

Operational biofouling targets for the ROPME Sea Area: species-resolved priorities for vessel lay-up biosecurity

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Abstract

Prolonged vessel lay-up allows fouling assemblages to accumulate before ships re-enter transport networks, creating an acute biosecurity hazard for the Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area (RSA) and the ports it connects to. Preparedness requires biological targets, not vector and pathway information alone. Drawing on the validated RSA biosecurity baseline, we identify seven extant very high-priority benthic fouling species associated with shipping and port environments, and cross-check them against an independent metabarcoding and photographic survey of the Saudi Gulf coast. Eight baseline species were recovered by that survey: six classified as extant, including three of the seven fouling targets, and two classified as horizon, whose detections constitute new occurrence evidence requiring verification. We set these targets within a five-component species–vessel–port prioritisation and define its limits. Regional source-species baselines, kept responsive to independent records, are a prerequisite for species-targeted inspection and surveillance in the RSA.

Keywords: Strait of Hormuz; ship biofouling; marine biosecurity; non-native species; risk identification

1 Introduction

When commercial vessels remain stationary for extended periods, biofouling can accumulate substantially because submerged surfaces become more susceptible to colonisation (Davidson et al. 2020; International Maritime Organization [IMO] 2023). Niche areas such as sea chests, chain lockers, rudders and other recessed or protected structures are particularly susceptible because they can be difficult to access, coat and manage effectively (de Castro et al. 2018; Hayes et al. 2019). Once vessels return to service, accumulated biofouling assemblages may be transported through highly connected shipping networks and released across multiple recipient ports (Seebens et al. 2016; Ruiz et al. 2022).

The 2026 closure of the Strait of Hormuz left an unprecedented number of commercial vessels stationary in the Gulf and the Sea of Oman. Together with adjacent parts of the Arabian Sea, these comprise respectively the Inner, Middle and Outer sections of the Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area (RSA), which includes eight Member States: Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. (Lincoln et al. 2021). The biosecurity implications of the eventual return of stranded vessels to service have been set out elsewhere (Tamburri et al. 2026) and are regional in origin as the organisms available for uptake during a lay-up are those present in the region where the vessels sat.

Vector and pathway information identifies exposure but cannot discriminate among the species responsible for it, whereas species-based analyses yield targeted watch lists for surveillance and management (Barry et al. 2008; Azmi et al. 2015; Miralles et al. 2021). Without a validated source-region baseline, authorities lack a defensible basis for deciding which species should shape inspection design, which diagnostics to deploy and which source–recipient combinations warrant priority when resources are limited (Bishop and Hutchings 2011).

Prolonged lay-up increases transport opportunity and propagule pressure but does not by itself establish species-specific invasion risk. Invasion is a sequential process in which an organism must overcome the barriers of transport, introduction, establishment and spread in turn (Blackburn et al. 2011). Vessel numbers, submerged surface area and network connectivity influence several of these steps, but none identifies the species for which the complete sequence is biologically plausible.

Here we identify the fouling species that a regional inspection and surveillance programme in the RSA should be prepared to find. We set out the operational subset of very-high-priority extant fouling species in the validated regional baseline (Vilizzi et al. 2026), test that subset against independent survey evidence from the Saudi Gulf coast and place the resulting targets within a prioritisation linking source occurrence to vessel, route and recipient-port information.

2 Biological targets for regional inspection and surveillance

Pathway management is most useful when tied to a validated list of biological targets. A general instruction to monitor for (invasive) non-native species is inadequate during an event involving hundreds or thousands of vessels, particularly where surveillance resources are constrained (Bishop and Hutchings 2011). Rapid visual surveys, scrape samples, settlement panels, targeted molecular assays and metabarcoding differ in sensitivity, taxonomic coverage, cost and turnaround (Hayes et al. 2005; Chebaane et al. 2026). Biofouling quantity can be estimated without identifying every organism, but its biosecurity significance depends on species composition and location, and niche areas are often disproportionately fouled (Coutts and Dodgshun 2007; Peters et al. 2019; Georgiades et al. 2020, 2026).

