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# Dose of truth—Monitoring marine non-indigenous species to serve legislative requirements

Maiju Lehtiniemi [a,*], Henn Ojaveer [b], Matej David [c], Bella Galil [d], Stephan Gollasch [e], Cynthia McKenzie [f], Dan Minchin [g,i], Anna Occhipinti-Ambrogi [h], Sergej Olenin [i], Judith Pederson [j]

[a] Finnish Environment Institute, Marine Research Center, PO Box 140, 00251 Helsinki, Finland
[b] Estonian Marine Institute, University of Tartu, 2a Lootsi, 80012 Pärnu, Estonia
[c] Dr. Matej David Consult, Korte 13e, SI-6310 Izola, Slovenia
[d] National Institute of Oceanography, PO Box 8030, Haifa 31080, Israel
[e] GoConsult, Grosse Brunnenstr. 61, D-22763 Hamburg, Germany
[f] Fisheries and Oceans Canada Northwest Atlantic Fisheries Centre, PO Box 5667, St. Johns, NL, Canada A1C 5X1
[g] Marine Organism Investigations, Ballina, Killaloe, Co Clare, Ireland
[h] Department of Earth and Environmental Sciences, University of Pavia, Via S. Epifanio, 14, I-27100 Pavia, Italy
[i] Marine Science and Technology Center, Klaipeda University, H. Manto 84, 92294, Klaipeda, Lithuania
[j] MIT Sea Grant College Program, E38-300 Cambridge, MA 02139, United States

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ABSTRACT

Non-indigenous species (NIS) are recognized as a global threat to biodiversity and monitoring their presence and impacts is considered a prerequisite for marine environmental management and sustainable development. However, monitoring for NIS seldom takes place except for a few baseline surveys. With the goal of serving the requirements of the EU Marine Strategy Framework Directive and the EU Regulation on the prevention and management of the introduction and spread of invasive alien species, the paper highlights the importance of early detection of NIS in dispersal hubs for a rapid management response, and of long-term monitoring for tracking the effects of NIS within recipient ecosystems, including coastal systems especially vulnerable to introductions. The conceptual framework also demonstrates the need for port monitoring, which should serve the above mentioned requirements but also provide the required information for implementation of the International Convention for the Control and Management of Ships Ballast Water and Sediments. Large scale monitoring of native, cryptogenic and NIS in natural and man-made habitats will collectively lead to meeting international requirements. Cost-efficient rapid assessments of target species may provide timely information for managers and policy-advisers focusing on particular NIS at particular localities, but this cannot replace long-term monitoring. To support legislative requirements, collected data should be verified and stored in a publicly accessible and routinely updated database/information system. Public involvement should be encouraged as part of monitoring programs where feasible.



## 1. Introduction

Recognition of the significant threats posed by marine non-indigenous species (NIS) is evident in the recent bevy of national, regional and international conventions and legislations which require scientifically validated data for evaluation of their efficacy. Monitoring[1] and surveys[2] of NIS are, therefore, prerequisites for marine environmental management and sustainable development. Baseline surveys have been conducted in certain ports (*e.g.* [35,46,34]), however, consistent monitoring for NIS seldom takes place. Canadian and German monitoring programs of marine NIS are examples of long-term commitments. The program in Canada has been conducted since 2005 with the aim of early detection of NIS, rapid response and providing advice for management decisions [13]. A recent national risk assessment for ballast water introductions to Canada was conducted for the Arctic, Pacific and Atlantic to determine the relative risk of coastal and domestic shipping and to determine the effectiveness of current regulations by Transport Canada in preventing NIS from entering Canadian waters [14]. In Germany a targeted monitoring program for alien species along the German North Sea and Baltic Sea coasts including port monitoring was started in 2009 [6]. Biennial or

* Corresponding author.
*E-mail address:* maiju.lehtiniemi@ymparisto.fi (M. Lehtiniemi).

[1] Monitoring: program of collection of data by standardized methods at regular intervals, related to specific factors, designed to provide information on the characteristics of the factors and their changes with time.

[2] Survey: collection of data providing a snapshot view of a particular area at a particular time.

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triennial monitoring of native and NIS of macroalgae and macroinvertebrates have been conducted in marinas and harbors on the northeast coast of the USA, from Maine to New York City [81]. The European Union has undertaken legislative measures to manage NIS, including the EU Marine Strategy Framework Directive (MSFD), Biodiversity Strategy and most recently Regulation on the prevention and management of the introduction and spread of invasive alien species. The MSFD places emphasis on the "trends in abundance, temporal occurrence and spatial distribution in the wild of non-indigenous species …". Marine biological monitoring in European waters is regionally or nationally based, covering specific environments or taxonomic groups and often conducted as part of international programs (*e.g.* Baltic Marine Environment Protection Commission, HELCOM, Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR). However, monitoring seldom targets NIS and does not cover all habitats and areas that NIS may occupy [41].

