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Running Title: Advances in marine biofouling risk management

Managing the risk of marine bioinvasion via biofouling: trends in methods of assessment, policy, and legislation

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ABSTRACT

Maritime shipping has been recognized as the main pathway of species transference throughout the world. Ballast water or fouling on vessels have become the main vectors of aquatic species transportation between coastal marine ecosystems, which can lead to significant social, economic and ecological negative impacts. Approximately 55% of non-indigenous marine species (NIS) can be associated with vessel biofouling. However, acting to prevent, detect, manage, and control bioinvasion via biofouling is relatively recent. To improve NIS management, several risk assessment frameworks have been proposed. This research undertook a systematic bibliographic review aiming to investigate whether and how risk assessment has been used to manage marine bioinvasion via biofouling. We analyzed 410 scientific studies published by December 31, 2023, via the Scopus database, filtered by keywords, title, and abstract. The paper describes the parameters and methodologies used for assessing bioinvasion risks. Furthermore, it discusses the incorporation of risk assessments into global, regional, and country-level public policies, the latter based on countries that publish the most on the topic. This research highlights the scarcity of mandatory measures in the management of biofouling as well as the urgent need for standardized risk assessment methodologies and for the incorporation of the effects of climate change into these assessments. The development of advanced data analysis tools and a unified strategy to effectively address the complex challenge of marine bioinvasions is also suggested.

KEYWORDS: RISK MANAGEMENT, NON-INDIGENOUS SPECIES, RISK ASSESSMENT, MARINE BIOINVASION, LEGISLATION.

INTRODUCTION

Marine bioinvasions are one of the most important human-induced pressures threatening marine ecosystems (OJAVEER et al. 2018). These invasions have increased significantly in recent decades due to the dispersal of species associated with the rise in trade and maritime transport (SEEBENS et al. 2013). Ballast water and biofouling associated with commercial and oil vessels, recreational boats, and man-made submerged structures act as vectors to the introduction of invasive marine species (CARLTON, 1989).

Biological invasions can negatively impact social and economic sectors (OJAVEER et al. 2015). The dispersion of non-indigenous species (NIS) can contribute to significant changes in the global biogeographic patterns (biodiversity and distribution) and lead to the development of homogeneous biological communities, with low species diversity (CAPINHA et al. 2015). The introduction and potential establishment of NIS generates high costs due to the damage caused to the ecosystem and causes a greater expenditure of economic resources that should be allocated to its control in the management of protected areas (RUIZ et al. 2011; DIAGNE et al. 2021). In some European countries and in the USA the invasive green algae *Caulerpa taxifolia* was quickly detected. In California, the government acted six months later, which enabled it to be eradicated in two years with an investment of US$ 7,000,000. In the Mediterranean, procrastination for years enabled the species to spread to several locations along the European coast (SIMBERLOFF et al. 2013).

Vector is the physical means by which a NIS is transferred to the non-native ecosystem (CREED et al. 2016), so information about this displacement is very important for the prevention and management of bioinvasion. According to Hewitt et al. (2010), approximately 55% of non-indigenous marine species can be associated with vessel biofouling. However, acting to prevent, detect, manage, and control bioinvasion via biofouling is relatively recent. These actions gained visibility around a decade ago, especially after the Guidelines for the Control and Management of Ships' Biofouling, published in 2011 and recently revised (see International Maritime Organization, 2011; 2023), and the Guidance for Minimizing the Transfer of Invasive Aquatic Species Via Hull Fouling on Recreational Vessels, from 2012, both published under the scope of the International Maritime Organization (IMO) (DAVIDSON et al. 2016). Despite these recommendations, biofouling management associated with activities conducted at the sea are not yet fully organized, either at international or national levels. According to Davidson et al. (2016), points of concern regarding colonization, transfer, and possible establishment differ among the maritime industry, environmental managers, and scientists. Furthermore, there is still a discussion regarding the areas of the vessel's hull that should be sampled and evaluated. Although the niche areas differ from the horizontal and vertical hull surfaces of vessels in their heterogeneity and are considered hotspots for the accumulation of biofouling on vessels, industry studies tend to ignore niche areas in their methods (COUTTS & TAYLOR 2004; THOMASON, 2009; DAVIDSON et al. 2016).

Evaluating and predicting possible transfer of NIS is a key task to reduce the environmental and socioeconomic impacts caused by bioinvasion worldwide (CAMPBELL & HEWITT 2011; HEWITT et al. 2011; DAVIDSON et al. 2016; KACIMI et al. 2021). However, there are still no standardized measures for the prevention/prediction of bioinvasions, mainly due to the variety of input parameters that can be considered. In this context, the risk assessment enables the evaluation of the probability and potential impact of risks, particularly in marine biosecurity. This involves five steps: defining objectives, recognizing hazards, evaluating risk likelihood, assessing consequences, and calculating overall risk (CAMPBELL & HEWITT, 2011). Most risk assessment methodologies are divided into multi-criteria decision analysis and probabilistic modeling. Nevertheless, the parameters used in these analyses are quite different depending on the adopted approach. The synergy of abiotic, biotic, and anthropogenic factors on marine bioinvasion is complex and may vary depending on the specific characteristics of the marine environment in question and the invasive species involved. Understanding and monitoring these factors is important to minimize the impact of invasive species on marine ecosystems. Nowadays, the main approaches consider several parameters related to the characteristics of vessels, (hull size, sailing speed, transport routes), geographic distances (biogeographic patterns), environmental factors (seawater temperature, salinity, etc.), species status, and impact potential (HEWITT et al. 2009).

This article investigates how global risk assessment of bioinvasion via biofouling has been approached regarding parameters evaluated and State adoption as a public policy for managing vessel biofouling.

METHODS

A list of research articles published by December 31st, 2023, was compiled using the Scopus database. We used the following terms as search parameters: "Risk assessment" OR "Risk analysis" AND "Biofouling" OR "Fouling" AND "Non-indigenous species" OR "Nonindigenous species" OR "Bioinvasion" AND "Marine" OR "Ocean" AND "Guidelines" OR "Act" OR "Law" OR "Plan" AND "Regulation" OR "Legislation" OR "Policy, each of them applied to keywords, titles, or abstracts. Then, we accessed the list of references of each article and used the citation searching method to ensure that all relevant publications were considered (Rethlefsen et al., 2021). Based on the conceptual bibliographic analysis conducted on 410 articles, we focused on risk assessment to manage bioinvasion via biofouling to investigate whether and how risk assessment has been used to manage marine bioinvasion via biofouling.

GLOBAL DEVELOPMENTS

For the investigation of global trends and evolution, we evaluated two metrics from the literature review: author keywords and scientific production per country. These two aspects were analyzed from the number of publications per year and percentage of publication in two periods (before 2011 and between 2011 and 2022). We selected 2011 because it was the publication year of the first IMO Guidelines on Biofouling (International Maritime Organization, 2011).

RISK ASSESSMENT METHODOLOGIES

Based on the literature review, we conducted a screening to identify, among the documents related to the description of methods, the primary approaches, techniques, and features for the estimation/classification of bioinvasion risk via biofouling. Six documents (Table 1) were selected among which we identified three different assessment approaches: Statistical Modeling (SM), Multi-Criteria Decision Analysis (MCDA), and hybrid method (SM and MCDA).

POLICY AND LEGISLATION

We also analyzed how risk assessment has been incorporated into the public policies and legislation that deal with marine bioinvasion management via biofouling. First, we identified 17 articles that contained the terms “guidelines,” “act,” “law,” “plan,” “regulation,” “policy,” and “legislation” in the title. As for country-level policy and legislation strategies, we focused on the countries that published the most on the subject. According to our results these were: the United States, the United Kingdom, New Zealand, and Australia, each of them with more than 50 publications listed. After reading the remaining 13 articles, we conducted a citation search to deepen knowledge about the strategies explored in the documents, consulting legislation and government publications, as well as cited scientific articles.