The RSA provides the transboundary spatial and institutional framework within which regional marine biosecurity evidence can be assembled, validated and translated into coordinated action. However, this regional framework is not adopted by recent contributions,

including Tamburri et al. (2026), which uses the term ‘Gulf region’ and draws principally on the studies by Clarke et al. (2020) and Chebaane et al. (2026) to characterise its non-native and biofouling biota.

Source occurrence must also be resolved below the scale of the entire RSA. A vessel laid up near Kuwait (Inner section) cannot automatically be assigned the same candidate species pool as one that remained in Omani waters east of the Strait of Hormuz (Middle section), because environmental conditions, assemblages and introduction pathways differ across the region (Lincoln et al. 2021). Conversely, national inventories alone may underrepresent transboundary distributions where monitoring intensity and taxonomic capacity differ among Member States. The appropriate starting point is a harmonised regional inventory that retains Member State-level occurrence: this is what the validated RSA baseline provides (Vilizzi et al. 2026).

That baseline re-screened and extended the earlier regional assessment of Clarke et al. (2020) using current taxonomy, geographic verification and Member State-level validation, and placed 39 extant species in the very high-priority tier (Vilizzi et al. 2026). Seven are benthic fouling organisms closely associated with shipping and port environments: the tunicates *Botrylloides niger*, *Didemnum psammatoedes* and *Symplegma brakenhielmi*; the serpulid *Hydroides elegans*; the barnacle *Amphibalanus subalbidus*; and the bivalves *Brachidontes pharaonis* and *Perna perna* (Table 1). This subset is not a ranking of export probability, but it combines verified regional occurrence, high management priority and an established association with ship biofouling, and so defines what a regional inspection programme should be equipped to recognise.

The comparison with Clarke et al. (2020) demonstrates why an updated source-region baseline matters operationally. *Didemnum psammatoedes* and *Hydroides elegans* were not screened in the earlier study but were subsequently confirmed as extant and were ranked as very-high priority, whereas *Brachidontes pharaonis* and *Perna perna* had been treated as

horizon species but were shown by the revised evidence to be extant in the RSA. A source-region watch list based solely on the earlier classifications would therefore omit these four very-high-priority biofouling species despite their likelihood of uptake. Further, screening scores increased substantially for *Amphibalanus subalbidus* and *Symplegma brakenhielmi* (Table 1). However, these shifts should be interpreted with caution since the assessors and the calibration procedure both differed between screening exercises. The status reassignments rest on verified records and are robust; the score changes additionally reflect assessor and calibration effects.

The significance of these species cannot be generalised across recipient ports, because their biogeographic status differs among regions (Soto et al. 2024). A transfer is a potential new introduction only where the species is absent and non-native to the recipient region; where it is native, arrival is not an introduction, although non-local genotypes or associated pathogens may still carry biosecurity implications (Georgiades et al. 2021); where it is already established, further arrivals may raise propagule pressure (Touchard et al. 2023). Although the importance of repeated introductions into established non-native populations has been recognised, a geographically broad ‘super-spreader’ scenario (Tamburri et al. 2026) may not capture the local status of candidate species at individual recipient ports with the same resolution. Vessel movements and environmental similarity remain important determinants of transport and establishment opportunity (Seebens et al. 2016; Donelan et al. 2025), but the invasion significance of a movement is ultimately species- and recipient-specific (Leung et al. 2012). The super-spreader analogy is therefore strongest at the level of transport opportunity, whereas the resulting bioinvasion consequences must be evaluated for individual species–recipient port combinations.

Independent survey evidence provides a partial test of these targets. In a recent survey of pontoons, docks and settlement panels at 12 sites along approximately 300 km of the Saudi Gulf coast by DNA metabarcoding and photography (Chebaane et al. 2026), 57 non-native or

cryptogenic species were detected, with richness and relative abundance greatest in industrial and commercial ports. Species-level comparison with the RSA baseline identified eight matches: six species were classified as extant (*Amathia verticillata*, *Botrylloides niger*, *Diplosoma listerianum*, *Hydroides elegans*, *Polyclinum constellatum* and *Symplegma brakenhielmi*) and two were classified as horizon (*Botrylloides violaceus* and *Mytilus galloprovincialis*). Three of the seven fouling species, *Botrylloides niger*, *Hydroides elegans* and *Symplegma brakenhielmi*, were recovered by an independent method. The two horizon detections are the more consequential result, because both species are classified in the baseline as absent from the RSA. They constitute therefore new occurrence evidence requiring taxonomic and geographic verification before any status change, as species-level assignment from metabarcoding remains constrained by sparse regional reference libraries. The survey also covered part of the Saudi Gulf coast only (Inner RSA). Both findings point to the same requirement: a source-region baseline is useful only if it remains responsive to independently validated new records.

