Meeting Date: 08/25/26
Staff: C. Scianni

Staff Report 52 (Informational)

SUMMARY:

The Commission's Marine Invasive Species Program (MISP) recently published two influential peer-reviewed scientific research articles through collaborative efforts with colleagues within California and throughout the globe.

The first paper, California's Marine Invasive Species Program: 25 years of comprehensive pathway management, was published in the journal *Management of Biological Invasions*. This paper focuses on the first 25 years of MISP's existence (2000-2024) and highlights the shipping-related invasive species pressures on California waters during this time and the positive impacts our comprehensive regulatory program has had on the shipping industry and California's environment.

During this 25-year period, nearly a quarter million vessels arrived at California ports, representing enough cumulative underwater surface area that is susceptible to biofouling accumulation to cover an area 2.3 times the size of the city of Los Angeles. These ships cumulatively discharged enough ballast water to fill 92,000 Olympic-sized swimming pools. To assess whether these vessels complied with the requirements of the Marine Invasive Species Act, staff not only reviewed vessel-submitted mandatory reporting forms for every arriving vessel, but also conducted nearly 50,000 onboard vessel inspections. Results of MISP efforts include a three-fold reduction in the number of new detections of nonindigenous species in California waters.

The second paper, Closure of the Strait of Hormuz may trigger a bioinvasion super-spreader event, was published in the journal *Biological Invasions* through a collaboration between MISP staff and 23 other marine scientists spread across the globe. This paper highlights the likely unprecedented accumulation of species on the hulls of more than 1,500 ships idled for months in the warm, biologically productive Persian Gulf. This paper describes the potential for these heavily fouled vessels to create a super-spreader event (similar to rapid spread of diseases like COVID-19) once the Strait of Hormuz opens and these vessels reenter service, resulting in the potential for elevated risk of species introductions at all ports that these vessels may transit to in the months that follow.

EXHIBITS:

A. Scianni C, Ceballos-Osuna L, Thompson JL, Nedelcheva R, Mackay J, Dobroski N, Rietl A, Shiba S, McBride S, Vasquez M, Falkner MB (2026). California's Marine Invasive Species Program: 25 years of comprehensive pathway management. *Management of Biological Invasions* 17 (in press).

B. Tamburri MN, Carlton JT, Blakeslee AMH, Bortolus A, Canning-Clode J, Carvalho S, Chang AL, Davidson AC, Donelan SC, Drake LA, Fowler AE, Freestone AL, Haram LE, Hewitt CL, Miller AW, Muirhead JR, Outinen O, Robinson TB, Ruiz GM, Scianni C, Schwindt E, Tepolt CK, Therriault TW, Galil BS (2026). Closure of the Strait of Hormuz may trigger a bioinvasion super-spreader event. *Biological Invasions* 28, 177.

Exhibit A

Management of Biological Invasions (2026) Volume 17 **Article in press**

CORRECTED PROOF

Management in Practice

California's Marine Invasive Species Program: 25 years of comprehensive pathway management

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Abstract

California began implementing what became known as the Marine Invasive Species Program (MISP) on 1 January 2000, in response to concerns about the role of ballast water in nonindigenous species introductions and the lack of mandatory ballast water management within the U.S. During the ensuing 25 years, the multi-agency MISP has evolved into a well-known, comprehensive program that focuses on improving ballast water and biofouling management to reduce the likelihood of successful species introductions and species monitoring to determine program effectiveness. During these 25 years, 238,923 vessel arrivals, accounting for nearly 3,000 km^2 of vessel total wetted surface area, discharged approximately 230 million metric tons of ballast water at California ports, placing enormous pressures on California's aquatic environments. To mitigate these pressures, MISP has enforced ballast water management regulations since 2000 and biofouling management regulations since 2017, inspecting nearly 50,000 vessel arrivals and issuing over 5,500 administrative and operational violations to improve outreach and compliance. Coincident with these efforts, the detection rate of new aquatic nonindigenous species (NIS) in California likely attributable to ballast water and/or biofouling has decreased from 4.4 ± 2.8 (SD) per year during 1990–2004 to 1.4 ± 0.8 (SD) per year during 2005–2024, with only one new NIS likely attributable solely to ballast water since 2015. California's MISP, including its collaborative relationships with other regulatory entities and the shipping industry, has seemingly had numerous positive impacts on the California environment and has facilitated cooperation across the international shipping industry and must continue to adapt to new challenges in future years to continue being an effective leader in environmental stewardship.

Key words: ballast water, biofouling, nonindigenous species, prevention, vector management, shipping

Introduction

On 1 January 2000, the State of California began implementing what became known as the California Marine Invasive Species Program (MISP), a novel program designed to reduce the likelihood of nonindigenous species (NIS) introductions from commercial maritime vessels (California Legislature 1999, 2003). Over the next 25 years, MISP has developed into a well-known,

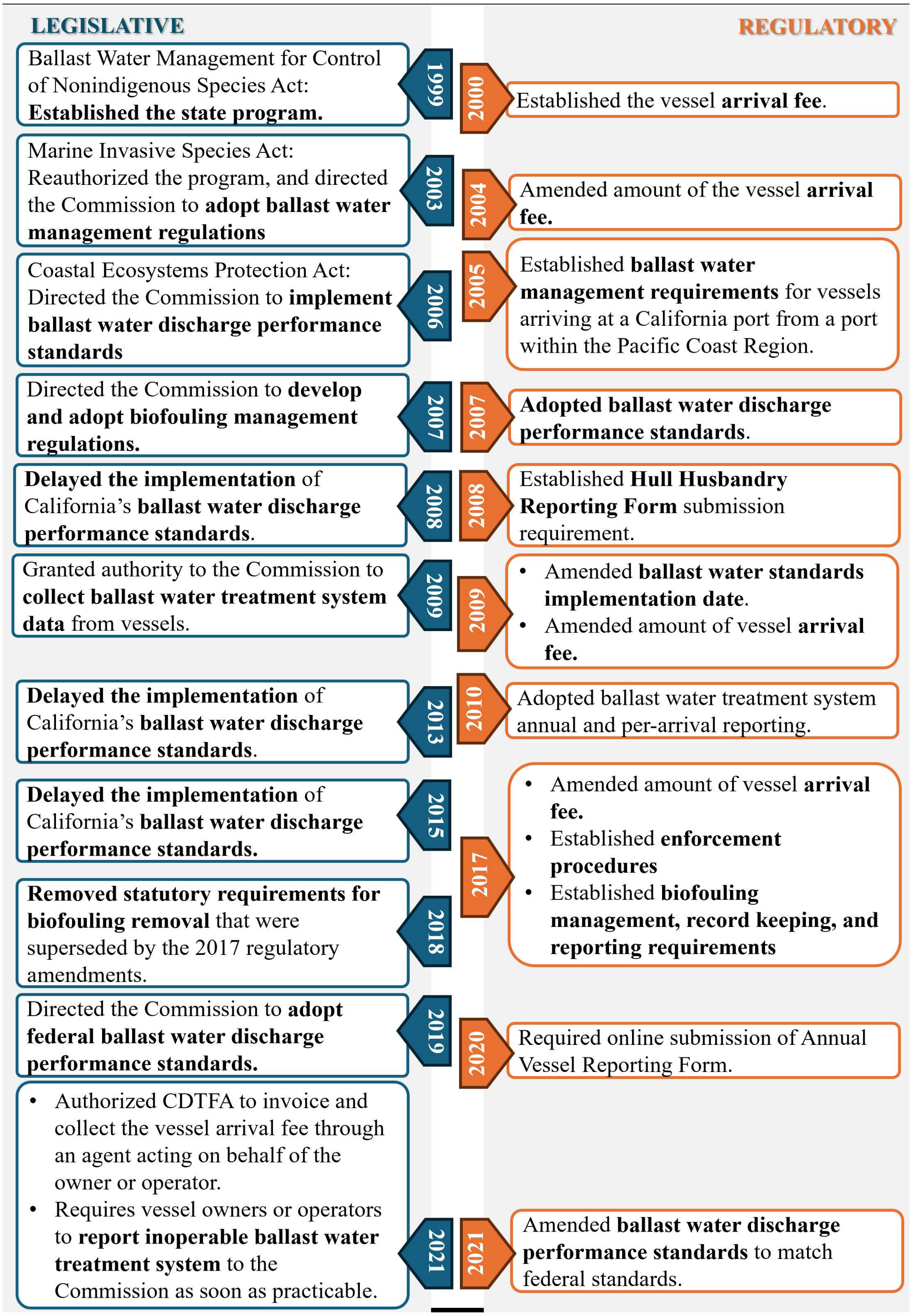

Figure 1. Legislative and subsequent regulatory actions taken to improve the effectiveness of the Marine Invasive Species Program.

comprehensive program focused on improving the management of vessels' ballast water and biofouling through science-based regulations development and implementation (see Figure 1 for overview of legislative and regulatory actions) and species monitoring to assess the effectiveness of those regulations.