NIS are defined as species introduced outside of their natural range (past or present) and outside of their natural dispersal potential by intentional or unintentional human activities [76]. Further invasive alien species (IAS) are defined as spatially expanding NIS which may threaten biological diversity, impact the environment and humans [76]. The most common pathways for marine NIS introductions are vessels (via ballast waters and as ships' and leisure craft biofouling), culture activities, and through canals and canalized waterways, with regionally varying magnitudes [61,24,9]. However, the scope and focus of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) is broader and includes, in addition to NIS dealt with in detail in the current account, potentially harmful cryptogenic and native species and pathogens (*i.e.* harmful aquatic organisms and pathogens, HAOP) (*e.g.* [30]).

This paper presents a review of monitoring approaches, encompassing a range of coastal environments which are especially vulnerable to introductions (*e.g.* [51,71,65,100,25]), to provide a conceptual framework for practical monitoring. The importance of early detection of NIS in bridgehead sites and dispersal hubs is highlighted; and different approaches how monitoring for NIS within marine ecosystems may be undertaken is demonstrated. The following sections identify current international requirements concerning NIS monitoring.

## 2. Monitoring requirements under international instruments

The EU Biodiversity Strategy [20] seeks an extensive knowledge concerning marine NIS. Target 5: "Combat Invasive Alien species" of the Biodiversity Strategy requires that "…by 2020, Invasive Alien Species and their pathways are identified and prioritised, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new Invasive Alien Species…". While it is unlikely that the target will be fully met by the deadline, there is a pressing need to undertake surveys and monitoring as further NIS are continually recorded and earlier introductions expand their range (*e.g.* [24,26]). Early confusion in setting out the necessary actions to fulfill the aim set out by the EU Biodiversity Strategy led to the failure to meet the 2010 target [19]. One area that requires action is the identification of high-risk NIS that are deemed invasive and may cause harm. The goal is to develop approaches to prevent further introductions, identify potential invaders, document secondary spread and dispersal of already present NIS, and implement approaches to eradicate, manage, and control priority NIS where this is practicable. With this in mind the Regulation on the prevention and management of the introduction and spread of IAS has been recently adopted [18].

The EU MSFD requires Member States to take measures to achieve or maintain Good Environmental Status (GES) by 2020 [16]. The MSFD Commission Decision on criteria on GES of marine waters includes NIS under Descriptor 2 [17]. In order to fulfill the requirements of MSFD, Member States are charged with gathering data as to '…NIS trends in abundance, temporal and spatial distribution notably in risk areas, in relation to the main vectors and pathways, ratio between invasive NIS and native species in some well-studied taxonomic groups that may provide a measure of change in species composition and impacts of non-indigenous invasive species at the level of species, habitats and ecosystem, where feasible…'.

A federal regulatory proposal to manage Aquatic Invasive Species (AIS) as part of the Canadian Fisheries Act is being developed in collaboration with the Canadian provinces [13]. The monitoring requirements to support these regulations have not been established.

The BWM Convention, adopted by the International Maritime Organisation (IMO) in February 2004, enters into force twelve months after the date on which more than 30 States, with combined merchant fleets not less than 35% of the gross tonnage of the world's merchant shipping, have signed this Convention. As of July 2014, 40 states have ratified the BWM Convention, representing 30.25% of the world merchant shipping gross tonnage (Status of Convention at www.imo.org). The BWM Convention sets global standards and requirements to avoid the transfer of HAOP including harmful NIS within ballast water and its associated sediments. The BWM Convention calls on the Parties to individually or jointly monitor the effects of ballast water management in their waters. The BWM Convention further states that a Party should inform mariners of areas under their jurisdiction where ballast water should not be taken up due to known unfavourable conditions implying that monitoring should be undertaken to document the presence (or absence) of HAOP [42]. The BWM Convention also states that vessels on certain routes can be exempted from the application of BWM requirements based on a risk assessment (RA) according to the IMO Guidelines requiring reliable data on HAOP in related ports [42,43]. Both the United States and Canada adopted approaches for managing ballast water and the risk of NIS introductions which require monitoring [95,96].

Although managers and policy makers have recently come to recognize the importance of biofouling of commercial vessels and recreational boats in the dispersal of NIS, no international convention exists to address this issue. Yet guidelines for management and minimizing the transfer of biofouling on both ships and recreational craft have been adopted at IMO [44,45] including assessments of the biofouling. The objectives of the guidelines are to provide practical guidance to related states, ship crews and owners, shipbuilders, ship yards, anti-fouling paint manufacturers and suppliers and any other involved in shipping industry, on measures to minimize the risk of transferring IAS as biofouling.

