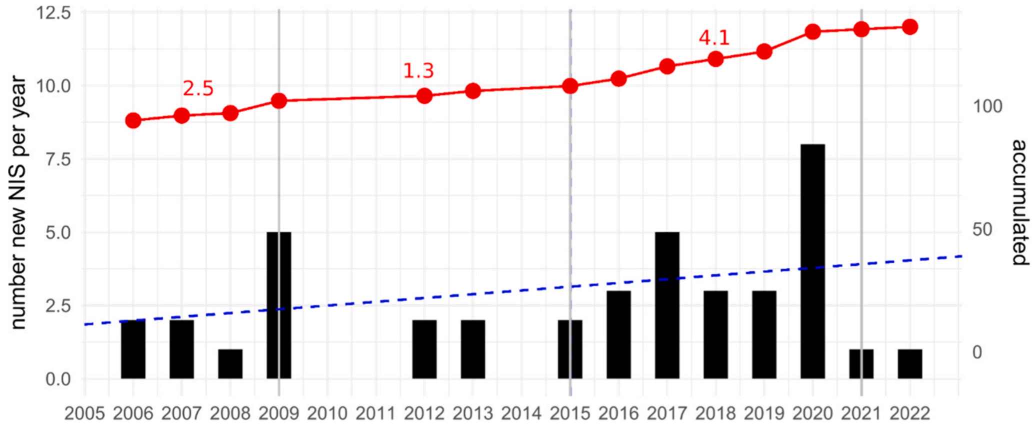

Fig. 3. Annual new NIS records (black bars) in each period, along with the trends represented by red line in the cumulative (accumulated) new NIS records. Numbers above the curves indicate the slopes of the cumulative records and indicate the NIS introduction rate (#NIS per year) calculated by linear regression models. The overall trend in annual new NIS records is represented by the blue dotted line and was assessed using linear regression models (R^2=0.11, *p-value*=0.26).

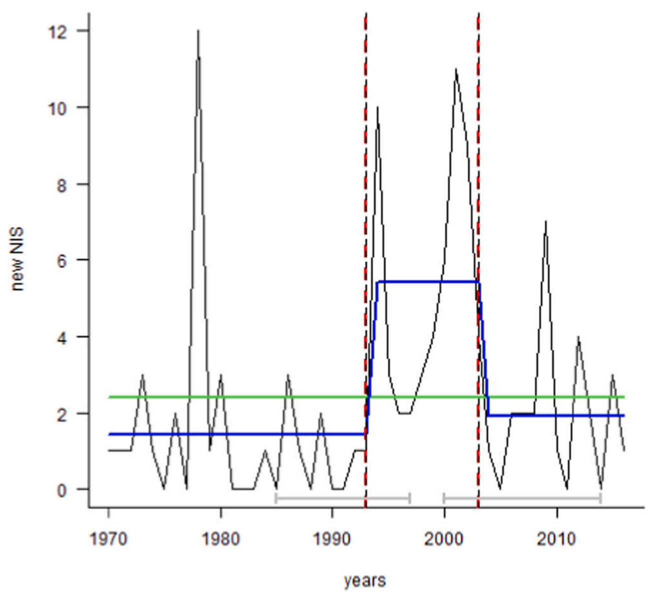

Fig. 4. Graphical output of breakpoint analysis in the Black Sea. Vertical dashed red line indicates breakpoint years. The green line shows the null model of no temporal change in new NIS numbers with 95 % confidence intervals (CIs) in grey brackets; and blue line represents fitted mean values before and after the identified breakpoints.

Table 1
Results of the breakpoint analysis: break dates indicate the years when the structural change occurs, and reference values the segments yearly mean of new NIS before and after the break. In bold the reference value of the last reference period.

Marine Region	Break dates	segments yearly means	Reference Period begins
Black Sea	1993, 2003	1.42, 5.40, **1.92**	2004

the number of NIS is calculated for every year in the period and for each manageable pathway. Then, the percentage of NIS by pathways is obtained for each period. The average across manageable pathways is calculated for the reference period and subtracted to the reference value (Table 1). In the Black Sea, the percentage reduction of manageable pathways is 80 %, as a result the threshold value is less than one species a year (about 0.40 species* yr^{-1}).

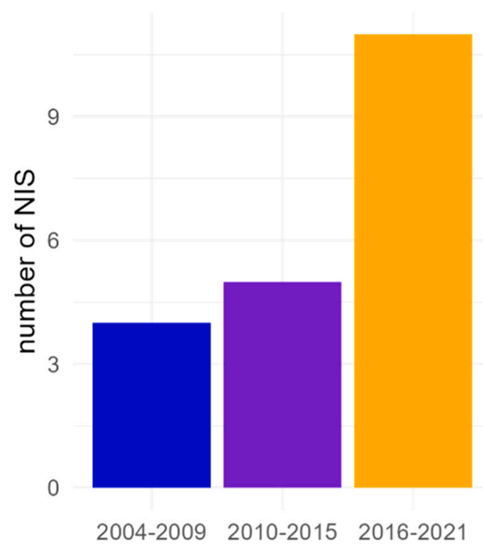

Fig. 5. Number of new NIS in the Black Sea until 2021. The bars indicate the number of invasions per time period: 'before the MSFD' (blue), 'first reporting'(purple), and 'second reporting'(orange).

3. Conclusions

In this paper, the Black Sea dataset was analysed using four different approaches or indicators with the aim to highlight progresses and limitations across regional seas.

