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Risk Assessment

Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK

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Abstract

Electronic decision-support tools are now an essential component of government strategies to battle non-native species, with taxon-specific, paper-based risk analysis schemes often being replaced by taxon-generic tools. This study reports on the development of a decision-support tool for aquatic species, the Aquatic Species Invasiveness Screening Kit (AS-ISK), which replaces five taxon-specific toolkits for amphibians, freshwater and marine fish and invertebrates (FISK, MFISK, FI-ISK, MI-ISK, Amph-ISK). Adapted from Pheloung et al.'s Weed Risk Assessment (WRA), the "-ISK" toolkits were also "self-automated workbooks" in Excel® VisualBasic® architecture of the 'WRA. In creating AS-ISK, we incorporated the conceptual approach (questions and guidance) of the generic risk screening module of the European Non-native Species in Aquaculture Risk Analysis Scheme (ENSARS) into a single "turnkey application" that was based on the Excel® VisualBasic® architecture used by the WRA and its "-ISK" derivatives. Applicable to virtually all climatic zones and all aquatic plants and animals regardless of ecosystem (marine, fresh, brackish water), AS-ISK comprises 49 basic questions on the taxon's biogeographical and historical traits and its biological and ecological interactions. In compliance with the "minimum requirements" for use with the new EU Regulation on invasive alien species of EU concern, AS-ISK includes a preamble of background information on the species as well as questions on its potential socio-economic impacts and those on ecosystem services, and an additional section (six questions) for the assessor to predict how forecasted changes in climate are likely to influence the risks of introduction, establishment, dispersal and impact of a species. Following a concise but detailed description of AS-ISK, an example assessment of the Manila clam *Ruditapes philippinarum* is provided, with the French northern coastline as the risk assessment area, to demonstrate use of this decision-support tool. AS-ISK is available for free download at: http://www.cefas.co.uk/nns/tools/.

Key words: risk analysis, marine, brackish, freshwater, FISK, *Ruditapes philippinarum*

Introduction

Decision-support (DS) tools are central to the risk analysis of non-native species, assisting in the identification (screening) and assessment of risks associated with non-native species (NNS) as well as providing support to decision makers involved in NNS management (David et al. 2012). The screening of potentially invasive NNS is the first step in the risk analysis process, aiming to identify which species are likely to be invasive (and therefore require a comprehensive assessment of risks) and which are less likely to be invasive (and therefore are less likely to require detailed analysis). Decision-support (DS) tools are widely supporting decision-making processes in business, social sciences, medicine, politics, games, information technologies, and transport, and they are major building blocks in environmental management and science today. One of the key DS tools developed for the screening of NNS has been the Weed Risk Assessment (WRA) of Pheloung et al. (1999), which has been applied around the globe (Gordon et al. 2008; Leung et al. 2012). The WRA template was adapted for freshwater fishes, yielding the Fish Invasiveness Screening Kit (FISK), which included some user-interface enhancements over the WRA but most importantly the requirements that assessors justify their responses (e.g. provide bibliographic references) and that they rank their level of confidence in each response. The FISK v1 template was used to develop four other taxon-based concurrent "sister" screening tools (Copp et al. 2005, 2009) for: freshwater invertebrates (FI-ISK), marine invertebrates (MI-ISK), marine fish (MFISK) and amphibians (Amph-ISK). These sister tools have been applied less often than FISK, the known applications are: FI-ISK – freshwater crayfishes in Italy (Tricarico et al. 2010) and Greece (Papavlasopoulou et al. 2014), and the blue crab *Callinectes sapidus* Rathbun in Greece (Perdikaris et al. 2016); MI-ISK – comparison of MI-ISK with a new Canadian screening tool for marine invertebrates (Drolet et al. 2015); Amph-ISK – recently applied to assess the potential invasiveness of non-native amphibians, with the RA area being the EU, including the autonomous islands of Macaronesia (namely the Azores, Madeira and Canary Islands) but not the overseas territories of EU countries (Kopecký et al. 2016); and MFISK – applied to two marine fishes, the red lionfish *Pterois volitans* and the spotted porcupinefish *Diodon hystrix* (Copp et al. 2013). The weakness of FISK v1 and its sister DS tools was that they had been adapted from the WRA within a Temperate Zone (European) context, and therefore some questions were inappropriate (or even not applicable) to other climate zones. Therefore, the questions, guidance and user interface of FISK v1 were thoroughly reviewed and revised, resulting in FISK v2 (Lawson et al. 2013). So far, FISK v1 and v2 have been applied in at least 17 countries/regions across five continents (Copp 2013).

