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METHODS

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A framework to support alien species regulation: the Risk Analysis for Alien Taxa (RAAT)

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Abstract

Human livelihoods and well-being in almost all regions of the world depend on taxa which are alien. Such taxa also, however, threaten human health, sustainable development, and biodiversity. Since it is not feasible or desirable to control all alien taxa, decision-makers increasingly rely on risk analyses to formalise the best available evidence of the threats posed and whether and how they can be managed. There are a variety of schemes available that consider the risks of alien taxa, but we argue a new framework is needed: 1) given major recent developments in international frameworks dealing with biological invasions (including the scoring of impacts); 2) so that decisions can be made consistently across taxa, regions and realms; 3) to explicitly set out uncertainties; and 4) to provide decision-makers with information both on the risks posed and on what can be done to mitigate or prevent impacts. Any such scheme must also be flexible enough to deal with constraints in capacity and information. Here we present a framework to address these points – the Risk Analysis for Alien Taxa (RAAT). It outlines a series of questions related to an alien taxon's likelihood of invasion, realised and potential impacts, and options for management. The framework provides a structure for collating relevant data from the published literature to support a robust, transparent process to list alien taxa under legislative and regulatory requirements, with the aim that it can be completed by a trained science graduate within a few days. The framework also provides a defensible process for developing recommendations for the management of assessed taxa. We trialled the framework in South Africa and outline the process followed and some of the taxa assessed to date.

Keywords

Biological invasions, policy, regulations, risk analysis, risk assessment, risk management

Introduction

Species are being moved around the world by humans, both accidentally and deliberately, with the rate of introduction of new species showing few signs of declining (Seebens et al. 2017). Once introduced, some of these species establish and spread without further human assistance. There are also numerous species that have already been introduced and that will likely become invasive in future. While many alien taxa are highly beneficial, some can have significant negative impacts on the recipient environment and human livelihoods (Pimentel 2011; Blackburn et al. 2014). This makes management of the most problematic alien taxa a necessity. However, it is not feasible, desirable or necessary to manage all aliens and prioritisation is needed (McGeoch et al. 2016).

International agreements under the World Trade Organisation (WTO) require the assessment of risks before certain activities involving an alien taxon, especially trade, can be restricted, or before a new taxon should be allowed for import. These agreements recognise the standards set by the International Plant Protection Convention (IPPC; FAO 1996) and the World Organisation for Animal Health (OIE 2011). Such risk assessments are aimed at distinguishing potentially harmful taxa from those that are benign.

We argue that for successful management and the development of efficient regulations, three components are required, namely, risk assessment, risk management, and risk communication. While elements of each have been developed in different cases separately (see for example Branquart et al. 2016; Booy et al. 2017), regulatory decisions regarding biological invasions rest on all three components: (i) risk assessment consists of the likelihood and consequences of an alien taxon causing negative impacts (Daehler and Virtue 2010); (ii) risk management deals with options to reduce the risk, including due consideration of potential benefits; and (iii) risk communication details how the information is made accessible (Branquart et al. 2016). Therefore, besides the mandatory risk assessments prescribed by the international agreements, regulatory decisions need also to take risk management into account, i.e., management feasibility, benefits of the taxon, and potential conflicts between/amongst stakeholders [see van Wilgen and Richardson (2012) for examples of the costs of ignoring such considerations]. Furthermore, decisions are often only successful and implementable if stakeholders understand the risks associated with the taxon. To gain the support from the general public and other stakeholders, engagement and clear communication regarding risks is crucial and this is where risk communication has its place. Therefore, to support decision-makers, the broader process of risk analysis is required (Convention on Biological Diversity 2002). There is a plethora of frameworks that have been developed to address particular parts of the problem, but they are mostly taxon-specific (Leung et al. 2012) and often do not link to probabilities or are not mathematically consistent (Holt 2006). Furthermore, risk analyses need to be transparent and repeatable and align with national and international agreements, policies, and best practice (e.g. Verbrugge et al. 2010; Essl et al. 2011; Heikkilä 2011; Kumschick and Richardson 2013; Roy et al. 2018).

Much progress has been made in recent years in the way we analyse risks and aspects thereof. For example, impact scoring schemes have been developed which enable the comparison of a wide range of impacts between taxa and habitats – most notably the Environmental Impact Classification for Alien Taxa (EICAT; Hawkins et al. 2015, IUCN 2020a, b) and its socioeconomic equivalent, SEICAT (Bacher et al. 2018) (more detail in Consequences section below). More thought has also been given to the management aspect of the decision-making and prioritisation processes (e.g. Booy et al. 2017).

Decisions often have to be made on the basis of limited evidence. Therefore, risk analyses should explicitly highlight uncertainties and flag where recommendations are based on projections. Moreover, consideration should be given as to when the precautionary principle is appropriate. As set out by the Convention on Biological Diversity in their guiding principles related to alien species that threaten ecosystems, habitats or species: "… The precautionary approach should also be applied when considering eradication, containment and control measures in relation to alien species that have become established. Lack of scientific certainty about the various implications of an invasion should not be used as a reason for postponing or failing to take appropriate eradication, containment and control measures" [guiding principle 1 (Convention on Biological Diversity 2002)].

In order to deal with undesirable consequences and to mitigate future impacts, policy frameworks for the regulation of alien taxa have been developed for many countries (McGeoch et al. 2010; Early et al. 2016). For example, the European Union (EU) has developed new legislation to ensure a consistent response to the threat of alien taxa by all member states (EU Regulation 2014). Such regulations often include lists of species for which certain activities like trade, propagation and movement are prohibited or restricted and which require mandatory management interventions (Garcia-de-Lomas and Vilà 2015). Decisions on the categorisation of alien taxa in these lists require a transparent and evidence-based analysis of risk.

Here we present a practical framework for the analysis of risks associated with alien taxa and provide a structure for collating scientific evidence. We provide detailed information on the framework including how and why it was developed and its structure and content. Lastly, we provide some results from applications of RAAT and outline how the framework can aid and support the regulation and listing of alien taxa, using the South African legislative background as an example.

The Risk Analysis for Alien Taxa (RAAT) framework

We first outline how and why the framework was developed and tested, provide general guidance on how risk is scored and confidence estimated, and present the overall structure of the framework followed by a detailed description of each section.

Development and testing of the RAAT

The risk analysis framework presented here was specifically designed for the purpose of listing alien species under the regulatory framework of the South African National

Environmental Management: Biodiversity Act (NEMBA, Act 10 of 2004) Alien and Invasive Species Regulations (hereafter called the NEM:BA A&IS Regulations; Department of Environmental Affairs 2014; for details of how the framework aligns with the regulations, see Suppl. material 1). The development of the RAAT framework was initiated in 2015, in response to the promulgation of the NEM:BA A&IS Regulations. The regulatory lists of 2014 were informed by expert opinion, but the decisions taken and recommendations made were not clearly documented (see Kumschick et al. 2020a for a discussion). As the regulatory lists specify taxa which need to be controlled and for which other restrictions are in place, it has social and economic implications and has been contested in a number of cases [van Wilgen and Wilson (2018); see also Novoa et al. (2015) for a discussion on listing alien Cactaceae]. A framework was therefore required to (retrospectively) provide evidence for listing in a consistent transparent manner (e.g. Woodford et al. 2017).

