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Information Management

European Alien Species Information Network (EASIN): supporting European policies and scientific research

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Abstract

The European Alien Species Information Network (EASIN) was launched in 2012 by the European Commission to facilitate the exploration of existing alien species information and to assist the implementation of European policies on biological invasions. At the core of EASIN, there is an inventory of all known alien and cryptogenic species in Europe (the EASIN Catalogue, herein published), which includes relevant information, such as taxonomic classification, pathways of introduction, year and country of first introduction. Spatial records of species occurrence in Europe are stored in the EASIN geo-databases, integrating data from many data providers and the literature. All this information is publicly available through a widget framework, providing easy to use and flexible tools for searching and mapping. The EASIN datasets have been used for pan-European or regional assessments of pathways and gateways of alien invasions, towards the fulfilment of the related targets of the Convention on Biological Diversity and of European policies. Moreover, in support of the new EU Regulation on the prevention and management of the introduction and spread of invasive alien species in Europe, an Early Warning and Rapid Response System is being developed by EASIN.

Key words: biological invasions, EASIN, Europe, information systems, invasive alien species

Introduction

Europe is severely affected by biological invasions, which impact biodiversity, ecosystem services, economy and human health (Kettunen et al. 2009; Shine et al. 2010; Vilà et al. 2010; Kumschick and Nentwig 2010; Roques 2011; Vaes-Petignat and Nentwig 2014; Katsanevakis et al. 2014a). A conservative estimate of the annual damage caused in the European Union (EU) by alien species is € 12 billion (Kettunen et al. 2009; Shine et al. 2010). The need for robust action to control biological invasions and thus mitigate their

impacts has been globally recognized, and several related instruments have been adopted.

The Convention on Biological Diversity (CBD) calls for the "compilation and dissemination of information on alien species that threaten ecosystems, habitats, or species, to be used in the context of any prevention, introduction and mitigation activities" (CBD 2000). The objective set by Aichi Biodiversity Target 9 is that "by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment". This objective is reflected in Target 5 of the EU Biodiversity Strategy (EU 2011). In Europe, the Marine Strategy Framework Directive (MSFD; EU 2008) also recognises alien marine species as a major threat to European biodiversity and ecosystem health, requiring Member States to consider them when developing strategies so that all European Seas reach Good Environmental Status by 2020. The new EU Regulation (EU 2014) on the prevention and management of the introduction and spread of invasive alien species is a dedicated instrument to mitigate the impacts of biological invasions in Europe. The European Commission, European countries, and their relevant authorities will have, under the new EU legislative instrument, obligations and commitments in respect to invasive alien species (IAS). These include prioritising pathways for prevention, identifying the most harmful species for responses (list of species of EU concern), enforcing effective early warning and rapid response mechanisms for the IAS of EU concern, eradicating such species at an early stage of invasion, and taking management measures for IAS that are widely spread.

Sufficient high quality information on alien species ecology, distribution, pathways of introduction, impacts, and effective management strategies is a prerequisite for the efficient prevention, early detection, rapid response, management of biological invasions (Lee et al. 2008; Simpson et al. 2009; Hulme and Weser 2011; Gatto et al. 2013), and the effective implementation of the above-mentioned legislative instruments. In Europe and globally, there is plenty of available information, but it is scattered across many different information systems and databases. To effectively support policies and scientific research on biological invasions in Europe, and to efficiently use the already accumulated knowledge, there is a need for standardization, harmonization and integration of existing online and offline information systems (Gatto et al. 2013). To achieve this goal, the European Commission's Joint Research Centre (JRC) launched the European Alien Species Information Network (EASIN) in September 2012 (http://easin.jrc.ec.europa.eu). The stated aim of EASIN was to "facilitate the exploration of existing alien species information from distributed sources through a network of interoperable web services, and to assist the implementation of European policies on biological invasions" (Katsanevakis et al. 2012).

EASIN works in partnership with European and global data providers to facilitate access to key data and information on alien species, promotes the principles of open-source, ensures accreditation of data publishers and data owners, highlights the work of other initiatives, increases their visibility, and facilitates direct access to the original information/data (Katsanevakis et al. 2013a). A data discovery portal (http://easin.jrc.ec.europa.eu/) has been implemented, which focuses on the information that is needed by officers and scientists to support decision-making (e.g. distribution of IAS, pathways of introduction, records of invasiveness in Europe and globally, and management alternatives). Tools and web services that allow easy exploration, visualization, and best use of alien species data have been developed and are continuously improved. Furthermore, EASIN is directly supporting the new Regulation (EU 2014) by developing a dedicated Early Warning and Rapid Response System, as therein provisioned.