Yet, the constraint of these taxon-specific risk screening tools is that they do not cover the wide range of potentially invasive organisms that occur in aquatic ecosystems, such as plants and algae (e.g. seaweeds). To overcome this limitation, the European Non-native Species in Aquaculture Risk Analysis Scheme (ENSARS), which was developed for the European Union (EU) Regulation on the use of aliens in aquaculture (European Commission 2007), includes a taxonomically-generic screening module for identifying potentially invasive organisms associated with any aquatic environment, namely marine, brackish and freshwater (Copp et al. 2008, 2016a, 2016b).

The aim of the present study was to convert the paper-based ENSARS generic screening module into an electronic toolkit based on the FISK v2 (Lawson et al. 2013) template, but with considerable enhancement for wider deployment as a stand-alone software application, and to incorporate the "minimum requirements" (page 11 in Roy et al. 2014) for the assessment of species with regard to the recent EU Regulation on the prevention and management of the introduction and spread of invasive alien species (European Commission 2014). The specific objectives were to: 1) review and refine the protocols of the ENSARS generic screening module to ensure that they are fit for purpose and consistent with the minimum requirements for use with EU legislative instruments (European Commission 2007, 2008, 2014), and that they may be incorporated into the 49-question scoring framework used in the WRA and its FISK-type derivatives; 2) construct a FISK-like electronic toolkit to create the Aquatic Species Invasiveness Screening Kit (AS-ISK) and describe the main elements of its functionality, including its potential use in several languages (currently: English, French, Italian, Spanish, Turkish); and 3) provide a trial assessment of the AS-ISK tool on the Manila clam *Ruditapes philippinarum*, with the coastline of France as the risk assessment (RA) area. Such is the interest in AS-ISK that an international workshop on its use (http://as-isk-calistayi.zdbf.duzce.edu.tr/en/) was convened within six months of this DS tool being released for free download.

Methodology

Protocols

Questions and guidance in the ENSARS generic screening module were critically reviewed concurrent with the questions and guidance in FISK v2 during face-to-face and Skype™ meetings between authors GHC, HT and PDS. In the revision process, particular attention was directed towards characteristics that are considered to facilitate the invasions of aquatic environments of all types. As such, the review and revision process involved the criteria described for FISK v2 (Lawson et al. 2013) to achieve: 1) improved clarity, where changes reduced ambiguous terminology or uncertainty in interpretation of questions; 2) enhanced ecological applicability, where modifications addressed a wider range of ecological characteristics; and 3) increased climatic suitability, where changes allowed for increased flexibility of climate-match source information or direct incorporation of physiological tolerances.

Two new components were added to ensure consistency with the minimum requirements recently identified for the listing of invasive species of concern with regard to recent EU legislation

(European Commission 2014): 1) a "preamble" in which the reason for carrying out the assessment and the taxonomy, native and introduced ranges of the species are described; and 2) a short postscript section comprised of (six) additional questions on how the altered conditions predicted by current climate change models (wherever applicable) are likely to affect the invasiveness of the species being assessed.

In the WRA, the questions are grouped into sectors, which are not defined other than as: agriculture, environment, horticulture, garden and services. However, on the WRA Excel® RA scoring sheet these are defined as: A = Agriculture, E = Environmental, N = Nuisance and C = Combined (Pheloung et al. 1999), and in FISK the "A" sector was renamed as Aquaculture (Copp et al. 2005). For AS-ISK, these sectors were re-evaluated to assist in the assessment of which of them were likely to be affected by or associated with the taxon.

