Biological Conservation 173 (2014) 98–107

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Making non-indigenous species information systems practical for management and useful for research: An aquatic perspective

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ARTICLE INFO

Article history:
Received 21 November 2012
Received in revised form 25 July 2013
Accepted 28 July 2013
Available online 24 August 2013

Keywords:
Introduced species
Large Marine Ecosystems
Information sharing
Database
Bioinvasion management

ABSTRACT

Biological invasions attract increasing attention from scientists, policy makers and various management authorities. Consequently, the knowledge-base on non-indigenous species (NIS) continuously expands and so the number and availability of web resources on NIS rises. Currently there are more than 250 websites on NIS, ranging from global to regional and national. Many of these databases began as inventories of NIS, but evolved to include information on NIS origin, introduction history, pathways, vectors, and more. The databases have been used increasingly for scientific analyzes, though key information needs for bioinvasion management and research are only partially met. In this account we describe an advanced information system dealing with aquatic NIS introduced to marine, brackish and coastal freshwater environments of Europe and adjacent regions (AquaNIS). AquaNIS differs substantially from existing NIS information sources in its organizational principles, structure, functionality, and output potential for end-users, e.g., managing aquaculture or ship's ballast water. The system is designed to assemble, store and disseminate comprehensive data on NIS, and assist the evaluation of the progress made towards achieving management goals. With the coming into force of the EU Marine Strategy Framework Directive and similar legislation addressing the problem of biological invasions, the availability of advanced, scientifically validated and up-to-date information support on NIS is essential for aquatic ecosystem assessment and management. Key issues related to electronic information systems, such as data management principles and long-term database maintenance, are discussed.

1. Introduction

As biological invasions attract increasing attention from scientists, policy makers, management authorities and the wider public, the number and availability of electronic resources on non-indigenous species (NIS) rises. Currently there are more than 250 websites on NIS worldwide (GISIN, 2013). The geographical scope of these information resources varies from global (e.g., GISD, 2013) to regional (e.g., Baltic Sea Alien Species Database, 2013; CIESM, 2013) and national (e.g., Mastitsky et al., 2012; S.I.B.M. Allochthonous Species Group, 2013; Nehring, 2013). Many of these databases began as inventories of NIS, but evolved to include keys for NIS identification, donor and origin regions, introduction histories, pathways, vectors, etc.

NIS databases are increasingly being used for research. During the last decade information derived from these on-line sources was used in the peer-reviewed literature to: (a) aid the compilation of NIS lists for specific areas (e.g., Gollasch and Nehring, 2006; Zaiko et al., 2007; Galil, 2009a, 2012; Westphal et al., 2008; Occhipinti-Ambrogi et al., 2011), (b) prioritize the most impacting NIS (e.g., Cambray, 2003; Olenina et al., 2010; Savini et al., 2010), (c) identify, quantify and summarize the ecological impacts of specific taxa or functional groups (e.g., Butchart, 2008; Vilà et al., 2009; Occhipinti-Ambrogi and Galil, 2010; Kuebbing et al., 2013), (d) define the major pathways and vectors responsible for NIS introductions (e.g., Gollasch, 2006; Hulme et al., 2008; Marchini et al., 2008; Minchin et al., 2009; Savini et al., 2008, 2010; Galil, 2012), (e) analyze species traits and ecological preferences (e.g., Prinzing et al., 2002;

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http://dx.doi.org/10.1016/j.biocon.2013.07.040

Paavola et al., 2005; Strayer, 2010), (f) assess the risks posed by NIS species on economies and ecosystem services (e.g., Occhipinti-Ambrogi, 2000; Baker et al., 2005; Campbell et al., 2008; Diederik et al., 2011), (g) assess the risk of certain NIS introduction vectors (e.g., Gollasch et al., 2011), and (h) provide recommendations for management measures (e.g., Casal, 2006; Olenin et al., 2011; Wilgen et al., 2012). However, we also found that information is often cross referenced, shared and recited by various databases.

Most NIS databases are based on summarized secondary data, which is of limited use for managers and policy makers. Some databases, lacking rigorous scientific validation procedures, may contain, on occasion, inaccurate or erroneous data. Very few on-line sources contain substantiated data concerning NIS impacts, though legislators and environmental managers are mainly interested in NIS populations that have significant impacts on the environment, quality of life, economy and/or human health (Olenin et al., 2011). The deficiencies and contradictions among online NIS information resources hamper and handicap NIS risk assessments, prioritization of management options and implementation of invasive species policies (Gollasch et al., 2007; David and Gollasch, 2008; Hulme and Weser, 2011). It is widely acknowledged that scientifically validated, continuously updated and maintained databases are the most reliable source for information on NIS status, their population dynamics, ecology and thereby serve as a strong basis for undertaking control measures (Genovesi, 2001). In order to be effective, information must be placed within the context and organized in a manner that is both logical and standardized (Simpson et al., 2006). Data management issues and long-term maintenance are both fundamental to providing an effective, pragmatic and accurate tool.

Here we describe an online information system on aquatic NIS introduced to marine, brackish and coastal freshwater environments of Europe and neighboring regions (AquaNIS) with one regional sea component (Baltic Sea) already opened for the wider public. AquaNIS inherited and incorporated multiple NIS data collections from earlier projects and initiatives to which the co-authors contributed, acknowledged in the Credits section of AquaNIS (www.corpi.ku.lt/databases/aquanis).

2. AquaNIS concept and implementation

An important feature of AquaNIS is its flexible, easily extendible structure, where new data blocks and functional modules may be added as necessary. Presently data are organized in four interrelated data blocks: "Introduction event", "Species", "Geography" and "Impacts" (Fig. 1). Data within blocks are grouped according to attributes, e.g., Development trait, Pathways and vectors.