Overall, the available regional evidence is complementary rather than interchangeable. Clarke et al. (2020) provided the original structured screening; Chebaane et al. (2026) contemporary, site-resolved survey data for part of the Inner RSA; and Vilizzi et al. (2026) the validated, Member State-resolved and risk-prioritised baseline.

3 From targets to prioritisation

3.1 Species–vessel–port prioritisation

Preparedness is more tractable if the event is treated as a set of species–vessel–port combinations rather than as a single regional threat. The relevant unit is a species that plausibly occurs at the source, can be transported by a particular vessel, is likely to survive the voyage, and may reach a recipient port where the consequences justify intervention. This adapts established methods that integrate species, pathway and recipient-area information (Barry et al.

2008; Azmi et al. 2015; Hayes et al. 2019; Miralles et al. 2021); the addition here is the validated, geographically resolved source-species layer.

The prioritisation comprises five linked components (Fig. 1). It is decision-structuring rather than predictive and prescribes no numerical weights, because the quality of vessel, route and recipient-port evidence differs among events and jurisdictions.

1. *Source-region baseline*. Validated occurrence, Member State records and priority species (Vilizzi et al. 2026), related for operational use to actual lay-up positions and recent movements. Absence of a Member State record is not demonstrated biological absence, because inventories remain sensitive to survey effort and taxonomic resolution (Latombe et al. 2017; Ojaveer et al. 2018).
2. *Vessel exposure*. Lay-up location and duration, vessel type and size, fouling condition, niche areas and cleaning history, which together determine where organisms are retained and transported (Davidson et al. 2020; Georgiades et al. 2021; IMO 2023).
3. *Route conditions*. First port of call, voyage duration, temperature and salinity exposure, and freshwater exposure, which together modify whether organisms acquired during lay-up remain viable on arrival (Seebens et al. 2016; Donelan et al. 2025).
4. *Recipient port*. Local species status, environmental suitability, habitats, and establishment and spread potential, assessed independently of source-region screening outcomes (Leung et al. 2012; Carvalho et al. 2023).
5. *Response capacity*. Inspection capability, targeted sampling, cleaning options, surveillance infrastructure and rapid response measures, which differ substantially among ports and particularly in data-poor regions (Carvalho et al. 2023).

3.2 *Translating the prioritisation into action*

Before departure, or as early as possible before arrival, authorities should assemble vessel-specific information on lay-up history, hull and niche-area condition, cleaning history, recent and planned ports, expected voyage conditions, and the relevant source-region species. Existing guidance already covers the vessel-specific elements (IMO 2023); the source-region species layer allows recipient authorities to prepare targeted inspection before berthing rather than after release.

Detection methods can then be matched to the targets and the vessel's condition: close-range imagery and scrape sampling for conspicuous external fouling, targeted molecular assays for confirmation of predefined species and metabarcoding for broader detection of cryptic assemblages (O'Shaughnessy et al. 2023; Sempere-Valverde et al. 2025; Chebaane et al. 2026). The purpose is not to prescribe a single surveillance method, but to ensure that available methods are informed by the species plausibly associated with the source region and vessel.

Route and recipient information then refine priority. Environmentally similar first ports of call provide an initial pathway screen (Tamburri et al. 2026), but source occurrence and recipient species status determine which species–vessel–port combinations warrant greatest attention. Priorities should therefore remain dynamic as routes change, vessels are cleaned, new source records appear or recipient status is clarified. ROPME is well placed to maintain the validated baseline, receive Member State updates and communicate status revisions to recipient authorities (Carvalho et al. 2023; Egawa et al. 2026).

3.3 *Scope, limitations and refinement*

The RSA baseline should be used within its intended scope. Screening scores calibrated for the RSA describe invasiveness within that risk assessment area; they are not export-risk scores for recipient regions elsewhere and should not be transferred between areas (Copp et al. 2016). The very high-priority tier identifies a source candidate pool, not risk at the destination. The baseline

also covers only species available for uptake within the RSA, not organisms a vessel may have retained from earlier voyages; movement history and direct inspection remain necessary.