The aim of this paper is to present EASIN and its approach for harmonizing and integrating information on alien species, describe the main structural components of EASIN, discuss related technical issues and developments, and portray the role of EASIN for supporting European policies. Furthermore, the inventory of alien species of Europe (EASIN Catalogue version 4.0 as of November 2014) with useful information for each species (taxonomic classification, year and country of first introduction, status, pathways of introduction) is included as Supplementary material, to be publicly available. Some scientific outputs from the integrated information provided through the EASIN Catalogue are summarized to demonstrate some of the applications of the system.

EASIN Catalogue

The EASIN catalogue (Supplement 1) is the core of the EASIN platform (Katsanevakis et al. 2012),

entailing the basic information needed (1) to efficiently link to existing online databases and retrieve spatial information for alien species distributions in Europe, (2) to access more detailed information in other sources, such as research articles, factsheets and webpages, and (3) to analyse spatial and temporal trends and patterns of biological invasions. The EASIN Catalogue is essentially a pan-European inventory of alien and cryptogenic species with species-specific information such as taxonomic classification, pathways of introduction, year and country of first introduction in Europe, and native range in Europe (in cases where species are native in some regions of Europe and alien in others).

The first version of the EASIN Catalogue was compiled by harmonizing and integrating information from 43 online databases (as described in detail in Katsanevakis et al. 2012). Subsequently, this initial compilation of the Catalogue was checked, revised, and updated by taxonomic experts. The latter process has been completed for all aquatic species and most of the terrestrial groups (see Supplement 1).

In the EASIN Catalogue, each species has a unique identification code. A formal procedure is followed for updating the catalogue so that all modifications and updates are traceable. A versioning mechanism, based on the LSID (Life Science Identifiers) approach (TDWG 2011), allows tracking of any change in the catalogue. A unique LSID is generated by the system for each collection of species selected by the user. This LSID will allow the user to reach the latest revision of the EASIN catalogue data, when accessing the EASIN system again. If updates take place in the meantime, the system will provide notifications for the updated species.

Since May 2014, an Editorial Board (EB) was launched, responsible for all changes and updates of the EASIN Catalogue (http://easin-eb.jrc.ec.europa.eu) The EASIN EB is the key tool for the quality assurance of the EASIN Catalogue. The Members of the EB are taxonomic experts responsible for specific groups of species. The EB is supported by an online platform that allows registered users to make suggestions for corrections/additions to the EASIN Catalogue, e.g. in relation to nomenclature, status of a species, missing species, pathways of introduction, etc. A registered user can open a discussion by raising a Ticket about a species, which will be assigned to the relevant EB Member. The discussion takes place among EB Members and registered users. At the end of it, the Ticket will be rejected or accepted, and a Notification including the new species data will be sent to the EASIN Catalogue Master, who will be responsible for updating the EASIN Catalogue.

EASIN databases

The EASIN databases' technology currently in use relies on Microsoft solutions (SQL Server plus related services) and the main structure actually consists of three distinct databases (Figure 1):

A) 'Catalogue', where the EASIN Catalogue is stored and all its changes are tracked;
B) 'Cache', where the information retrieved by the data providers participating in the network is indexed, harmonized and integrated;
C) 'Geo', where the information retrieved by the data providers is transformed and becomes available for providing maps and performing spatial analysis.

The EASIN data broker service, created for allowing the EASIN platform to index heterogeneous data resources managed by different data providers, uses the Catalogue database for identifying the alien species to be checked for records of occurrence. Each data provider has its particular data model, storage type, publishing approach, and standard that follows a specific data brokering procedure. Three different categories are identified so far: offline data providers (Access Database, ArcGIS Database, Excel File); online data providers with private access (SQL Database); online data providers with public access (XML File - Web Service).

In case of changes in species and related records on each data provider, the EASIN data broker tags and clusters the records, retrieving information about spatial, temporal, and publisher references, and then harmonizing and integrating these data in the 'Cache' database. The information indexed and retrieved by the EASIN data broker from the data providers includes the name of the species, when and where the species was found, and a reference to the original source of the record. Depending on the data provider, the dates (when), the locations (where) and the sources (who reported) are reported in different formats – (x, y) coordinates, ARCGis Shape, SQL geom, or plain text – and they are stored in the Cache database using the standard GML model defined by the Open Geospatial Consortium (OGC 2014).