Electronic toolkit

The original WRA toolkit (Pheloung et al. 1999) was available as a "self-automated workbook" (*sensu* Bovey et al. 2009) written in Microsoft™ Excel® for Visual Basic for Applications (VBA®) code. The WRA template was later adapted for use with FISK v1 to accommodate all necessary changes for application to freshwater fish and replicated into its "sister" versions, and eventually upgraded to FISK v2 (Lawson et al. 2013). However, the software architecture of the "-ISK" programs, albeit improved relative to the original WRA template by virtue of its dialog-driven interface, was still somewhat primitive. This is unlike a "turnkey application" (*sensu* Walkenbach 2007), also known as "dictator application" (Bovey et al. 2009), which represents the most advanced level of Excel VBA® software development.

Specifically, a turnkey application allows complete distinction between user interface, business logic and data access/storage tiers; this is ensured by separating the data/user interface from the underlying code. This turnkey software architecture was employed for development of AS-ISK, whose graphical user interface (GUI) consists of a collection of tightly controlled dialogs that separate the user interface from the data storage layer (and with the code-based business logic tier located in between). The end result of this upgrade is a turnkey application that allows complete control over the end user's interaction (Supplementary material Figure S1, which like all other supplementary figures mentioned here below may be found in the Appendix 1; whereas the cited tables are found in a separate, supplementary Excel® file). The programming of AS-ISK was done in VBA 7.0 for Excel® 2013 for Windows™ by LV under on-going advice and feedback from, and beta-testing by, the rest of the project team. AS-ISK is available for free download at http://www.cefas.co.uk/nns/tools/ (5 April 2016).

Trial assessment

The Manila clam was used for the trial AS-ISK assessment, with the French North Atlantic coastline as the risk assessment area, because the species has become widespread throughout most of Europe, including the French Atlantic coastline, inducing changes in benthic community structure and acting as a host for novel pathogens (Goulletquer 1997). The Manila clam was introduced in France in 1972 to diversify oyster culture at the time drastically affected by disease-related mortalities (Goulletquer and Héral 1997). Development of this new shellfish culture required greater knowledge of the species' biological traits, reproduction control, environmental requirements and new grow-out facilities (Goulletquer et al. 1989). Following rapid development, Manila clam culture was drastically affected by several diseases (Goulletquer 1997; Goulletquer and Héral, 1997; Arzul et al. 2012), including massive mortalities due to the brown ring disease (BRD: *Vibrio tapetis*) (de Montaudouin et al. 2016, Paillard 2004) and by the species' natural dispersal.

In spite of its near-collapse, Manila clam culture continued to be promoted and this led to the establishment of feral populations during the 1990s (Goulletquer and Héral 1997; Flassch and Leborgne 1992; de Montaudouin et al. 2016), which subsequently have been targeted by important commercial fisheries (de Montaudouin et al. 2016). The comprehensive aquaculture research programme established during the 1980s (Goulletquer 1997; Flassch 1992) and all related research aimed to develop sustainable fisheries, e.g. stock assessment, population dynamics, fishery models (Bald et al. 2009; Caill-Milly et al. 2012), have provided the necessary information to carry out the present AS-ISK trial assessment on Manila clam. Moreover, updated information was obtained through a literature review (Dang et al. 2010, 2013; Caill-Milly et al. 2012; de Montaudouin et al. 2016) and disease-related status was provided by the European Union Reference Laboratory (EURL) for Mollusc Diseases (2015).