For the bibliographic analysis of this section, some specific questions were raised: What types of legal acts provide regulations on biofouling? What is the scope of these regulations, considering environmental, economic, temporal, or geographical aspects (e.g. Which vectors are targeted? Which activities or actors are affected? Which areas does the standard apply to?) And finally: Do these regulations impose obligations or do they only give recommendations?

RESULTS AND DISCUSSION

RISK ASSESSMENT OF MARINE BIOINVASION VIA BIOFOULING: KEY PARAMETERS

The parameters related to the risk of marine bioinvasion may vary depending on the methodology used (Figure 1), but can be organized according to four components:

(I) INTRODUCTION POTENTIAL

Related to the human-mediated translocation (intentional or unintentional) of an organism to a region outside its natural biogeographic range (HEWITT et al. 2011). The introduction potential is based on how NIS can be introduced into the new environment. This component is also associated with specific characteristics from species, donor and recipient regions, and information about the transport such as anti-fouling system criteria, and vessel information (HEWITT et al. 2011).

(II) ESTABLISHMENT POTENTIAL

Related to the process of survival and development of a self-sustaining population to a new environment. The establishment potential is estimated considering the biological characteristics and the local environment conditions (FLOERL et al. 2009; HEWITT et al. 2011) which interfere with the ability of the NIS to establish themselves in the new environment.

(III) IMPACT POTENTIAL

Changes in the structure and functioning of ecosystems, considering predation, competition for resources, diseases, and other factors. The impact potential is associated with species characteristics and status reported and estimated if the invasive species has already been introduced elsewhere and what the impact was recorded.

(IV) UNCERTAINTIES

Uncertainty is usually associated with the available information about the invasive species, transport, characteristics of donor/recipient regions, and associated impacts. Uncertainties can also fall on the methodology used for the risk assessment. All of these aspects must be taken into account (MANDRAK et al., 2012).

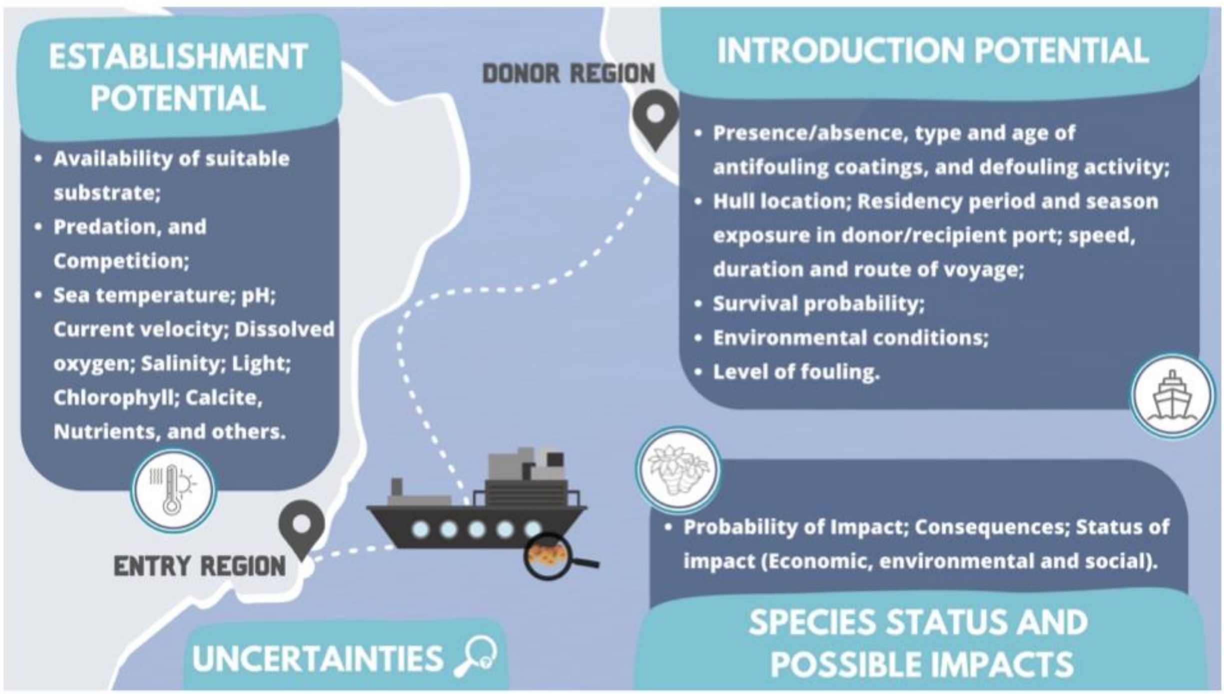

Figure 1: Key parameters for risk assessment of marine bioinvasion via biofouling.

INFLUENCE OF THE ENVIRONMENTAL PARAMETERS

Abiotic factors such as temperature, salinity, current velocity, nitrate, dissolved oxygen, calcite, iron, among others, can influence the process of marine bioinvasion in several ways. For example, temperature can influence the rate of reproduction and growth of invasive and native species and invasive species that are able to tolerate a wide range of temperatures may have a competitive advantage over native species that are more sensitive to temperature variations (KACIMI et al. 2021). Salinity can also influence the survival and reproduction of invasive species, as some species may be more tolerant of variations in salinity than others (KACIMI et al. 2021). Currents can influence the dispersal and distribution of invasive species, enabling them to spread over long distances and colonize new areas (COELHO et al. 2022). Nutrient availability can also influence the survival and growth of invasive species, especially in coastal regions that are most affected by pollution and eutrophication (YU et al., 2019). The availability of calcite is important for skeleton construction of several organisms like corals (CARLOS-JUNIOR et al. 2014). Dissolved oxygen can play an important role in the bioinvasion process, since many invasive species have different oxygen needs than native species in an ecosystem (GOBLER & BAUMANN, 2016). Some invasive species can adapt to low-oxygen environments, whereas others may have higher oxygen needs. In marine environments, iron availability can be limiting for the growth of some species, and the addition of iron can be used as a fertilizer to promote the growth of algae and other aquatic plants (HAN et al. 2021). In summary, abiotic factors play a key role in the process of marine bioinvasion, influencing the ability of invasive species to survive, grow, and reproduce in new environments and compete with native species.

Although chlorophyll is not an abiotic factor, it is strongly influenced by them. It does not play a direct role in bioinvasion, but the changes that occur in the composition of the algal community in an ecosystem because of the bioinvasion can affect the efficiency of photosynthesis in native species, which can, in turn, facilitate the NIS establishment process (MALTSEV et al., 2021).

METHODOLOGIES FOR RISK ASSESSMENT

We observed that there are three methods most commonly applied to assess the risk of NIS bioinvasion: Multicriteria Decision Analysis, Statistical and Hybrid.

Risk assessment is used to determine the likelihood of a particular event occurring and its possible consequences (HEWITT et al., 2011). This process evaluates scientific, and economic evidence to identify potential invasive species and assess the level of invasion risk associated with a species or pathway (ROY et al., 2017). According to Roy et al. (2017), there are more than 70 tools that were developed during the last decades aimed at risk assessment of marine bioinvasion, including ballast water and biofouling sources. These tools have been listed by Srebaliene et al. (2019) and include the following terms: protocols, frameworks, kit, scheme, system, tool, index, and others.

Most methodologies used for risk assessment are related to the Multicriteria Decision Analysis approach (Table 1). This approach relies on data collected from several documents, such as inspection reports, online forms, questionnaires, and control spreadsheets as a basis for risk classification (HEWITT et al. 2011; CAMPBELL and HEWITT, 2013). Thus, apart from on-site measured information, like the level of fouling, these documents include a rating for each event based on specific criteria. For example, Campbell and Hewitt (2011) show models for risk classification of introducing organisms to the Australian coast, built with multiple matrices, each associated with a different criterion. The authors also include: (a) information on the presence/absence of the evaluated species by location, (b) a probability matrix of event occurrence, (c) a consequence matrix according to potential impacts, and (d) a risk matrix.

Nevertheless, The IMO Biofouling Guidelines (2023) advocate for a preventive strategy against biofouling by evaluating biofouling risk profiles for both hull and niche areas, along with monitoring several risk parameters throughout vessels' operation.