The final step is the transformation of the retrieved records and occurrences to the EASIN

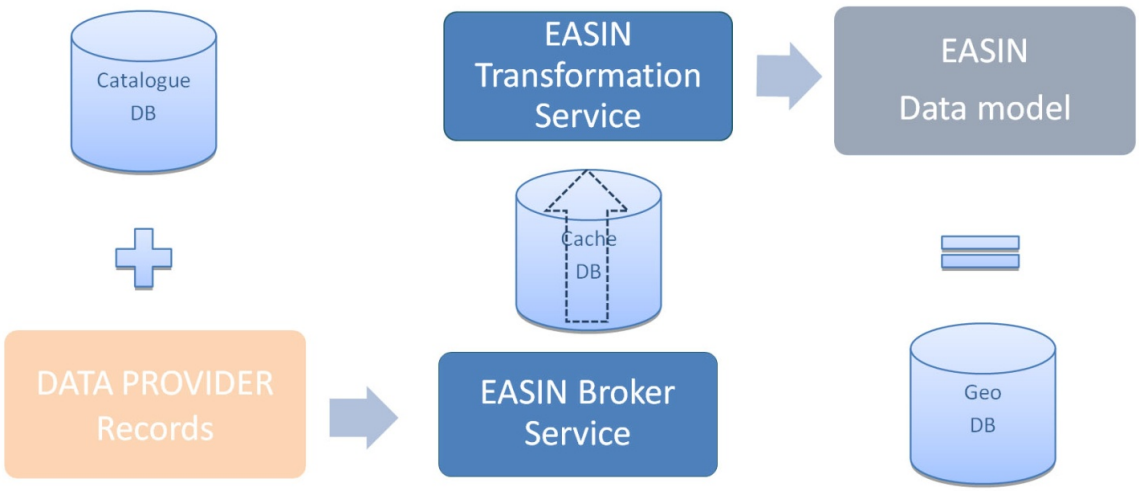

Figure 1. Flow chart of information among the three EASIN databases: 'Catalogue', 'Cache', and 'Geo'. Specific information about species (valid name, common names, synonyms) are extracted from the Catalogue database and used for retrieving the related records of occurrence from the data providers through the EASIN broker service. The records (together with temporal information and publisher references) are harmonized and stored in the Cache database. Then through the EASIN transformation service, the records are transformed and integrated to the EASIN data model and stored into the Geo database, ready to be exported for creating maps and for spatial analysis.

data model and their storage in the 'Geo' database, ready to be exported for creating maps and for spatial analysis (Figure 1).

EASIN Tools & Services - Widget Framework

The Widget Framework (http://easin.jrc.ec.europa.eu/use-easin) provides tools and services through which harmonized information from the EASIN Catalogue, and species records from the 'Geo' database are exposed to the public. Any person or organisation might query for any combination of species across Europe by searching for species names or by filtering elements of the EASIN catalogue, such as taxonomic classification, environment, impact, species status, and pathways (Figure 2). After defining such a query, the user can obtain a map showing the spatial distribution of records of the selected species across Europe. Currently, maps of occurrence records can be created at four levels: by country, marine eco-regions, river basins, and on a standard 10×10 km grid. Moreover, the result can be narrowed or widened by excluding/including data providers, excluding/including the native range of species that are partially native in Europe (i.e. for species that are native in some European regions but alien in others), and by selecting only records within a specified time range. The results of the search and mapping widgets can be saved by each user and retrieved again in the future. The widget framework can be embedded within any internet site without any need for installation, as it is simply loaded remotely when the web page is opened. Moreover, the Widgets are completely platform-independent as all that a user or a third party embedding the widgets needs is a web browser (see more details in Katsanevakis et al. 2012).

EASIN-Lit

EASIN-Lit (abbreviation of EASIN-Literature) was developed by the JRC to facilitate access to spatial data published in the scientific and grey literature (Trombetti et al. 2013). It consists of a geo-database of geographic datasets on species records and distribution ranges. Furthermore, published information at country level (mainly national reviews) is also compiled to build national inventories of reported alien species. EASIN-Lit is connected to the EASIN platform contributing to the enrichment of the geo-spatial catalogue and the improvement of the EASIN maps of species records. The process of retrieval of spatial data from the literature is on-going, and regular updates are made publicly available through the EASIN portal.