The seven fouling species are an operationally focused subset of the 39 very-high-priority extant species identified in the RSA baseline, not an exhaustive list of possible transfers. Others are associated primarily with ballast water, internal systems or alternative pathways, and lower-ranked species should not be excluded where recipient conditions are more favourable. Uncertainty in source occurrence, identification and monitoring coverage should remain explicit (Latombe et al. 2017; Ojaveer et al. 2018).

We emphasise that the prioritisation is set out here rather than applied: we do not link individual lay-up positions, vessel movements or first ports of call to the species targets, and the framework accordingly assigns no destination-specific risk. The 2026 lay-up provides the opportunity to do so, by combining vessel movement records, source occurrence, inspection findings and subsequent detections in recipient regions.

4 Conclusions

Prolonged vessel lay-up in the RSA creates an acute and time-limited biosecurity problem, and every available response such as inspection, route forecasting, early detection, rapid communication depends on knowing what to look for. The validated regional baseline supplies that reference and identifies seven extant fouling species as the operational targets for the current event. Independent survey data recover three of them and also record two species the baseline classifies as absent, a reminder that regional baselines are provisional and must remain open to verified new records. The same problem will recur: trade disruption, corridor closure, port congestion and emergency lay-up all produce atypical movements of vessels and organisms. Pathway information indicates how organisms may move; source-region baselines indicate what authorities should be prepared to find.

CRedit authorship contribution statement

Lorenzo Vilizzi: Conceptualization, Writing – original draft, Writing – review & editing. **Aisha F. Al-Marhoun:** Writing – review & editing. **Qusaie E. Karam:** Writing – review & editing. **Zainab Al-Wazzan:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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383 Tables

384 **Table 1.** Fouling species identified as very-high-priority in the updated Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area (RSA)
385 biosecurity baseline (Vilizzi et al. 2026), with comparison against their treatment in Clarke et al. (2020). The seven taxa were explicitly identified by Vilizzi et al. (2026) as
386 benthic fouling organisms closely associated with shipping and port environments. For each species, the status in the RSA is provided according to Clarke et al. (2020) and
387 revised in Vilizzi et al. (2026): Extant = already present in the RSA; Horizon = not yet present in the RSA. Based on the Aquatic Species Invasiveness Screening Kit (AS-ISK:
388 Copp et al. 2016), the following scores are provided for each species-specific screening record: BRA = Basic Risk Assessment; BRA+CCA = Basic Risk Assessment plus
389 Climate Change Assessment. n.a. = not applicable because the species was not screened by Clarke et al. (2020). Scores ≥ 50 identify species in the very-high-priority tier (Vilizzi
390 et al. 2026). Member State occurrence indicates verified records in the updated RSA baseline and should not be interpreted as implying identical biogeographic status in each
391 jurisdiction. Absence of a Member State from the table indicates absence of a verified record in the baseline rather than demonstrated biological absence. **Changes in scores and**
392 **tier placement between assessment exercises should be interpreted with caution because the exercises also differed in assessors and calibration.**