A small part of the evaluated documents address risk analysis based on statistical modeling. For example, the work of Kacimi et al. (2021), develops a model to estimate the risk of port-to-port invasion, based on vessel trips to the port of Arzew in Algeria, which in turn is an adaptation of Seebens et al. (2020) focused on the transport of NIS by ballast water. This methodology considers that the invasion probability is the product of the probabilities of alien or not introduction, and establishment. They used level of fouling, species occurrence, geographic, vessel, and abiotic factors data as features.

As for the hybrid approach, according to Azmi et al. (2014), many countries have limited information about species within their jurisdictional boundaries. To help solve it, they develop two risk models to identify an effective marine biosecurity risk management approach in areas with scarce biological data.

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Table 1. Summary of methodologies for risk assessment (SM: Statistical modeling, and MCDA: Multi Criteria Decision Analysis).

Approach	Technique	Features	Type of document	Reference
MCDA	Inspection report, questionnaire, or form	Antifouling and defouling strategies, vessel information, abiotic factors	Legal document	IMO Biofouling guidelines review (2023)
SM	Environmental similarity and biogeographical dissimilarity	Level of fouling, species status, geographic distance and scale, abiotic factors	Research article	KACIMI et al., 2021
MCDA	Inspection report, questionnaire, or form	Antifouling and defouling strategies	Legal document	Brazilian government (SEI/IBAMA, 2019)
Hybrid	Bioregion pathway and species-based exposure	Species status, vessel information, geographic distances	Research article	AZMI et al., 2014
MCDA	Inspection report, questionnaire, or form	Species status, vessel information, propagule pressure, and impacts	Research article	CAMPBELL & HEWITT, 2013
MCDA	Inspection report, questionnaire, or form	Species status, vessel information, and impacts	Legal document	Australian government (CAMPBELL & HEWITT, 2011)

GLOBAL EVOLUTION OF THE RESEARCH ON RISK ASSESSMENT

Figure 2 shows that most of the documents listed here are related to "non-indigenous species" (the term used in this paper) and "invasive species," because these keywords are intrinsically connected to risk assessment and bioinvasions, as well as "biological invasions" and "risk assessment" itself.

They are followed by the term’s "biofouling" and "ballast water," which are the main vectors for the transport of exotic species (OJAVEER et al., 2018; DIASAMIDZE & SHOTADZE, 2019; BAILEY et al. 2020). Regarding these last two topics, note that a shift in the evolution over the years occurred in 2019, when "biofouling" began to concentrate on a greater number of documents than "ballast water". The percentage of documents published between 2011 and 2022 for each keyword is presented in Figure 2b. It was calculated based on the ScientoPy library (Ruiz-Rosero et al., 2019)

Furthermore, note the presence of the term "climate change," which, according to several studies (CAPINHA et al., 2015; GIAKOUMI et al., 2016; MACIC et al., 2018; SEEBENS et al. 2021), can act as a facilitator of increased bioinvasion worldwide. The terms "biosecurity" and "management" also appear, which are related to policies, legislation, and the overall risk analysis (CAMPBELL & HEWITT, 2011).

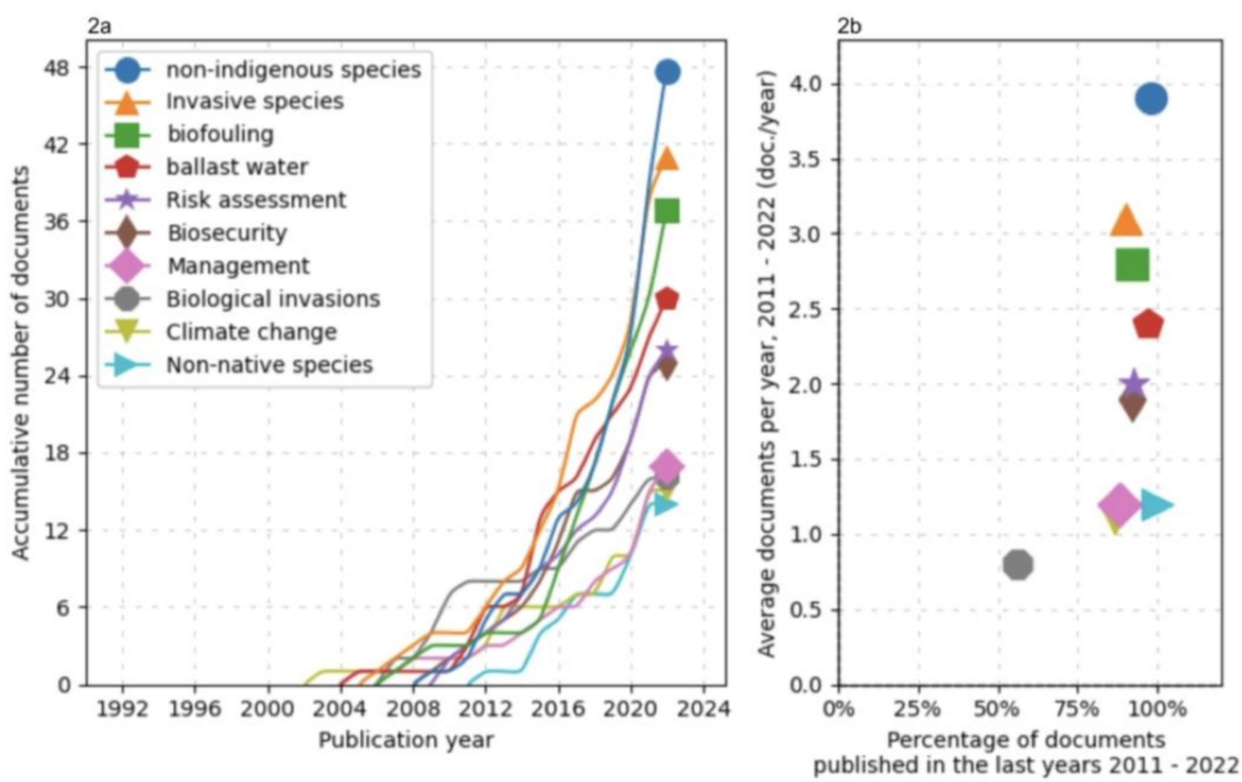

Figure 2: Number of documents and percentage of documents published between 2011 and 2022.

To evaluate the development of international knowledge on risk assessment, we collected data on the number of publications from the fifteen countries with the highest production, as well as data on the percentage of documents published before 2011 and between 2011 and 2022 (Figure 3).

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The results show the United States has consistently been at the forefront of publishing documents related to the topic of risk assessment (Figure 3). Also, the United Kingdom surpassed Australia in publications per year in 2016 and continues to outpace Australia (Figure 3).

Additionally, in 2022, note the formation of six groups with publication numbers that are relatively close (Figure 3). They are composed of: (1) the United States; (2) the United Kingdom; (3) Australia and New Zealand; (4) Spain and Canada; (5) Italy and Germany; and (6) France, Portugal, Brazil, South Africa, Sweden, Greece, and Ireland.