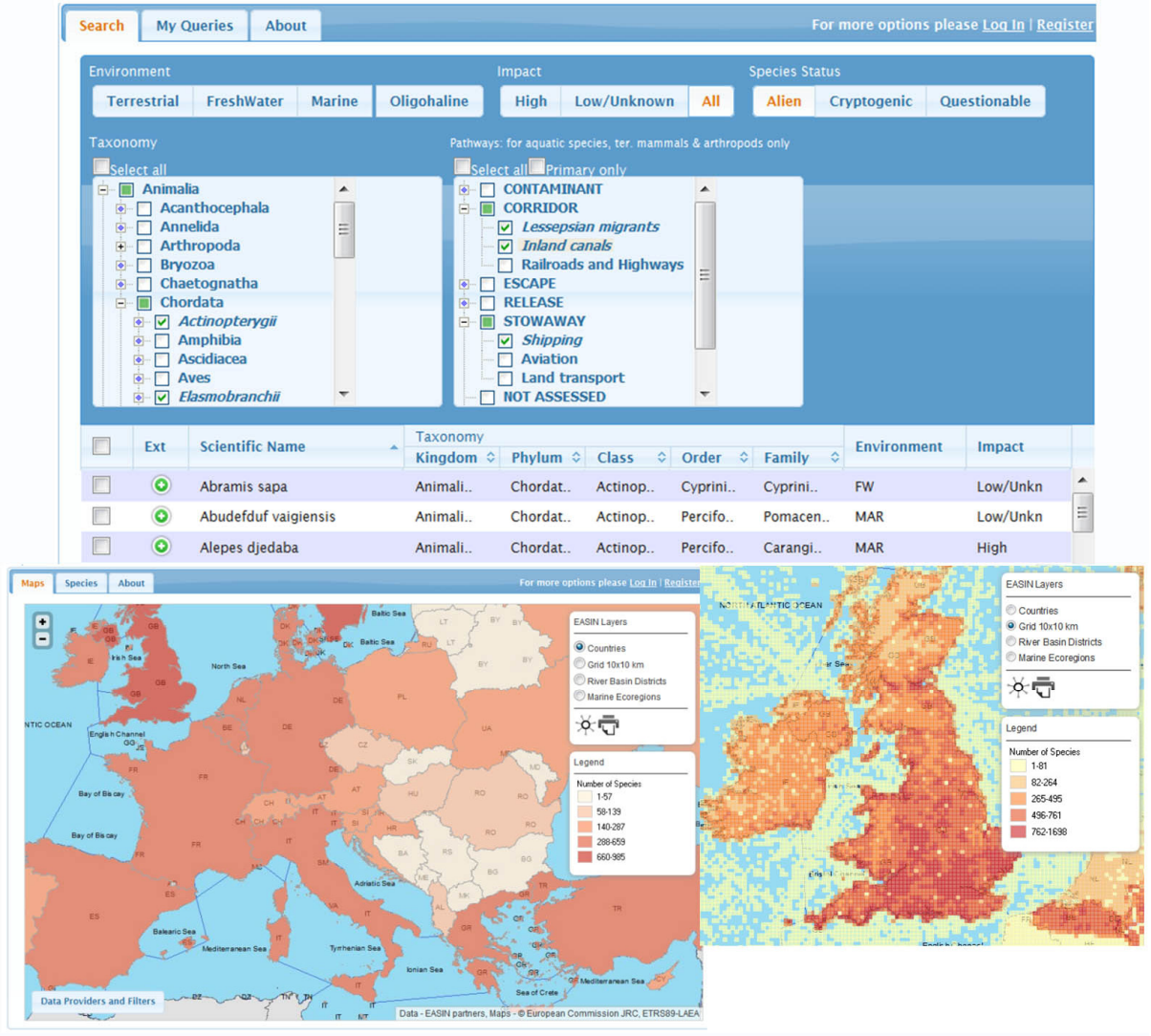

Figure 2. The EASIN widget for searching/mapping the spatial distribution of records of groups of species, selected based on various criteria (top), and examples of such maps on a country level (bottom, left) and on a 10×10 km grid (bottom, right).

From each analysed publication, data about location, year of sampling and citation are retrieved and stored in the EASIN-Lit geo-database. All the geo-referenced records are subject to verification by checking against site descriptions or place names as described in the paper, to avoid acquiring false data. If the reported location is not geo-referenced, a conversion of cited locations or maps to a spatial format is performed with the best possible accuracy. When available, a hyperlink to the full text of the article or to the publisher's webpage is also included in the database record.

Many journals, such as *Aquatic Invasions*, *Biodiversity Data Journal, BioInvasions Records*, *Marine Biodiversity Records*, and *Mediterranean Marine Science* encourage the inclusion and regularly include in their published articles georeferenced records of alien species. These journals constitute an important source of alien species records, and may even substantially contribute to early warning and rapid response systems (Panov et al. 2011), as the one currently under development by EASIN.