## 3. Surveys and monitoring approaches

Survey results form a baseline of information against which the future change may be monitored. Surveys are often conducted at high risk sites and may be more or less comprehensive, ranging from a single species [91] to a multi-taxa harbor surveys [35]. Once surveys have provided 'baseline' data, risk-based priorities concerning pathways, 'hot spots' and NIS monitoring are identified. Bridgehead sites and dispersal sites ('hot spots') are high volume recipient and donor locales, perhaps at the convergence of more than a single vector/pathway (*e.g.* species arriving in ballast water may be transported in fouled leisure craft). Monitoring implies a long-term continuous sampling at defined intervals to detect changes in population distribution, size and impact. Priorities for monitoring, particularly in large or complex areas, need to take into account the physical forcing, operating vectors and their relative propagule delivery, the mosaic of habitats and sampling abilities [77]. Time, cost and extent of spatial coverage are important to define exact monitoring plans. The situations that dictate the sampling sites are dependent upon the objectives of each survey and vary according to circumstances (Table 1).

Managing NIS is a global issue that is best achieved when scientists, policy-advisers and managers work together as a team that includes decision-makers involved in the management of conventions and international legislation. The next sections provide some examples of monitoring that have already been shown to be both effective and practical in achieving these overall management aims.

### 3.1. Early detection and localized targeted surveillance

Taxonomic expertise is a prerequisite for detection of NIS, as otherwise they may escape attention for years (*e.g.* [86,76,77]). This has to be taken into account when revising the monitoring programs. In many regions taxonomic knowledge of indigenous organisms is deficient, confounding the identification of organisms originating from other parts of the world which is even more demanding. Consequently, many organisms may remain unidentified. An international network would be very beneficial in linking the taxonomic expertise available. Following detection and identification of a novel NIS, a targeted survey of the applicable vicinity may determine its abundance and range. If a risk assessment (RA) determines a taxon as possibly harmful, eradication may be attempted as soon as possible. Eradication of newly introduced NIS provides the best opportunity for ridding the species (Fig. 1), though in the marine environment few eradication attempts have been successful (*e.g.* [22,1]). Even if eradication is unsuccessful, some measure of control may be possible to prevent the spread to other areas and early detection is vital to this type of mitigation [11]. Targeted monitoring should be undertaken in bridgehead sites and dispersal hubs and areas considered to be environmentally sensitive and/or vulnerable (*e.g.* Marine Protected Areas, lagoons and estuaries).

**Table 1**
Monitoring/survey types, their advantages and disadvantages and legislative acts for which they give data for. BWMC = IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments, MSFD = EU Marine Strategy Framework Directive, WFD = EU Water Framework Directive, EU reg. = EU regulation on invasive alien species, RA = risk assessment.

| Monitoring/ survey type | Environment studied | Advantages | Disadvantages | Relative costs | Requirements, codes | References |
|---|---|---|---|---|---|---|
| Harmful aquatic organisms and pathogens for IMO BWMC | Ports and surounding area, *i.e.* anchorages and port approaches | Inform vessels when HAOP are present in ports, monitor BWM measures efficiency, support RA for exemptions | Extensive monitoring program | $$ | BWMC | [8,9,42,43] |
| Export licensing requirements, veterinarian services | Stock in advance of export | Notifiable diseases and pests not transmitted | Unknown syndromes, parasites may be spread | $ | ICES, OIE | [38,39,52,72] |
| Rapid assessment surveys | Selected according to likely areas of arrival/impact: breakwaters, marinas, aquaculture sites *etc.* | Can be repeated on a regular basis, marinas have easy access | Some NIS may be missed | $ | MSFD, EU reg, BWMC if done in port | [3,55,58,81,92] |
| Target species | Specific sites where target occurs | Rapid evaluation enabling rapid response | Some NIS may be missed | $ | MSFD, EU reg | [60,67,91] |
| Port surveys | Ports and vicinity | A detailed account of the status of species at a site, possibly exemptions from ballast water management requirements | Time consuming and expensive, taxonomist service required | $$ | BWMC, IMO Guidelines G7, MSFD, EU reg | [34,35,46,84] |
| At border customs / consignment service | On hub areas on arrival of consignments | Potential seizure before product is dispersed | Contaminants (associated species) not recognised | $ | EU reg | [56] |
| Long-term monitoring, hitchhiking on other surveys | Rivers, canals, transitional, coastal and offshore | Provides current status data, monitoring/survey already is taking place | Often too late to manage, but mitigation possible. Not all sampling methods can be employed, not all habitats are covered | $$ | MSFD, WFD, EU reg | [48,53] |
| Surveys of navigation buoys/ offshore structures | Rivers, canals, transitional, coastal and offshore | Provides current status data | Weather dependant and only covers sessile biota | $($) | MSFD, EU reg | [50] |
| Marina surveys | Marinas in port regions and about coastal areas | Good results for sessile biota and easy access | No in-fauna, mobile or pelagic study | $($) | MSFD, EU reg | [2,58,81] |
| Shellfish biosecurity | Shellfish production sites | Determine recognised toxins/ pathogens in shellfish tissue | Toxins not sampled for or new toxins may be present | $$ | | [68,90] |
| Genetic monitoring | Of specific taxonomic groups | Also effective for small biota | Contamination may be an issue, needs a full species reference library | $$ | BWMC, MSFD, WFD | [21] |
| Risk assessment profiles of species/areas | Selected species/regions | Predictive warnings of potential impact, possibly exemptions from ballast water management requirements | Ballast water management exemptions valid for up to 5 years, exemptions may be revoked | $$ | BWMC, IMO Guidelines G7 | [9,10,31,39] |
| Diver surveys, involving public participation | Diving sites including reserves and wrecks | Sampling of sites not normally otherwise examined. When organised high observation levels; good for general survey of areas | Misidentifications and smaller NIS likely to be overlooked; require voucher specimens | $ | | [12,27] |