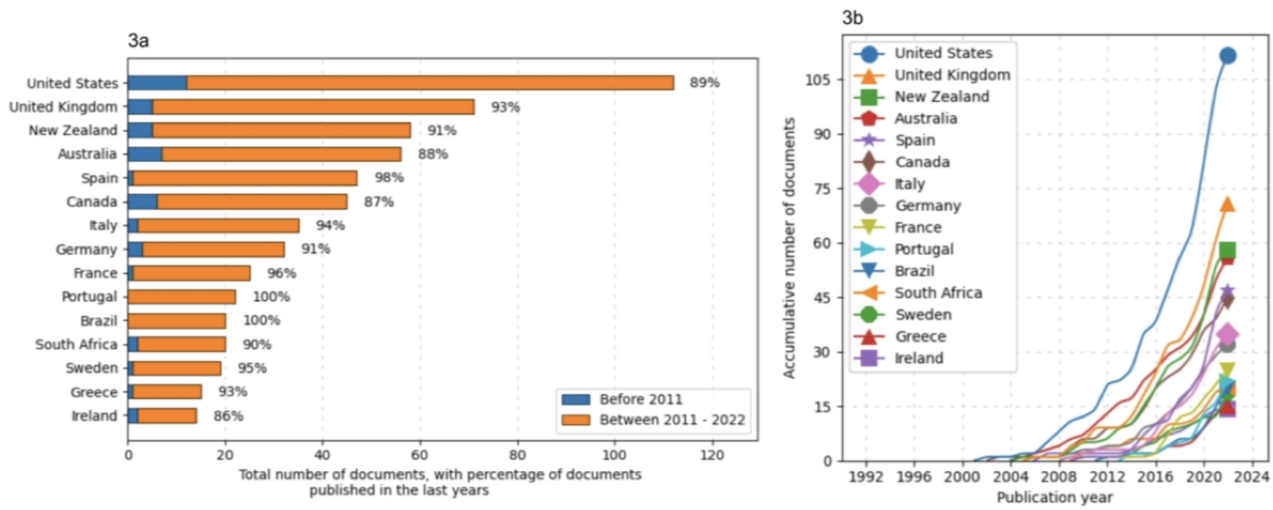

Figure 3: Trends in the research on risk assessment per country.

POLICY, LEGISLATION AND OTHER DEVELOPMENTS

We created a table to illustrate how risk assessment has been incorporated into public policies and legislation that deal with the management of marine bioinvasion via biofouling (see Table 2). As OJAVEER et al (2018) observed, policy documents and strategies to reduce the introduction and spread of NIS have been increasing since the second half of the twentieth century, after several high-profile invasions, but with significant time lags, limited success and focused on only a subset of transfer mechanisms. Specifically, regarding biofouling, this trend is even more recent, with a strong influence from the documents published by the IMO on the subject.

The remainder of this section summarizes our findings by jurisdictional scale.

GLOBAL EFFORTS

From the 1980s, when the first international treaty concerned with the protection of the marine environment was signed, to the present day, the review identified 13 legal documents related to the management of biofouling with a global mandate. Following the chronological order in which they were adopted, the most frequently cited are the United Nations Convention on the Law of the Sea (UNCLOS), the Convention on Biological Diversity (CBD) Guiding Principles on Invasive Alien Species, and the IMO Guidelines on Biofouling. They will be discussed in detail below.

(I) UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS)

UNCLOS, also known as the "constitution for the oceans" (KOH, 1982), dedicates an entire part (Part XII) to the protection and preservation of the marine environment. As a legally binding treaty, it contains both a general obligation on states (art. 192) and specified measures relating to certain sources of marine pollution, such as land-based pollution, atmospheric pollution, discharges, vessels, and installations (art. 194). Article 196 deals specifically with the introduction of NIS that "may cause significant and harmful changes in the marine environment," establishing that "States shall take all necessary measures to prevent, reduce and control such introduction, whether accidental or intentional".

Some limitations must be highlighted. First, although this no-harm imperative (*Neminem Laedere*) is mandatory, it only bears a due diligence obligation, which means States are obliged to take preventive measures, but damage itself is not prohibited (WINTER, 2018). The focus lies on pollution, not delving into clear obligations aimed at protecting marine biodiversity beyond taking measures related to rare and fragile ecosystems and habitats of threatened or endangered species (art. 195, para. 5), and fisheries resources (art. 61-68). In addition, since UNCLOS does not link NIS introduction expressly to pollution, the precise interpretation of the provision, and therefore the consequences it entails, remain under debate (KÖCK & MAGSIG, 2018).

(II) CBD COP GUIDING PRINCIPLES FOR THE PREVENTION, INTRODUCTION, AND MITIGATION OF IMPACTS OF ALIEN SPECIES THAT THREATEN ECOSYSTEMS, HABITATS, OR SPECIES

The Convention on Biological Diversity (CBD), adopted in 1992, is the main international agreement in force on biodiversity protection. As a framework convention, although mandatory, it is based on overarching objectives and principles that may be further elaborated via protocols and action-oriented documents (ECKARDT et al, 2023). This calls on States to protect all ecosystems, habitats, and populations of species (see WINTER, 2018 and TANAKA, 2015). Article 8 (h) calls each Contracting Party as far as possible and as appropriate, "to prevent the introduction of, control or eradicate those alien species which threaten ecosystems".

Under this background, the CBD Guiding Principles on IAS were adopted at the 6th Conference of the

Parties (COP 6), in 2002 (COP 6 Decision VI/23). It establishes 15 non-binding principles to guide governments and organizations to develop strategies that minimize the impacts due to invasive species. It adopts a "three stage hierarchical approach" (see arts. 2, 13, 14 e 15), focusing on: 1st) taking measures to prevent the introduction or establishment of alien species, 2nd) eradicating invasive organisms, and 3rd) implementing containment measures and control of bioinvasions immediately. Principle 7 expressly suggests conducting "risk analysis of the threats posed by alien species and their potential pathways of entry," whereas principle 11 encourages risk analysis of unintentional introductions promoted by specific activities, such as fishing, maritime transport, aquaculture, and tourism. It therefore prioritizes prevention, as the best cost-benefit strategy, for which the management of the pathways of NIS introduction is given a central role (Schucksmith and Shelmerdine, 2015).

(III) IMO BIOFOULING GUIDELINES

Under the slogan "safe, secure and efficient shipping on clean oceans," the International Maritime Organization (IMO), the UN's specialized agency for maritime affairs, has paid special attention to marine pollution from vessels (International Maritime Organization, 2013). In the bioinvasion realm, ballast water was the first vector to be regulated by the IMO, first by the adoption of Guidelines in 1997, and then by signing the Ballast Water Management (BWM) Convention in 2004, which only entered into force in 2017.

In 2001, the International Convention on the Control of Harmful Anti-fouling Systems on Ships was adopted. However, management of biofouling only began to be formally discussed by the organization`s Marine Environment Protection Committee (MEPC) in 2006, with its own document (Resolution MEPC 207(62)) approved in 2011 (SCIANNI et al, 2021). The 2011 IMO Biofouling Guidelines focused on the development and implementation of vessel-specific Biofouling Management Plans (BFMP) and Biofouling Record Books (BFRB) to guide preventive and reactive biofouling management (CUNNINGHAM et al, 2019). Risk assessment of marine bioinvasion was mentioned in the session dedicated to in-water inspection, cleaning, and maintenance. This was a foreseeable measure for States to evaluate the risk of in-water cleaning activities and minimize potential threats, which may include biological, environmental, geographical, and sanitary aspects (Art. 7.6).

The IMO Biofouling Guidelines were followed by several related IMO efforts (e.g. Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft, from 2012, and Guidance for Evaluating the 2011 Guidelines for the Control and Management of Ship’s Biofouling to Minimize the Transfer of Invasive Aquatic Species, from 2013 (SCIANNI et al, 2021)). In 2018, the Subcommittee on Pollution Prevention and Response was assigned to conduct a review of the document (SCIANNI et al, 2021), which was concluded at MEPC´s eightieth session, with the adoption of Resolution MEPC 378(80) from July 2023. In the recently published version, Appendix I suggests a proactive risk assessment approach for hull and niche areas based on monitoring various risk parameters during vessel operation. This includes the identification of the niche areas most susceptible to biofouling (risk areas), definition of the risk profile for biofouling accumulation of the vessel and establishment of a system for monitoring risk parameters.

We also highlight the existence of legal strategies adopted by other regulatory texts of global reach that are less disseminated in the literature, but which were also identified in our review. This is the case of the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) and the World Organization for Animal Health (WOAH) Aquatic Animal Health Code, pioneers in indicating the conduction of risk analysis to prevent damage caused by biofouling. In 1994, the SPS Agreement already set binding requirements (e.g., use of science, risk assessment, minimal impacts on trade, transparency) for establishing national regulations to protect human, animal, and plant (Lodge et al, 2016), while in 1995 the WOAH Aquatic Animal Health Code had already included a specific section giving instructions on how to conduct risk analysis (OJAVEER et al, 2018). Finally, there is the Kunming-Montreal Global Biodiversity Framework (GBF), adopted in December 2022, during the fifteenth UN Biodiversity Conference (CBD COP 15). Although not mandatory, it deserves to be mentioned for the boldness of Target 6, which aims at "reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent by 2030, and eradicating or controlling invasive alien species, especially in priority areas, such as islands" (see decision CBD/COP/DEC/15/4).