Prior to 2000, there were no requirements in California, or anywhere in the U.S., for vessels to manage their ballast water. However, concern about ballast water gained momentum after the detection, and eventual establishment, of invasive zebra mussels (*Dreissena polymorpha*) in the Great Lakes during the 1980s (Hebert et al. 1989; Griffiths et al. 1991). This zebra mussel invasion of the Great Lakes spurred the adoption of the federal Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (U.S. Congress 1990) and reauthorization under the National Invasive Species Act in 1996 (U.S. Congress 1996). While these efforts helped to improve the state of ballast water management in the U.S., the measures that resulted were voluntary.

Concurrently, concerns about the invasive mitten crab (*Eriocheir sinensis*) in the San Francisco Bay were widespread after their detection in local waters in 1992 and establishment by 1994 (Cohen and Carlton 1997; Rudnick et al. 2003; ANSTF 2003). *Eriocheir sinensis* had interfered with operations at state and federal water diversion and power plants (Siegfried 1999; Veldhuizen and Stanish 1999), and their burrows had undermined the integrity of levies, particularly in the south San Francisco Estuary watersheds (Rudnick et al. 2003). Unmanaged ballast water was identified as a possible vector for their introduction (Cohen and Carlton 1997).

In the absence of mandatory U.S. federal requirements for ballast water management, and with increasing evidence of the role of ballast water in the worldwide translocation of species (Carlton 1985; Carlton and Geller 1993; Mills et al. 1993), California state lawmakers began drafting legislation that would establish a state program to require vessels to manage ballast water prior to discharge. Early versions of the draft law proposed a permitting system whereby the State Water Resources Control Board would issue individual permits to each vessel that intended to discharge ballast water in state waters. However, determining that a permitting program set up to issue individual permits for up to 11,000 vessel arrivals per year would be impractical, the bill was completely revised to create a comprehensive regulatory program (e.g., regulation development and enforcement, data collection, research funding, monitoring, dedicated funding mechanism). Thus, the Ballast Water Management for Control of Nonindigenous Species Act was signed into law by the California Governor in October 1999 (California Legislature 1999) and was later reauthorized and renamed as the Marine Invasive Species Act in 2003 (California Legislature 2003).

Responsibilities of the resulting Marine Invasive Species Program are shared across four state agencies: California State Lands Commission (CSLC), California Department of Fish and Wildlife (CDFW), California Department of Tax and Fee Administration, and State Water Resources Control Board (Figure 2). As directed by the California State Legislature, MISP is focused on prevention of NIS introduction through vector management. The program

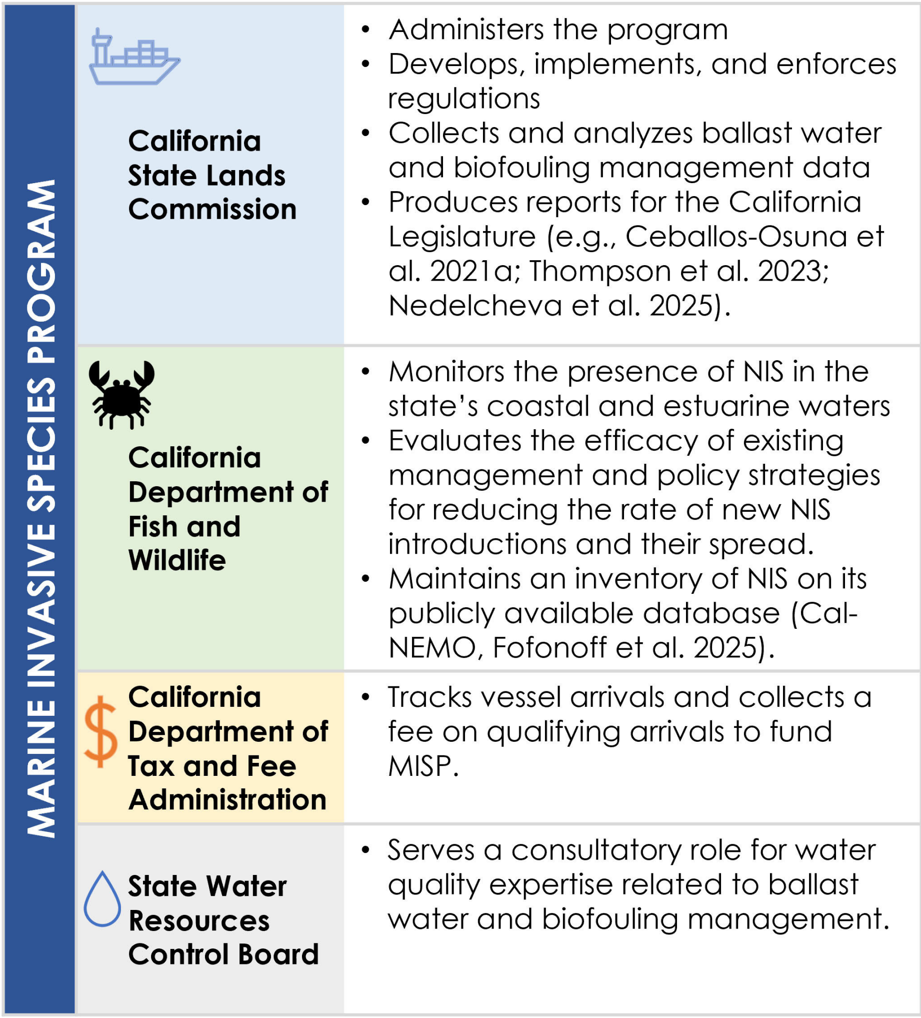

Figure 2. Responsibilities of the four partner departments of the California Marine Invasive Species Program.

has no authority or funding to respond when a new species detection is made. Other state and federal entities, including CDFW's Invasive Species Program (a distinct program from MISP), are responsible for coordinating responses (e.g., Golden Mussel Response Framework; California Department of Fish and Wildlife [CDFW] 2025a).

During the 25 years of MISP's existence, the program has evolved to more holistically manage vessel behaviors that contribute to species transport and introduction. Initially focused on ballast water exchange as the primary strategy for managing ballast water, MISP adopted aspirational technology-forcing ballast water discharge performance standards in 2007 that are yet to be implemented. As technology is not yet available to meet the 2007 standards, MISP adopted and implemented ballast water discharge performance standards in 2021 that are aligned with the U.S. federal standards implemented by the U.S. Coast Guard (USCG) in 2012 and by the U.S. Environmental Protection Agency in 2013 (Table 1). California's current ballast water discharge performance standards are also numerically similar to standards adopted by the International Maritime

Table 1. Timeline of California, U.S. federal, and international voluntary and mandatory ballast water and biofouling policies.

Year	Jurisdiction	Policy	Reference
1996	U.S. federal	Ballast Water exchange requirements – Voluntary	National Invasive Species Act (U.S. Congress 1996)
2000	California	Ballast Water exchange requirements – Mandatory	Ballast Water Management for Control of Nonindigenous Species Act (California Legislature 1999)
2004	U.S. federal	Ballast Water exchange requirements – Mandatory	Federal Register 2004
2004	International – IMO	Ballast Water Management Convention adopted	International Convention for the Control and Management of Ships' Ballast Water (IMO 2004)
2011	International – IMO	2011 IMO Biofouling Guidelines – Voluntary	Resolution MEPC.207(62) (IMO 2011)
2012	U.S. federal	USCG Ballast Water discharge performance standards – Mandatory	Federal Register 2012
2014	New Zealand	Craft Risk Management Standard for Biofouling – Voluntary	Ministry for Primary Industries [MPI] 2014
2017	California	Biofouling Management Regulations – Mandatory	California Code of Regulations 2017
2017	International – IMO	Ballast Water Management Convention enters into force – Mandatory	International Convention for the Control and Management of Ships' Ballast Water (IMO 2004)
2018	New Zealand	Craft Risk Management Standard for Biofouling – Mandatory	Ministry for Primary Industries [MPI] 2014
2022	California	Ballast Water Discharge Performance Standards – Mandatory	California Code of Regulations 2021
2022	Australia	Biofouling Management Regulations – Mandatory	Australian Government 2021
2023	International – IMO	2023 Revised IMO Biofouling Guidelines – Voluntary	Resolution MEPC.378(80) (IMO 2023)
2025	Brazil	Biofouling Management Regulations – Mandatory	Directorate of Ports and Coasts [DPC] 2025

Organization (IMO) in 2004 and implemented in 2017 (IMO 2004). However, these international standards are not enforced in the U.S. because the U.S. is not a signatory to the IMO's International Convention for the Control and Management of Ships' Ballast Water. In 2017, MISP also became one of the first entities globally to adopt and implement mandatory comprehensive biofouling management regulations (Scianni et al. 2021) requiring all vessels arriving at California ports to develop and maintain a Biofouling Management Plan and Record Book.

In this paper, we present patterns of vessel behaviors and inspection results to highlight MISP's contributions toward helping shape behavior change within the maritime shipping industry, and we analyze the rate of new aquatic NIS detections in state waters to highlight the potential MISP contribution toward resource protection for the state. We also identify challenges associated with state-centered regulation of an international industry and opportunities for close collaboration with partner states, U.S. federal agencies, and other countries to reduce invasion risk and improve compliance around the globe.