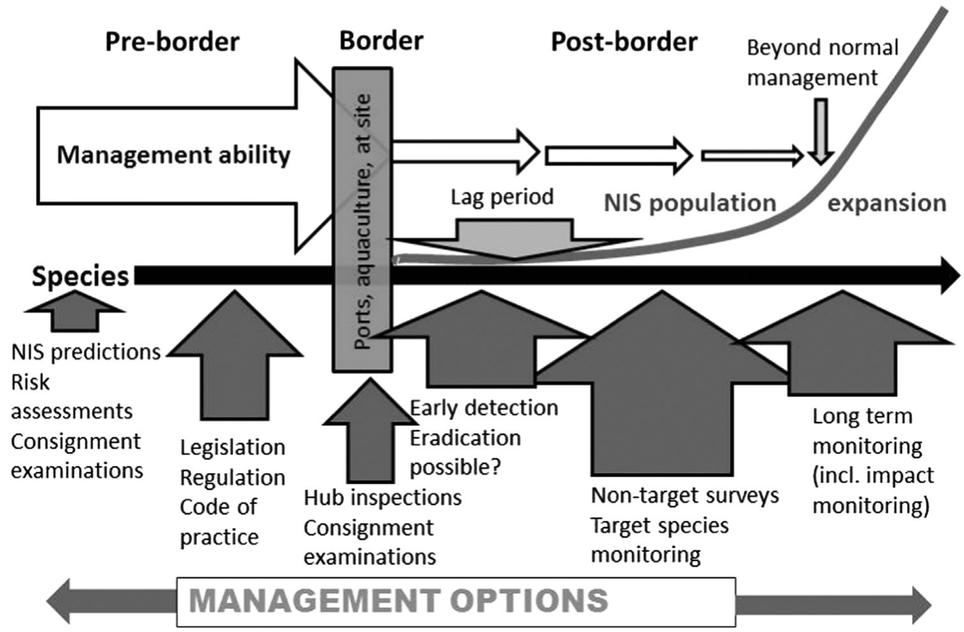


**Fig. 1.** The schematic picture of management ability and options and monitoring/survey possibilities at different phases of the introduction and spread of a non-indigenous species into a new country. The width of the dark grey arrows indicates the perceived range over which a specific management action might take place. The white arrows indicate the management capability of controlling an invasion of an NIS.

#### 3.1.1. *Hotspots related to shipping*

Shipping is a major vector for global introductions of marine NIS both via ballast water and as biofouling [37] but the species transferred are not limited to NIS and include also potentially harmful cryptogenic and harmful native species. The level of biofouling on commercial vessels remains high [98], since antifoulants replacing the banned tributyltin are not as efficient in preventing fouling [59]. Propagules introduced in ballast and biofouling are mainly released within ports alongside berths, but also at anchorage and port approaches [8]. As a result, the associated port structures, *e.g.* active berths, channel markers, tug/pilot vessel berths, and slipways act as substrates for NIS attachment [35]. The soft sediments within ports may act as seed banks for resting stages of some species such as dinoflagellates and zooplankters. Since the majority of marine species spend part of their life cycle within the water column, ballast water may carry many taxonomic groups, whereas fouling biota comprise small-sized sedentary, burrow dwelling or clinging species, though large species whose life history includes an appropriate life stage may be disseminated as well. Hence, a high diversity of species can be secondarily dispersed from ports in ballast and fouling, and therefore ports should be considered priority areas for monitoring.