REGIONAL DEVELOPMENTS: THE EUROPEAN UNION STRATEGY

In the regional international sphere, the European Union, officially created in 1992, with the signing of the Maastricht treaty, stands out as a lawmaker on bioinvasions. However, as Ojaveer et al. (2018) observes, still under the mantle of the European Community, article 11.1(b) from the Convention on the Conservation of European Wildlife and Natural Habitats, from 1979, already required contracting parties "to strictly control the introduction of non-indigenous species". In 1992, the Habitats Directive called on states to regulate the introduction of NIS, to avoid damage to natural habitats, fauna, and flora (Art. 22(b)).

As for aquatic environments, the Aquaculture regulation (EC n. 708/2007) went further, by establishing directives for the management of permits as a necessary condition for authorizing the introduction of exotic or absent species. The procedure is based on guidelines supported by data generated from risk assessment, aiming to issue permits associated with low invasion risks. The European Marine Strategy Framework Directive (2008/56/EC) is among the mandatory instruments and is specifically aimed at the marine environment. Although it is mandatory, it is part of the EU's secondary law (see Treaty on the Functioning of the European Union – TFEU – art. 288), which means that Member States must transpose them by defining the form and methods that are applicable into their national legal systems to be effective at national level (OJAVEER et al. 2018). This recognizes the marine environment as a precious heritage and defines the aim to maintain biodiversity and dynamic and diverse oceans and seas clean, healthy, and productive. As part of the framework, it provided for achieving or maintaining good environment status by 2020 (art. 1), it committed states to adopt strategies to protect, preserve, prevent, and restore the marine environment and defined a series of qualitative descriptors for determining good environmental status (KÖCK and MAGSIG, 2018). Descriptor 2 is dedicated to NIS that were introduced by human

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activities, which should be kept "at levels that do not adversely alter the ecosystems" (MSFD, Annex I, 2008).

The most important document for invasive species management came in 2014, with Regulation (EU) n. 1143 of the European Parliament and of the Council of 22 October 2014. This established the List of invasive alien species of Union concern, drawn up from risk assessments that must involve consideration of not just the risks but also the benefits of introduction (art. 5 (h)) (Köck 2015: 168). The species of organisms listed there can no longer be imported, kept, bred, purchased, used, exchanged, and released (art. 7). In addition, this document includes guides and determinations on the analysis of pathways of introduction (art. 13), setting up surveillance systems (art.14 ff.) and eradicating the not yet established IAS "of Union concern" (art. 17 ff.), along with the necessary requirements for applying the program to combat and monitor IAS in practice (art. 3 ff.) (KÖCK and MAGSIG, 2018).

The EU Regulation on IAS (EU 1143) has a supplementary document devoted to IAS risk assessment, the Commission Delegated Regulation (EU) 2018/968, which was published in 2018. This sets out a description of the common elements, as well as a risk assessment methodology to submit requests for the inclusion of invasive alien species on the Union list.

COUNTRY-LEVEL INITIATIVES

Our findings pointed out the United States, the United Kingdom, New Zealand, and Australia, respectively, as the main publishers concerning risk assessment to manage bioinvasion via biofouling. Even though the United Kingdom, formed by England, Scotland, Wales, and Northern Ireland, ranked second, the case of the Shetland Islands was the only one to stand out among the consulted articles (see Appendix 1). Therefore, we will discuss in detail the strategies developed by the United States of America (US), New Zealand, and Australia, since they have been considered as precursors of a relatively solid system of standards on the matter, contributing not only for implementing the international targets and recommendations but also to their design (LODGE et al, 2016).

(I) UNITED STATES OF AMERICA

Since the 1990s, the United States developed federal legislations concerned with the negative impacts of NIS on its coastal waters. First came the Non-Indigenous Aquatic Nuisance Prevention and Control Act, which was a response to the introduction of zebra mussels and other species into the Great Lakes region via ballast water. In 1996, it was amended to include the National Invasive Species Act of 1996 (NISA), which granted authority to the United States Coast Guard (USCG) to prevent the introduction and spread of aquatic nuisance species, including via hull fouling (SCIANNI et al., 2021). Since March 2017, it requires the removal of fouling organisms from the vessel's hull, piping, and tanks regularly and dispose of any removed substances in accordance with local, state, and federal regulations (see 33 CFR 151, Subpart D, Section 2050 (f)).

Under the purview of the U.S. Environmental Protection Agency (USEPA), the National Pollutant

Discharge Elimination System (NPDES), under the provisions of the Clean Water Act, establishes the basic structure for regulating discharges of pollutants into the waters of the United States. This sets requirements regarding the issuing of permits for in-water cleaning (IWC), hull coatings, anchor chains, seawater piping, hull cleaning, as well as routine or upon request inspections and reports (see title 33, § 1251 et seq. of the U. S. Code). In 2018, the Vessel Incidental Discharge Act (see § 1322) was adopted, aiming to provide national standards of performance for marine pollution control devices for discharges incidental to the normal operation of vessels, including the discharge of biofouling from a vessel during a period in which the vessel is not undergoing active cleaning activities (called "passive biofouling"). However, USEPA only adopted their final VIDA standard of performance in September 2024, and the U. S. Coast Guard still has two years to develop corresponding implementation, compliance, and enforcement regulations so that it can become effective.[1] Note the existence of rapid risk assessment protocols developed by the US Fish and Wildlife Service (USFWS). The entity is responsible for identifying injurious wildlife whose importation should be barred. Although the procedures also respond to climate change, they do not apply to exclusively marine species (LODGE et al, 2016).

Therefore, when focusing on the marine environment, one must look upon California's initiatives. In 2007, an amendment placed a mandate on the California State Lands Commission to develop and adopt biofouling management regulations (SCIANNI et al, 2021). The Biofouling Management to Minimize the Transfer of Nonindigenous Species from Vessels arriving at California Ports, as part of the California Code of Regulations (CCR) entered into force in October 2017. This is applicable for vessels over 300 gross registered tons capable of carrying ballast water, placing requirements such as biofouling management plans and record books (like the 2011 IMO Biofouling Guidelines, but with specific conditions) as well as annual vessel reporting. Vessels that incur violations during first inspection after becoming subject to requirements have a 60-day grace period for correcting the identified deficiencies. If they are not corrected, the vessel will receive a Notice of Violation (see Title 2, Division 3, Chapter 1, Article 4.8). As Scianni et al (2021) highlights, this flexibility is a helpful tool to increase awareness and encourage compliance since California has a compliance rate of over 99% after grace period expiration and subsequent inspection.

(II) NEW ZEALAND

New Zealand is also a world-leading country regarding its biosecurity system, which is based in effective and proactive legislation and policy to manage invasive species. The legal framework is provided by the Biosecurity Act 1993 and encourages national and regional government collaboration, as well as affected parties and stakeholders' engagement (GEORGIADES et al, 2020).

Under this framework, the Craft Risk Management Standard for Biofouling on Vessels Arriving to New Zealand (CRMS-BIOFOUL) became effective in 2014. It placed NZ as the first country to institute a standard

[1] See: https://www.epa.gov/vessels-marinas-and-ports/vessel-incidental-discharge-act-vida.

for biofouling applicable to all classes of international vessels. Risk assessments were conducted by the competent public body during its development and risk rating for vessel profiling is part of its implementation (GEORGIADES et al, 2020). It established the "clean hull" obligation, which means to follow the thresholds defined according to the duration of the stay in the country. During the first four years, compliance with the requirements was voluntary, becoming mandatory in 2018 (SCIANNI et al, 2021). As of October 2023, all biosecurity requirements for biofouling, except for ballast water risks associated with a vessel, are located in the updated CRMS for Vessels (2023).