Currently, EASIN-Lit covers existing data about the distribution of alien species in the marine,

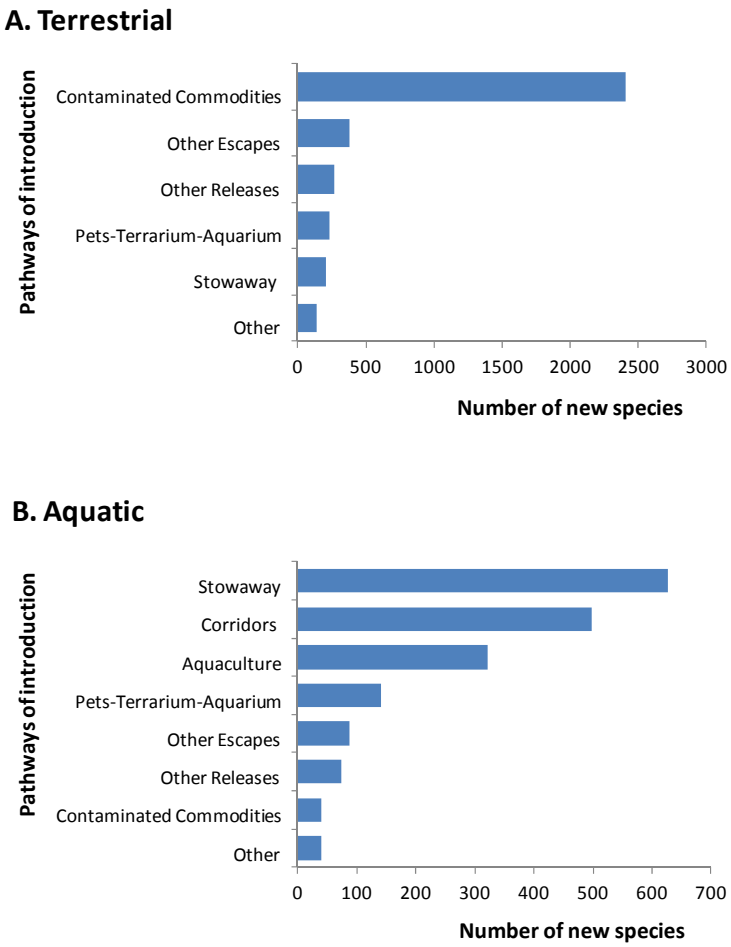

Figure 3. Number of terrestrial (A) and aquatic (B) alien species known or likely to be introduced by each of the main pathways. Some species (377 terrestrial and 268 aquatic) are linked to more than one pathway. Pathways of introduction shown are Stowaway (introductions due to shipping, aviation and land transport), Corridors (through the Suez canal and inland canals), Aquaculture (escapes or contaminants), Pets-Terrarium-Aquarium (releases or escapes), Other Escapes (from zoos, botanical gardens, ornamental planting, cultivation, livestock, use of live food-bait), Other Releases (due to biocontrol, game animals, landscaping-erosion control), and Contaminated Commodities (due to trade of contaminated commodities and packaging materials).

terrestrial and freshwater environments. Information from 466 publications has been included, covering geo-referenced records for 344 species (6729 single records) and country-level occurrences for 2350 species.

EASIN scientific outputs

The EASIN database has been already used to support scientific research on biological invasions. As the marine part of the EASIN Catalogue was the first to be validated and filled with important information (i.e., pathways, year and country of first introduction, occurrence records), the first EASIN-based studies had a marine focus. An analysis of the taxonomic identity and distribution by country of all alien and cryptogenic marine species of Europe was the first published study out of the EASIN datasets (Katsanevakis et al. 2013b). This was followed by assessments of the pathways and gateways of introduction of marine aliens in Europe and trends in new introductions (Katsanevakis et al. 2013c; Nunes et al. 2014). EASIN spatial data were used to assess how biodiversity patterns in the Mediterranean Sea are shaped by human activities (Katsanevakis et al. 2014b). In the later study, the alien-to-native ratio of fish and invertebrates richness was estimated in the Mediterranean Sea, which is one of the suggested indicators for the assessment of Good Environmental Status according to the MSFD (EU 2010).

In the current version of the EASIN Catalogue (v4.0; see Supplementary material), there is information on pathways, countries and time of first introduction for most of the taxonomic groups: all aquatic species and terrestrial arthropods, mammals, reptiles, amphibians, birds, nematods, fungi, chromists, and invasive plants.