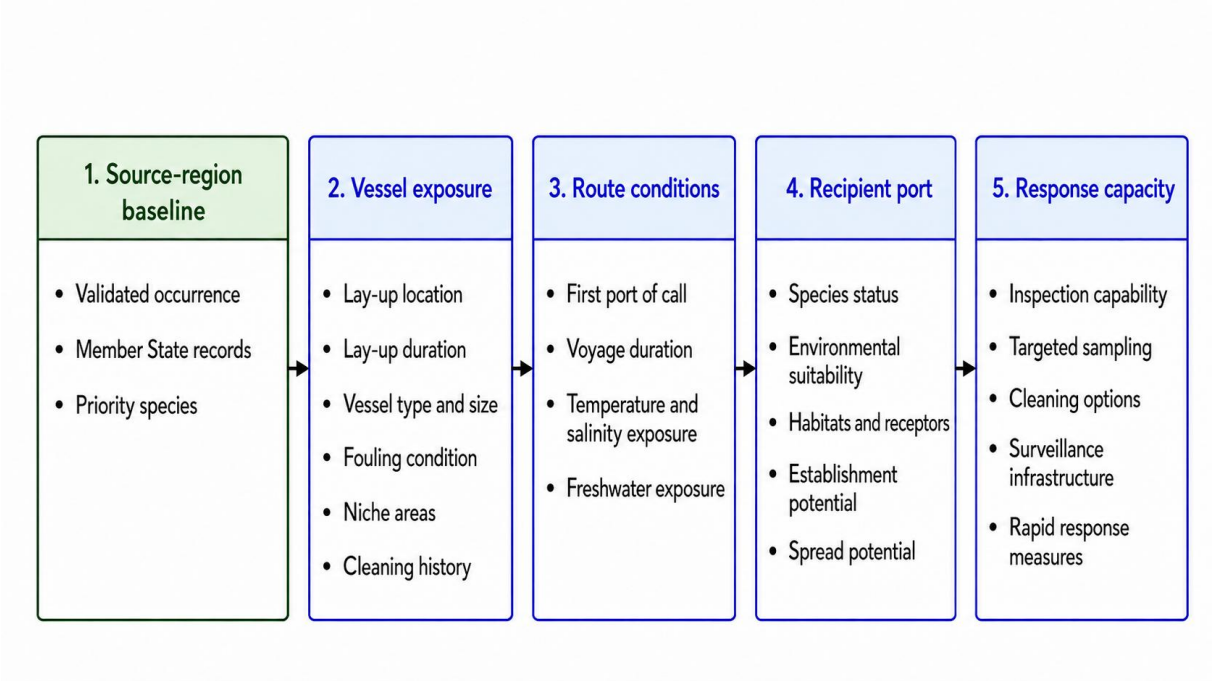
Species	Clarke et al. (2020)		Vilizzi et al. (2026)		Member State occurrence	Operational significance
	RSA status	BRA / BRA+CCA	RSA status	BRA / BRA+CCA		
<i>Amphibalanus subalbidus</i>	Extant	32.0 / 24.0	Extant	41.0 / 53.0	Iran, Iraq	Climate-adjusted score increased, changing operational interpretation and ranking it as very-high-priority.
<i>Botrylloides niger</i>	Extant	36.0 / 36.0	Extant	42.5 / 54.5	Bahrain, UAE	Retained from Clarke et al. (2020), but its updated BRA+CCA score places it in the very-high-priority tier.
<i>Brachidontes pharaonis</i>	Horizon	36.0 / 48.0	Extant	39.0 / 51.0	Kuwait, Oman, Saudi Arabia	Treated as horizon (i.e. absent in the source region) by Clarke et al. (2020), but recorded as extant (i.e. present in the source region) in the updated baseline.
<i>Didemnum psammotodes</i>	Not screened	n.a.	Extant	52.0 / 64.0	Iran, Oman	Absent from Clarke et al. (2020) despite being confirmed as extant and very-high-priority in the updated baseline.
<i>Hydroides elegans</i>	Not screened	n.a.	Extant	43.0 / 53.0	Iran, Kuwait, Oman, Qatar, Saudi Arabia	Absent from Clarke et al. (2020) despite being confirmed as extant and very-high-priority in the updated baseline.

Species	Clarke et al. (2020)		Vilizzi et al. (2026)		Member State occurrence	Operational significance
	RSA status	BRA / BRA+CCA	RSA status	BRA / BRA+CCA		
<i>Perna perna</i>	Horizon	23.0 / 29.0	Extant	38.0 / 50.0	Oman	Treated as horizon (i.e. absent in the source region) by Clarke et al. (2020), but recorded as extant (i.e. present in the source region) in the updated baseline.
<i>Symplegma brakenhielmi</i>	Extant	31.0 / 31.0	Extant	46.0 / 58.0	Bahrain	Substantial increase in both scores, particularly under climate change, resulting in placement in the very-high-priority tier.

393

Figure legends

Fig. 1 The five linked components of species–vessel–port prioritisation following prolonged vessel lay-up: the validated Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area (RSA) source-region species baseline (Vilizzi et al. 2026), vessel exposure, route conditions, recipient port and response capacity.



400 **Fig. 1**