After the 2012 amendments, the Biosecurity Act 1993 enabled national and regional pest management plans for managing IAS biofouling (GEORGIADES et al, 2020). This promoted a change of focus in the management approach by enabling agencies to declare invasive or harmful species as "pests" and place rules on the vectors rather than on the species themselves to reduce bioinvasions risk (CUNNINGHAM et al, 2019). The Fiordland Marine Regional Pathway Management Plan, in the Fiordland Marine Area (in NZ´s Southland), was the first regional plan of the country to be developed and implemented (CUNNINGHAM et al, 2019). After following the many steps councils must follow before implementing a plan with enforceable rules, i.e. demonstrating that the benefits of a plan will outweigh its costs, and that formal consultation takes place with those that may be affected by the new rules, the plan became operative in 2017. The plan applies to all vessels and consists of three rules: (i) to hold a Fiordland Clean Vessel Pass (CVP); (ii) to meet the three following standards: to have hull biofouling of "no more than a slime layer and goose barnacles" (including niche areas), to have all marine gear and equipment on the vessel visibly clean treated and dry, and that any on-board residual seawater has been treated or is visibly clean and treated; (iii) to keep records of the actions taken to meet the required standards and provide those records upon request (CUNNINGHAM et al, 2019).

(III) AUSTRALIA

Australia is a country heavily affected by NIS. Perhaps this is why it was also a forerunner in regulating marine bioinvasions, with the Voluntary ballast water guidelines for vessels entering Australian ports from overseas (1990). Along with the US Aquatic Nuisance Prevention and Control Act, it contributed to the IMO Ballast water guidelines, published in 1991 (OJAVEER et al, 2018).

In terms of recommendations to manage marine biofouling, Australia and New Zealand have a common document: the Australian and New Zealand Antifouling and IWC Guidelines, published in 2015, and drafted since 2011 (TAMBURRI et al, 2021). It provides guidance on "best-practice approaches for the application, maintenance, removal and disposal of anti-fouling coatings and the management of biofouling and invasive aquatic species on vessels and movable structures in Australia and New Zealand" (Department of The Environment and New Zealand Ministry for Primary Industries, 2015). According to the government's website, the document targets decision-makers and an updated version is expected to be released in 2024. Additional guidance is also provided for some activities, such as offshore oil and gas production, commercial fishing vessels and the aquaculture industry.

Vessel operators shall also comply with the Australian Biofouling Management Requirements (ABFMR) set out within the scope of managing unacceptable levels of biosecurity risk from the Biosecurity Act 2015 (see Division 5), when operating under biosecurity control within Australian territorial seas. That means submitting a pre-arrival report to demonstrate compliance with one of the following management practices: (i) implementation of an effective biofouling management plan and record book; (ii) cleaning all biofouling within 30 days prior to arriving in Australian territory; or (iii) an alternative biofouling management method pre-approved by the department of Agriculture, Fisheries and Forestry (DAFF, 2023). This should also be observed where territorial or state management legislation exists, e.g. in Northern Territory, Queensland, and Western Australia, either mandatory or voluntary.

The timeline below highlights the main normative strategies developed, both at the level of the countries that publish the most about bioinvasion via biofouling, as well as at a regional and global level (see Figure 4). To sum up, legislation on marine bioinvasion is becoming more and more aware of the threats represented by biofouling. Concerns of the international community regarding the protection of marine environment began in the 1970s, with the conferences that culminated in the signing of UNCLOS, in 1982. At the time, more general and non-obligatory normative provisions prevailed. Furthermore, for many years the notion that ballast water from ships would be the main vector for the introduction of non-native non-indigenous species into the marine environment was dominant in science. Only after the 2011 IMO Biofouling Guidelines, predictions surpassed the level of taking measures (using expressions such as "take action" and "regulate") into a more rigorous approach, with more precise obligations around bioinvasion via biofouling, specially through national initiatives. Standards that apply risk assessment appear in this context of growing concern about biofouling and the taking of mandatory measures, alongside predictions such as analysis of pathways, monitoring and setting up management measures, with the aim of enabling the achievement of greater predictability and security. Accordingly, country-level strategies incorporate risk assessment either to guide decision-makers while defining general standards that may be established by the norms, or as part of the recommendations and obligations that must be observed by specific stakeholders. New Zealand is an example of the first, whereas the Biosecurity Plan for the Shetland Islands implements the latter.

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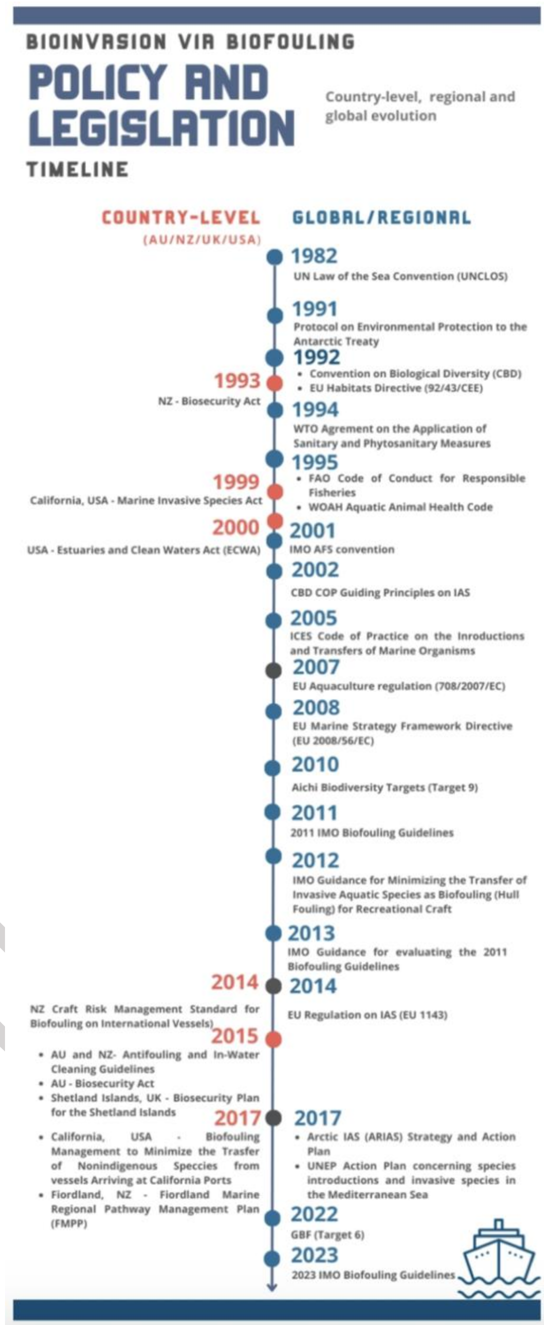

Figure 4: Country-level, regional and global policy and legislation evolution towards the incorporation of risk analysis for the management of marine bioinvasion via biofouling.

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CHALLENGES AND FUTURE DIRECTIONS

Marine bioinvasion risk assessment enables identifying non-indigenous species with the greatest potential to cause negative impacts in a region. Conducting this type of analysis guides decision-making on measures to prevent, control, and manage such NIS, reducing the financial and environmental costs associated with their presence. However, in view of the growing number of cases and studies on the subject, standardizing the methodologies for quantifying the extent of NIS' effects and evaluating their potential risks has become a necessary step (SREBALIENE et al., 2019). Adopting a certain methodology or approach for risk assessment as part of a public policy for managing bioinvasion via biofouling could be a mean to guide states and entrepreneurs in this direction. Nevertheless, the collected data show, both at the international and national levels, legislation that expressly mentions risk assessment is scarce. Although commitments on biofouling management are increasingly bold, including the establishment of targets, such as the above-mentioned GBF, countries are still in their infancy when it comes to adopting mandatory measures on the subject. In addition, marine bioinvasion risk analysis shows some difficulties that need to be considered, such as lack of data, spatial and temporal variability, complexity of ecosystems, and incorrect use of data. There is often a lack of data to accurately assess the invasive potential and ecological, economic, and social impacts of NIS, as well as incorrect assessment of the importance of each parameter used in an analysis. In this context, the use of smart tools and big data can help analyze the large datasets needed for a more robust risk analysis. In addition to helping to identify patterns and relationships that would not be easily identifiable via traditional approaches.