Current approaches across marine seas are set using the best available scientific knowledge and understanding on NIS. HELCOM indicator is the only approach that has defined a threshold value for GES, while UNEP and OSPAR indicators do not have a defined threshold value for GES. Several reasons contribute to this gap, and a significant one is the lack of comprehensive monitoring NIS data. This limitation includes both aspect of spatial coverage of monitoring (e.g. hot-spot areas), taxonomic groups and habitats, and temporal coverage (e.g. effort) that affect the accuracy and reliability of the indicators' results. Delays in species reporting are not only related to methods of detection but also to monitoring networks and their interoperability.

Current baseline data for the Black Sea does not contain details on monitoring efforts, thus increasing the uncertainty in explaining the patterns of increase or decrease of introductions overtime (e.g. OSPAR and UNEP/MED indicators). Future improvements of this baseline with monitoring efforts could allow having more realistic estimates of trends and allowing discussing where and how to implement better monitoring programmes. From a recent review of D2 monitoring in the MSFD [21], it has been highlighted that MS do monitor elements and parameters for D2C1 across all four marine regions, Baltic, North East Atlantic, Black and Mediterranean Seas especially in coastal areas, but with monitoring frequencies that often do not reflect ecologically relevant time spans (e.g. 'as need', '6-yearly'). To this end, also the temporal scopes of monitoring programmes suggest large diversities across regions with areas needing development of guidelines and procedures to ensure consistency [6].

While continuing pursuing quality of taxonomic identification, new detection methods (e.g. metabarcoding from environmental DNA) should be promoted to shorten the existing bias of delays in reporting [1]. To this end opportunities lie in the exploitation of early warning systems and repositories for data management that are available for other topic-related policies (e.g. Regulation 1143/2014- [4]- European Alien Species Information Network, and AquaNIS).

Finally, 20 % of species in the Black Sea dataset do not have an assigned pathway, suggesting the need of optimising vector-related monitoring (e.g. at ports, aquaculture) and testing methods for document the importance of different vectors in NIS introductions.

In conclusion, this study underscores the importance of continually reviewing and adjusting NIS lists to align with the MSFD implementation. In relation to future assessment of NIS introductions in the Black Sea, consideration should be given to i) continue improving species data considering early detection and rapid response, ii) including information on monitoring efforts, and iii) documenting pathways of introduction. These efforts collectively contribute to advancing the understanding and management of NIS in marine environments, supporting the long-term sustainability and health of marine ecosystems.

CRediT authorship contribution statement

Pantea Elena: Writing – review & editing, Data curation. **Tabarcea Cristina:** Writing – review & editing, Data curation. **Torodova Valentina:** Writing – review & editing, Data curation. **Varshanidze Madona:** Writing – review & editing, Data curation. **Kvach Yuriy:** Data curation, Writing – review & editing. **magliozzi chiara:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Cardoso Ana Cristina:** Writing – review & editing, Conceptualization. **O. Son Mikhail:** Writing – review & editing, Data curation. **Japoshvili Bella:** Writing – review & editing, Data curation. **Stefanova Kremena:** Writing – review & editing, Data curation. **Kurt Güley:** Writing – review & editing, Data curation.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest related to this study. Furthermore, no ethical issues or concerns were identified during the research process.

Annex

Table A.1
Terms and definitions of species data collected for the D2C1 criterion. '* ' indicates manageable pathways

Terms	Definitions
non-indigenous	species means any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or micro-organisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce.
questionable	species with unresolved taxonomic status.
cryptogenic	species for which details on the alien status in a region are available but for which explicit evidence is lacking, implying that the species could be native
DD (data deficient)	lack of data for assessing the species
range expanding	species that dispersed by natural mechanisms into a region where did not formerly exist
year first introduction	it is the year of first observation of an alien species in the country
reference	bibliographic reference for the year of first introduction
pathways	pathways of introduction of the species according to the CBD list (Table 1 of UNEP/CBD/SBSTTA/18/9/Add.1 26 June 2014)
Confidence of assigned pathway	**HIGH**: There is direct evidence of a pathway/vector: The species was clearly associated to a specific pathway/vector at the time of introduction to a particular locality. This is the case e.g. in all intentional introductions (i.e. aquaculture/commodity) and in many cases of Lessepsian immigrants (when there was direct evidence of a gradual expansion along the Suez Canal and then in the localities around the exit of the Canal in the Mediterranean) **MEDIUM**: A most likely pathway/vector can be inferred: The species appears for the first time in a locality where a single pathway/ vector(s) is known to operate and there is no other rational explanation for its presence except by this pathway/vector(s). This applies to many species introduced by shipping or aquarium trade or as aquaculture contaminants. In some cases, a specific vector could not be inferred, e.g. some species probably introduced by shipping could not be further linked to ballasts or hull fouling and were classified as 'shipping/unknown'. In many cases inference is based on known examples of introductions elsewhere for the same or similar species, the biology and ecology of the species, the habitats and locales it occupies in both the native and introduced range, and its pattern of dispersal (if known), e.g. for a fouling species frequently recorded in/near ports, shipping has been assumed to be the most probable vector. **LOW**: One or more possible pathways/vectors can be inferred: The species cannot be convincingly ascribed to a single pathway/ vector. Inference is based on the activities in the locality where the species was found and may include evidence on similarly behaving species reported elsewhere.

Data availability

Data are publicly available through the JRC Data Catalogue

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