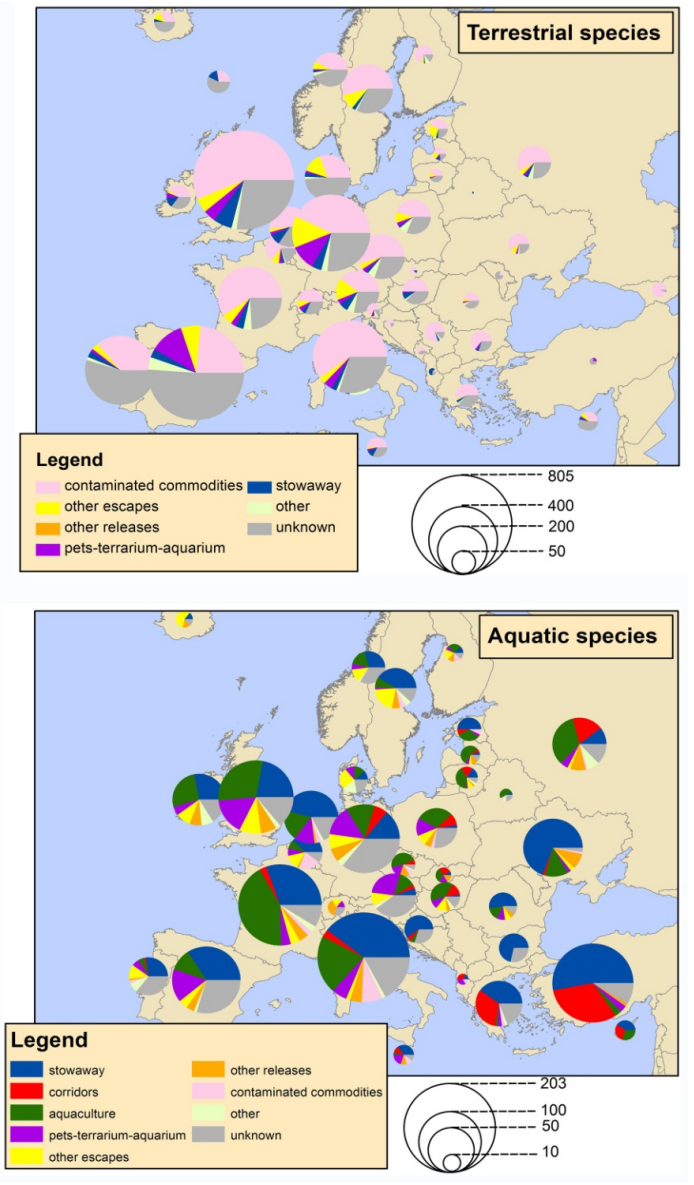

Figure 4. Geographic variation of the importance of main pathways of introductions in Europe, of aquatic and terrestrial alien species. The size of the pie charts indicates the approximate numbers of alien species per recipient country of first introduction. Species of European origin have been counted in the country of first introduction in their alien range. Outermost regions were excluded. A few species that were linked to more than one pathway were given a value of 1/k for each of the k associated pathways so that the overall contribution of each species to the pie charts was always 1. Pathway categories as in Figure 3.

The classification of pathways of introduction was based on the framework proposed by Hulme et al. (2008). Based on a thorough review of the scientific and grey literature, the country of initial introduction ('recipient country') and the year of initial introduction was identified for most of the assessed species. In some cases, recipient countries could be identified with certainty (e.g. most commodity species introduced for cultivation or aquaculture), while in other cases the country of first observation of the species in Europe was assumed to be the recipient country. The date of first observation of an alien species in Europe was used as the best available estimate of the year of its initial introduction, when the latter could not be determined with certainty.

Based on the current information of the EASIN Catalogue (7345 species assessed out of 15231 in total), the most important pathway of introduction for terrestrial aliens is by far the trade of contaminated commodities, while for aquatic species shipping (stowaway), corridors (mainly the Suez Canal but also inland canals) and aquaculture are the most important (Figures 3, 4).