Materials and methods

Most of the data described below are maintained in, and queried from, a purpose-built MISP database. Data reported by vessels, as described in this section, undergo quality control checks (e.g., initial review for complete and sensible data and data entry checks by a second person) before and after entry into the MISP database, and any missing or questionable data are quarantined until corrections or confirmations are solicited by CSLC staff and received from vessel crews. When potential noncompliance is detected before a vessel arrival, MISP staff contact the vessel to inform them with enough time to apply proper management and submit corrected report forms.

Data collection and quantification of shipping pressures on California

Vessel arrivals data (from 1 January 2000 to 31 December 2024) were initially obtained from advance arrival reports from the Marine Exchanges of Southern California and the San Francisco Bay Region. These data populate a daily schedule of vessel arrivals at all California ports (Figure 3) that is housed within the MISP database. These data were supplemented and verified with Ballast Water Management Reports (BWMR; OMB number 1625-0069) that were required to be submitted to MISP from all vessels arriving at a California port. The BWMR submitted to MISP is the same form vessels submit to the National Ballast Information Clearinghouse (NBIC); however, MISP is not affiliated with NBIC, and the submission requirements are set by separate state and federal statutes.

Over time, arrivals to the San Francisco Bay area were binned into smaller geographic categories. Prior to 1 January 2004, all arrivals within the greater San Francisco Bay area (including Sacramento and Stockton) were considered one port call. Beginning 1 January 2004, arrivals at each individual port were classified as separate port calls. Beginning 1 January 2017, all arrivals at a San Francisco Bay anchorage were classified as Port of San Francisco arrivals.

Total wetted surface area (TWSA) refers to the total surface area of a vessel, including recesses and appendages, that is submerged or exposed to water and can be used as a proxy for vessel area that can be colonized by biofouling organisms. TWSA values were calculated using equations from Ceballos-Osuna et al. (2021b), using vessel gross tonnage data obtained from the MISP database.

Ballast water management data were obtained from BWMRs. All ballast water management data were queried from the MISP database, except for data on ballast water management strategies (e.g., ballast water exchange, ballast water treatment), which were queried from the MISP database for 2000–2004 and from NBIC (NBIC 2025) for 2005–2024.

Interventions

CSLC staff are directed by the Marine Invasive Species Act to board vessels to conduct inspections and examine onboard documents for at least 25% of vessel arrivals statewide and issue violations when detected. Vessels were selected for inspection via a risk matrix that categorizes vessels as high,

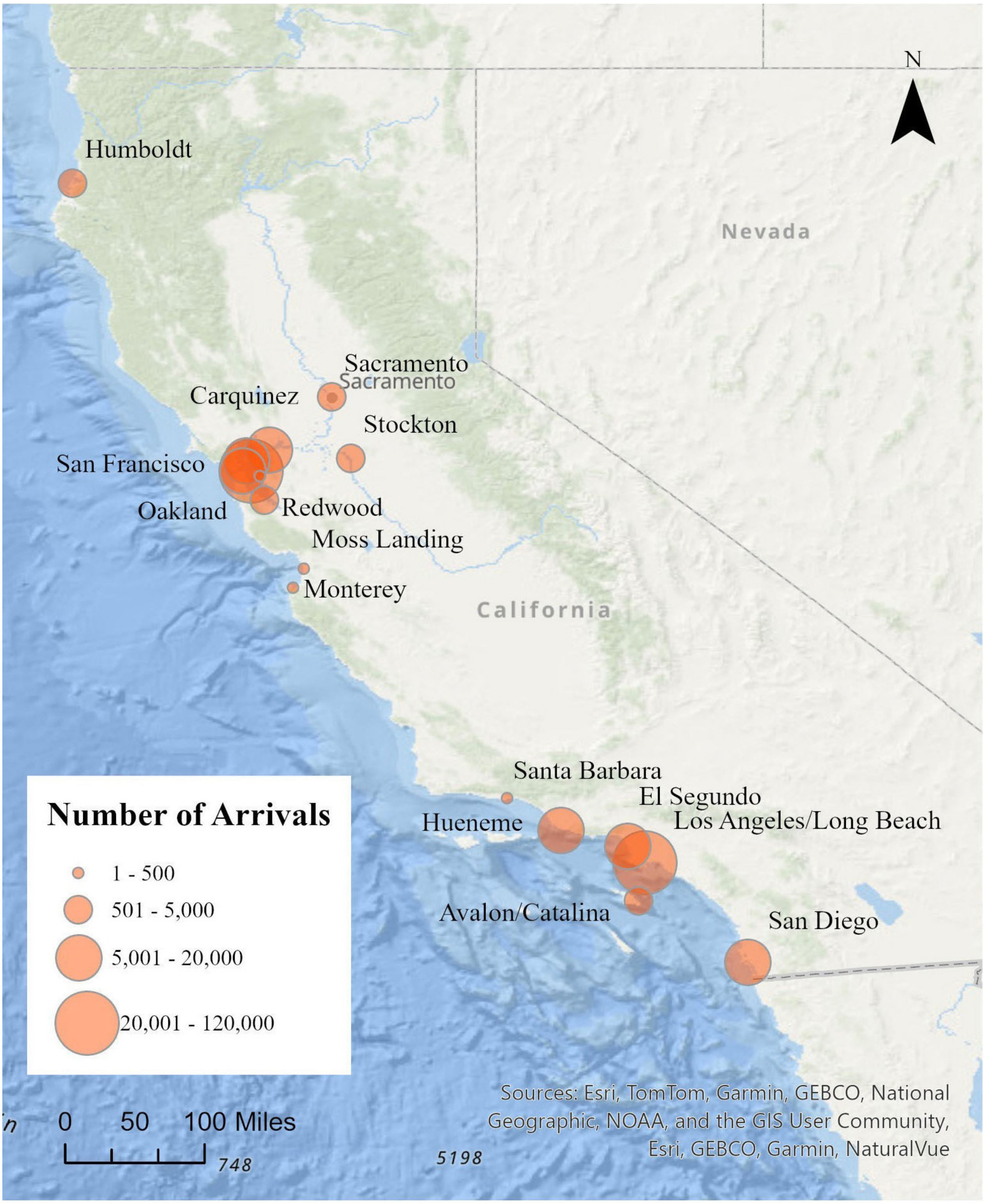

Figure 3. Map of California ports and the cumulative number of vessel arrivals at each port between 2000 and 2024.

medium, or low priority (e.g., discharging ballast water, previous violation, new to California, first arrival since becoming subject to biofouling regulations are among the categories that result in high priority). Vessel inspection and violations data were obtained from MISP inspection checklists housed in the MISP database.

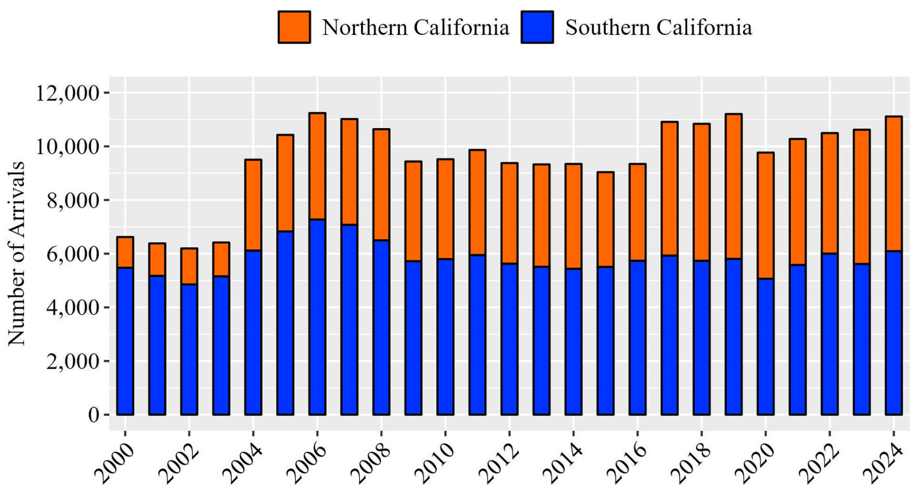

Figure 4. Number of arrivals at northern and southern California ports per year.

Potential impact of MISP on rate of new NIS detections

NIS detection data were obtained from the CDFW California Non-native Estuarine and Marine Organisms (Cal-NEMO) database (Fofonoff et al. 2018). The Cal-NEMO database, which is specific to California, is nested within the Smithsonian Environmental Research Center's (SERC) National Estuarine and Marine Exotic Species Information System (NEMESIS). Cal-NEMO is populated with species records obtained via new and historical published records and targeted MISP surveys managed by CDFW and performed by SERC (e.g., Ruiz and Geller 2018; Geller et al. 2025).

First detection data were obtained by querying all California locations and all dates, filtering by ballast water and hull fouling as vectors. Queried data were exported to Microsoft Excel to retain the first detection for each species, while removing subsequent occurrences. To determine if the rate of detection has changed over time, the number of new ballast water and/or biofouling-vectored species detections per year were compared for the time periods 1990–2004 and 2005–2024 using Welch's t-test, because the datasets did not meet the assumption of equal variances, with α set at 0.05.