2.1. "Introduction event" data block

The basic data entry in AquaNIS is an introduction event record, documenting a species introduction into a recipient region (Fig. 1). Here, the recipient region is a country and/or a country sub-area within a Large Marine Ecosystem (LME) or LME sub-region. The date of the first record indicates when a species presence was noticed in a region, according to different levels of certainty (year, decade or century). In AquaNIS only the first record of a NIS arrival to a recipient region is recorded. For example, if a NIS arrives to the recipient region "Italy-Adriatic Sea" this is recorded as an introduction event (see Section 2.3). The same species arrived to another recipient region within the same country, "Italy-Western Mediterranean", would be counted as another introduction event. So far, multiple arrivals of the same species into the same recipient region are not recorded, but may be remarked upon in the comment boxes provided. To address certain management requirements, e.g., ballast water management related risk assessment, an even more detailed occurrence of NIS can be documented in AquaNIS to the level of ports and port vicinities.

Species status refers to either a species being non-indigenous or cryptogenic (CS). In AquaNIS the following definitions are being used:

- Non-indigenous species (synonyms: alien, exotic, introduced, non-native): a species, subspecies or lower taxa introduced intentionally or accidentally by a human-mediated vector outside its natural range (past or present) and outside its natural dispersal potential (Occhipinti-Ambrogi and Galil, 2004; Olenin et al., 2010).
- Cryptogenic species: a species, which cannot be reliably demonstrated as being either non-indigenous or indigenous (sensu Carlton, 1996).

In each case information on the population status is provided and classified according to three levels of certainty: low, moderate (Table 1) and high. The latter is applied if a species' population status has been assessed using BINPAS (Bioinvasion Impact/Biopollu-

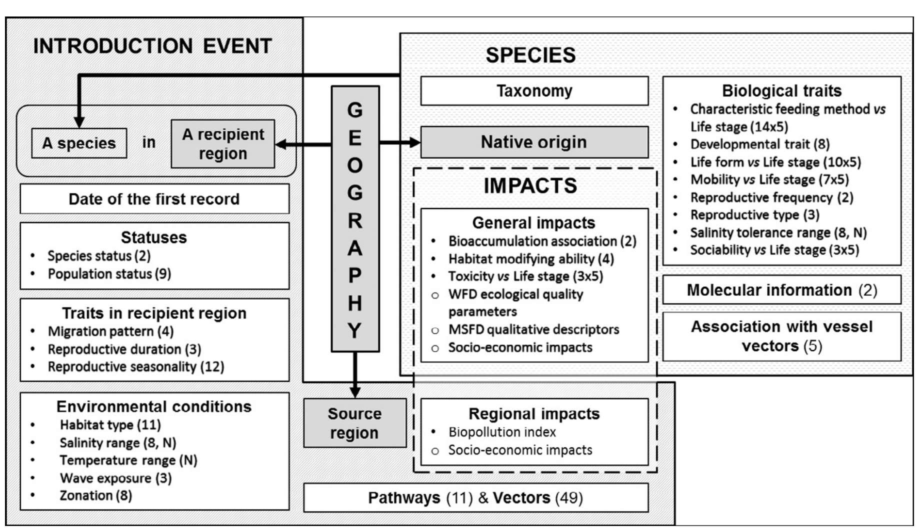


Fig. 1. Present structure of AquaNIS: two main (Introduction events and Species), one supporting (Geography) and one composite (Impacts) data blocks and attributes within them. Numbers in parentheses indicate how many predefined values are covered by each attribute; "N" means that numerical values are entered; "x" indicates a matrix of possible choices. Attributes indicated by open bullet points are under development.

Table 1
Low and moderate levels of certainty applied for the species population status.

Level of certainty	Value	Criteria
Low	Unknown	There is no reliable information on population status of a species
	Established	A species is known to form a reproducing population in a wild
	Not established	There is no evidence of a species' reproducing population in a wild
Moderate	Extinct (no recent record)	There are old records where a species was noted but have not been seen in the same region since
	Rare (single record)	There are only casual observations or a single record of a species' presence available
	Common	A species with successfully reproducing populations in an open ecosystem, which are unlikely to be eliminated by man or natural causes. Not dominating native communities
	Abundant	A species with successfully reproducing populations in an open ecosystem, which are unlikely to be eliminated by man or natural causes. Locally dominating native communities
	Very abundant	A species with successfully reproducing populations in an open ecosystem, which are unlikely to be eliminated by man or natural causes. Largely dominating native communities
	Outbreak	A species undergoing pulse-like, short-term (days to few months) exponential population growth during which they have an adverse effect on biological diversity, ecosystem functioning, socio-economic values and/or human health

tion assessment System) linked with AquaNIS (Narščius et al., 2012; BINPAS, 2013).

Following the introduction the population status may change over time, the NIS may spread to other localities within the recipient region and establish different levels of abundance. Changes in population status track the dynamics of an introduction. In AquaNIS the terminology used to describe the population status in a specific introduction event corresponds to the unified framework based on stages and barriers recently proposed by Blackburn et al. (2011). For example, "rare (single record)" in AquaNIS relates to NIS present but not reproducing (i.e., population "C0–C2" in the Blackburn et al. scheme). This opens an opportunity to use the Blackburn et al.'s model for scoring NIS populations. In combination with data on impacts (see Section 2.4) this will make AquaNIS more informative.

How a species was introduced to a recipient region is entered under attributes "pathways" and "vectors". A pathway is the route that a NIS took to enter or spread to a recipient region, while a vector is a transfer mechanism or the physical means by which a species was transported (Minchin et al., 2009). Each pathway may have a number of vectors. For example, the pathway "vessels" includes such vectors as "ballast water", "ballast tank sediments", "sea chests", "ship's hull", etc. More than one pathway and several vectors may be involved in a transfer of a species. A combined drop down and checkbox menu provides a choice of 11 pathways linked to 49 vectors. Following an entry, the level of certainty is required (Table 2). Both accidental and deliberate introductions are considered at a similar level of details.