During the development of this framework, regular meetings with decision-makers [mainly representatives from the Biosecurity Division of what was, at the start of the process, the South African Department of Environmental Affairs (DEA), but became the Department of Forestry, Fisheries and the Environment (DFFtE) in 2020] were held to ensure their needs were taken into account and the framework was relevant for the intended purpose. The first version of the framework was used by graduate students at the Centre for Invasion Biology at Stellenbosch University (CIB) to assess taxa from a wide range of taxonomic groups and feedback from this exercise was used to refine it, providing additional clarification and guidance. The second version was reviewed by the Alien Species Risk Analysis Review Panel (ASRARP), a panel of South African experts set up by the South African National Biodiversity Institute (SANBI) to review risk analyses for alien taxa [both those performed in relation to the import of species not yet present in the country and those performed in relation to the regulation and listing of alien taxa under the NEM:BA A&IS Regulations (Kumschick et al. 2020a)]. The panel includes independent experts on biological invasions and risk analyses, with representatives from private and public entities and experts on a wide range of taxonomic groups. The issues raised by the ASRARP on the framework were mainly related to details in the wording which could lead to misunderstandings. These were subsequently addressed, and a new draft was reviewed by representatives from different organisations, including the DEA, members of the ASRARP, the SANBI, and the CIB. Finally, RAAT was signed off by the ASRARP before submission as a report to the DEA in March 2017. A revised version was subsequently uploaded to a pre-print server to make it widely accessible (Kumschick et al. 2018).

Initially, several risk analyses were piloted by ASRARP members, but after the first three risk analyses were approved, subsequent risk analyses were submitted by SANBI staff, students, and post-docs not affiliated with ASRARP to ensure a separation between the review panel and the assessors. The risk assessors (who had various backgrounds and levels of education, including alien species managers, taxonomists, post-graduate students, and researchers), were trained to use the framework during five courses that were run over 2018–2019 (Table 1, several additional courses were held in 2020 based on an accepted draft of this paper). The courses provided valuable feedback in terms of how the framework should be worded to avoid inconsistencies and to clarify the calculations of likelihood and risk specifically. Moreover, as the risk analyses were submitted for review at the meetings of the ASRARP and reviewed by independent experts, the framework has been further refined by adding sections on management that could help clarify specific issues on sub-specific entities. The framework presented here has thus been tested and refined in practice over two years (Suppl. material 2).

RAAT is yet to be either formally adopted in South African legislation or included as an official guiding document, but it is being used by officials to justify applications to revise the listing of taxa under their mandate. Even though RAAT was initially designed for the purpose of listing alien species under the NEM:BA A&IS Regulations, the intention was always to create a system that can be used more generally to aid decisions regarding management prioritisation and the listing of taxa under policy frameworks. Therefore, throughout the framework, the questions posed and options for answers were designed to be generic and applicable across regions. However, in the Suppl. material 2, these are worded specifically with the South African context in mind for local decision-makers and managers to determine the appropriate categories as referenced in the NEM:BA A&IS Regulations.

Scoring risk and confidence

RAAT consists of a series of questions which need to be answered by the person assessing an alien taxon of interest. The accuracy of an analysis relies, amongst other factors, on ensuring that a thorough literature review on the taxon under assessment is conducted. Some information can be extracted from national and international databases on native and alien species, such as the Global Invasive Species Database (http://www.iucngisd.org/gisd/), CABI's Invasive Species Compendium (https://www.cabi.org/isc/), Global Biodiversity Information Facility (https://www.gbif.org/), and the Red List of Threatened Species (http://www.iucnredlist.org/). However, primary literature should preferably be consulted and included. Information from the native range can be useful, including indigenous knowledge.

If insufficient information is published on the taxon, closely related taxa should be considered, for example, congeners (e.g. Bomford 2008). However, it needs to be clearly stated when such information is used, and which species was selected as a surrogate and why. Species with similar life history traits and behaviour are preferred. All information must be documented and referenced to be able to review how recommendations were developed and when assumptions were made and to facilitate updating the analysis as suitable information becomes available.

Taxonomists and other experts should be consulted for the risk analysis process to fill gaps in literature, especially for sections initially scored data-deficient for a given taxon. Expert opinion is beset with biases that are well understood and described (Burgman 2016). To minimise such biases, all information sources need to be documented, includ-

Table 1. Taxa analysed using the Risk Analysis for Alien Taxa (RAAT) framework under the South African NEM:BA A&IS regulatory lists of 2014 as revised 2016 with recommendations approved by the Alien Species Risk Analysis Review Panel up until end March 2020. Details of permit conditions (including cases where the listing varies depending on specific conditions, for example, for *Oreochromis niloticus*) are not shown. Listing categories are as follows: 1a – Nation-wide eradication target; 1b – Control target; 2 – Control target with permits; 3 – Control targets with certain exemptions. As species listed as 1b can also have exemptions, category 3 is redundant and is not considered as an option in the RAAT framework. All species assessed so far are known to be present in South Africa, except *Myocastor coypus* which was recommended to be listed as "prohibited". LIK is likelihood; CON is consequence; and MAN is management (see Figure 1).

Type of organism	Scientific name	LIK	CON	Risk	MAN	Current listing	Recommended listing
Arthropod	*Acarapis woodi* (Rennie, 1921)	Probable	MO	High	Difficult	1b	1b
Plant	*Acacia stricta* (Andrews) Willd.	Probable	MO	High	Medium	1a	1a
Plant	*Ailanthus altissima* (Mill.) Swingle	Fairly probable	MR	High	Medium	1b	1b
Bird	*Anas platyrhynchos* (Linnaeus, 1758)	Probable	MV	High	Medium	2	1b (with exemptions)
Plant	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob. (= *Eupatorium adenophorum* Spreng.)	Probable	MR	High	Medium	1b	1b
Arthropod	*Carausius morosus* Sinety, 1901 [listed under Phasmatodea species (Jacobson & Blanchi, 1902)]	Fairly probable	MO	High	Difficult	1b (all Phasmatodea)	1b (*Carausius morosus* Sinety, 1901)
Plant	*Chondrilla juncea* L.	Probable	MV	High	Difficult	1a	1a
Plant	*Coreopsis lanceolata* L.	Probable	MO	High	Difficult	1a (Sterile cultivars or hybrids are not listed)	1b (the appropriateness of exemptions for sterile cultivars or hybrids was not assessed)
Mollusc	*Crassostrea gigas* (Thunberg 1793)	Probable	MR	High	Difficult	2	2
Plant	*Eugenia uniflora L.*	Probable	MO	High	Medium	1b	1b (with exemptions)
Plant	*Iris pseudacorus* L.	Probable	MR	High	Difficult	1a	1b
Plant	*Jatropha curcas* L.	Fairly probable	MO	High	Medium	2	1b
Plant	*Lilium formosanum* Wallace (= *L. longiflorum* Thunb. var. *formosanum* Baker)	Probable	MO	High	Difficult	1b	1b
Plant	*Melaleuca hypericifolia* Sm.	Probable	MN	High	Easy	1a	1b
Mammal	*Myocastor coypus* (Molina, 1872)	Unlikely	MR	High	Medium	2	Prohibited
Mollusc	*Mytilus galloprovincialis* Lamarck, 1819	Probable	MV	High	Medium	2	2
Fish	*Oreochromis niloticus* (Linnaeus, 1758)	Fairly probable	MV	High	Difficult	2	2
Plant	*Paspalum quadrifarium* (Lam 1791)	Fairly probable	MO	High	Medium	1a	1b
Arthropod	*Penaeus indicus* H. Milne-Edwards, 1837 [listed as *Fenneropenaeus indicus* (H. Milne-Edwards, 1837)]	Fairly probable	MC	Medium	Difficult	2	Delist
Plant	*Psidium cattleianum* Afzel. ex Sabine	Probable	MO	High	Medium	1b	1b
Bird	*Psittacula krameri* (Scopoli, 1769)	Probable	MV	High	Medium	2	1b
Bird	*Pycnonotus cafer* (Linnaeus, 1766)	Probable	MR	High	Easy	2	1a
Plant	*Ricinus communis* L.	Probable	MO	High	Medium	2	2
Plant	*Robinia pseudoacacia* L.	Fairly probable	MV	High	Difficult	1b	1b
Plant	*Sagittaria platyphylla* (Engelmann) J.G Smith	Probable	MO	High	Difficult	1a	1b
Plant	*Sasa ramosa* (Makino) Makino & Shibata	Very unlikely	MO	Low	Easy	3	Delist
Plant	*Senna bicapsularis* (L.) Roxb	Probable	MO	High	Medium	1b	1b
Plant	*Sphaeropteris cooperi* (F. Muell.) R.M. Tryon	Fairly probable	MR	High	Medium	Not listed	1b
Plant	*Syzygium jambos* L. Alston	Probable	MO	High	Easy	3	1b (with exemptions)
Arthropod	*Vespula germanica* (Fabricius, 1973)	Probable	MV	High	Medium	1b	1b