Results

Shipping pressures on California

A total of 238,923 vessels, representing 2,948 km^2 of TWSA, arrived at California ports between 1 January 2000, and 31 December 2024. Most of the arrivals occurred in southern California ports (San Diego, El Segundo, Los Angeles/Long Beach, Catalina, Hueneme, Santa Barbara), accounting for 81% of recorded arrivals prior to 2004, 61% during 2004 through 2016, and 54% during 2017 through 2024 (Figure 4). These changes are most likely a result of the changes made to reporting requirements for arrivals within the San Francsico Bay area in 2004 and 2017, as described in the Methods. Most of these arrivals originated in the Americas or the western Pacific.

The type of vessels that arrived at California ports varied over time. Some of these fluctuations (e.g., decreased container vessel arrivals in 2009 and decreased passenger vessel arrivals in 2020) were due to global recessions resulting from the global financial crisis in 2009 and the COVID-19 pandemic in 2020 (Supplementary material Figure S1). Notably, a reduction in container vessel arrivals in recent years has coincided with an increase in tank vessel arrivals, resulting in almost equivalent arrival counts in 2024.

During these 25 years, 16% of reporting vessels arriving at California ports discharged ballast water, accounting for 230 million metric tons of ballast. Most of this ballast water was discharged by bulk (45% of all discharged ballast water despite accounting for only 10% of arrivals) and tank vessels (34% of all discharged ballast water despite accounting for only 9% of arrivals) (Figure 5). Although ballast water from across the globe has been discharged in California, approximately 87% was sourced from the Americas, western Pacific, or open ocean (Figure 6).

Ballast water management methods have evolved since 2000 because of regulatory changes in California, the U.S., and globally. Ballast water exchange (BWE) was the primary management method until 2019, but ballast water treatment (BWT) and a combination of BWE and BWT both increased rapidly starting in 2016 (Figure 7).

Interventions

CSLC staff inspected 49,540 vessel arrivals, representing approximately 21% of all vessel arrivals during this 25-year period (Figure 8). These inspections resulted in 5,158 administrative violations (e.g., improper recordkeeping, late form submission) spread across 8% of the inspected vessel arrivals and 479 operational violations (e.g., no, or incomplete, ballast water management) spread across 1% of inspected vessel arrivals (Figure 8).

Potential impact of MISP on rate of new NIS detections

Between 1990 and 1999 (i.e., the decade prior to the inception of MISP), 3.6 ± 2.2 (SD) new aquatic NIS likely attributable to ballast water and/or biofouling were detected per year in California waters. There is a variable lag period (e.g., 1–5 years) between a successful species introduction and the likelihood of detecting it (Crooks and Soule 1999; Rilov et al. 2004; Crooks 2005), often because the population needs time to grow to a level that allows them to be detected. Because of this lag period, it is likely that new species detected between 2000 and 2004 were introduced prior to the existence of MISP. When the species first detected during 2000–2004 are added to the first detections from 1990–1999 (i.e., the overall period between 1990 and 2004), the rate of new aquatic NIS likely attributable to

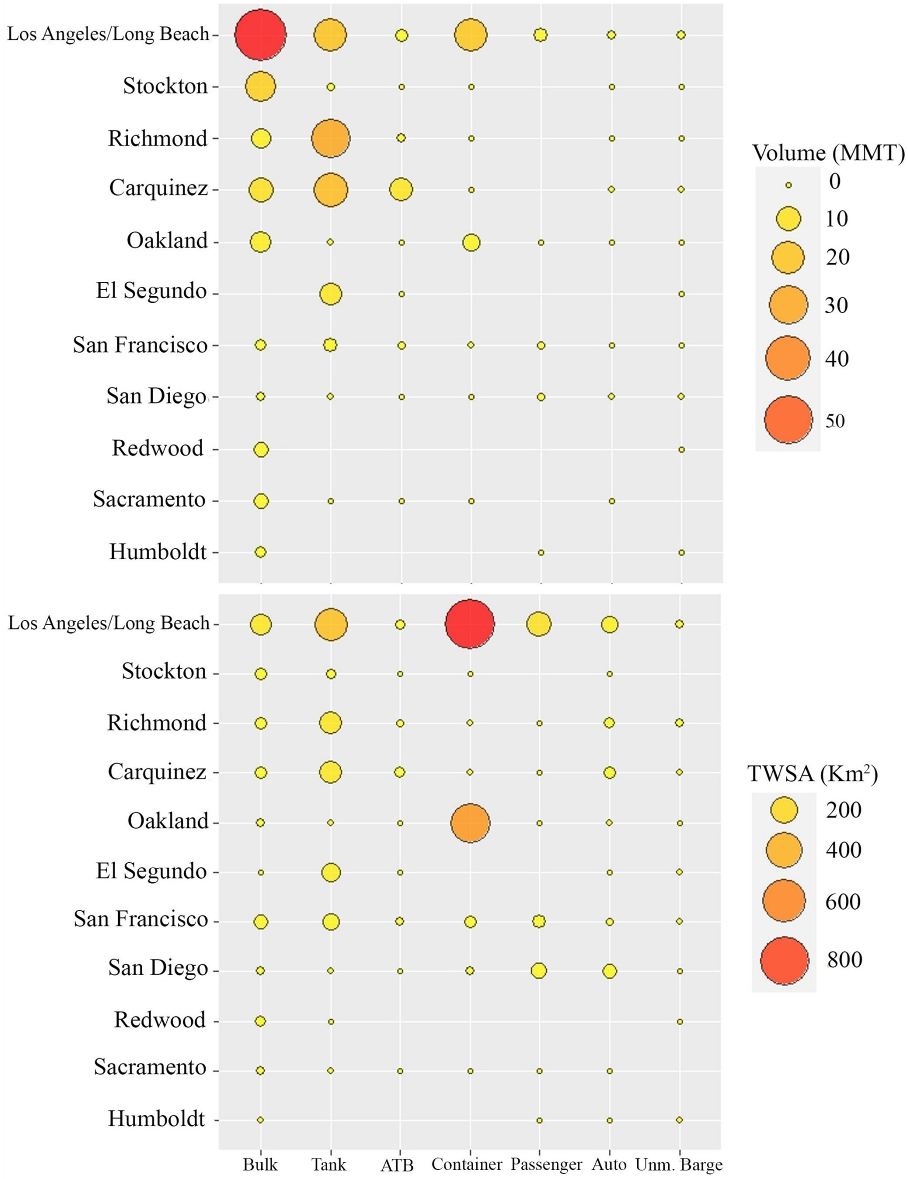

Figure 5. Cumulative (A) ballast water discharge volume and (B) total wetted surface area (TWSA) between 2000 and 2024, by vessel type and port.

ballast water and/or biofouling detected was 4.4 ± 2.8 (SD) per year. Since then (i.e., between 2005 and 2024), the rate was significantly lower ($p = 0.001$), at approximately 1.4 ± 0.8 (SD) new aquatic NIS likely attributable to ballast water and/or biofouling detected per year in California waters. Noticeably, there has been only one new aquatic NIS, *Shoemakerella* cf. *cubensis* (Amphipoda), attributable *solely to ballast water* detected between 2015 and 2024 (Figure 9).

Discussion

Impacts on California's environment

During the 25 years of the Marine Invasive Species Program's existence, commercial shipping, via ballast water discharge and biofouling, has continued to place enormous pressures on California's ports and adjacent environments.

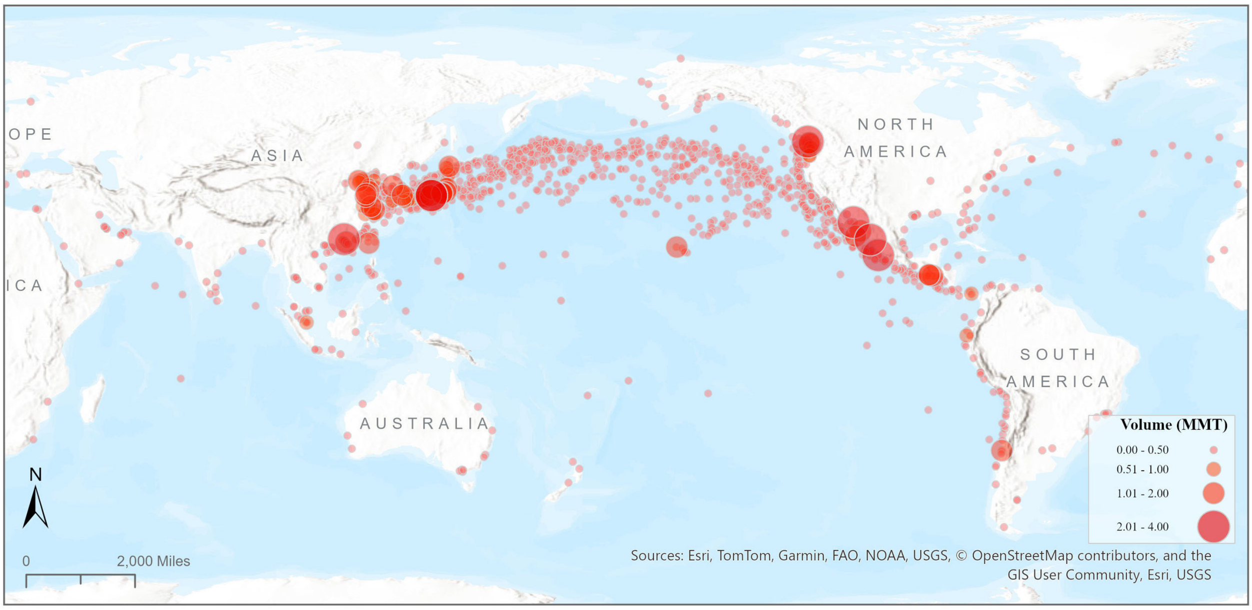

Figure 6. Source of ballast water discharged in California between 2000 and 2024.