Port survey protocols developed in Australia [35], New Zealand [46], USA [84] and in framework of GloBallast (http://globallast.imo.org) serve as models for developing harmonized approaches. Only New Zealand maintains long-term surveillance (http://www.marinebiosecurity.org.nz/). HELCOM and OSPAR have recently proposed comprehensive guidelines for a port sampling protocol for the Baltic and North Seas [34], and Adriatic countries have agreed on a comprehensive harmonised Port Baseline Survey Protocol for HAOP for the purpose of the BWM Convention implementation that covers also NIS for the needs of MSFD (http://www.balmas.eu). In the port monitoring process the sampling frequency, the habitats to be included, the number of sampling locations, and the availability of taxonomic expertise would need to be considered in detail. It is also recommended to acknowledge that the hazardous and often dangerous conditions encountered in port areas (such as constraints imposed by navigation, hazardous cargo berths, activity-profile of some areas, and security issues) may also impose limitations on the methodologies that may be applied in terms of access and duration of people or equipment on site.

#### 3.1.2. *Hotspots related to coastal and off-shore artificial structures*

Artificial coastal structures (*e.g.* pontoons in leisure craft marinas, groins, armored coastlines erosion defences), and off-shore platforms (*e.g.* energy farms, floating buoys, traps, aquaculture facilities and more) provide hard substrates enabling the incremental spread of NIS that use these structures as 'stepping stones'. The number and size of these structures continue to increase (*e.g.* [63]) enabling range expansions that would not be possible otherwise. In some regions the only hard substrates are offshore breakwaters providing an optimal environment for some NIS, *e.g.* the muricid *Rapana venosa* and for *Codium fragile* in the northern Adriatic Sea [92,5]. Pontoons and other immersed parts of the artificial structures are not usually treated with antifouling coatings and so can develop extensive biofouling. Thus, these structures should be monitored for NIS.

The increased presence of both stationary and temporary (*e.g.* oil rigs with biofouling, [98], and offshore fish farms—see below) artificial structures in the marine environment is a matter of concern, as they may pose opportunities for the introduction, further spread and establishment of NIS.

#### 3.1.3. *Hotspots related to culture activities*

NIS may be intentionally or unintentionally introduced to the wild through aquaculture: *e.g.* the red king-crab *Paralithodes camtschatica* released in the Barents Sea [47,40], the Pacific oyster *Crassostrea gigas* in Europe [87,64] and the Manila clam *Ruditapes philippinarum* in the Mediterranean Sea. The organisms may further introduce other NIS; their parasites, epibionts, and disease agents [56,66]. Fish and shellfish farming often take place in close proximity to other pathways and their vectors. The spread of parasites, epibionts and diseases arising not only from stock movements, but also from other sources (incl. ballast water and biofouling) has been poorly studied and is a cause of concern.

The ICES Code of Practice [39] provides guidelines, most of which form part of the European Requirements for the cultivation of such species [15]. These requirements cover issues of impact, likelihood of establishment and recruitment, and rearing of F1 generations in quarantine before release. The volume and variety of stock movements require close monitoring. Pre-border and at-border inspection provide the most effective controls where consignments of stock have veterinarian documentation to indicate freedom from specific parasites, diseases and epibionts (Fig. 1). Marine farms engaged in raising NIS should be monitored for escapees and unintentionally introduced NIS.

#### 3.1.4. Bridgehead sites related to canals

The two largest canals connecting major water bodies are the Suez Canal that connects the Red Sea with the Mediterranean, and the Panama Canal that connects the Atlantic and Pacific Oceans [7,23]. Canals increase the concentration of shipping traffic and serve as a conduit for marine NIS [89]. Both the Suez and Panama canals are planning expansions that are expected to increase the size and number of traversing ships, and NIS [24]. Currently half of the NIS recorded in the Mediterranean Sea are considered to have been introduced through the Suez Canal [26]. Establishing monitoring programs close to terminals of both canals would serve as early warning systems to the regional NIS management.

### 3.2. Presence–absence and abundance monitoring as part of routine biological monitoring programs

Monitoring of NIS may take advantage of ongoing surveys such as multidecadal plankton/benthos surveys, young-fish surveys, inspections at aquaculture installations, buoyage management and dry-dock cleaning activities, if methodologies are standardized. These opportunities should be effectively utilized because lack of awareness and means often result in NIS becoming apparent only after populations have been established and spread, thus limiting management options (Fig. 1).

Records of presence–absence of NIS in non-targeted monitoring can provide the number of NIS in a given area, but in many cases also temporal occurrence and spatial distribution of NIS can be obtained, as required by the MSFD [16]. Because shipping and aquaculture are considered the primary vectors for introductions [65,24,26], ports, marinas and aquaculture facilities, and their vicinity, should be the priority areas for surveys and monitoring (see Section 3.1). However, secondary introductions and natural spread expand NIS range beyond the original recipient locale, necessitating monitoring of larger regions, in some cases the entire coastal littoral.