ing listing which experts were consulted and their expertise in the respective topic. It is also possible, and preferable in many cases, that taxa are assessed in working groups rather than by a single assessor to minimise bias (Burgman et al. 2011). In the South African case, and based on international best practice (e.g. Defra 2015), review of analyses through the ASRARP provides another mechanism to avoid bias (Kumschick et al. 2020a).

Assessors can also, of course, be biased and there is often considerable uncertainty when interpreting data (McGeoch et al. 2012; Vanderhoeven et al. 2017) and which is difficult to avoid. Clear guidance on how to respond to each question in the RAAT and formalised descriptions of each response option is provided in the form of scenarios to minimise assessor bias. It is important to indicate how confident the assessor is in the response provided (Carrington and Bolger 1998). The confidence score should give an indication on how confident the assessor is that the answer provided is correct. This generally depends on the amount and quality of data available on the taxon. We followed the guidelines as described in the European Plant Protection Organisation (EPPO) pest risk assessment decision support scheme and as published in Hawkins et al. (2015) for confidence ratings (see also Suppl. material 5).

Structure of the RAAT

The RAAT is divided into five sections and includes all aspects of risk analysis, namely risk assessment (sections 2 and 3), risk management (section 4), and risk communication (sections 1 and 5) (Fig. 1). The sections are abbreviated with three-letter acronyms: 1) Background (BAC) provides information on the assessor, the taxon under consideration, and information needed to perform the analysis; 2) Likelihood (LIK) assesses biological, ecological, and behavioural traits of the taxon that could lead to its arrival, establishment, and spread; 3) Consequences (CON) include the recorded and potential impacts of the taxon; 4) Risk management (MAN) includes questions related to the ability to control a taxon, whether the taxon is beneficial in some situations, and provides recommendations for management and/or listing of taxa; 5) Reporting provides guidance on how to communicate the outcomes of the analysis. This last section does not consist of questions, but is a compilation of the results of the previous four sections and provides an easily digestible summary for the communication of recommendations to stakeholders. Each section is discussed below.

1) Background

It is important to clearly outline the scope of the analysis to clarify what is assessed, for which region, and by whom. This section therefore includes the region of interest, the taxon for which the analysis is performed, and information on the taxon, as this forms the basis for data collection (Table 2).

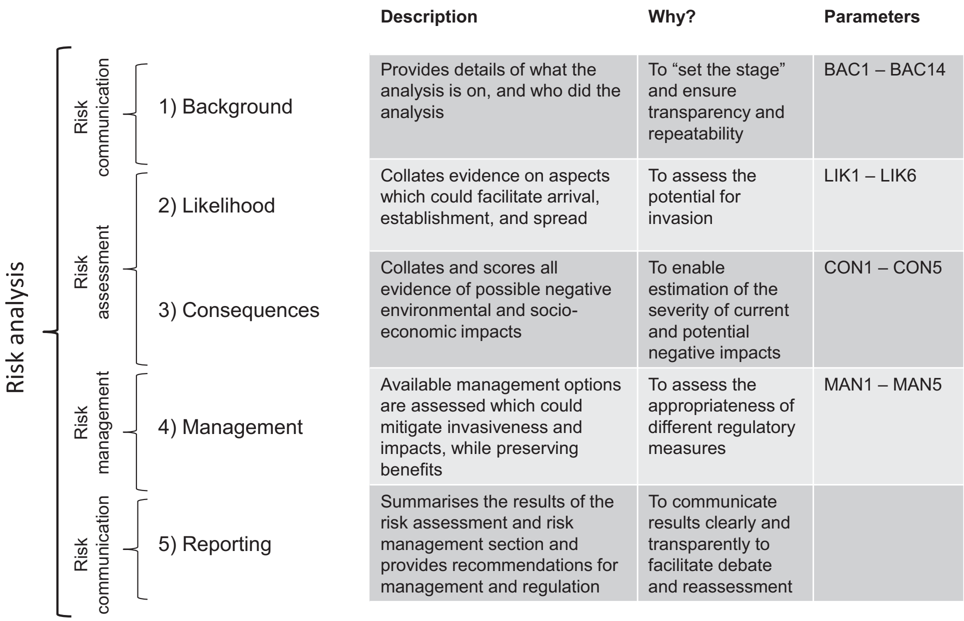

Figure 1. A schematic of the Risk Analysis for Alien Taxa framework described here. For each section a number of parameters need to be assessed (more detail in Table 2).

The region for which the risk analysis is performed is referred to as the *Area* (developed from the concept by D'Hondt et al. 2015). In most cases, analyses will be undertaken at a national level (e.g. South Africa), but the structure of the framework allows the analyses to be undertaken for different spatial units (e.g. for a national park or for the southern African region). However, the *Area* must be clearly specified and all questions referring to the *Area* specifically consider information with respect to the region chosen.

The taxon under assessment is referred to as the *Taxon*. The *Taxon* can be a species, sub-species, infra-specific entity, genus or any other taxonomic level. Risk analyses are mostly carried out on individual species as a standard taxonomic entity as, mostly, this is the level at which information is available, but this is not always appropriate, feasible or desirable. For example, different taxonomic levels are preferable: if the taxonomy of a group is not well resolved (e.g. some genera within the family Cactaceae, Novoa et al. 2015); if species are difficult to distinguish but the whole group (i.e. genus or family) poses a significant threat (e.g. certain taxa of mites or plant pathogenic rust fungi); and if there are important differences between sub-species or infra-specific entities (e.g. varieties and cultivars; see Datta et al. 2020 and Gordon et al. 2016). Ideally the analysis should consider whatever taxonomic grouping for which the risk is the same (e.g. Wilson et al. 2011), though in practice, this is very hard to achieve and species level assessments are therefore most common.

Table 2. A list of the parameters and information needed to complete the Risk Analysis for Alien Taxa.