Nevertheless, climate change and biological invasions have been extensively discussed in conservation strategies (GIAKOUMI et al., 2016; GUIDETTI & DANOVARO, 2018; MACIC et al., 2018). However, the synergistic effect between these two processes has been neglected. According to several authors (SEEBENS et al. 2021; ROY et al., 2017; CAPINHA et al., 2015), the pattern of marine species distribution is under significant threat due to climate change-induced shifts in survival and species maintenance boundaries, either leading to expansion or contraction, and anthropogenic dispersal. For example, extreme natural events, such as floods, tsunamis, and strong winds, can promote the expansion of NIS and provide them with openings for colonization in previously unoccupied regions. Consequently, non-indigenous species could gain advantages from climate change. As a result, it is crucial to revise and incorporate potential climate change effects into risk assessments, as suggested by Roy et al. in 2017.

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AUTHOR CONTRIBUTION

F. C. X.: Conceptualization; Methodology; Software; Formal Analysis; Writing – original draft; Writing – review & editing;
F. C. B. A.: Conceptualization; Formal Analysis; Investigation; Writing – original draft; Writing – review & editing;
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L. V. R. de M.: Conceptualization; Writing – review & editing
D. M.: Conceptualization; Writing – review & editing
L. C.: Conceptualization; Writing – review & editing
S. C.: Conceptualization; Writing – review & editing
B. V.: Conceptualization; Writing – review & editing
R. C.: Supervision; Resources; Project Administration; Funding Acquisition; Writing – review & editing.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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Table 2- Policy and legislation framework for managing marine IAS biofouling based on risk assessment.

Jurisdiction	Title	Adoption year	Legal type	Mandatory?	Actor/ activity affected	Relevant excerpts and commentaries
Global (UN)	UNCLOS	1982	Convention	Yes	States	Art. 196. "States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto".
Global (UN)	Convention on Biological Diversity (CBD)	1992	Convention	Yes	States	Article 8 (h) calls each Contracting Party, as far as possible and as appropriate "to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".
Global (WTO)	SPS Agreement	1994	Agreement	Yes	States	Art. 5. "1. Members shall ensure that their sanitary or phytosanitary measures are based on an assessment, as appropriate to the circumstances, of the risks to human, animal or plant life or health, taking into account risk assessment techniques developed by the relevant international organizations. 2. In the assessment of risks, Members shall take into account available scientific evidence; relevant processes and production methods; relevant inspection, sampling and testing methods; prevalence of specific diseases or pests; existence of pest- or disease-free areas; relevant ecological and environmental conditions; and quarantine or other treatment. 3. In assessing the risk to animal or plant life or health and determining the measure to be applied for achieving the appropriate level of sanitary or phytosanitary protection from such risk, Members shall take into account as relevant economic factors: the potential damage in terms of loss of production or sales in the event of the entry, establishment or spread of a pest or disease; the costs of control or eradication in the territory of the importing Member; and the relative cost-effectiveness of alternative approaches to limiting risks."
Global (FAO)	FAO Code of Conduct for Responsible Fisheries	1995	Code	No	Fisheries, aquaculture and mariculture	art. 9.3.1 - "(…) efforts should be undertaken to minimize the harmful effects of introducing non-indigenous species or genetically altered stocks used for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the

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						spread of such non-indigenous species or genetically altered stocks into waters under the jurisdiction of other States as well as waters under the jurisdiction of the State of origin. States should, whenever possible, promote steps to minimize adverse genetic, disease and other effects of escaped farmed fish on wild stocks."
Global (among Contracting Members)	WOAH Aquatic Animal Health Code	1995	Code	No	Several	Section 2 is dedicated to Risk Analysis (Chapter 2.1.)
Global (IMO)	International Convention on the Control of Harmful Anti-fouling Systems on Ships	2001	Convention	Yes	Ships	Article 4. (1) In accordance with the requirements specified in Annex 1, each Party shall prohibit and/or restrict: 1. (a) the application, re-application, installation, or use of harmful anti-fouling systems on ships referred to in article 3(1)(a) or (b); and (b) the application, re-application, installation or use of such systems, whilst in a Party's port, shipyard, or offshore terminal, on ships referred to in article 3(1)(c),and shall take effective measures to ensure that such ships comply with those requirements.
Initially regional (North Atlantic and adjacent seas), but encourages all countries around the globe to adopt it.	ICES Code of Practice on the Introductions and Transfers of Marine Organisms	2005	Code	No	Several	The document builds on previous versions adopted firstly in 1973 and updated in 1994. Appendix B is devoted to risk assessment. It states that " (...) there will be an assessment of each potential hazard as to the probability of the establishment and consequences of the establishment in the receiving environment. Mitigation factors and management issues will also be reviewed. The precautionary principle will be taken into account in the final outcome of the risk assessment".
Global (IMO)	IMO Guidelines for the Control and Management of Ship's Biofouling to Minimize the Transfer of Invasive Aquatic Species	2011	Guideline	No	Vessels	The document is intended to provide a globally consistent approach to the management of biofouling. A revised version was adopted in July 2023. Annex - "7. In-water inspection, cleaning and maintenance. (...) 7.6 It may be appropriate for States to conduct a risk assessment to evaluate the risk of in-water cleaning activities and minimize potential threats to their environment, property and resources. Risk assessment factors could include the following: 1. biological risk of the biofouling organisms being removed from the ship (including viability of

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						the biofouling organisms or the ability to capture biofouling material); 2. factors that may influence biofouling accumulation, such as changes to the operating profile of the ship; 3. geographical area that was the source of the biofouling on the ship, if known; and 4. toxic effects related to substances within the anti-fouling coating system that could be released during the cleaning activity, and any subsequent damage to the anti-fouling coating system."
Global (IMO)	IMO Guidance for minimizing the transfer of invasive species as biofouling (hull fouling) for recreational crafts	2012	Guideline	No	Recreational crafts	Annex - "5 HOW CAN BIOFOULING BE MINIMIZED? If your recreational craft is normally kept in the water (regardless of whether it is trailerable or not), an appropriate anti-fouling coating system and good maintenance are the best way of preventing biofouling accumulation. If you regularly operate recreational craft in both marine and fresh waters, this may help to reduce the accumulation of biofouling (many marine fouling species do not easily survive in fresh or brackish water and vice versa) however, a good maintenance regime is still essential."
Global (UN General Assembly)	Aichi Biodiversity Targets	2010	Target	No	Several	Target 9: "By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment."
Global (UN)	CBD COP Guiding Principles on IAS (COP 6 Decision VI/23)	2002	Decision	No	States	Guiding principle 7 - "(...) 2. States should consider putting in place appropriate measures to control introductions of invasive alien species within the State according to national legislation and policies where they exist". 3. These measures should be based on a risk analysis of the threats posed by alien species and their potential pathways of entry. Guiding principle 11: "Common pathways leading to unintentional introductions need to be identified and appropriate provisions to minimize such introductions should be in place. Sectoral activities, such as fisheries, agriculture, forestry, horticulture, shipping (including the discharge of ballast waters), ground and air transportation, construction projects,

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						landscaping, aquaculture including ornamental aquaculture, tourism, the pet industry and game-farming, are often pathways for unintentional introductions. Environmental impact assessment of such activities should address the risk of unintentional introduction of invasive alien species. Wherever appropriate, a risk analysis of the unintentional introduction of invasive alien species should be conducted for these pathways.”
Global (IMO)	IMO Guidance for evaluating the 2011 Biofouling Guidelines	2013	Guideline	No	Ships	Annex - 1. Context. “(...) 1.3 This guidance is provided to assist Member States and observers who wish to collect information needed to undertake future reviews of the Guidelines, and to do this in a more consistent way. The Guidance identifies the types of performance measures (section 3) that could help to assist in evaluating the different recommendations in the Guidelines. A party wishing to collect information may do so for all or only some of these measures.”
Global (UN General Assembly)	Kunming-Montreal Global Biodiversity Framework (GBF)	2022	Framework	No	Several	Target 6: “Eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent by 2030, and eradicating or controlling invasive alien species, especially in priority sites, such as islands”.
Regional (Antarctica)	Protocol on Environment al Protection to the Antarctic Treaty	1991	Protocol	Yes	Several	Annex. 2 (Conservation of Antarctic Fauna and Flora). Art. 4(1). “No species of living organisms not native to the Antarctic Treaty area shall be introduced onto land or ice shelves, or into water, in the Antarctic Treaty area except in accordance with a permit. [...] 3. Permits under paragraph 1 above shall: (a) be issued to allow the importation only of cultivated plants and their reproductive propagules for controlled use, and species of living organisms for controlled experimental use; and (b) specify the species numbers and, if appropriate, age and sex of the species to be introduced, along with a rationale, justifying the introduction and precautions to be taken to prevent escape or contact with fauna or flora.