In accordance with the international directives and conventions, and as a good practice, routine biological/fisheries monitoring programs, that cover pelagic and benthic habitats, are already in place in many regions (*e.g.* [32]), and where appropriate, could be combined with standardized NIS targeting surveys with only moderate cost increase (Table 1). To monitor 'at risk' areas (see Section 3.1), national authorities may wish to evaluate NIS data needs for compliance with instruments, re-assess their present biological monitoring programs, and modify the programs accordingly [41] taking into account the seasonality of species and their opportunities to become dispersed by anthropogenic and natural vectors. Analyses of existing biological data is helpful in discerning the temporal and spatial patterns of NIS records [71,73,48] giving essential information on the potential gaps in on-going monitoring programs.

### 3.3. Monitoring for impact assessment

Marine NIS impacts may vary greatly, causing changes at different levels of biological organization, from genetic structure of local populations to alteration of communities, habitats, functioning of ecosystems and ecosystem services [97,82]. Data concerning NIS impacts are needed for the risk assessments (including BWM Convention), and for prioritizing species of greatest management concern (*e.g.* for MSFD and EU Regulation for IAS).

One option for the impact assessment is the biopollution assessment method that takes into account the abundance and distribution range of a NIS in relation to native biota within a recipient area. In this assessment the extent of the area is predefined and referred to as the assessment unit, such as an estuary, a marine protected area, a marina or an aquaculture site and for a defined period of time [75]. The impact upon native communities, habitats and ecosystem functioning is then evaluated based on data collected or published results from corresponding areas. The biopollution level (BPL) takes account of the impact according to five levels, defined as: no measurable impact, weak, moderate, strong and massive impact. NIS with lower levels of impact do not influence the final assessment although several NIS may be present. This makes an evaluation both practical and rapid to undertake although it does require a basic knowledge of the most impacting species present within a chosen assessment unit [80,100]. For areas where such information is lacking the required data may be gathered rapidly because it is the most impacting species that is used in each assessment, and is normally easily recognized. Biological data from a time-series can aid in evaluating changes in ecosystem function. The monitoring needs for impact assessment vary between areas depending on the level of existing knowledge concerning the most harmful NIS of the assessment unit.

The impact assessment is also of key importance for BWM requirements when risk assessment is concerned. This refers to the identification of target species in the species specific risk assessment approach [10].

## 4. Considerations and methodology for NIS monitoring

### 4.1. Temporal resolution

Monitoring and targeted surveys should take into account temporal habits (diurnal/nocturnal/seasonal) and life-history of NIS (Table 2). Tracking of seasonal-scale abundance fluctuations of NIS populations, evaluating an impact assessment or considering ballast water management exemptions, requires ambitious and concerted monitoring effort. Surveys for plankton and for pelagic stages of *e.g.* molluscs and benthic invertebrates may require a

**Table 2**
Suggested sampling frequency requirements for monitoring of presence–absence and population dynamics (abundance and/or biomass) of NIS of different taxonomic groups and varying life cycle lengths.

| Organism group | Presence/ absence | Population dynamics |
|---|---|---|
| Pathogens and other disease agents | Seasonal | Variable |
| Phytoplankton | Seasonal | Frequent, depending on biosecurity requirements |
| Zooplankton | Seasonal | Monthly (bi-weekly) |
| Benthic vegetation | Seasonal/ annual | Seasonal/annual |
| Zoobenthos | Annual | Annual |
| Fish | Annual | Annual at specific times (*e.g.* reproduction) |

high frequency of sampling (*e.g.* [90]). Monitoring that targets longer lived biota requires less frequent sampling (Table 2; see also [73]). For some groups (*e.g.* fish) annual sampling may be confined to a specific season [33]. Replicate samples would be needed to minimize the possibility of missing a NIS due to spatially variable patchiness of biota (*e.g.* [99]). Due to temporal aspects the risk assessment based exemptions from BWM requirements may also require, in addition to a baseline survey, regular semi-annual (spring and autumn) or annual monitoring in ports [10].

### 4.2. Methodological considerations

In an ideal world standard methodologies facilitate cross comparisons, but rarely this is the case. In the case of plankton, benthos, nekton and macrophytes, collection and sampling are routine. However, exceptions occur: for phytoplankton see Majaneva et al. [53] and for zooplankton see Gollasch et al. [29]. Special attention should be given to certain taxa such as small sized or fragile species (*i.e.* gelatinous zooplankton), which are often damaged, overlooked, unrecognised or undersampled and thus can be under-represented unless specifically targeted [25]. Further, some taxa may require specific sampling methods, such as condo-traps designed to capture small decapods [36] or maximising the efficiency of macrophyte collections [57]. Special attention should be given to monitoring sessile biota. A common method for this is the deployment of settling plates, which are successfully used in many places along European, North American coasts, Hawaii and New Zealand [88,94,28]. These have been standardized using grey PVC plates ($14\ \text{cm} \times 14\ \text{cm}$) deployed at specific depths and durations and adopted also in sampling protocols for ports [34]. Other methods used in NIS monitoring involve standard photographic procedures [28] and video recordings [93], although species identifications may require voucher samples. SCUBA diver visual surveys are also used and have the advantage of sampling species which are not easily identified in the field.