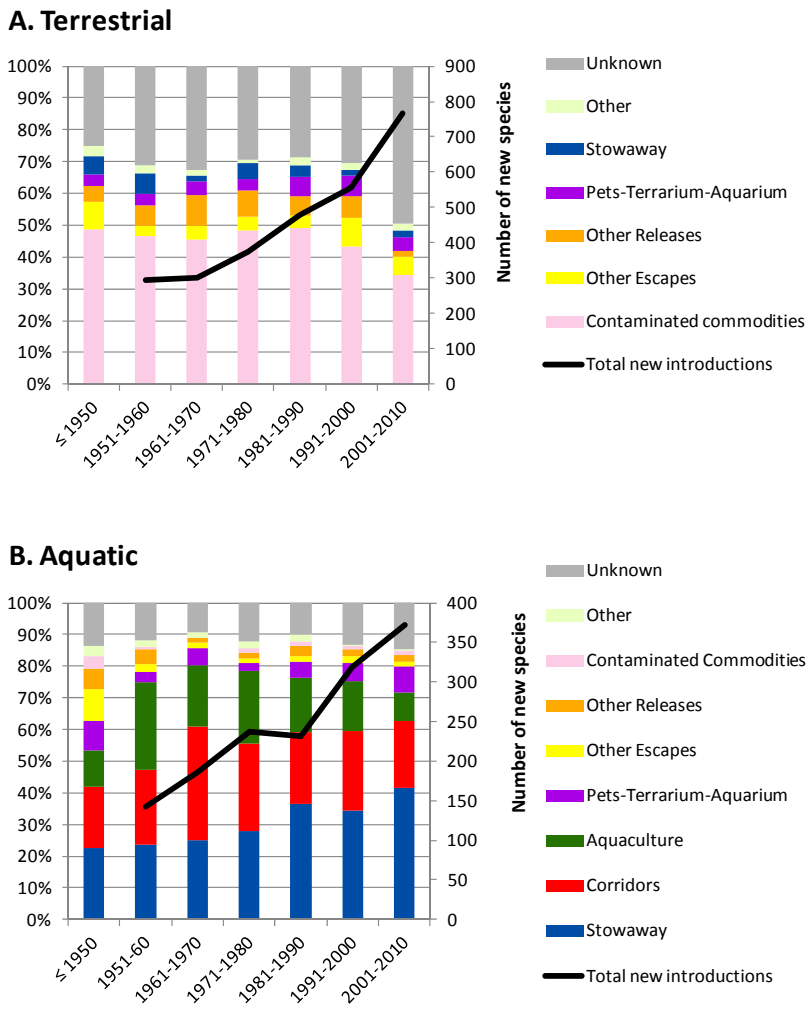

Figure 5. Trends and temporal variation of the importance of main pathways of introductions in Europe, of terrestrial (A) and aquatic (B) alien species. Pathway categories as in Figure 3.

For many of the assessed species (especially terrestrials) there was no way to infer with certainty the most probable pathway of introduction. In a number of cases, the pathway has been assumed from the organism biology (e.g. for phytophagous insects related to plants) or the location of the first records (e.g. Red Sea species found in the eastern Mediterranean near the Suez Canal) but for others it has been flagged as unknown until new evidence is provided (Figures 4, 5).

There was an important spatial variation by country in both the number of new introductions, with some countries acting as important gateways for alien species, and in the relative importance of pathways (Figure 4). For example, 'corridors' are very important pathways in the countries of the eastern Mediterranean (due to the Suez Canal) and in the countries of the southern and eastern Baltic Sea (due to inland canals) but are of less or no importance for the western European countries. In this analysis we included both aliens to Europe (i.e. species that are not native in any European country) and aliens in Europe (i.e. species that are native in some European countries and alien in others), hence our conclusions might slightly differ in comparison to other works that included only species alien to Europe (e.g. Roques 2010).

It is evident that the integrated large datasets provided by EASIN allow for analysis and prioritization of pathways, as specified by the Aichi Biodiversity Target 9, and Target 5 of the EU Biodiversity Strategy. Furthermore, trends of new introductions (Figure 5) are valuable indicators for assessing the effectiveness of management measures, in the sense that the outcome of targeted