Section	Parameter	Description	Definition and purpose
Background	BAC1	Name of assessor(s)	To identify the person who performed the assessment.
	BAC2	Contact details of assessor(s)	For means of contacting the assessors in case of questions, further information required or if the assessment needs revision.
	BAC3	Name(s) and contact details of expert(s) consulted	Identifies experts which were consulted.
	BAC4	Scientific name (including the authority) of *Taxon* under assessment	Gives information on the species, sub-species, variety, genus or other taxonomic entity under assessment.
	BAC5	Synonym(s) considered	Information on which synonyms were considered for the assessment.
	BAC6	Common name(s) considered	Information on which common names were considered for the assessment.
	BAC7	What is the native range of the *Taxon*?	Information on the distribution range of the taxon is important for the assessment as the framework is designed for alien species specifically.
	BAC8	What is the global alien range of the *Taxon*?	This is crucial as, for some questions, only information in the alien range is considered.
	BAC9	The *Area* under consideration	Delimits the geographic scope of the assessment area.
	BAC10	Is the *Taxon* present in the *Area*?	Crucial for management recommendations (e.g. prevention vs. control).
	BAC11	Availability of physical specimen	To link the identification of the taxon to a physical sample, as it is important to be able to refine the identity (BAC 4) in the light of new information and following taxonomic revision or the detection of errors in identification.
	BAC12	Is the *Taxon* native to the *Area* or part of the *Area*?	Important for management as this framework only deals with alien species.
	BAC13	What is the *Taxon's* introduction status in the *Area*?	Knowing the introduction status of populations (e.g. as per the Unified Framework of Biological Invasions, Blackburn et al. 2011) can aid with management decisions.
	BAC14	Primary (introduction) pathways	This information will be used to answer questions on likelihood of entry.
Likelihood	LIK1	Likelihood of entry via unaided primary pathways	The probability of the T*axon* to arrive and enter an area without human assistance.
	LIK2	Likelihood of entry via human aided primary pathways	The probability of the *Taxon* to arrive and enter an area human aided.
	LIK3	Habitat suitability	Forms part of the likelihood of a *Taxon* to establish.
	LIK4	Climate suitability	Forms part of the likelihood of establishment.
	LIK5	Unaided secondary (dispersal) pathways	Assesses spread potential.
	LIK6	Human aided secondary (dispersal) pathways	Assesses spread potential aided by humans.
Consequence	CON1	Environmental impact	Includes impacts caused by the *Taxon* on the environment through different mechanisms, based on EICAT (Hawkins et al. 2015).
	CON2	Socio-economic impact	Includes impacts caused by the *Taxon* on human well-being and livelihood, based on SEICAT (Bacher et al. 2018).
	*CON3	Closely related species' environmental impact	If no data on the *Taxon* itself are available, this includes impacts caused by related taxa on the environment through different mechanisms.
	*CON4	Closely related species' socio-economic impact	If no data on the *Taxon* itself are available, this includes impacts caused by related taxa on different socio-economic sectors.
	CON5	Potential impact	Assesses the potential impact of the T*axon* in the A*rea*, if invasive.
Management	#MAN1	What is the feasibility of stopping future immigration?	Important for effectiveness of control, as new influx of propagules needs to be stopped to control the *Taxon* effectively and sustainably.
	#MAN2	Benefits of the *Taxon*	Socio-economic and environmental benefits are included to assess the need of stakeholders for the *Taxon.*
	#MAN3	Ease of management	To provide indication of how easy the *Taxon* is to manage in the *Area* as this will influence risk management decisions.
	#MAN4	Has the feasibility of eradication been evaluated?	Indicates whether the feasibility of eradicating the *Taxon* from the *Area* has been formally evaluated. Note the evaluation of eradication feasibility is a separate process to the risk analysis framework.
	#MAN5	Control options and monitoring approaches available for the Taxon	Provides an overview of control options available.
	#MAN6	Any other considerations to highlight?	Can aid the development of management plans, permit conditions and exemptions.

* not assessed if CON1 and CON2 can be filled in respectively, i.e. information on impact is available for the *Taxon*; # not assessed if risk is low for the *Taxon*

2) Risk assessment: Likelihood

The section on likelihood assesses the probability of the *Taxon* to arrive, establish, and spread in the *Area*, with two questions for each process (arrival, establishment, and spread), resulting in six questions in total (LIK1–LIK6 in Suppl. material 2). These include questions on habitat and climate suitability and likelihood of entry and spread via aided and unaided pathways. Each answer is expressed as a probability value p, with all the levels and scenarios described in the narrative section and each level representing an order of magnitude difference. If the answer is not known after consulting literature and experts, following a precautionary principle, the answer is treated as p = 1 for the rest of the assessment, though noting that no answer was supplied and so highlighting an obvious area where more research is needed (Hulme 2012). For each probability level, we give general examples to provide guidance. These are structured as follows:

- Extremely unlikely (p = 0.000001): as likely as winning the lottery, if you play it once.
- Very unlikely (p = 0.0027): as likely as a new person you meet having their birthday on the same day as yours.
- Unlikely (p = 0.027): as likely as rolling two sixes when playing dice.
- Fairly probable (p = 0.5): as likely as getting heads when flipping a coin, i.e. fifty-fifty.
- Probable (p = 1 for calculation purposes): more likely to happen than not.

The probability levels of all the questions in this section are combined to calculate the likelihood of an invasion occurring. The final likelihood is calculated as the product of the maximum scores for each stage, i.e. p(arrival) [= max(LIK1, LIK2)] × p(establishment) [= max(LIK3, LIK4)] × p(spread) [= max(LIK5, LIK6)] (Suppl. material 2)].

RAAT thus incorporates some basic considerations of probabilities by multiplying the likelihoods of a taxon to cross the barriers in the invasion process, i.e., if the taxon cannot cross a certain barrier, the likelihood of establishment is decreased (Suppl. material 2: Fig. S2).

3) Risk assessment: Consequence

As it is important to get a comprehensive understanding of the potential harm caused by an alien taxon, it has been suggested that both environmental and socio-economic impacts should be included in risk assessments (e.g., Kumschick and Richardson 2013; Roy et al. 2018). The assessment of current and potential impacts, or consequences, is based on recent developments of impact scoring schemes (Blackburn et al. 2014; Nentwig et al. 2016; Bacher et al. 2018). EICAT is used for the assessment of environmental impacts (Blackburn et al. 2014; Hawkins et al. 2015). It was adopted by the International Union for the Conservation of Nature (IUCN) as a standard for the classification of alien taxa (IUCN 2020a, b), to be used alongside the Red List for the conservation of biodiversity. For socio-economic impacts, we initially used parts of the Generic Impact Scoring System (GISS) (Nentwig et al. 2016; see Kumschick et al. 2018). Since then, a new scoring scheme, more similar to EICAT and more consistent in the way impact levels are assigned, was published, namely the SocioEconomic Impact Classification of Alien Taxa (SEICAT) (Bacher et al. 2018). The version of the framework presented here therefore uses SEICAT instead of the GISS (Suppl. material 2), although all approved risk analyses reported in Table 1 are based on the GISS.

These impact scoring schemes have been shown to be intuitive to use, robust (Kumschick et al. 2017a, b), and transparent, and have proven to be applicable for a wide range of taxa (e.g., Kumschick et al. 2015; Evans et al. 2016; Kumschick et al. 2017a; Rumlerova et al. 2017; Hagen and Kumschick 2018; Kesner and Kumschick 2018; Nkuna et al. 2018). This makes them suitable for use as a component in a risk analysis framework. Another common feature of these impact assessment schemes is that all available evidence of impacts in the global alien range (including the *Area*) of the *Taxon* is collated and used for scoring (Hawkins et al. 2015; Nentwig et al. 2016; Bacher et al. 2018; see also Table 3 for an overview of the different impact levels). The guidelines cover each mechanism and sector through which alien taxa can affect the recipient regions, including competition, herbivory, and hybridisation for environmental impacts; and safety, material assets, and health for socio-economic impacts.

Table 3. Impact levels for the assessment of consequences in the risk assessment, based on Hawkins et al. (2015) and IUCN (2020a, b); Environmental impact), Bacher et al. (2018; Socio-economic impact), and this study (Potential impact).