NIS may go undetected due to difficulties in species identifications and similarities, especially at larval and juvenile stages, at initial stages of invasions or when occurring at low densities. Molecular genetic methods can be helpful in determining marine NIS identities, as well as their sources, routes of invasions, and the genetic make-up of founding populations. Furthermore, recent advances in molecular methods offer promising tools for assessment of early detection, fundamental connectivity within and among source and introduced populations, invasion dynamics, trophic ecology, interactions between NIS and native species—all of which are essential for quantifying their effects on recipient communities (*e.g.* [83]). Molecular methods can also be used for the rapid identification of cholera bacteria [69] and NIS can be identified from genetic profiles within water [21]. Molecular genetics, supplemented with observational and historical records, experimental studies and field surveys, is essential for documenting the full extent of marine bioinvasions, and for providing information for the development of effective conservation policies and competent management.

### 4.3. Rapid assessments

Rapid assessment is ‘a synoptic assessment, which is often undertaken as a matter of urgency, in the shortest time frame possible to produce reliable and applicable results for its defined purpose’ [85]. Protocols for rapid assessment of marine and coastal biological diversity are available (UNEP/CBD/SBSTTA/8/INF/13 [81]). Rapid assessment monitoring for targeted species enables direct reporting to management when a notable species is encountered and the ‘field’ work can be undertaken by a small group of experts. The method is cost-effective and relevant when prompt management response is sought, but unsuitable for detection of newly arrived introductions.

Target lists of NIS reduce sampling effort, over full inventories of biota present, and are more relevant for a swift management response. Leisure craft marinas and floating pontoons in port regions provide easy access at any tidal state and are known sites of colonisation by a wide range of NIS [3,58,62,11]. For some existing facilities rotating thrash screens of power stations [67], or fishermen’s nets have been used for monitoring non-indigenous crabs and fish. Over the last decade, NIS in marinas have been studied within different world regions involving several taxonomic specialists (*e.g.* [6,81]) and can be used for identified IAS. Once an IAS target has been located, a more expansive survey for that species is frequently developed.

The other approach of sampling can be one-day targeted species assessments/confirmation in response to new reports. It can involve underwater viewers, cameras, snorkeling, diving and collection of material and environmental parameters. Longer duration surveys of up to four days may involve a large, multi-agency team of investigators conducting monitoring in high-risk ports and in response to detection of high risk species [91,54] and their impact on ecosystems. The gathered information may be used as input to risk assessments for the NIS, and if warranted, may result in the development of a further Rapid Response Plan.

The Abundance and Distribution Range (ADR) (see [75]) is a rapid assessment monitoring method that involves sampling at selected areas within an assessment unit, and is facilitated by the on-line service BINPAS [70]. It is useful for large, easily seen and clearly identifiable, fouling NIS which can be rapidly surveyed within hours to provide an ADR and an indication of the level of impact such a species may have on an environment (see Section 3.3). The size of the assessment unit varies and may be an aquaculture site, marina, navigation buoys or standard young fish trawl monitoring site. Selecting thirty or more sampling positions enables the calculation of an NIS abundance and distribution range [60]. The ADR method can also show change over time if survey is repeated. The approach is rapid and can be undertaken in the absence of time consuming methods, such as the use of quadrats. For management purposes this method is both practical and cost-efficient.

### 4.4. Public involvement

Public involvement can aid in detection of NIS. Divers, anglers, leisure craft users and school children help to track the spread of NIS [27,49]. Volunteers (citizen scientists) may look for a restricted number of species, and the data can be used to identify range expansions (http://www.salemsound.org/mis/mismethd.htm). Partnerships with the aquaculture, fisheries and leisure craft industries may enable early detection of NIS arrivals. The advent of electronic communication facilitates the usage of online websites (*e.g.* http://www.pac.dfo-mpo.gc.ca/ais-eae/help-aide-eng.html, www.riistakala.info/alien_species/) in reporting NIS observations. Websites also aid in providing up-to-date information on identification, distribution and means of preventing further spread. Public involvement increases general awareness on the NIS problem and may therefore help in preventing further intentional introductions.

## 5. Reporting and storing monitoring data

There is little value in monitoring NIS unless the knowledge obtained is timely and can be directly used by research and management [74]. Online information sources have already been used for the compilation of NIS lists for specific areas, prioritizing the most impacting NIS (*e.g.* target species lists), defining their pathways and vectors and recommendations for management ([79] and references therein). Consequently, data obtained by monitoring and surveys should be quality assured and available for exchange by researchers and managers worldwide. This becomes possible either through a centralized information system or through distributed databases that integrate data from a wide range of NIS monitoring programs.