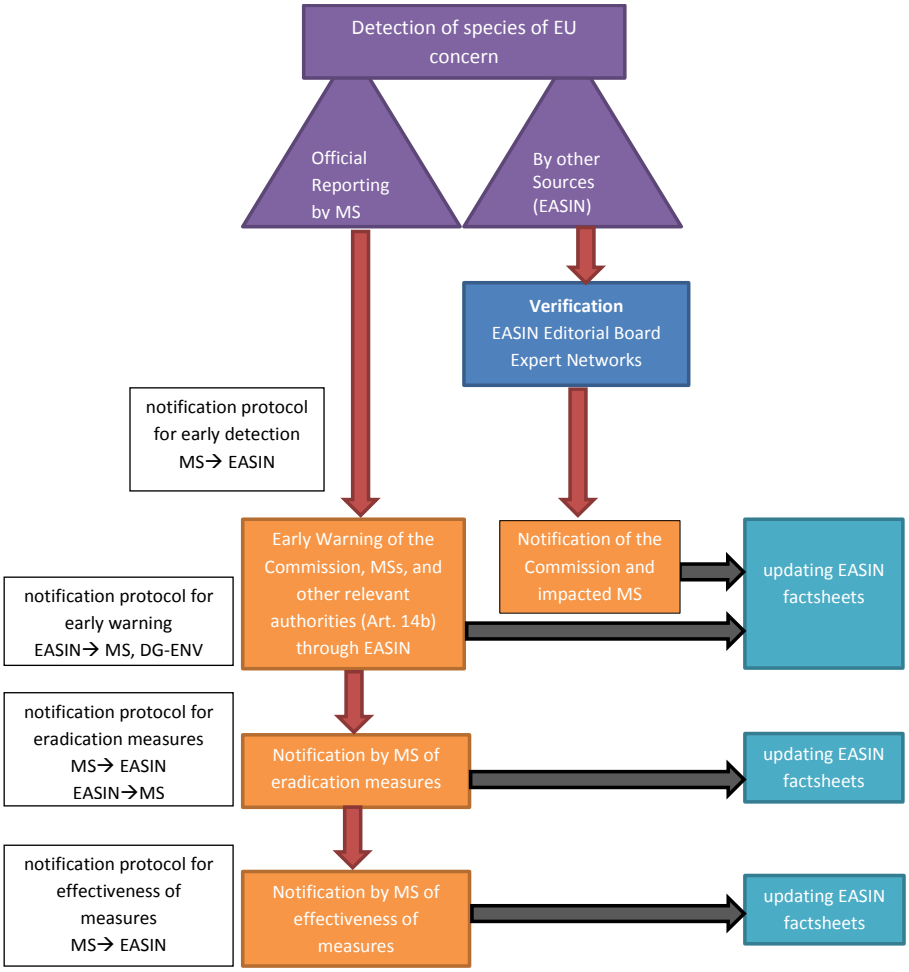

Figure 6. Flow chart for the early warning and rapid notification system for IAS of European concern to be implemented through EASIN in support of the new IAS Regulation. MS: Member States; DG-ENV: Directorate-General for the Environment (European Commission).

measures for a specific pathway should be reflected in a decreasing trend (see also Rabitsch et al. 2012). This has been demonstrated, e.g. for introductions of marine species by aquaculture, whose rate has decreased the last decade, after the adoption of relevant codes of practise and legislative instruments (Katsanevakis et al. 2013c).

EASIN Early warning system

The development of a sound early warning and rapid response system is crucial for preventing the establishment and spread of invasive alien species (Genovesi et al. 2010). The envisaged Early Warning and Rapid Response System, provisioned by the new EU Regulation on invasive alien species (EU 2014), foresees that detection and reporting of such species is made officially by member states through dedicated surveillance and monitoring mechanisms. EASIN is the European Commission platform that will support member states in implementing this system. Member states should report new populations of invasive alien species of EU concern detected on their territory directly to EASIN through a notification protocol for early detection (Figure 6). Such a protocol includes contact details, information on the detection (species, date, type of detection, confirming authority, related surveillance system, number of individuals, invaded area, assessment of establishment status, pathway information), and geographical information. This leads to an Early Warning of the Commission and other EU member states by EASIN.

Once an early warning has been issued, the affected member state needs to identify and implement the most appropriate eradication measures, which should be notified to EASIN through a related notification protocol. Through EASIN, this notification will be forwarded to the Commission, and it will also be made publicly available. Finally, member states should also submit to EASIN a notification when the eradication programme has been successfully completed through a notification protocol on the completion of eradication. Through EASIN, such notifications will be forwarded to the Commission and the information will be again made publicly available. It should also be possible for member states to share through EASIN information about the effectiveness of the measures taken. All the information gathered will be included in species-specific factsheets created by EASIN.

In parallel, EASIN may have access to reports of new populations of IAS of EU concern in the territories of member states through its 'informal network', e.g. through records published in the scientific literature or reported in other information systems. Such records, once verified by the EASIN Editorial Board, will be informally shared with the Commission and the relevant member states but will only lead to measures after the impacted member states issue a formal early detection notification (Figure 6).

Future Developments

EASIN is the European Commission's dedicated system to support the new Regulation on the prevention and management of the introduction and spread of invasive alien species in Europe. In the immediate future, EASIN will closely collaborate with Member States to timely provide all the necessary tools and information for the implementation of the new Regulation. The enlargement of the EASIN is an on-going process, and discussions are underway with many potential new partners, including national databases. The further development of EASIN-Lit, especially as a tool for early notification, by including recent new records of invasive species published in the literature, is also foreseen. Implementing the Infrastructure for Spatial Information in the European Community (INSPIRE) rules and protocols in EASIN to expose geo-spatial data in accordance to the INSPIRE Directive (EU 2007) is also among the short-term targets of EASIN.

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Supplementary material

The following supplementary material is available for this article.

Appendix 1. EASIN Catalogue v4.0.

This material is available as part of online article from:
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