Impact levels	Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Environmental impact (CON1 & CON3)	Causes at least local extinction of native species, and irreversible changes in community composition; even if the alien taxon is removed the system does not recover its original state.	Causes changes in community composition, which are reversible if the alien taxon is removed.	Causes local population declines in native species, but no changes in community composition.	Causes reductions in individual performance, but no declines in native population sizes.	No effect on performance of individuals of native species.
Socio-economic impact (CON2 & CON4)	Local disappearance of an activity from all or part of the area invaded; change is permanent and irreversible for at least a decade after removal of the alien taxon.	Local disappearance of an activity from all or part of the area invaded; change can be reversible within a decade after removal or control of the alien taxon.	Negative effects on well-being leading to changes in activity size; fewer people participating in an activity, but the activity is still carried out.	Alien species make it difficult for people to participate in their normal activities although the number of participants in any activity does not change.	No deleterious impacts reported despite availability of relevant studies with regard to its impacts on human well-being.
Potential impact (CON5)	The *Taxon* is a transformer in its native range, has ecosystem engineering properties or possesses other traits which suggest irreversible impacts on the community composition in the *Area* to occur. The *Taxon* is a pest of agricultural production in the native range and/or has the potential to cause high losses.	The *Taxon* has traits which suggest major impacts on native communities in the *Area*, but these impacts are likely to be reversible. The *Taxon* has traits which can lead to high losses to economy.	The *Taxon* possesses several undesirable traits. Due to the traits of the *Taxon* and/or its behaviour, it is expected to reduce population sizes of at least one native species. Economic loss is expected to be medium.	The *Taxon* does not possess any traits which could lead to effects on native species population sizes, but reduction in native individuals' performance is expected. Minor economic loss is possibly widespread.	Due to the traits of the *Taxon*, no effect on native individuals' performance is expected. No socio-economic loss is expected. The *Taxon* does not possess any undesirable traits.

These impact classification schemes, however, only consider impacts for which evidence is available (see also Kumschick et al. 2020b). Due to the lack of comprehensive impact studies for most species in most regions (e.g. Pyšek et al. 2008; Evans et al. 2016; Bacher et al. 2018; Kumschick et al. 2017a), the impact of alien species is likely under-reported. We therefore included the possibility to use data from congeners or other closely related species with similar life history traits to the RAAT framework (similar to Bomford 2008). Furthermore, to estimate potential and currently unrecorded impacts of the *Taxon* in the *Area*, we include considerations on the *Taxon*'s traits, behaviour, ecology, and impacts recorded in the native range (Table 3). This results in three to five questions related to impact – depending on data availability for the *Taxon* itself (Table 2). As we are interested in what the worst that could happen is, the maximum of the different impact scores is used as the consequence score.

The consequence score, together with the final probability from the Likelihood section, calculated as described above, are used to assess the level of risk (low, medium, high; as shown in Table 4). If the risk is low, no prioritised management or regulations are recommended and there is no requirement to complete the risk management section of the framework. If the risk is medium or high, however, the risk management section must be completed.

4) Risk Management

Generally, the distinction between whether or not (as opposed to how) to regulate a *Taxon* relies on the risks it poses to the recipient environment and economy. For taxa that are not yet present in an area and for which decisions on importation are required, this can be a relatively straightforward process: if the *Taxon* poses a high risk, it should not be allowed for import, but if it is low risk, it can be considered safe for import (e.g. Keller and Kumschick 2017). However, decisions regarding taxa that are already present and potentially well established in an area and are in use for various purposes, also depend on how easily they can be managed. Since management does not happen in isolation from the rest of society, social perceptions and benefits provided by the *Taxon* need to be assessed and accounted for in these cases (e.g., Zengeya et al. 2017). Unlike in the risk assessment section of the framework, where clear answers and probabilities are provided to determine the level of risk, the inclusion of benefits is dependent on the agenda of various stakeholders, priorities of decision-makers and the influence

Table 4. Table on how to determine the risk score from the likelihood and consequence assessments.

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

of key stakeholders (e.g. Kumschick et al. 2012; Woodford et al. 2017). To keep the process transparent, we make provision for these aspects to outline how the inclusion of benefits influences management decisions and which benefits were included (Suppl. material 2).

Furthermore, once a taxon has been identified as posing a medium or high risk, one needs to consider what can be done to manage the risk. For taxa already present in the *Area* (i.e., for which prevention is no longer an option), this will often require a detailed evaluation of management options, the development of management plans, an assessment of financial resources, and a process of prioritisation of potential interventions (Wilson et al. 2017). Such detailed assessments are beyond the intended scope of the RAAT framework, as they also depend on political decisions and the allocation of resources. However, the RAAT framework provides for some basic management considerations which allow for a broad classification of how to treat certain risks. Therefore, the aim of this section is to provide some guidance as to which broad management goals should be investigated and what information is required in order to prioritise management actions.

The assessment of risk management is more open-ended, but needs to be documented in detail to assure transparency of decisions. In the RAAT framework, this includes socio-economic and environmental benefits, the feasibility to stop future immigration of the *Taxon,* and basic considerations regarding management feasibility (Suppl. material 2). The latter are based on Wilson et al. (2017) and Panetta and Timmins (2004) and include: a) accessibility of populations, b) whether detectability is time-dependent, c) time to reproduction, and d) propagule persistence of the *Taxon*. A scoring approach leads to a basic assessment of the ease of management.

Further to the assessment of these traits, it is important to note that for an assessment of eradication feasibility, a detailed study including, for example, the delimitation of all alien populations of the *Taxon*, population estimates, management trials, and some estimate of the return on investment of different competing strategies, should be conducted (Wilson et al. 2017). Eradication should not be set as a target if not evaluated in detail, as this could lead to a waste of limited resources (e.g., Cacho et al. 2007). To aid this process, there is a question in the framework asking if an eradication feasibility study has been performed for the *Area* (MAN4 in Suppl. material 2) and a further question on control options available (MAN5 in Suppl. material 2).

The answers provided in the risk management section feed into Fig. 2, which leads to broad recommendations on how to manage a *Taxon*. These differ, based on whether the *Taxon* is already present in the *Area*, whether prevention or eradication are feasible goals, and whether the *Taxon* has benefits to the *Area*, such that it might be a conflict species that could be allowed with a permit under certain conditions (Fig. 2).

5) Risk communication

Once the level of risk has been determined and options for management and benefits evaluated, it is crucial to clearly communicate the outcomes of the analysis to stakehold-