The source region of a NIS is the area the species was introduced from to the recipient region. Depending on the information available it may be ascribed to a particular locality (e.g., port), a country, a LME or a larger ocean region. The source region of a NIS is often confused with the native origin, but due to secondary spread of a NIS a neighboring country or LME may be acting as a source. For example, the seaweed *Caulerpa taxifolia* (Vahl) C. Agardh, native to tropical coastal areas in the Caribbean, Indian and Pacific Oceans, was first noted in the Mediterranean in 1984 near the Musée Océanographique de Monaco, and in 1992 it was reported from Italy, whence it arrived from French waters (Galil, 2009b). Another NIS, the Ponto-Caspian water flea *Cercopagis pengoi* (Ostroumov, 1891) was first recorded in the vicinity of Estonian ports where it was introduced from the Black Sea (Cristescu et al., 2001). It then spread to neighboring Latvia, Finland and Sweden, the source region being Estonia. Later it spread to Lithuania, Russia (Kaliningrad) and Poland, here the source region may have been Estonia, Latvia, Finland or Sweden (Telesh and Ojaveer, 2002).

Following an introduction, the key environmental conditions for a NIS are recorded such as: habitat type, salinity range, and wave exposure. Traits of a NIS in the recipient region include its reproductive duration, seasonality, and migration pattern accessed through an array of drop-down menus and checkboxes. This information is specific to the introduction event, in contrast to the global knowledge on a NIS provided in the "Species" block.

2.2. "Species" data block

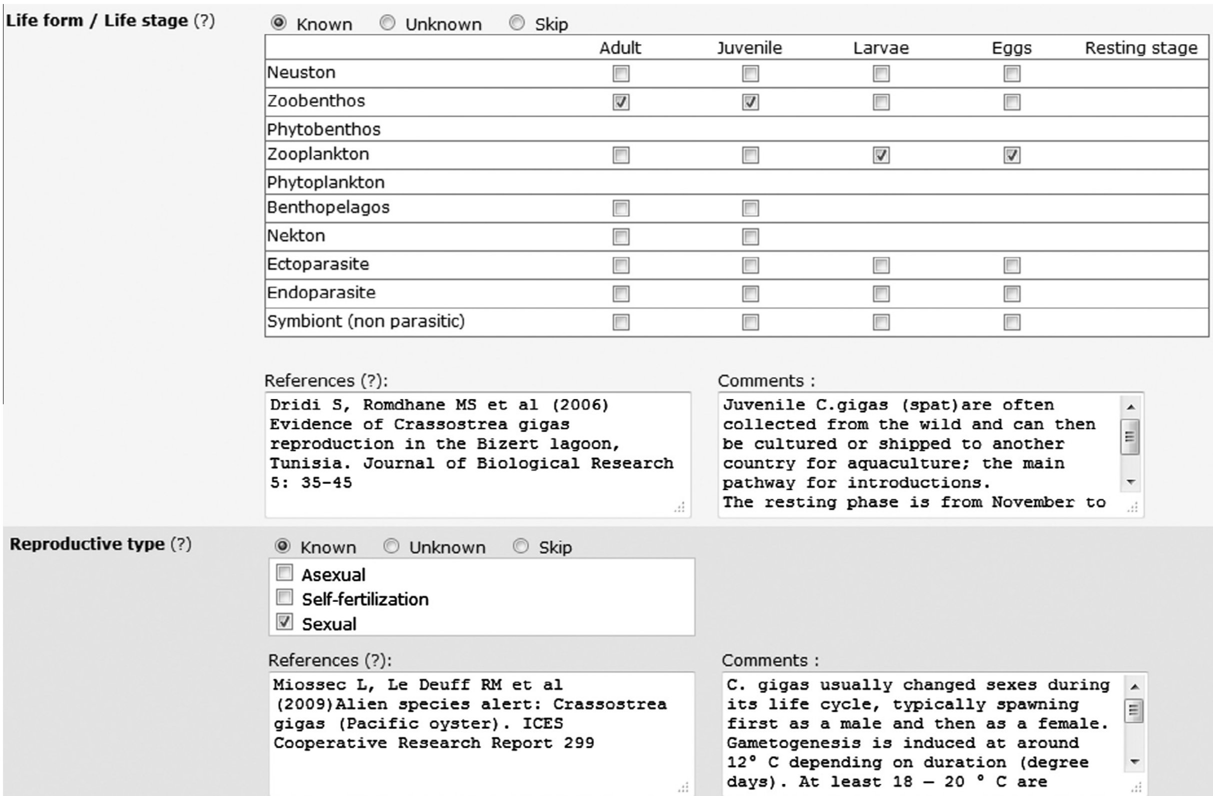
This block contains information on a NIS from native and invaded areas worldwide. This includes its taxonomy, native origin, recorded biological traits, etc. (Fig. 1).

Taxonomy is based on the updated accounts in a global organism-specific database, WoRMS (Appeltans et al., 2012), and is linked to list of NIS in a form of drop-down menu, so preventing typing errors while entering data. Native origin refers to a region where a species is native, i.e., where it has evolved or arrived there by natural means, without intentional or unintentional intervention of humans (sensu Pyšek and Richardson, 2010). It can be indicated according to its biogeographical range at different levels of scale from ocean to a LME or a country coast within a LME.

Biological traits cover eight attributes (Fig. 1). Those which may change during the life history cycle of an organism (life form, socia-

Table 2
Levels of certainty applied for pathways and vectors.