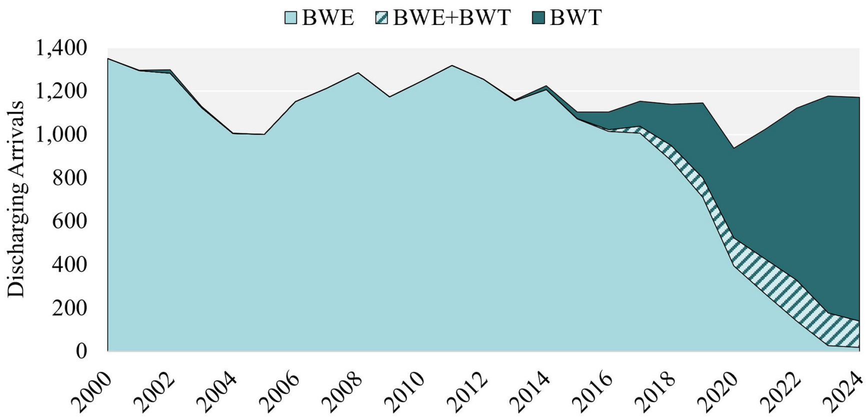

Figure 7. Ballast water management strategies for discharging arrivals.

A total of 238,923 vessel arrivals from 15,646 unique vessels have called on California ports during this time, representing a cumulative TWSA of 2,950 km^2. This amount of underwater vessel surfaces available to biofouling is equivalent to 1.9 times the size of London (Greater London) or 2.3 times the size of the city of Los Angeles. Vessels discharged 230 million metric tons of ballast water into California waters during this time, a volume equivalent to approximately 92,000 Olympic-sized swimming pools.

The ballast water and biofouling management regulations implemented and enforced under authority of the Marine Invasive Species Act have placed effective, protective management requirements on these vessel activities with the goal of reducing the likelihood of successful NIS introductions. These protective science-based policies and the collaborative relationship between MISP, other regulatory entities, and the shipping industry have coincided with a considerable reduction in newly detected NIS in California waters, especially those species attributed to ballast water and/or biofouling

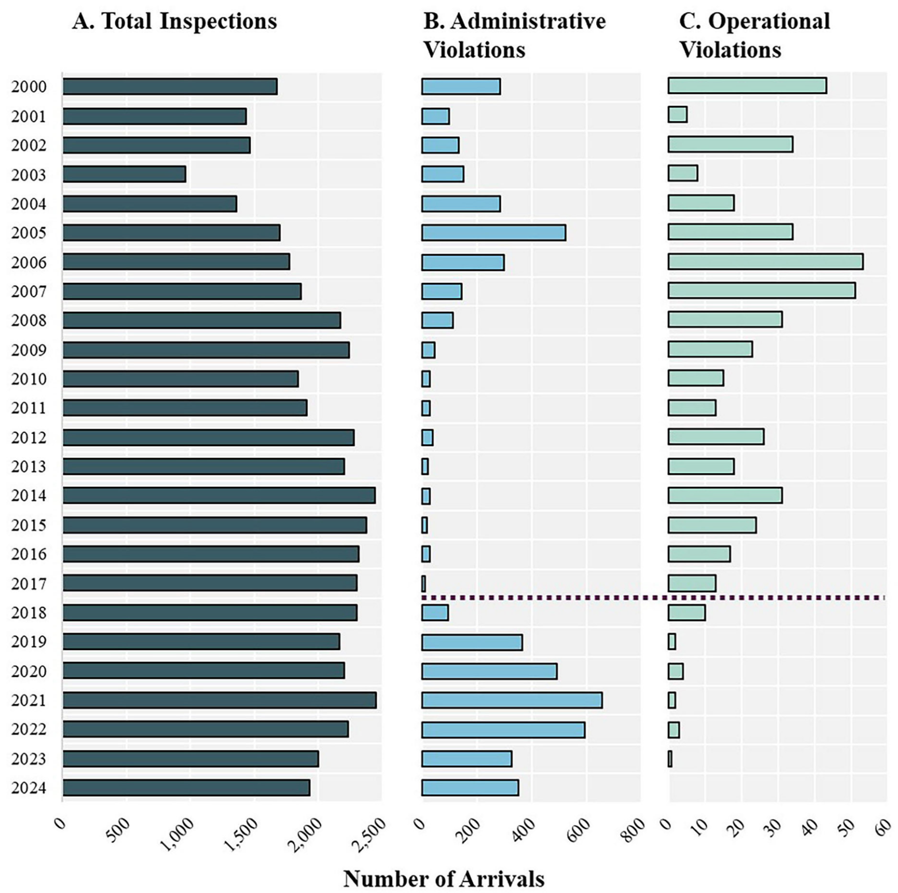

Figure 8. Number of (A) arrivals inspected, (B) administrative violations (e.g., recordkeeping) and (C) operational violations (e.g., undermanaged ballast water).

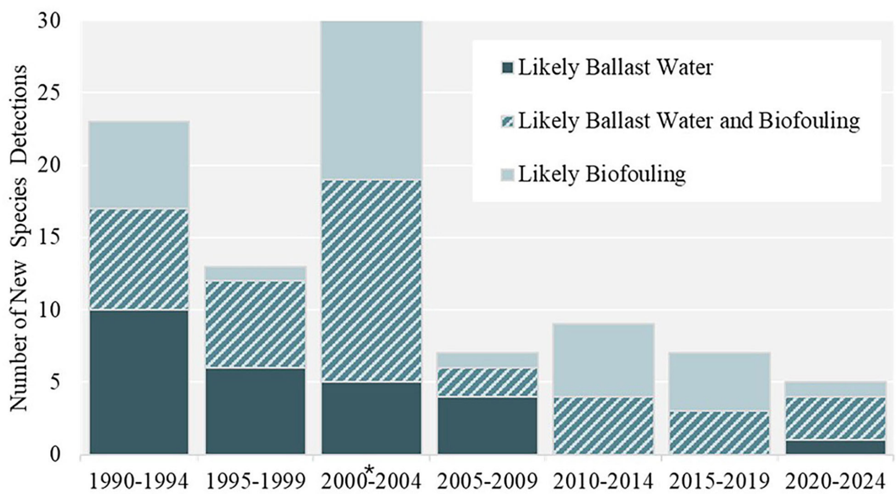

Figure 9. Number of new nonindigenous species attributable to ballast water and/or biofouling that were detected in California per 5-year period between 1990 and 2024.

(Figure 9). This reduction in the rate of newly detected NIS in California waters coincides with the reduction of un- or undermanaged ballast water, vessel hulls, and other wetted surfaces (e.g., niche areas like sea chests and rudders) that result from implementation and enforcement of MISP regulations, similar to the reduced invasion rate observed in the Great

Lakes after implementation of ballast water management requirements (Ricciardi and MacIsaac 2022). The contribution of MISP actions to these results cannot be completely separated from contributions from international or U.S. federal actions; however, California's MISP has consistently filled gaps created by international requirements, which are neither in effect nor enforced in the U.S., and by federal exemptions (e.g., exempted ballast water management for vessels not transiting outside 200 nautical miles from land between port calls). While California, U.S., and international regulations do not completely eliminate the likelihood of NIS introductions (e.g., *Limnoperna fortunei* detected at the Port of Stockton in 2024, likely introduced via *either ballast water and/or biofouling*; California Department of Fish and Wildlife [CDFW] 2025b; unpublished data), the rules in place greatly reduce the likelihood of these introductions.

Although state, federal, and international ballast water and biofouling regulations can reduce the likelihood of NIS introduction from commercial vessels, they do not directly address risk from recreational vessel biofouling in the U.S. While not authorized to regulate recreational vessels, MISP led an effort through the Western Regional Panel on Aquatic Nuisance Species (WRP 2025) to develop voluntary biofouling management guidance for recreational vessels throughout the western U.S. and Canada (WRP 2021). Additionally, the IMO released voluntary biofouling management guidance for recreational craft in 2012 (IMO 2012) to highlight actions boaters can take to minimize biofouling. While voluntary, these measures raise awareness and contribute to a better understanding of vessel maintenance and responsible boating.