Results

Protocols

Similar to FISK, the first 49 questions (Qs) in AS-ISK are grouped into two main sections in which the biogeographical and historical traits of the taxon (13 Qs in total) and its biological and ecological interactions (36 Qs in total) are assessed. However, distinct to AS-ISK relative to FISK, an additional section (*Climate change*) comprised of six Qs has been included to assess the likely impact that predicted changes in climate would have (where applicable) on the assessor's responses to Qs related to the risks of introduction, establishment, dispersal and impact (Table S1). As a result, Qs 1–49 in AS-ISK are now part of the *Basic Risk Assessment* (BRA) module (refer to the Supplementary Information document for details on revisions to BRA questions relative to FISK). The additional six climate change Qs (50–55) that comprise the *Climate Change Assessment* (CCA) module may or may not be applicable for use, depending upon whether or not the risk assessment (RA) area is predicted to undergo future changes in climate. The first three CCA questions (Qs 50–52) allow the user to assess the potential effect of predicted future climatic conditions on the organism's risks of entry, establishment and dispersal, respectively; and in the final three CCA questions (Qs 53–55), the assessor is asked to assess the potential effect of predicted climate conditions on the likely magnitude of potential impacts on biodiversity, ecosystem structure and ecosystem services, respectively.

Overall, the scoring system in AS-ISK remains largely the same as used in the WRA and its FISK (v2) family of adaptations. However, a re-weighting of the scores for a number of (near-identical or similar) Qs has been implemented whenever required for both consistency and interpretation purposes (Table S1). Also, to compensate for the halved number of Qs in the *Resource exploitation* relative to FISK's *Feeding guild* category a "Yes" answer to Q26 is now assigned a score of 5 (hence, totalling a maximum of 7 if a "Yes" answer is also given to Q27). Finally, each of the new *Climate change* Qs gains a score of −2, 0 and 2 depending on whether a "Decrease" (Qs 50–52) or "Lower" (Qs 53–55), "No change", or "Increase" (Qs 50–52) or "Higher" (Qs 53–55) response is given. As a result of the changes in the scoring system, the possible values for the BRA score range from −12 to 64 (previously, −15 to 57 in FISK), and for the CCA score from −24 to 76.

In re-evaluating the sector designation of questions used in FISK, "Aquaculture" has been re-named as "Commercial" (C) and thus encompasses all commercially-related questions; "Environmental" (E) has remained as such; and "Nuisance" has been re-named as "Species or population nuisance traits" and comprises Qs related thereof. Also, for certain Qs, the combinations CS and ES have been included, with the result that these scores are assigned to both sectors.

Electronic toolkit

As a turnkey application, AS-ISK is designed as a stand-alone Excel®-based toolkit that is independent from the source data. Compared to the previous WRA and FISK semi-automated workbooks, a turnkey application provides two major benefits: 1) for the end user, it allows the assessor to work seamlessly on database spreadsheets either located on the local computer or accessible from a network; and 2) for the developer, it facilitates provision of feedback and support by software updates that will simply replace (overwrite) previous releases.

Because nearly 95% of the previous code from FISK was re-written during development of AS-ISK for the purposes of macro- and micro-optimisation (i.e. increased overall and routine-specific computational speed and efficiency, respectively), and a major re-design was applied to the GUI, limited comparability remains between AS-ISK and FISK (v2) except for the overall question-wise and scoring structure of the toolkit. A component-wise (dialog-based) overview of the full range of features and capabilities of AS-ISK is provided in the Supplementary Information document. This includes the following sub-sections:

Pre-loading – A check is performed for Excel® version compatibility.

Start – AS-ISK requires a spreadsheet, with the options of opening either an *Existing* or a *New* assessment worksheet or by *Import* of a previous assessment worksheet created by one of the FISK family of toolkits for re-assessment under AS-ISK (Figure S2). The user can also select from five language options (i.e. English, French, Italian, Spanish, Turkish) with which to carry out the assessment

Main Assessment Workspace – The core user interface where all assessment-related data manipulations can be performed (Figure S1).

New/Edit – The user provides all details of the taxon being assessed, either by creating a new assessment (Figure S3a), editing an extant assessment (Figure S3b), or batch editing multiple assessments (Figure S3c).

Replicate – Permits replication of an assessment selected from the *Main Assessment Workspace* (Figure S4).