Level	Criteria
Direct evidence	The species was actually found associated with the specific vector(s) of a pathway at the time of introduction to a particular locality within a recipient region
Very likely	The species appears for the first time in a locality where a single pathway and/or vector(s) is known to operate and where there is no other explanation that can be argued for its presence except by this likely pathway and/or vector(s)
Possible	The species cannot be convincingly ascribed to a single pathway, but is known to be introduced by this pathway(s) elsewhere
Unknown	Occurrence of a given NIS cannot be clearly explained



Life form / Life stage (?) ◉ Known ○ Unknown ○ Skip

	Adult	Juvenile	Larvae	Eggs	Resting stage
Neuston	☐	☐	☐	☐	
Zoobenthos	☑	☑	☐	☐	
Phytobenthos					
Zooplankton	☐	☐	☑	☑	
Phytoplankton					
Benthopelagos	☐	☐			
Nekton	☐	☐			
Ectoparasite	☐	☐	☐	☐	
Endoparasite	☐	☐	☐	☐	
Symbiont (non parasitic)	☐	☐	☐	☐	

References (?): Dridi S, Romdhane MS et al (2006) Evidence of Crassostrea gigas reproduction in the Bizert lagoon, Tunisia. Journal of Biological Research 5: 35-45

Comments : Juvenile C.gigas (spat)are often collected from the wild and can then be cultured or shipped to another country for aquaculture; the main pathway for introductions. The resting phase is from November to

Reproductive type (?) ◉ Known ○ Unknown ○ Skip

☐ Asexual
☐ Self-fertilization
☑ Sexual

References (?): Miossec L, Le Deuff RM et al (2009)Alien species alert: Crassostrea gigas (Pacific oyster). ICES Cooperative Research Report 299

Comments : C. gigas usually changed sexes during its life cycle, typically spawning first as a male and then as a female. Gametogenesis is induced at around 12° C depending on duration (degree days). At least 18 – 20 ° C are

Fig. 2. Examples of entry format: Life form – Life stage matrix indicating life forms within the life cycle (top) and checkbox to specify reproductive type (bottom) for the Pacific oyster *Crassostrea gigas*.

bility, characteristic feeding method and mobility) are related to five history-stages (adult, juvenile, larva, egg and resting stage) and this data is presented as a matrix (Fig. 2). Other attributes (reproductive frequency, reproductive type and developmental traits) have menus to select predefined values. All values are briefly explained in pop-up notes.

Salinity tolerance range of a NIS may be indicated either by choosing the predefined Venice System (1958) zones or by entering minimum to maximum salinity levels. Molecular information indicates whether molecular markers are available for a species. The latter provides tools to identify NIS, their origin and history of introduction, their detection and monitoring. Association with vessel vectors provides verified records of a species transfer by ballast water, biofouling, tank sediments, etc. from any world region. This is different from the attributes pathways and vectors within the "Introduction event" data block where information has to be related to a given recipient region.

2.3. "Geography" data block

This block supports all geographic information used for entries in "Species" and "Introduction event" data blocks. Information is arranged in a hierarchical order ranging from oceans, ocean sub-regions, Large Marine Ecosystems (LMEs), sub-regions of LMEs to smaller entities, from which a user can make a selection (Fig. 3).

Large Marine Ecosystems (LMEs) are extensive areas of ocean space of 200,000 km^2 or more, characterized by distinct hydrographic regimes, submarine topography, productivity, and trophically dependent populations, adjacent to the continents in coastal waters where primary productivity is generally higher than in open ocean areas (sensu Sherman and Duda, 1999). The map of LMEs and all accompanying information is publically available at the NOAA (2013) website and may be used for the analysis of NIS distribution patterns, pathways, native origin, etc., within AquaNIS. Additional sea regions, not covered by the LME system (NOAA, 2013), are included to complete geographical coverage of marine and coastal regions (Fig. 4).

All countries are linked to relevant LMEs or LME sub-regions. This provides database search combinations "country + LME" or "country + LME sub-region" for different coasts and for a country that borders different seas, e.g.: "Germany within the LME 23 Baltic Sea", "Italy within the Adriatic Sea, a sub-region of LME 26 Mediterranean Sea". Such arrangement allows to indicate native origin or the source region of a NIS with different level of accuracy, from oceans to an LME or a country if known.

2.4. "Impacts" data block

The "Impacts" data block consists of two parts, containing different sets of data. One part (General impacts) includes information on species impacts from any world region, while the other one (Regional impacts) involves data on species impacts recorded in a particular recipient region.

2.4.1. Global knowledge on impacts (General impacts)

Evidence of environmental and socio-economic effects, documented in the peer-reviewed literature, is stored under general impacts. For example, the attribute "toxicity" refers to the ability of a NIS to produce a poison; "bioaccumulation" shows that a species may accumulate natural (e.g., phytotoxins) and/or anthropogenic (e.g., pesticides, and heavy metals) toxins. "Habitat modifying ability" means a given NIS is known to change or provide new habitats or is a keystone species (sensu Jones et al., 1994).

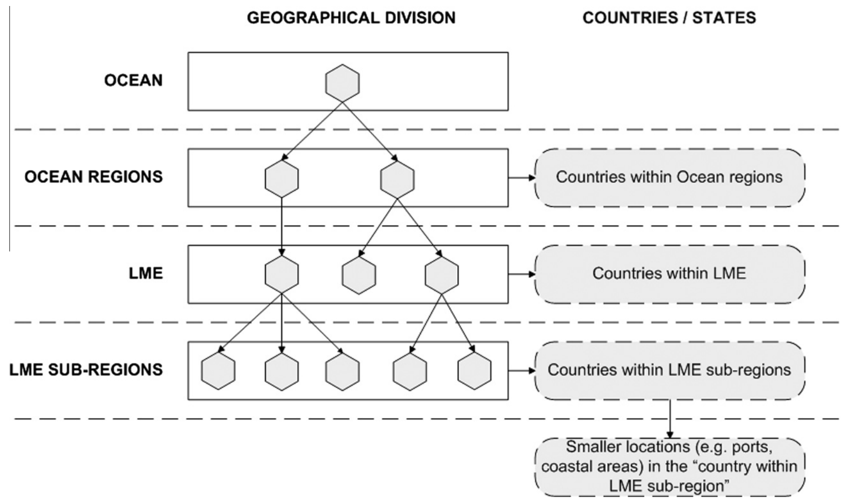


Fig. 3. The principal scheme of the GEOGRAPHY data block. LME – Large Marine Ecosystem (NOAA, 2013). LME sub-region – a relatively large, geographically well-defined sea area within an LME, e.g., Adriatic Sea within the LME 26 Mediterranean Sea. The list of countries is adopted from the UN Population Division's quinquennial estimates and projections (United Nations, 2012).