Impacts on the international shipping industry

California's MISP shepherded in mandatory ballast water management at a time when it was voluntary in the U.S., importantly demonstrating that effective biosecurity risk reduction (i.e., reduced propagule delivery via ballast water) was possible on a mandatory basis. The number of administrative and operational violations was relatively high during the early years of the program, but both violation types gradually decreased between 2005 and 2009 (Figure 8). The sharp decrease in operational violations starting in 2019 was most likely the result of enforcement regulations adopted by CSLC in 2017 (Figure 1). Once CSLC began issuing monetary penalties for violations associated with un- or undermanaged ballast water discharges (e.g., maximum penalty of US$27,500 for discharge, per tank, of unmanaged ballast water), the number of these types of violations quickly decreased, similar to increased compliance with U.S. federal reporting requirements after penalties were established (Miller et al. 2011).

MISP also promoted effective ballast water treatment since the early 2000's. At the direction of the California Legislature, MISP adopted technology-forcing performance standards in 2007 (Figure 1) with a goal of increasing the capabilities of treatment technologies. MISP also funded and supported early research that contributed to the development and testing of ballast water treatment systems, including partially funding a ballast water treatment demonstration project with Matson and Ecochlor in 2004, partially funding a 2008 installation and testing project with American President Lines (APL) and the ballast water treatment system manufacturer N.E.I, and contributing funds in 2009 for the retrofit of the *T/S Golden Bear* at the California Maritime Academy to become an IMO and U.S. Coast Guard type approval test laboratory. MISP also funded the development and testing of a purpose-built ballast water sampling tool and published guidance for sampling ballast water for compliance assessment (Loiacono et al. 2024) and a comprehensive assessment of the feasibility of barge-based ballast water treatment in California to determine if that approach would enable vessels to meet more stringent ballast water discharge standards (Glosten 2018).

MISP was an early adopter of mandatory biofouling regulations at a time when biofouling management was voluntary across the globe (Scianni et al. 2021), again showing that effective biosecurity risk reduction was possible on a mandatory basis. The increase in administrative violations identified during inspections starting in 2017 (Figure 8) resulted mostly from this transition to mandatory biofouling management plans. California's biofouling management regulations contain a provision that allows a 60-day grace period for vessel operators to correct deficiencies in the biofouling management plan or record book once identified, and most vessels (97%; Scianni et al. 2021) that receive an initial administrative violation are compliant during their subsequent inspection after the expiration of the 60-day grace period. Through inspections and follow-up with vessel owners, MISP helped facilitate improvements in biofouling management and the development of comprehensive Biofouling Management Plans for vessels trading on a global scale.

By continually leading through implementation of new regulations where federal and international gaps existed and by supporting important applied research, MISP has improved the overall knowledge and understanding of reducing the likelihood of NIS introduction and aquatic invasive species risk in general. The impact of these actions on the shipping industry is strongly suggested in the improved compliance rates observed over time (e.g., Figure 8C).

Keys to success

The long-term success of California's MISP is dependent on a variety of factors. Of critical importance is the comprehensive MISP outreach and inspection programs. MISP inspectors board vessels at all ports across California, from the Port of San Diego at the southern border with Mexico to the Port of Humboldt Bay near the northern border with Oregon. In addition to assessing compliance with the Marine Invasive Species Act and associated regulations, all MISP inspections include targeted outreach to vessel crews to share information about invasive species impacts, ballast water and biofouling management requirements, and to answer questions to ensure a more comprehensive understanding of why compliance with MISP regulations is important. Outreach materials are continuously updated to provide the most relevant information to vessel crews and are distributed to the vessels and made available on the MISP website (MISP 2025).

Because commercial shipping is a global industry, the success of MISP also results from coordination with regional, federal, and international regulatory and industry partners. Ongoing engagement through the Pacific Ballast Water and Biofouling Group (PBWBG 2025), Western Regional Panel on Aquatic Nuisance Species, and close coordination with New Zealand's Ministry for Primary Industries and Australia's Department of Agriculture, Fisheries, and Forestry while developing California's biofouling management regulations have been crucial to policy development and implementation efforts. Continued coordination and shared learning through positive feedback loops with these groups, and others, has enabled consistent pathway management across the region and globe and helps to further reduce risks and improve overall compliance.

The continuing evolution of MISP has also played a large role in the program's success. Initially created to regulate ballast water exchange for vessels arriving at California ports after operating outside California, the program has added new components (e.g., biofouling management regulations) and enhanced others (e.g., ballast water discharge performance standards) through numerous legislative and regulatory actions throughout the history of the program (Figure 1). This expansion of responsibilities and continuous improvement, along with the shipping industry's drive for compliance, has played a role in reducing the rate of NIS introductions throughout the State of California and possibly across the globe.

Looking ahead

Several existing and emerging challenges will need to be addressed as California's MISP continues into the next 25 years and beyond. One existing challenge is the regulation of an international industry by a state program. Continued engagement with industry and regulatory partners, with transparent communications and outreach, across the region and globe remains a critical component to the functioning of MISP. This is even more crucial with the upcoming implementation of the Vessel Incidental Discharge Act (VIDA) regulations at the U.S. federal level. VIDA regulations will have a preemptive effect on components of state programs like MISP, requiring close communication with the U.S.

Environmental Protection Agency, the U.S. Coast Guard, and shipping industry partners to ensure effective and consistent implementation of state and federal regulations.

Climate change presents another challenge, as warmer waters lead to expanded species ranges and more survival opportunities (Canning-Clode and Carlton 2017; Fowler et al. 2025; Creed et al. 2026; Jayachandran et al. 2026; Mabrouki et al. 2026) for species that were previously unsuitable for establishment in California waters. Consistent vessel inspection and enforcement, alongside existing species monitoring efforts, are fundamental to addressing this challenge and to enable early detection of new species.

California's MISP has a long history of evolving when necessary to address new concerns or to adapt to new ballast water or biofouling management technologies or approaches. This adaptability must continue to ensure program effectiveness and consistent environmental protection for the state of California and beyond.

Authors' contribution

CS: research conceptualization, methodology, data analysis and interpretation, writing – original draft, writing – review and editing; LC: methodology, data analysis and interpretation, writing – review and editing; JLT: methodology, writing – review and editing; RN: methodology, writing – review and editing; ND: methodology, writing – review and editing; AR: methodology, writing – review and editing; SS: methodology, writing – review and editing; SM: methodology, writing – review and editing; MV: methodology, writing – review and editing; MBF: methodology, writing – review and editing.

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Ethics and permits

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Supplementary material

The following supplementary material is available for this article:

Figure S1. Vessel type arrival patterns.

Figure S2. Proportion of vessel arrivals that discharged ballast water in California.

Exhibit B

Biol Invasions (2026) 28:177
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BRIEF REPORT

Closure of the Strait of Hormuz may trigger a bioinvasion super-spreader event

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Abstract The ongoing conflicts in the Middle East are causing substantial humanitarian, economic, and geopolitical impacts and disrupting global trade. While the human and economic effects remain the focus of most immediate concern, a pending ecological crisis is also unfolding. The closure of the Strait of Hormuz on February 28, 2026, stranded an estimated 1500 ships in the Persian/Arabian Gulf, with hundreds more anchored in the Gulf of Oman. Prolonged stationary periods lead to substantial biofouling penalties for ships, as marine microbes, algae, and invertebrates rapidly colonize and grow on submerged surfaces. This accumulation not only impairs vessel operations but also creates significant environmental risks. A major concern is the high likelihood that these idle ships will facilitate the extensive spread of economically and ecologically damaging invasive species as they re-enter the global shipping network. Given the unprecedented scale and duration of this mass lay-up of ships, conditions are primed for

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a large-scale, marine bioinvasion "super-spreader" event as regular maritime trade in the region resumes. The combination of extensive biofouling growth and species accumulation, and the sheer number, size, and global reach of affected vessels, has created an immense international biosecurity threat. Here, we highlight the biosecurity risks arising from the closure of the Strait and provide recommendations to mitigate them. We urge relevant stakeholders worldwide, including ship operators, port authorities, and environmental managers, to prepare now for the backlog of ship biofouling management requirements and to implement appropriate actions to abate this extraordinary biosecurity threat.

Keywords Ship biofouling · Biosecurity · Strait of Hormuz · Laid-up ships · Non-indigenous species

Introduction

In the modern history of ship lay-ups (vessels remaining at anchor or dockside for an extended period of time), the number of ships that have been trapped due to the closure of the Strait of Hormuz is unparalleled. More than 1500 large commercial ships remained idle in the Persian/Arabian Gulf and the Gulf of Oman, hereafter referred to collectively as the "Gulf region", starting on February 28, 2026 (e.g., World Bank 2026). These vessels have arrived with biofouling organisms from a wide range of source regions and are now acquiring (and will likely depart with) extensive biofouling communities of microbes, algae, and invertebrates from the Gulf region. This massive intermingling of ships and biofouling will result in the inevitable release of non-indigenous species (NIS) at the lay-up sites and in the spread of marine species across the globe once the idle ships resume their trade routes.