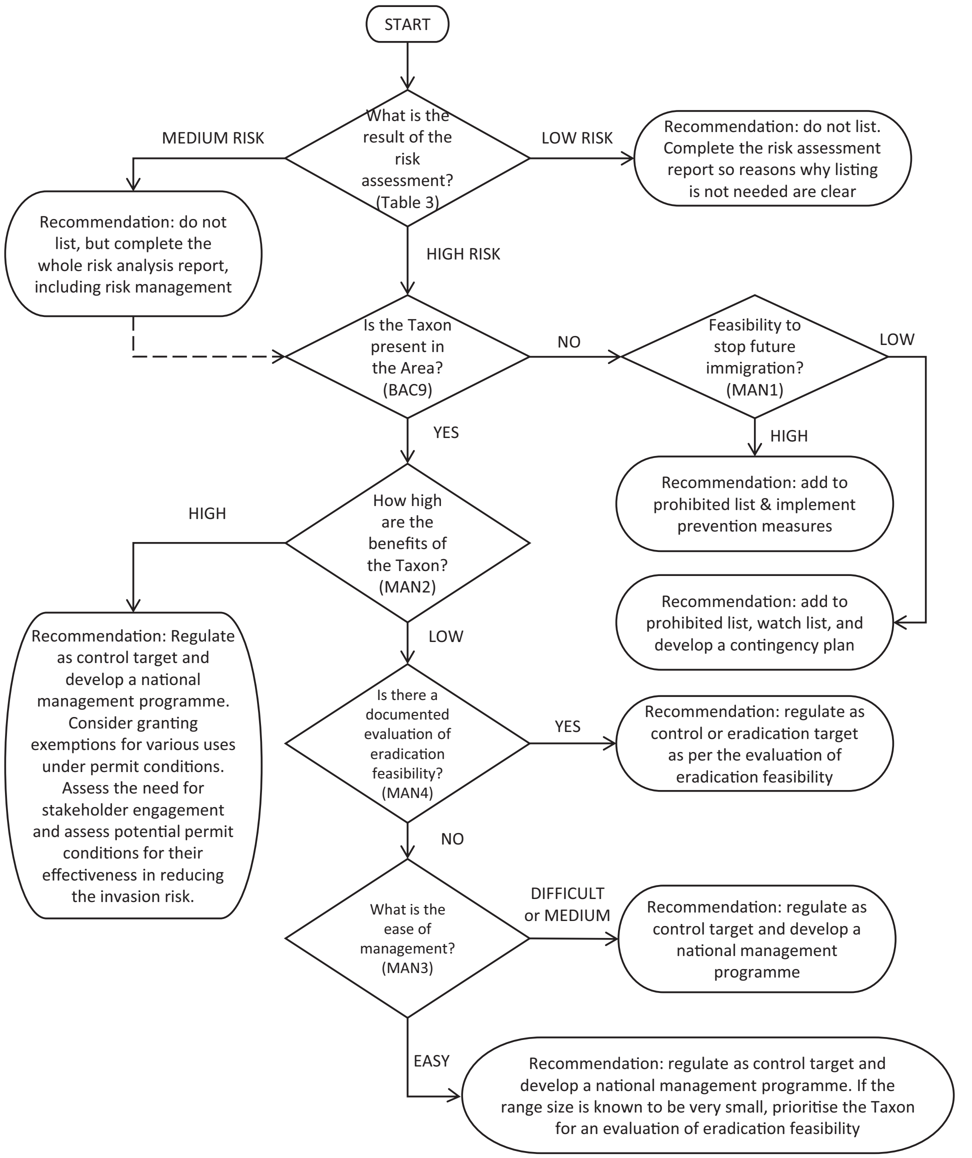

Figure 2. A decision tree for determining the appropriate regulatory response for species which are considered to be of medium or high risk during the risk assessment process. The information in brackets refers to question numbers in the RAAT framework (Table 1 and Suppl. material 2).

ers, including the general public, policy-makers, traders, and users of the *Taxon*. We identify two important components of risk communication. First, stakeholders need to be engaged during the risk analysis process for assessors to obtain information on the *Taxon* and to gain the support of stakeholders in the process (e.g., Novoa et al. 2018). There are often formal regulatory processes of stakeholder engagement and, in contentious cases, an independent scientific assessment might be needed (Scholes et al. 2017), but if conflicts are to be avoided, engagement should happen close to the outset of the process. Second, risk communication is important to provide stakeholders with sufficient information to understand the recommendations and be in a position to know under which circumstances decisions would change, for example, how new information will influence risk. Therefore, communication needs to be simple enough to reach understanding, but needs to provide enough information to underpin the decision.

In the RAAT framework, we incorporated several communication strategies to reach these goals. We provide a decision tree which uses information from the analysis to make recommendations on the management strategy for the *Taxon.* Fig. 2 describes how to arrive at recommendations for the management and regulation from the answers provided in the risk analysis. This depicts a simplified decision-making process which can be easily understood by policy-makers and stakeholders, while the details to feed into the flow diagram are documented and provided in detail in the full analysis. Furthermore, in addition to providing all details of the risk analysis with information on each parameter, we provide a template for an easy-to-digest summary and reporting sheet, including the conclusions from each section, with short descriptions on the *Taxon* itself, impacts, risks, ease of management, and benefits. An example of a summary sheet is given in the Suppl. material 3.

Application in South Africa

As discussed previously, the RAAT framework was tested and applied by different groups. This process has helped us to significantly refine (and we believe improve) the framework over time. It has also highlighted that, while the RAAT framework is fairly straightforward, some scientific experience is needed and assessors must be able to obtain a certain level of knowledge on alien taxa and the processes related to their invasion and impacts. Access to literature and experts is, therefore, also crucial. In South Africa for example, many employees of government agencies who initially tested the framework only had limited access to scientific literature and they therefore initially could not appropriately fill in some of the information required, even though relevant literature was available on the taxon (but not accessible to them).

To date, most taxa analysed with RAAT are of high risk (Table 1), which does not represent an ideal sample of taxa for a test of the applicability of the framework. This bias is due to the mandate of SANBI to analyse species which are currently regulated under the NEMBA A&IS Regulations, but for which no risk analysis had been performed to date. In addition, most taxa analysed so far are already present in South Africa (which was defined as the assessment area for all analyses). Ideally, species with different invasion statuses and risks should be analysed to test the RAAT framework further.

Notably for 13 of the 29 listed species that were assessed, a change in the listing category was recommended (Table 1). This is, again, likely due to the biased selection of taxa – in some cases, taxa were selected for analysis as they were contentious or it was felt the current category was inappropriate. However, it is clear that the listing of taxa, as determined during the original process, will be substantively different from the recommendations obtained by the process outlined here (i.e., completing the RAAT framework with the results reviewed and approved by ASRARP). The RAAT/ASRARP process (see Kumschick et al. 2020a) produces recommendations that are based on the best available scientific evidence, are peer-reviewed, and are transparent. The decision to list taxa, however, is the prerogative of the relevant government departments subject to a mandated requirement for public consultation. As of August 2020, the DFFtE was still in the process of establishing a cross-governmental decision-making panel on the risks of biological invasion. It is anticipated that ASRARP recommendations will be discussed at the meetings of such a panel.

Another lesson learnt was that it was important to train assessors in the application of the RAAT framework if uncertainties and misunderstanding in the questions, answer levels, and verbal descriptions were to be minimised (as also suggested by Sutherland and Burgman 2015). Such training ensures that the assessors applying the framework have a basic level of knowledge on risk analysis, alien taxa, and related processes. The training courses we ran also highlighted some important considerations to be made regarding the application of the RAAT framework. Firstly, there were some insights into the level of prior experience needed to complete a risk analysis. A BSc Hons degree in a relevant field (natural sciences) was mostly sufficient to understand the concepts provided after training, but a postgraduate degree (e.g. Masters) in a relevant field and experience in having authored a scientific publication (and specifically the experience of having responded to critical review comments) is very valuable in order to successfully complete a risk analysis and be able to respond appropriately to ASRARP reviews. Secondly, after training, the time to perform a risk analysis is 4–6 days, excluding the review by ASRARP and external reviewers, with the bulk of the time usually spent reviewing literature on a taxon. This is often increased due to the initial lack of access to primary literature.

While the RAAT framework strives to be objective, there is no guarantee that ASRARP and the assessor conducting the risk analysis agree on the outcome. During ASRARP deliberations it was decided that, if an assessor does not agree with changes requested by the ASRARP, an assessor can withdraw their risk analysis report and their report cannot subsequently be used by ASRARP or a third party. This has only happened once so far, but the issue of recognising potential biases is important – assessors who are knowledgeable on a taxon are likely to have specific views and motivations, while ASRARP members also have their own predilections.

Ideally, several experts should assess the same species and working groups and workshops held to reach final decisions on which species to list under national regulations (Sutherland and Burgman 2015). However, this was not an option in the South African case due to budgetary and time constraints. Increasingly, risk analyses are discussed at appropriate national working groups before submission to ASRARP [e.g., national working groups on alien Cactaceae, alien grasses, and a working group on alien animals in the Cape Floristic Region (Kaplan et al. 2017; Visser et al. 2017; Davies et al. 2020)]. The intention is that the risk analyses, once approved, represent both the best available scientific evidence and are also a consensus of those working on the species.