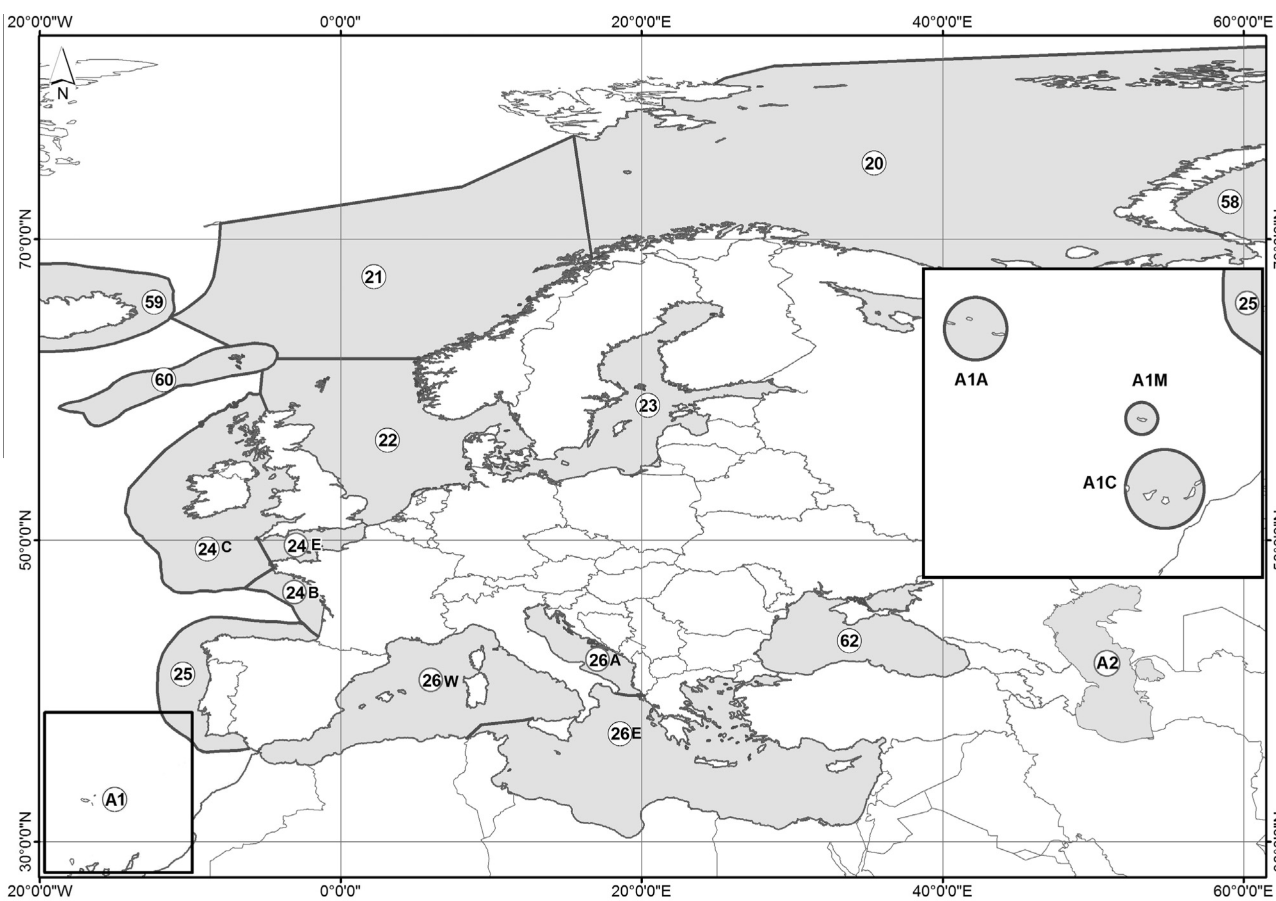


Fig. 4. Large Marine Ecosystems (LMEs) and LME sub-regions, where non-indigenous and cryptogenic species introduction events are recorded in AquaNIS. Numbers in open circles indicate Large Marine Ecosystems: 20 – Barents Sea; 21 – Norwegian Sea; 22 – North Sea; 23 – Baltic Sea; 24 – Celtic-Biscay Shelf with sub-regions (24C – Celtic seas, 24E – English Channel, 24B – Biscay); 25 – Iberian Coastal; 26 – Mediterranean Sea with sub-regions (26W – Western Med, 26A – Adriatic Sea, 26E – Eastern Med); 59. Iceland Shelf; 60 – Faroe Plateau; 62 – Black Sea. Additional LME-like regions: A1 – Macaronesia with sub-regions (A1A – Azores, A1M – Madeira, A1C – Canary Islands); A2 – Caspian Sea.

Two additional data attributes are being developed to support the decision process by managers and researchers measuring progress towards the implementation of both the EU Water Framework Directive (WFD) and the EU Marine Strategy Framework Directive (MSFD). Impacts on WFD ecological quality parameters will show how NIS may change the biological, physico-chemical and/or hydromorphological quality elements, while impacts on MSFD qualitative descriptors, will show how invasive NIS may alter indicators used to evaluate the environmental status set by the MSFD descriptors.