Questions & Answers (Q&A) – Assessment for the taxon selected from the *Main Assessment Workspace* (Figure S5) is completed by responding to a sequence of 55 questions and ranking the level of confidence/certainty associated with their response using the confidence rankings recommended by the International Programme on Climate Change (IPPC 2005): "Low" confidence (2 out of 10 chance), "Medium" confidence (5 out of 10 chance), "High" confidence (8 out of 10 chance), "Very high" confidence (9 out of 10 chance); see also Copp et al. (2008, 2016a).

Trial assessment of Manila clam

The AS-ISK scores for Manila clam were 33.5 and 45.5 for the BRA and CCA, respectively, and the confidence level was equal to 0.74 (Table S2).

Biogeography/Historical – Seven of 13 questions in this section were attributed positive ("Yes") responses, resulting in a rather high score (11.5) for this species, which is already well known to be invasive. Adverse impacts were only reported at the ecosystem services level, whereas no socio-economic negative impacts, including on aquaculture, were forecasted (note that any benefits generated by a NNS should not normally be included in NNS risk analysis). Also, several pathways of introduction are well identified for this species, and knowledge gained over the last 40 years of its occurrence in European waters has led to a very high level of assessor confidence in the responses, except for the climate matching data, which was ranked at medium confidence.

Biology/Ecology – A slight majority of undesirable traits (seven of 12 questions) were recorded for Manila clam, mainly due to its adaptive capacity as an euryhaline, eurythermal species and also an active and competitive filter-feeder. Although edible and targeted as a commercial species being a high-value seafood, this species may be a vector of shellfish disease transfers into the RA area, with adverse effects on the pelagic and benthic trophic levels of the recipient ecosystem. With regard to reproduction effort and dispersal mechanisms, Manila clam is characterized by high gamete production, leading to a similarly high density of pelagic larvae, whose dispersal is facilitated by seawater currents. In addition to natural dispersal, aquaculture/marketing represents an additional vector of dispersion of this species, resulting in elevated probabilities of introduction and dispersal. The species is also highly tolerant, and the likelihood of eradication is low due to its dispersal mechanisms. Collectively, these traits result in a score of 22 for this section, with a high to very high confidence level in the responses.

Climate change – In both its native and introduced ranges, Manila clam thrives in warmer marine waters (e.g. the Mediterranean Sea), so the predicted increases in water temperature of the Greater North and Celtic seas resulted in positive responses to all of the Qs on how future climatic conditions are likely to affect the invasiveness of Manila clam in the RA. This resulted in the maximum (correction) score of 12 for this section, which results in an overall score of 45.5 (Table S2).

Discussion

Decision-support tools for identifying potentially invasive NNS are increasingly used to inform the decision-making process regarding management of NNS, and this is evident with previous screening protocols such as FISK (Copp 2013). In the same way that risk assessments are dynamic, requiring revision when new data and/or information become available on a species, so are risk analysis tools. Indeed, FISK v2 (Lawson et al. 2013) represented a marked improvement over the initial version of that screening tool (Copp et al. 2005; IPCC 2005) by broadening its climatic applicability and enhancing the functionality of the GUI. Similarly, AS-ISK advances the development of FISK and the other WRA-inspired screening tools for aquatic species through: 1) a transition from a taxonomic-specific to a generic focus; 2) the incorporation of background information on the species; 3) the inclusion of questions on previously overlooked (or under-developed) issues, i.e. potential socio-economic impacts and those on ecosystem services; and 4) a new post-assessment evaluation of how predicted climatic conditions might affect the risks of the organism's introduction, establishment, dispersal and impact. These improvements were complemented by a change in program architecture to a turnkey application, which effectively functions like most commercial software packages in that the user interface and data are separated from the underlying program code. Therefore, rather than having the assessment data embedded within the screening tool (as do the more primitive WRA, FISK and sister tools), AS-ISK creates or imports datasets dynamically for the creation/addition/editing/deletion of new assessments and upon closure exports the resulting assessment dataset as a separate data file in Excel® format, which is retrievable and usable independent of AS-ISK.