Dealing with risks that vary significantly with context

Beside the need to set appropriate management goals after risk analysis, there are some other considerations to be made specifically in the South African context. The NEMBA A&IS Regulations set out four potential listing statuses, all linked to specific conditions (Department of Environmental Affairs 2014; Kumschick et al. 2020b): Category 1a: eradication targets; Category 1b: control targets (potentially with exemptions); Category 2: control targets for which certain activities are allowed under permits with conditions; Category 3: control targets with exemptions. During the development and testing of the RAAT framework, it became clear that, with a desktop study (such as the RAAT framework) alone, these categories cannot always be conclusively determined. We therefore recommend that many of the management specific recommendations should be developed on a case by case basis for the species regulated. This includes, for example, suitable permit conditions for category 2 species, management goals for category 1b species (e.g., containment or asset protection, and the need for area-specific management), and the situations under which species can be exempt from conditions (this included category 3 species which are effectively listed the same as category 1b species with some specified exemptions according to the NEM:BA and its A&IS Regulations). Such exemptions could include trees declared as national monuments and protected as "heritage" (e.g., Dickie et al. 2014) should they prove not to contribute to the invasion. A related issue is that of subspecific entities – certain cultivars or varieties could be considered safe for cultivation even if the "parental stock" is invasive (e.g. Datta et al. 2020; Gordon et al. 2016). There is provision within the RAAT framework to assess sub-specific entities separately, but often data on underlying traits are missing (e.g., proof of sterility).

We believe that the RAAT framework is not the place to develop the details of such risk management issues in depth. This should rather be an integral part of the development of national management programmes for particular taxa that can elucidate where and when control should be targeted and when, perhaps, control will be ineffective (for South African examples of such plans, see, for example, van Wilgen et al. 2011; Le Maitre et al. 2015; Terblanche et al. 2016; and the discussion in van Wilgen and Wilson 2018).

Discussion and Way Forward

Biological invasions pose a variety of threats and risk analysis frameworks are needed to explicitly assess and help co-ordinate efforts to manage these. Many decision-support tools for the management of alien taxa have been developed (reviewed by Heikkilä 2011; Leung et al. 2012; Kumschick and Richardson 2013). The RAAT framework takes advantage of the lessons learnt from the application of previous schemes (e.g. Roy et al. 2018) and, therefore, has several key advantages: it provides a comprehensive structure, it addresses all the aspects of risk analysis in one framework, and it is applicable across taxa and regions. RAAT therefore provides a transparent and evidence-based tool to underpin policy decisions and to assist in the prioritisation of alien taxa for management.

Threats posed by biological invasions include not only individual alien taxa, but also invasion pathways and threats posed collectively to specific sites (CBD 2002; McGeoch et al. 2016; Essl et al. 2020). While the RAAT framework focuses on species-based assessments (Kumschick and Richardson 2013), it can feed into pathway and area-based approaches. By formalising risk in a practical and mathematically sound manner, we believe the RAAT framework provides a valuable additional tool for decision-makers, both to assess and manage the threat posed by alien species that are proposed to be deliberately and legally introduced, and to provide a co-ordinated way of providing the evidence base to justify regulating alien species already present in a country.

Ideally, a risk analysis framework for alien species would recommend the most appropriate management goal for an alien species to be regulated (e.g., see Booy et al. 2017). However, the RAAT framework is not exhaustive in terms of making decisions on which management goal is the most suitable for any taxon. Such decisions often need detailed consideration of political and budgetary constraints. In particular, the RAAT framework in isolation does not provide recommendations as to whether a taxon can be eradicated, but rather relies on detailed analysis of eradication feasibility (e.g., Panetta and Timmins 2004; Wilson et al. 2017). Our framework can, however, prioritise taxa for which more information should be gathered for this purpose.

More generally, the RAAT framework does not provide management plans for any taxon recommended for regulation as a control target (Fig. 2). There are several additional considerations that will need to be made when drafting management plans, for instance: Will stakeholders be opposed to management (e.g. access to land)? Are control efforts ethical? Might it be feasible to contain populations? Or should asset protection be the main goal of management? Should resources be spent to develop new control measures, for example, biological control? Such issues are important when attempting management and to reduce and mitigate the risks caused, but need to be considered explicitly outside of the RAAT framework and in many cases need practical considerations outside the realms of a desktop analysis.

In the next phase of development, the RAAT framework will be calibrated to adjust the preliminary cut-off levels set to assign risk categories (e.g. Kumschick and Richardson 2013). The questions, answer levels, and written descriptions as outlined in the Suppl. material 2 will not be affected by this process, but the levels of risk assigned, as shown in Table 3, might change according to the outcome. Generally, the RAAT framework allows for risk analyses to be updated if and when more information becomes available. Cut-off levels for low, medium, and high risk can be adapted if needed or as appropriate, however justification needs to be provided. It will also be important to assess the degree to which a risk analysis performed in South Africa on a given taxon can be used as the basis for a risk analysis of a given taxon in a different country or even a specific part of South Africa. As currently formulated, we suspect information on the likelihoods are context-specific, the potential consequences are more general and management considerations are a mix of the two, but this remains to be tested.

As more taxa in South Africa are analysed, new issues with the RAAT framework will undoubtedly arise. However, we feel that it represents a significant advance in making the process of regulating alien taxa more transparent, defensible, and more clearly linked to international protocols.

Accessibility of data

An updated version of the RAAT framework is appended here (Suppl. material 2, dubbed v1.2), but we plan to maintain the most recent version on the Zenodo server [DOI 10.5281/zenodo.3760907] and would encourage readers to check there for the latest version.

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Supplementary material 1

How the Risk Analysis Framework covers Section 6, Regulation 14-17, in the NEM:BA A&IS Regulations of 2014 (Appendix S1)

Authors: Sabrina Kumschick, John R. U. Wilson, Llewellyn C. Foxcroft

Data type: List of parameters and link to regulations

Explanation note: Questions in the Risk Analysis Framework and the aspects in the NEMBA A&IS Regulations (DEA 2014) they cover (Table s1.1) and aspects not covered in the Risk Analysis Framework which deal with the restricted activity regarding the permit application and are suggested to be requested for permit applications in a separate document (from NEMBA A&IS Regulations; DEA 2014) (Table S1.2).

Link: https://doi.org/10.3897/neobiota.62.51031.suppl1

Supplementary material 2

Risk Analysis for Alien Taxa framework, adapted to South African NEMBA A&IS Regulations (v.1.2) (Appendix S2)

Authors: Sabrina Kumschick, John R. U. Wilson, Llewellyn C. Foxcroft

Data type: Detailed guidelines for RAAT

Explanation note: Detailed guidelines for applying the Risk Analysis for Alien Taxa (RAAT) framework, including the reporting template.

Link: https://doi.org/10.3897/neobiota.62.51031.suppl2

Supplementary material 3

Example of RAAT (Appendix S3)

Authors: Sabrina Kumschick, John R. U. Wilson, Llewellyn C. Foxcroft

Data type: Example risk analysis

Explanation note: Example of a reporting sheet for the risk analysis of Psittacula krameria in South Africa. Note: this has been updated to the most recent format and is slightly different from the approved version.