The "socio-economic impacts" sub-component, also under development, will store data on NIS impacts on human uses within the aquatic environment, i.e., fisheries and aquaculture activities, shipping, including recreational boating, tourism, and human health. There are generic scoring systems for NIS, e.g., for terrestrial weeds (Pheloung et al., 1999), FISK for freshwater fish (Copp et al., 2009), for mammals and birds (Nentwig et al., 2010; Kumschick and Nentwig, 2010), which provide a framework to identify the most harmful species. A similar system is intended for aquatic species within AquaNIS.

2.4.2. Introduction event-specific knowledge on impacts (Regional impacts)

Environmental impact assessments in any specified locality affected by an introduction event may be carried out using the biopollution index (BPL) approach (Olenin et al., 2007; Olenina et al., 2010; Zaiko et al., 2011). BPL is based on a classification of the abundance and distribution range of NIS in a defined area (assessment unit) for a defined period of time. BPL numerically expresses the magnitude of these impacts on communities, habitats and ecosystem functioning aggregated in a BPL index which ranges from "no impact" (BPL = 0) to "massive impact" (BPL = 4). Assessments of BPL are guided by BINPAS freely available online (Narščius et al., 2012; BINPAS, 2013). The regional impact assessments may be updated according to different stages of invasion (Olenina et al., 2010). The addition of site specific socio-economic impacts for each introduction event is foreseen in the later version of AquaNIS.

2.5. Data input and output functions

Entries throughout AquaNIS are supported by explanations of terms and guidance is provided for data input throughout logically separated data attributes. Drop down and checkbox menus, designed to reduce possible human error, enable rapid data entry. Also free text fields may be used to store references and comments. Since data may be entered and modified by different data suppliers all changes are stored in a separate "track-changes" table. Although AquaNIS contains more than thirty attributes, not all of them are likely to be equally saturated with data. The system provides an opportunity to check data completeness for each attribute separating between "unknown" and "not entered" data. Such data completeness check is recommended before making any analysis.

The search function retrieves listings or matrices using interrelated data tables of any combinations of attributes, for example, biological traits, introduction date, pathways, regions, habitat type, etc. Lists and matrices can be exported and downloaded to MS Excel worksheet files. This function greatly facilitates the dimension of the database for specific needs (e.g., further analyzes with Primer, MatLab, etc.).

All entered data is checked as far as is possible to current taxonomic status and references are supplied to qualify each entry. This process is controlled by the AquaNIS Editorial Board, responsible for gathering, editing and validating data. The history of all entries is recorded for each species and introduction event tracing the chain of all alterations made by contributors.

3. AquaNIS in use: some examples

At present AquaNIS contains data on more than 1210 aquatic NIS and CS in 50 recipient regions in Europe and neighboring areas. The NIS list represents a broad spectrum of free-living and parasitic multicellular and unicellular organisms including 34 phyla, 68 classes, 187 orders, 515 families and 851 genera. These numbers are revised with the inclusion of newly recorded NIS and their spread into new regions, with changes to nomenclature and taxonomy. Because of the dynamic nature of the database, the species numbers, figures and all other calculated outputs are changing, so reflecting the level of our present knowledge. Below we provide examples of information, extracted from each of the separate blocks. We excluded from the analyzes those LMEs, for which the entered data require further verification.

3.1. Example 1: metazoan NIS richness by phyla in Europe's regional seas

The number of multicellular NIS recorded in AquaNIS from the Mediterranean Sea, Celtic Sea – Biscay Shelf, North Sea and Baltic Sea is 868. The most species rich taxonomic groups in these LMEs are: Mollusca, Arthropoda, Chordata, Annelida and Rhodophyta, comprising 28%, 19%, 18%, 11% and 10% of the total NIS, respectively (Fig. 5). Arthropods provide the highest number of species recorded from more than one LME.

3.2. Example 2: new arrivals

NIS have been recorded continuously, with approximately two new records annually during the past decade, in each LME (Table 3, and Fig. 6). The eastern Mediterranean is an exception, with an average of a dozen NIS records annually, mostly due to invasions through the Suez Canal (Galil, 2009a).

For the risk assessment of newly recorded NIS, it is important to know the "unique" NIS, i.e., those NIS only found to occur in a single LME region, as these species may spread further to neighboring seas. Such lists of "unique" NIS may be retrieved using the AquaNIS search result comparison function for each recipient region or any

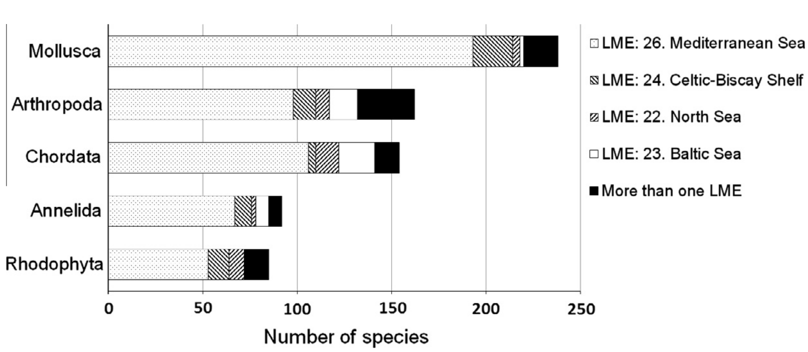


Fig. 5. Non-indigenous species richness of the largest phyla in four LMEs. The last segment on the right-hand side (colored black) indicates the number of NIS found within more than one of these four LMEs. Only multicellular organisms are included.

Table 3
Metazoan NIS recorded in LME of Europe and neighboring regions since the beginning of XXI century.