Risk analysis of NNS facilitates the effective partition of resources, which are often limited, highlighting species that pose the largest threat and therefore should be prioritised for full RA and potentially targeted by prevention and management strategies. The case assessment of Manila clam reveals that considerable information has been compiled through comprehensive scientific research in the 40 years since its introduction to European waters (de Montaudouin et al. 2016). During the 1970s, Manila clam was not forecasted to develop into rapidly expanding populations that would compete with indigenous aquaculture products (Flassch and Leborgne 1992; de Montaudouin et al. 2016), despite the fact that environmental conditions in Europe closely resembled those of the species' native range (Goulletquer 1997). However, by 1990, Manila clam landings from commercial fisheries in France were three times that of national aquaculture output, and feral populations along the French Atlantic coastline (e.g. Arcachon Bay and Morbihan Gulf in Southern Brittany) became the target of large commercial fisheries (Goulletquer and Héral 1997; de Montaudouin et al. 2016). At the same time, established Manila clam populations were being reported along the English Channel up to Southern England (Humphreys et al. 2015; Dewarumez et al. 2011), following a similar northward expansion as observed in the Pacific cupped oyster *Crassostrea gigas* (Dewarumez et al. 2011; Rohfritsch et al. 2013). As seawater temperatures have been gradually increasing since the 1970s, with significant changes in zooplankton and finfish abundances already reported between 1977 and 1989 (Tasker 2008), Manila clam is expected to continue its northward expansion. Moreover, climate change scenarios predict increasing air and seawater temperatures in the near future for the region of concern (Hulme et al. 2002), which is expected to facilitate this expansion.

More recently, Manila clam populations have shown an increasing dispersal pattern both in the U.K. and France along the English Channel coastline (Humphreys et al. 2015; Dewarumez et al. 2011). Those changes might also be of concern for other countries where the Manila clam populations are already well established (Rodriguez-Moscoso et al. 1992; Drummond et al. 2005; Campos and Cachola 2006; Sladonja et al. 2011; Çolakoğlu and Palaz 2014). Meanwhile, northwards dispersal pattern have been reported for both pelagic and benthic numerous organisms (Tasker 2008). The effects of on-going changes in Manila clam distribution, population dynamics, and associated impacts are therefore of major interest for the provision of up-to-date advice to decision makers so as to improve the conservation and management of marine ecosystems. Indeed, the case study assessment of Manila clam emphasises the need for improved risk screening of this species and to take an ecosystem approach when assessing species interactions and to assess other shellfish taxa of concern. This will help determine the relative invasiveness of Manila clam and as such its potential use an indicator in the trend assessments required for compliance with the Marine Strategy Framework Directive (Descriptor 2). Finally, although the BRA and CCA score achieved for Manila clam in the present study suggest high risk of invasiveness, further assessments of shellfish species are required to calibrate the above scores and specify corresponding thresholds, similar to what achieved in previous FISK applications (reviewed in Copp 2013).

In conclusion, AS-ISK is a free downloadable, user friendly, multi-language, easy-to-use DS tool for screening any aquatic species of non-native plant or animal, regardless of ecosystem (marine, brackish, fresh) or climatic zone to determine which species are likely to be invasive in the defined RA area. AS-ISK originates from internationally-accepted toolkits that have been developed over many years, e.g. Copp et al. (2005, 2009), Gordon et al. (2008, 2012), provides a quantitative output and is compliant with the "minimum requirements" (page 11 in Roy et al. 2014) for assessing species under the new EU Regulation on invasive alien species of EU concern (European Commission 2014). The rapid international interest in AS-ISK, evinced by a workshop held within a half year of its online release, suggests that this DS tool is likely to attract as wide application as its FISK predecessor and thus make an important contribution to the assessment and screening of invasive aquatic species required by key legislation.

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Supplementary material

The following supplementary material is available for this article:

Table S1. List of the 55 questions (Qs) making up the Aquatic Species Invasiveness Screening Kit (AS-ISK v1).

Table S2. AS-ISK v1 output for the Manila clam *Ruditapes philiipinarum* case study with regard to the species' expansion into colder European waters (Greater North Sea and Celtic Sea).

Appendix 1. Supplementary information.

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