The underlying inevitability of impending species translocations is based on the typical sigmoidal (s-shaped) curve that characterizes biofouling accumulation on submerged surfaces (Daly et al. 2025). Biofouling on static surfaces can reach the rapid growth phase after 10 days (e.g., Davidson et al. 2020), which is longer than typical residence times of less than 2 days for cargo vessels in most ports. When ships are idle beyond these time frames, biofouling develops aggressively as antifouling coatings become compromised from lack of movement (e.g., Casse and Swain 2006). The International Maritime Organization (IMO) recognizes that extended lay-ups substantially increase bioinvasion risks, recommending that vessels that idle for more than 18–30 days undertake "immediate actions before the next voyage" to manage biofouling (International Maritime Organaization IMO 2023).

Before this event, lay-ups have typically resulted in a single to a few hundred vessels becoming unexpectedly stationary. Lay-ups can occur due to corridor closures (such as the fully blocked Suez Canal for 6 days in 2021), or more typically because of vessel underemployment (loss of business or economic slowdowns) and port capacity bottlenecks (Ruiz et al. 2022). Ships

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may also be intentionally brought together in clusters of varying durations, such as for "Tall Ship" festivals, for jurisdiction claims, or when reserve military vessels are mothballed (e.g., Davidson et al. 2008). The connection between immobile biofouled ships and marine species invasions has long been recognized. For example, the invasion of the Australasian barnacle *Austrominius modestus* to western Europe during World War II was linked to New Zealand ships being held in English ports while awaiting convoy escorts (Southward 1998).

The Gulf shipping nexus, with the Strait of Hormuz its critical maritime chokepoint, supports transport of energy commodities (e.g., oil and gas), raw materials (e.g., fertilizers and minerals), and manufactured goods to global markets, especially in Europe and Southeast Asia (Fig. 1). It is not uncommon for well over 1000 vessels (including roughly 700–800 larger cargo ships and tankers) to be operating in the Gulf region at any one time, with an average of 130–140 of them (including between 60 and 70 very large oil and gas tankers) passing through the Strait of Hormuz each day (World Bank 2026). The majority of vessels in this region spend 1–3 days in port before departing. However, at the time of writing, ships in the Gulf region had remained idle there for at least 40-times longer than an average stay. Although a variety of vessel types and sizes operate in this region, the routine presence of a considerable number of very large ships (with correspondingly extensive submerged hull surfaces and niche areas vulnerable to biofouling) from around the world amplifies their exposure to diverse biofouling communities.

Here, we highlight the extreme worst-case scenario currently prevailing in the Gulf region, which exposes local and coastal ecosystems worldwide to elevated biosecurity risks. We further provide recommendations for immediate management interventions to mitigate these risks and identify longer-term monitoring and management measures that can be incorporated into contingency planning for both this potential super-spreader event and future vessel lay-up incidents.

Conditions for a marine bioinvasion super-spreader event

The Strait of Hormuz connects the shallow, soft-sediment-dominated, hypersaline Persian/Arabian Gulf with the adjacent, deeper and more rocky oceanic Gulf of Oman. The Persian/Arabian Gulf is a semi-enclosed sea with an average depth of 35 m, characterized by high salinity and temperature, limited water exchange, and strong evaporation (Joydas et al. 2024). Summer surface-water temperatures can reach approximately 38 °C, and winter temperatures range between 15 and 20 °C (Alosairi et al. 2011), with salinities often exceeding 40 psu (Kashkooli et al. 2022). Recent data also revealed a significant increase in the spatial and temporal extent and average number of marine heat waves in this region (Paradan et al. 2025). Extreme environmental pressures, combined with coastal industrialization and urbanization, have also directly reduced biodiversity in Gulf ecosystems (Naser 2014). These conditions are relevant to biosecurity risk because the remaining stress-tolerant taxa are more likely to survive transport, persist during vessel lay-up, and establish in recipient regions with similar or stressful environmental conditions.

Given the Gulf region's central role in global shipping networks (Fig. 1), there is a high probability of both the receipt and export of marine NIS. For example, a recurrent and escalating issue in the Gulf region is the occurrence of harmful algal blooms, including the non-indigenous dinoflagellate *Margalefidinium polykrikoides* near the Bandar Abbas and Qeshm Oil Terminals. Ship ballast water is considered a major pathway for the introduction of *M. polykrikoides* and other non-native algal species to the region (Mirza Esmaeili et al. 2021). A subsequent study listed 35 NIS from brackish and marine habitats in the region, with the great majority introduced through commercial shipping activities (Clarke et al. 2020). Notably, 57 cryptogenic and NIS biofouling species were identified growing on pontoons, docks, and research settlement panels surveyed at 12 sites along the western Persian Gulf coast, with species richness and relative abundance being greatest in ports (Chebaane et al. 2026).

Because most biofouling organisms are sessile, reproduction typically plays a large role in invasion success. Many marine invertebrates and algae reproduce in response to elevated temperatures and seasonal changes in environmental conditions (e.g., Donelan et al. 2022). Therefore, the Gulf region mass ship lay-up in the spring and summer of 2026 provides ideal conditions for biofouling growth and reproduction (Muthukrishnan et al. 2022). For

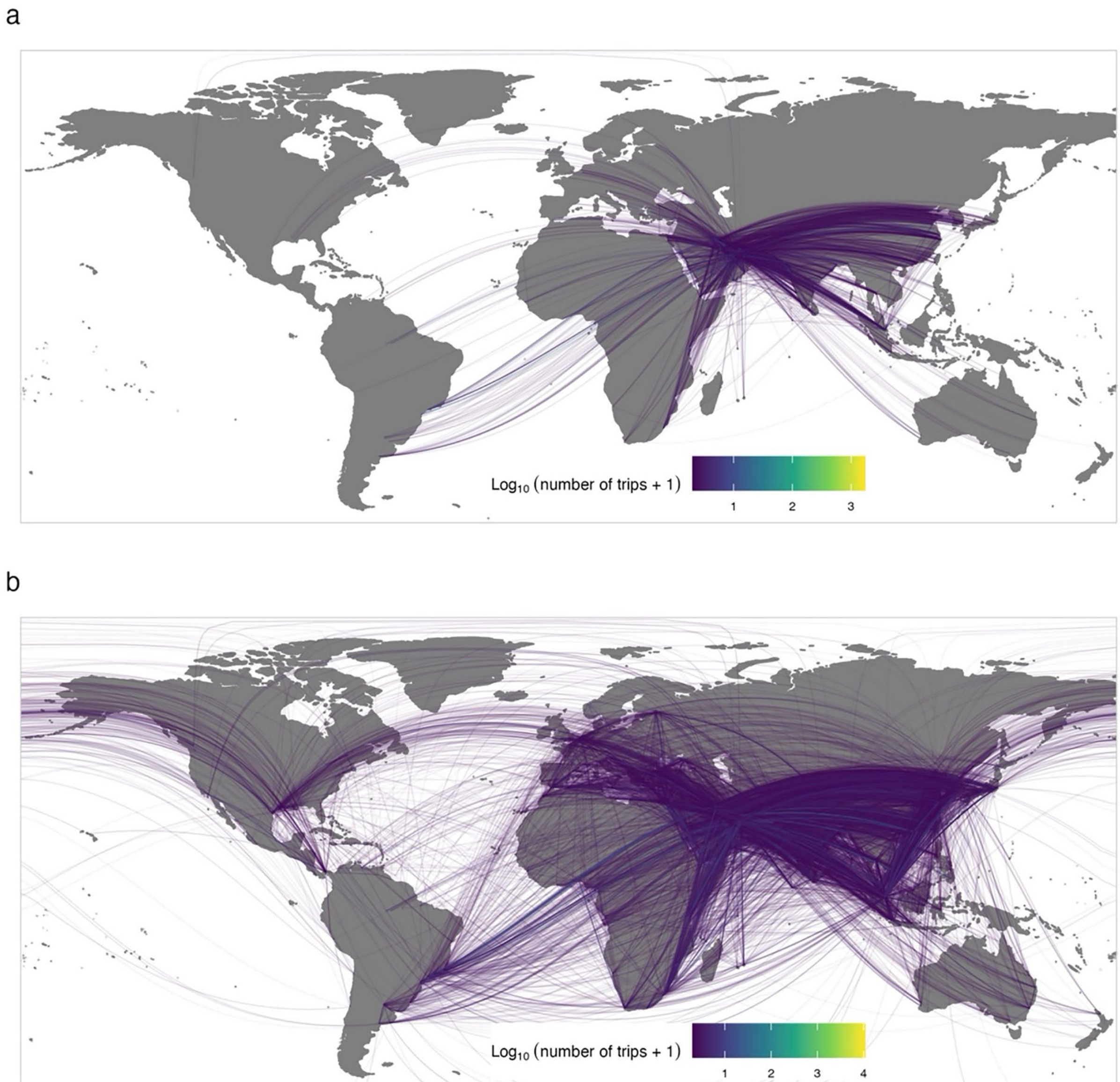

Fig. 1 Port calling source data provided by S&P Global and limited to ships located in the Gulf regions (i.e., Persian/Arabian Gulf and Gulf of Oman) between February 27, 2026 and June 13, 2026. The full shipping network consists of 3,027 unique ships, making 248,362 calls to 3,517 unique ports and anchorages. **a** is the connectivity of global source–destination port pairs for commercial shipping traffic after ships leave the Gulf region starting February 27, 2025, indicating common global reach in *one month after departure*. **b** is the connectivity of global source–destination port pairs for commercial shipping traffic starting February 27, 2025, after ships leave the Gulf region, indicating potential global reach in *one year after departure.*

example, the cosmopolitan barnacle *Amphibalanus improvisus* can release up to 36 larvae per adult per day at 30 °C (Donelan et al. 2025). Given the high densities of fouling organisms that can occur on ship hulls and niche areas (e.g., sea chests, rudders, and piping systems), individual vessels may have released millions of larvae during this lay-up period. The proximity of idle vessels provides abundant settlement substrate for these propagules, while the eventual resumption of shipping will facilitate their widespread dispersal.