LME/LME sub-region	Total number of metazoan NIS	Number of metazoan NIS since 2000	Number of unique metazoan NIS since 2000
22. North Sea	143	22	8
23. Baltic Sea	97	22	8
24. Celtic – Biscay Shelf	145	22	10
26 W. Western Mediterranean Sea	174	32	6
26A. Adriatic Sea	107	28	5
26E. Eastern Mediterranean Sea	546	209	168

other geographical level (LME sub-region, LME, etc.). The resulting lists may be further analyzed by searching the biological traits information, known pathways and/or vectors involved in the transfer of each species, or their native origin. The highest number (80%) of newly recorded NIS since the turn of the last millennium have been reported from the eastern Mediterranean Sea, part of the ongoing Erythraean invasion (sensu Galil, 2009a).

3.3. Example 3: temporal patterns of NIS and CS

The number of NIS in a given region or country is the most often used indicator for bioinvasions (EEA, 2012). It is assumed that regions with already large numbers of NIS are at greater risk of exposure to human mediated vectors of introductions and hence to future invasions (Olenin et al., 2010). Such data enables targeting of species dispersal hubs.

Distinguishing between NIS and CS is needed both in theoretical invasion ecology studies (Carlton, 2009) and in applied research. Some CS demonstrate invasive characteristics and may cause significant impacts (e.g., Olenina et al., 2010). Their origin may be deduced using molecular tools. As a result of this, and due to more careful and regular monitoring, datasets for NIS will become more complete.

There is a substantial difference in the cumulative number of NIS and CS recorded in two adjacent regions, the North and Baltic seas, with a higher number of records since 1900 in the North Sea (Fig. 6). However, the first record for almost 10% of NIS and CS remains unknown and influences the steepness of the accumulation curves. Using the AquaNIS database we found that the ratio of CS to NIS is lower in the Baltic Sea (10% versus 38% in the North Sea), probably because a new species is easier to spot in a species poor sea like the Baltic. This ratio is likely to decline in the future, due to increased attention paid to NIS detection; for example in the Baltic 40 NIS were added since 1970, but only a single CS, the dinoflagellate *Prorocentrum minimum* (Olenina et al., 2010).

The number of unicellular NIS and CS is low compared with the metazoans recorded in both seas. Generally, unicellular taxa are underestimated, due to their small size and taxonomic difficulties. For example, out of 107 species presently recorded in association with vessel vectors in AquaNIS, ca. 90% are metazoans.

4. Implications for management and strategic considerations

4.1. Serving management

AquaNIS is capable to integrate data from the existing blocks to derive information to support management. For example, in the mapping of the spread of NIS between and within LMEs, identifying principle pathways and vectors within countries and LMEs, defining the most invasive species as well as "next pests" (sensu Hayes et al., 2005) to provide target lists for monitoring. Supplementary information on biological traits, environmental ranges, and habitat preferences of NIS will serve to increase the accuracy of selecting NIS of management consequence. In addition, this information may be used in research of invasiveness determinants (van Kleunen et al., 2010) through traits comparisons between (i) invasive and non-invasive NIS, (ii) successful invasive NIS and expanding/common native species, and (iii) non-invasive NIS and declining/rare natives. Bioinvasion impact assessment tool integrated to the "Impacts" data block provides an opportunity to assess the magnitude of environmental impacts caused by NIS in recipient regions or localities within regions.

Furthermore, different uncertainties and incomplete knowledge related to NIS are addressed in AquaNIS by providing a distinction in data reliability (e.g., Tables 1 and 2). That clearly identifies possible sources of ambiguity, which have to be taken into account in both bioinvasion research and decision making process.

The structure of AquaNIS is sufficiently flexible to accommodate an additional block on various management options such as prevention, eradication, containment, control of spread and miti-

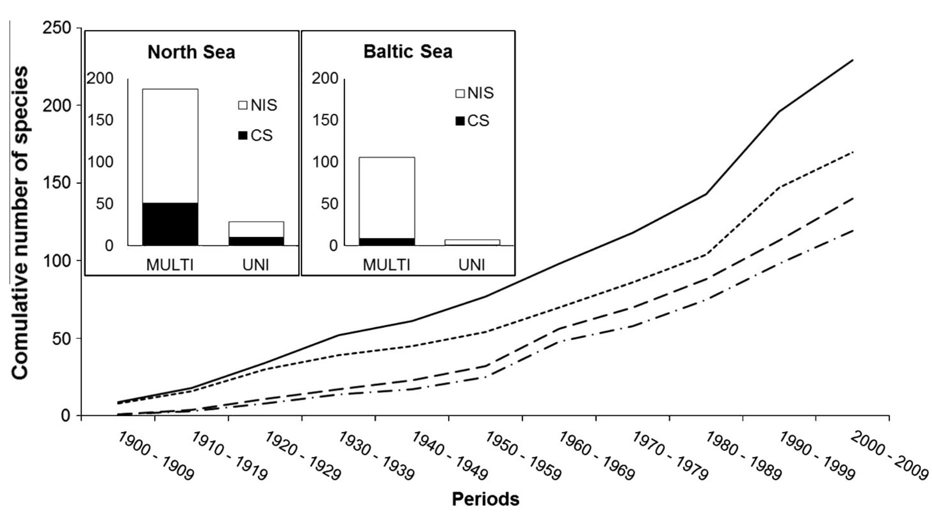


Fig. 6. Cumulative numbers of non-indigenous species (NIS) and cryptogenic species (CS) occurring in the North and Baltic seas since 1900. Inset: the difference in the numbers of metazoan (MULTI) and unicellular (UNI) NIS and CS for both seas.

gation (Lodge et al., 2006; Olenin et al., 2011). Here we provide some examples how AquaNIS can be used for management.