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Regional (European Union)	EU Habitats directive (92/43/CEE)	1992	Directive	Yes	States	Art. 22b Member States shall "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction. The results of the assessment undertaken shall be forwarded to the committee for information".
Regional (European Union)	EU Aquaculture Regulation (EC 708/2007)	2007	Regulation	Yes	Aquaculture	Art. 9. 1. "In the case of non-routine movement, an environmental risk assessment shall be carried out as outlined in Annex II 2. On the basis of the environmental risk assessment, the advisory committee shall give its opinion on the risk to the competent authority, using the summary report form set out in Annex II, Part 3. If the advisory committee finds that the risk is low, the competent authority may grant the permit without further formalities. 3. If the advisory committee finds that the risk associated with the proposed movement of aquatic organisms is high or medium in the sense of Annex II, part 1, it shall examine the application in consultation with the applicant to see if there are mitigation procedures or technologies available to reduce the level of risk to low. The advisory committee shall forward the results of its examination to the competent authority, detailing the level of risk and specifying the reasons for any reduction in risk, in the form specified in Annex II, Part 3 4. The competent authority may only issue permits for non-routine movements in cases where the risk assessment, including any mitigation measures, show a low risk to the environment. Any refusal of a permit must be duly motivated on scientific grounds

						and, where scientific information is as yet insufficient, on the grounds of the precautionary principle".
Regional (European Union)	EU Marine Strategy Framework Directive (EU 2008/56/EC)	2008	Directive	Yes	Several	"Descriptor 2: Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems."
Regional (European Union)	EU Regulation on IAS (EU 1143)	2014	Regulation	Yes	States	It establishes the adoption by the Commission of the list of IAS of union concern, whose items must follow all the required criteria, and shall be comprehensively reviewed every six years (art 4). It prohibits intentionally importing, keeping, breeding, transporting, trading, using, exchanging and releasing the listed species (art. 7). Regarding Member States, It also contains obligations to do with analyzing pathways of unintentional introduction and establishing plans of action (Art. 13), setting up surveillance systems to promote early detection (Art.14) and eradicating not yet established (Art. 17 ff.), along with putting in place management measures for widely spread IAS "of Union concern". It has a supplementary document on IAS risk assessment, the Commission Delegated Regulation (EU) 2018/968, which was published in 2018.
Regional (Arctic Council)	Arctic invasive alien species (ARIAS) Strategy and Action Plan	2017	Strategy and action plan	No	Several	Annex 1 (Implementation guidance) - Action 2.1: "Use tools such as risk analysis, horizon scanning, and site-based prioritization in identifying and assessing pathways that pose the greatest risk of biological invasions".
Regional (Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterran	UNEP Action Plan concerning species introductions and invasive species in the Mediterranean Sea	2017	Action Plan	No	States and international organizations	B. PRIORITIES - "B1. At national level. 1. Considering the lack of the data and knowledge necessary for impact and risk assessments, horizon scanning, and the implementation of management actions for prevention, control and eradication, priority at national level should be given to: 1. encouraging all necessary actions (e.g. research work, data collection, monitoring, national impact assessments, horizon scanning etc.) aimed at improving the available knowledge". C. ACTIONS REQUIRED TO ATTAIN THE OBJECTIVES OF THE ACTION

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ean)						PLAN - “C.1.4 Institutional framework. A mechanism should be set up, if possible, at the level of each country, to promote and coordinate the following actions: (...) cooperating with the concerned authorities in neighboring states regarding the detection of introduced species and risk assessment, (...)”. “C.2.2 Training. To support the implementation of the present Action Plan, a regional training session should be organized in collaboration with the concerned international organizations. In particular, it will deal with the main following themes: Methods and protocols for impact and risk assessments, and horizon scanning regarding new introductions of alien species; (...)”.
National (NZ)	Biosecurity Act	1993	Act	Yes	Public actors	It prescribes requirements for the exclusion, eradication and effective management of pests and unwanted organisms in New Zealand, setting the material and procedural basis for issuing Craft Risk Management Standards (see sections 24E to 24K). After the 2012 amendments, it allowed national and regional pest management plans for managing IAS biofouling.
National (NZ)	Craft Risk Management Standard for Biofouling on International Vessels (CRMS-BIOFOUL)	2014	Standard	Yes (since 2018)	Vessels	Issued under the NZ Biosecurity Act, risk assessments were carried out by the competent public body during its development and risk rating for vessel profiling is part of its implementation. It established the “clean hull” obligation to all operators or person in charge of a vessel. “” As of October 2023, all biosecurity requirements for biofouling are located in the updated CRMS for Vessels 2023.
National (USA)	Clean Water Act (CWA)	1972	Act	Yes	Several	It establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface water. In 2018, the VIDA was adopted, but it still needs implementation, compliance, and enforcement regulations.
National (USA)	Code of Federal Regulations	2017	Code	Yes	Non-recreational vessels, equipped with ballast tanks, operating in the waters of the US.	With the purpose of implementing the provisions of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (as amended by the National Invasive Species Act of 1996), it requires the removal of fouling organisms from the vessel's hull, piping, and tanks on a regular basis and dispose of any removed substances in accordance with local, state and federal regulations (see 33 CFR 151, Subpart D, Section 2050 (f)).

National (Australia and NZ)	Antifouling and In-Water Cleaning Guidelines	2015	Guideline	No	Several	The document provides guidance on "best-practice approaches for the application, maintenance, removal and disposal of anti-fouling coatings and the management of biofouling and invasive aquatic species on vessels and movable structures in Australia and New Zealand".
National (Australia)	Biosecurity Act	2015	Act	Yes	Vessels	Requires IMO-consistent biofouling management standards for vessels entering Australian territorial seas.
Sub-national (California, USA)	Marine Invasive Species Act	1999	Act	Yes	Vessels	In 2007, an amendment placed a mandate on the California State Lands Commission to develop and adopt biofouling management regulations.
Sub-national (California, USA)	Biofouling management to Minimize the Transfer of Non-indigenous Species from Vessels arriving at California Ports	2017	Regulation	Yes	Large vessels (>300 gross tons) capable of carrying ballast water	Like the 2011 IMO Biofouling Guidelines, it is based on vessels´ biofouling management plans (BFMP) and biofouling record books (BFRB). It provides for a 60-day grace period to be issued for vessels that have been found in violation of one or more of the regulatory requirements to correct the deficiencies.
Sub-national (Fiordland, NZ)	Fiordland Marine Regional Pathway Management Plan (FMPP)	2017	Plan	Yes	Vessels operating within the Fiordland Marine Area	It sets out three rules. The first rule determines that all vessels entering and operating within the Fiordland Marine Area must hold a Clean Vessel Pass, which means to abide by the following two other rules. The second rule requires them to meet hull and niche as well as residual seawater cleaning standards. The third rule requires the owner or person in charge of a vessel to keep records of all previous steps and make them available on request.