Ship biofouling also poses hidden risks. Many biofouling species are globally distributed and adapted to diverse environmental conditions (e.g., Viard and Tepolt 2025). Introducing new genetic diversity into established non-indigenous populations can promote genetic introgression, accelerating adaptation, and increasing their ability to spread and persist across a wider range of conditions (Touchard et al. 2023). In particular, the warm waters of the Gulf region are likely to select for heat-tolerant genotypes, which, if introduced to thermally-limited populations, may give them a greater adaptive buffer against future warming (Griffiths et al. 2021).

Biofouling communities can also act as reservoirs and vectors for non-indigenous parasites and pathogens, including some that can cause epidemics in commercially important species (Georgiades et al. 2021). Introduced parasites can affect native hosts through novel host-parasite interactions, often causing higher infection levels due to the absence of co-evolved defenses (Goedknegt et al. 2016), with warmer temperatures and denser assemblages exacerbating these impacts (e.g., Cohen et al. 2018). Introduced disease outbreaks are unpredictable but can cause economic and ecological impacts that far exceed those of the introduced host species itself (Georgiades et al. 2021).

Stressed ecosystems, such as industrial ports, are highly vulnerable to bioinvasion because environmental disturbances reduce community resistance (e.g., Stachowicz et al. 1999). By suppressing native species, opening up ecological niches, and increasing resource availability, disturbances allow invasive, fast-growing opportunist (e.g., tolerant and resilient) species to establish themselves; the added influence of high resource availability may further promote invasibility (Crooks et al. 2011). In the Gulf region, invasibility is paired with massive shipping volume, providing ample opportunity for the development of NIS assemblages. Thus, the highest biosecurity risk will likely be at first ports of call (Fig. 1), in particular those with similar environmental conditions as the Gulf region, including the ports of Jeddah (Saudi Arabia), Mumbai (India), Colombo (Sri Lanka), Singapore, to the east of the Strait of Hormuz, and the ports of Alexandria (Egypt), Piraeus (Greece), Algeciras (Spain) and Rotterdam (Netherlands) to the west, as environmental matching between donor and recipient regions facilitates establishment success (Seebens et al. 2016).

Recommendations

Ideally, biofouling on idle ships in the Gulf region should be removed before departure. In-water cleaning (IWC) of ship hulls and niche areas is widely practiced to manage biofouling (e.g., Tamburri et al. 2021). However, IWC debris should be collected and properly disposed of to minimize the release of live organisms, and coating-associated biocides and microplastics, into surrounding waters (Tamburri et al. 2025).

The application of IWC will surely be incentivized because of the direct benefits on ship operations, particularly reduced drag and fuel consumption (e.g., Schultz et al. 2011). However, this scenario is unlikely for most vessels given the urgency of evacuating stranded seafarers and restoring shipping movements, and due to limited regional IWC capacity and operational constraints associated with safety and logistics. As a result, demand will likely also shift to subsequent ports of call. The capacity of IWC in many recipient ports may also be insufficient to accommodate the anticipated surge in needed services, and cleaning operations may be restricted or prohibited in some jurisdictions, creating additional bottlenecks to mitigate biosecurity risks. Finally, the current trade disruptions and shifting shipping routes are expected to reshape maritime networks and port connectivity, expanding and making less predictable biosecurity risks linked to Gulf vessel traffic. We therefore strongly encourage a coordinated global network of safe and effective IWC services.

Given competing priorities and operational constraints, most vessels are unlikely to complete IWC before arriving at their next ports of call. We therefore propose additional measures to mitigate expected biosecurity risks:

- *Estimate vessel biofouling before departure*. Direct underwater observations are preferred, but efforts to estimate the level and extent of biofouling at the ship waterline can still be informative. Although vessel crews are unlikely to determine specific species present, general taxonomic information can be helpful to inform biosecurity mitigation at subsequent ports of call (e.g., macroalgae, barnacles, etc.). Additionally, documentation of underway ship power loss (due to increased biofouling drag), especially when compared to these metrics from before the lay-up, can be a useful proxy for the relative amount of biofouling on the submerged surfaces and corresponding biosecurity risk.

- *Forecast vessel routes and first ports of call.* Ship route forecasting efforts can help predict which ports idle vessels are likely to call after departing the Gulf region. This can facilitate forewarning of ports and support preparedness and possible interventions. Additionally, information on vessel routes can help revise biosecurity threat assessments in that some routes could reduce invasion risk (e.g., freshwater exposure when passing through the Panama Canal) but many are likely to enhance it (e.g., short voyages with little changes in ambient water temperature and salinity). Important considerations for ports expecting vessels from the Gulf region are also their similarity in environmental conditions (e.g., Seebens et al. 2016), the number and size (submerged surface area) of arriving vessels, arriving ship residence times, and capacity of local IWC services.
- *Implement early detection and rapid response at high-risk ports.* Ports within the likely sphere of impact should, if not already present, conduct NIS monitoring for early detection. Low-cost, rapid assessments (e.g., O'Shaugnessy et al. 2023) and settlement plate monitoring networks could be rapidly deployed in locations with minimal infrastructure and resources (e.g., Sempere-Valverde et al. 2025), while more advanced molecular tools could be considered in others (Chebaane et al. 2026). This can provide early detection of new species and initiate appropriate potential containment and mitigation efforts, even in data-poor situations (Carvalho et al. 2023).
- *Establish rapid alert and knowledge-dissemination networks.* Biosecurity warnings should be communicated quickly to all stakeholders, including port authorities, shipping operators, environmental agencies, IWC service providers, and regional biosecurity networks. Identifying trusted knowledge brokers across global recipient regions (e.g., Mediterranean, SW Atlantic, North Atlantic, Pacific, and Indian Oceans) will be essential to ensure that NIS warnings are translated rapidly into operational guidance, coordinated preparedness, targeted monitoring, and risk-reduction actions (Bortolus et al. 2025).

Conclusions

The prolonged mass lay-up of vessels in the Gulf region, together with conditions favorable for biofouling development, represents a significant risk factor for the large-scale dispersal of NIS upon the resumption of global shipping operations. Whether it becomes a global bioinvasion super-spreader event will now depend less on the biofouling communities already present on vessels than on the speed, coordination, and effectiveness of the responses that follow.

Biological invasions share common epidemiological features with infectious diseases, including transmission pathways, propagule pressure, network connectivity, amplification mechanisms, and the challenge of intervening before widespread dissemination occurs (e.g., Bortolus and Schwindt 2022). In this framework, biofouled vessels function as transmission vectors, prolonged lay-ups create conditions for the accumulation and amplification of potential invaders before their redistribution across multiple recipient regions, and ports act as nodes within a global connectivity network. As vessel operations resume, opportunities for prevention rapidly diminish, shifting management from risk avoidance to impact reduction or mitigation.

Lessons from epidemiology strongly suggest that the most effective responses prioritize prevention before large-scale dissemination. This principle is equally well established in invasion science and biosecurity, where prevention is consistently recognized as the most effective and cost-efficient management strategy compared with post-introduction control, containment, or eradication (Carvalho et al. 2023; Egawa et al. 2026). Early warning systems, risk forecasting, surveillance networks, targeted interventions, and coordinated communication are all fundamental components of disease preparedness and are equally relevant to marine biosecurity. The challenge is not simply to detect new species, but to identify emerging risks early enough to prevent their spread through highly connected global transport networks.

Current ship biofouling management and regulatory frameworks are insufficient to mitigate the impacts of large-scale, unplanned vessel lay-up events, which appear to be increasing in frequency and may pose substantially greater environmental risks than routine ship operations. While the human and economic consequences of events like the war in the Middle East will always remain the highest priority, ecological impacts cannot be overlooked. This underscores the need for coordinated action by governments, regulators, the maritime industry, and other stakeholders to strengthen biofouling management for both typical ship operations and varying lay-up scenarios.

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