4.1.1. EU Marine Strategy Framework Directive

An ecosystem approach to the management of the marine environment is the backbone of MSFD, a recent European legislation. Such an approach to management requires, amongst others, integrated ecosystem assessments to inform policy decisions and regulate human pressures (Borja et al., 2010; Elliott, 2011). There are only a few cases where information on NIS has been involved in marine ecosystem assessments (e.g., Ojaveer and Eero, 2011). Due to their significant impacts to marine ecosystem structure and function (e.g., Wallentinus and Nyberg, 2007), NIS should be considered as an integral component of such assessments. This need is even more pronounced and urgent, when considering that NIS may exert significant impact, e.g., on the dynamics of commercial fish stocks (e.g., Oguz et al., 2008). Estimation of the magnitude of bioinvasion impacts is a prerequisite for incorporation of NIS in environmental status assessments for the MSFD (Olenin et al., 2010). Zaiko et al. (2011) performed a regional scale analysis of such impacts, whereas all the supporting data was stored in BINPAS, an integral part of AquaNIS.

4.1.2. ICES code of practice

Aquaculture is one of the major pathways for the spread of NIS (Minchin et al., 2009). NIS which have been transferred with stock movements are registered in AquaNIS. The ICES code of practice, inter alia, calls to undertake risk assessments in advance of new introductions (ICES, 2005). Such assessments require information on a species life cycle, its native range, source region, environmental tolerances, natural and human-mediated dispersal mechanisms, etc., which may be stored in AquaNIS.

4.1.3. IMO ballast water management convention

The International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM Convention) has incorporated a selective approach: based on risk assessment, exemptions from BWM requirements may be introduced (IMO, 2007; David and Gollasch, 2008). The "same location" concept implies that certain vessels may be permanently exempted from BWM requirements in cases when the ballast water source and recipient ports are situated in the same location (Gollasch and David, 2012; David et al., 2013). Having available data about the presence and abundance of NIS in ports or their vicinities will support the identification of the biological similarity between the source and recipient ports, as well as the risk to transfer NIS. In the future an automated risk assessment module can be developed within AquaNIS using accumulated information.

4.2. A good database is a "living" database

Many NIS databases have been developed within the framework of short term national or international projects. Emphasis has often been placed upon database design involving sophisticated web-technologies more focusing on developing the database structure, and less on populating it with data and elaborating ecologically meaningful data output functions. As a result, the utility of the database peaked close to the end of a project resulting in scientific publications and reports for managers produced shortly afterwards.

A service-oriented information system AquaNIS with its flexible search functions enables environmental managers and others to extract the needed information. However, the utility of a database depends not only on the technologies used and the deliverables obtained by the project, but whether information derived from the database is demanded by users over time and how the system is being maintained after project termination. Unfortunately it is easier to obtain funding for developing new databases than for database collaboration, adaptation, improvement and maintenance (Simpson et al., 2006). Without continuous maintenance, update and data quality control, the usefulness of the database diminishes over time and its users may be hampered by outdated and therefore misleading information (Fig. 7). In an ideal situation the funding of a database should be secured at a basic level for technical support and for data management. The benefits of a "living" database grow as it accumulates and updates entries, incorporating them into the existing structure.

A scientific community is needed to achieve the long-term maintenance and reliability of the database, because it requires frequent updating and corrections (e.g., Costello, 2009; Costello et al., 2014). An effective information system requires an editorial board composed of scientists with taxonomic, biogeographic or other needed maritime expertise to ensure data quality. Relevant expert groups may be approached for assistance, such as the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) of the International Council for the Exploration of the Sea (ICES), and the Working Group on Ballast and Other Ship Vectors (WGBOSV), which has ICES, the Intergovernmental Oceanographic Commission (IOC) and the International Maritime Organization (IMO) as parent organizations.

AquaNIS differs substantially from existing NIS information sources in its organisational principles, structure, functionality, and output potential for end-users. The system is designed to assemble, store and disseminate comprehensive data on NIS. It may be used for management instruments in the future, because its structure is flexible, easily extendible, and new data blocks and functional modules may be added as necessary.

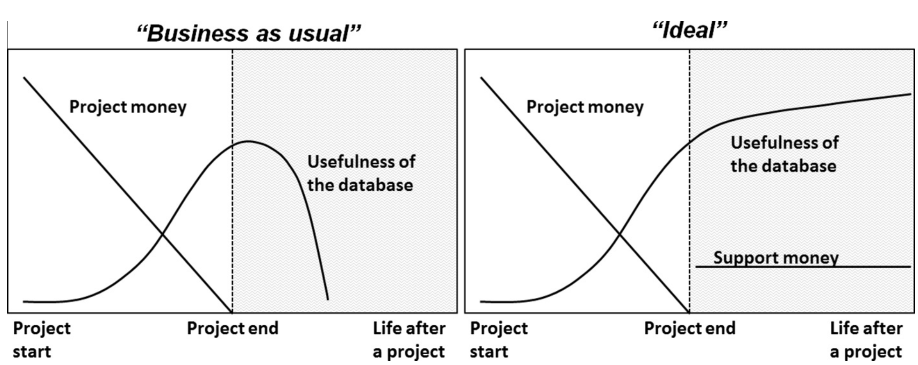


Fig. 7. Usefulness of the database under "Business as usual" and "Ideal" database management scenarios.

Acknowledgments

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement No. 266445 for the project Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS). HO was partly supported by the Estonian Ministry of Education and Research (Grant No. SF0180005s10) and by the project "The status of marine biodiversity and its potential futures in the Estonian coastal sea" 3.2.0802.11-0029 of Environmental protection and –technology programme of European Regional Fund. The authors appreciate the assistance of Greta Srėbalienė, Nadav Kallenberg, Romualda Chuševė and Maiju Lehtiniemi for populating AquaNIS with data, and Ingrida Bagdanavičiūtė for preparing the map. The authors are grateful to the Guest Editor and three anonymous reviewers for helpful comments and the ideas for future development of AquaNIS.

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