In order to facilitate the exchange between datasets and information systems, they should have a unified taxonomy (*e.g.* World Register of Marine Species), using standard definitions for a species status (NIS/cryptogenic/native), their life form, habitats where found, as well as associated environmental data. In addition, species should be assigned to pathways and vectors involved in their transmission according to levels of certainty [78]. The organizational principles, structure and functionality of information systems should allow for the assemblage, storage and dissemination of data compiled from various NIS monitoring programs.

There are many advantages to an accessible database. Data gathered can be used by the shipping industry and authorities for the BWM Convention and vessels' biofouling purposes, fishing and aquaculture industries and provincial and federal fisheries management and improve chances for management in an early phase of invasions. An accessible commonly-shared database would harmonize countries' reports for EU Commission (MSFD and EU regulation for IAS that states '…Member States shall establish a surveillance system of invasive alien species of Union concern, or include it in their existing system, which collects and records data on the occurrence in the environment of invasive alien species by survey, monitoring or other procedures…' [18]), and would help in the implementation of the BWM Convention.

Some countries have a national database and several databases exist for specific purposes, but few focus solely on NIS and cryptogenic species. One database gaining momentum is AquaNIS, an online information system for aquatic NIS introduced to marine, brackish and coastal freshwater environments of Europe and neighboring regions designed to assemble, store and disseminate comprehensive data [4]. At a later stage AquaNIS will possibly be expanded to also include HAOP, *i.e.* addressing harmful native and NIS also including cryptogenic species, to address the BWM Convention implementation requirements. The geographical component of AquaNIS is arranged in a hierarchical order ranging from oceans, ocean sub-regions, Large Marine Ecosystems (LMEs), sub-regions of LMEs to smaller entities, including ports, from which a user can make a selection [79]. Table 3 presents a reporting format, which facilitates the data upload from NIS and cryptogenic species surveys and monitoring programs to AquaNIS.

## 6. Conclusions

Harmonized standards and methodologies for NIS monitoring are needed for generating reliable and comparable results to faithfully serve the requirements of the national and international legislations such as the EU MSFD, the EU Regulation for IAS and IMO BWM Convention. NIS survey and monitoring programs should prioritize bridgehead sites and dispersal hubs and make use of rapid assessment methods when and where appropriate. Data should be verified and stored in an open-access continuously updated database. Cooperation and sharing resources with on-going monitoring programs

**Table 3**
The minimum information required for reporting of an introduction event of an NIS record or expansion to its distribution, to be of value, should provide a reference (published paper, report, personal communication, *etc.*) for each entry. Explanations as well as the provided example details appear in AquaNIS [4].

| Information field | Explanations | Example: observation of a new species |
|---|---|---|
| Species scientific name | According to a global organism-specific database WoRMS, incl. authority and year | *Cercopagis* (*Cercopagis*) *pengoi* (Ostroumov, 1891) |
| Species common name | Free text, to be added if known | Fishhook water flea |
| Taxonomic affiliation | (algae, crustacean, bivalve, fish) | Crustacean, cladoceran |
| Date of record | Year, month, day | 9. July 1992 |
| Recipient country | A country a NIS introduction event is registered for | Estonia |
| Area | Name of recipient large marine ecosystem (LME) and LME sub-region | Baltic Sea, Gulf of Riga |
| Location | Free text | Pärnu Bay |
| Location 58°13′; 28°14′ | coordinates | (Lat, long) |
| Habitat type | More than one option can be selected estuary, lagoon, sheltered coastal area, open coast, offshore, strait/sound, marina, aquaculture sites, marine protected area (MPA), ports, port vicinity | Estuary, sheltered coastal area, port vicinity |
| Species status | Non-indigenous species or cryptogenic species | Non-indigenous species |
| Population status | Indication of observation of a new species or expansion of distribution area of the already existing species: low level of certainty (unknown, established, not established), moderate level of certainty (extinct/no recent record, rare/single record, common, abundant, very abundant, outbreak) | Moderate level of certainty: abundant |
| Invasion pathway | To be identified by the level of certainty: direct evidence, highly likely, possible, unknown Invasion pathway: select one (in case of direct evidence) or more: aquarium trade, culture activities, live food trade, management, natural spread from long distances, natural spread from neighboring countries, canals (give name if known), research and education, vessels, wild fisheries | Highly likely: vessels/ballast water |
| Impacts | If documented from the recipient area: ecological, economic, social—please provide details. Potential and/or known impacts from native also to be included | Documented from invaded systems: decline in small-sized native zooplankton taxa, prey for pelagic planktivorous fish |

For details see [79].

would save decreasing resources and ensure that quality data is made available to decision makers.

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