Link: https://doi.org/10.3897/neobiota.62.51031.suppl3

Supplementary material 4

List of contributors to the risk analysis process in South Africa 2018, 2019 (Appendix S4)

Authors: Sabrina Kumschick, John R. U. Wilson, Llewellyn C. Foxcroft

Data type: List of assessors, reviewers and experts

Explanation note: Only people involved in risk analyses where the recommendation has been approved are noted here; there are many others who are currently involved as assessors, experts or reviewers, but they have not yet been involved in an approved risk analysis. Many other people were involved prior to 2018 (in particular the panel was set up and initially chaired by Philip Ivey), but the risk analysis framework had not been implemented at that stage. A 'Member' is someone who served on the Alien Species Risk Analysis Review Panel (with ex-officio members indicated with an asterisk); an 'Assessor' is someone who conducted a risk analysis; an 'Expert' is a person who is an Assessor and listed as someone who was formally consulted during the development of their risk analysis report; a 'Reviewer' is someone who reviewed a risk analysis report at the bequest of an ASRARP member (i.e. independent from the Assessor). In addition, Khensani Nkuna and Viwe Balfour assisted as part of the ASRARP Secretariat. It is intended that an updated list will be published annually on SANBI's website, but it can also be provided on request.

Link: https://doi.org/10.3897/neobiota.62.51031.suppl4

Supplementary material 5

Guidance regarding the use of the confidence rating (Appendix S5)

Authors: Sabrina Kumschick, John R. U. Wilson, Llewellyn C. Foxcroft

Data type: Guidance on confidence ratings

Explanation note: Guidance regarding the use of the confidence rating (taken from Hawkins et al. 2015, modified from the EPPO pest risk assessment decision support scheme (Alan MacLeod 09/03/2011; revised 28/04/2011; copied from CAPRA, version 2.74; 2)).

Link: https://doi.org/10.3897/neobiota.62.51031.suppl5

Supplementary Material 1

Appendix S1: How the Risk Analysis Framework covers Section 6, Regulation 14-17, in the NEM:BA A&IS Regulations of 2014

The proposed Risk Analysis for Alien Taxa framework is intended for collation of evidence for the listing of species under the NEM:BA A&IS Regulations (DEA 2014). It covers all aspects of Reg. 14, as well as some of Reg. 17 (Table S1.1), except the ones which are specifically related to permits (Table S1.2). Some additional information is included in the framework. Furthermore, it allows for a transparent documentation and decision-making process, as standardised answers are given with clear descriptions.

Information concerning restricted activity related to permit applications (i.e. Category 2 listed species and new imports) is not included in the framework, but should be requested in a separate document (Table S1.2). In future, when all species listed under the NEMBA A&IS Regulations have been assessed with the Risk Analysis for Alien Taxa framework, it will only be necessary for permit applicants to fill in this extra document on the restricted activity. This is more specific to the restricted activity and the area in which this will be carried out, but some aspects collected for the main risk analysis could be used to do these assessments, for example, 14(1)(c)(i).

Table S1.1: Questions in the Risk Analysis Framework and the aspects in the NEMBA A&IS Regulations (DEA 2014) they cover

Parameter	Description	NEMBA A&IS Regulations 2014
BAC1	Name of assessor(s)	17. (1) (a) The personal details and qualifications of the risk assessment practitioner carrying out the risk assessment
BAC2	Contact details of assessor(s)	17. (1) (a) The personal details and qualifications of the risk assessment practitioner carrying out the risk assessment
BAC3	Name(s) and contact details of expert(s) consulted	17. (1) (b) the personal details and qualifications of the expert consulted as required in regulation 15(3)(e)
BAC4	Scientific name of *Taxon* under assessment	14. (1) (a) (i) the taxonomy of the species, including its class, order, family, scientific name if known, genus, scientific synonyms and common names of the species
BAC5	Synonym(s) considered	14. (1) (a) (i) the taxonomy of the species, including its class, order, family, scientific name if known, genus, scientific synonyms and common names of the species
BAC6	Common name(s) considered	14. (1) (a) (i) the taxonomy of the species, including its class, order, family, scientific name if known, genus, scientific synonyms and common names of the species
BAC7	What is the native range of the *Taxon*?	14. (1) (a) (ii) the originating environment of the species, including climate, extent of geographic range and trends

Parameter	Description	NEMBA A&IS Regulations 2014
BAC8	What is the global alien range of the *Taxon*?	14. (1) (a) (ii) the originating environment of the species, including climate, extent of geographic range and trends (v) the history of domestic propagation or cultivation of the species, introductions and the extent of naturalisation in South Africa and elsewhere
BAC9	The *Area* under consideration	
BAC10	Is the *Taxon* present in the *Area*?	14. (1) (a) (v) the history of domestic propagation or cultivation of the species, introductions and the extent of naturalisation in South Africa and elsewhere
BAC11	Availability of physical specimen	
BAC12	Is the *Taxon* native to the *Area* or part of the *Area*?	14. (1) (a) (v) the history of domestic propagation or cultivation of the species, introductions and the extent of naturalisation in South Africa and elsewhere
BAC13	What is the *Taxon's* introduction status in the *Area*?	14. (1) (a) (v) the history of domestic propagation or cultivation of the species, introductions and the extent of naturalisation in South Africa and elsewhere
BAC14	Primary (introduction) pathways	
LIK1	Likelihood of entry via unaided primary pathways	14. (1) (a) (iii) persistence attributes of the species, including reproductive potential, mode of reproduction, dispersal mechanisms and undesirable traits
LIK2	Likelihood of entry via human aided primary pathways	
LIK3	Habitat suitability	14. (1) (a) (ii) the originating environment of the species, including climate, extent of geographic range and trends (vi) nutritional or dietary requirements of the species and, where applicable, whether it has a specialist or generalist diet (c) (ii) habitat (iii) disturbance regimes (iv) the presence of natural enemies, predators and competitors
LIK4	Climate suitability	14. (1) (c) (i) climate match
LIK5	Unaided secondary (dispersal) pathways	14. (1) (a) (iii) persistence attributes of the species, including reproductive potential, mode of reproduction, dispersal mechanisms and undesirable traits
LIK6	Human aided secondary (dispersal) pathways	
CON1	Environmental impact	14. (1) (a) (vii) the ability of the species to create significant change in an ecosystem; (viii) the potential to hybridise with other species and to produce fertile hybrids
CON2	Socio-economic impact	14. (1) (a) (vii) the ability of the species to create significant change in an ecosystem

Parameter	Description	NEMBA A&IS Regulations 2014
CON3	Closely related species' environmental impact	14. (1) (a) (iv) invasive tendencies of the species elsewhere and of close taxonomic relatives in South Africa and elsewhere
CON4	Closely related species' socio-economic impact	14. (1) (a) (iv) invasive tendencies of the species elsewhere and of close taxonomic relatives in South Africa and elsewhere
CON5	Potential impact	14. (1) (a) (iii) persistence attributes of the species, including reproductive potential, mode of reproduction, dispersal mechanisms and undesirable traits (vi) nutritional or dietary requirements of the species and, where applicable, whether it has a specialist or generalist diet (c) (v) the presence of potentially reproductive compatible species (2) (b) the possible impact of the species on the biodiversity and sustainable use of natural resources of - (ii) in any other area elsewhere in the Republic (c) the risks of the specimen serving as a vector through which specimens of other alien species may be introduced
MAN1	What is the feasibility of stopping future immigration?	14. (2) (e) any measures proposed in order to manage the risks
MAN2	Benefits of the *Taxon*	17. (1) (d) key economic, social and ecological considerations that will guide a decision on whether or not to issue a permit
MAN3	Management feasibility	14. (2) (e) any measures proposed in order to manage the risks
MAN4	Is an eradication feasibility study available?	14. (2) (e) any measures proposed in order to manage the risks
MAN5	Control options and monitoring approaches available for the Taxon	14. (2) (e) any measures proposed in order to manage the risks
MAN6	Any other management considerations to highlight?	14. (2) (e) any measures proposed in order to manage the risks

Conclusions in framework:

(3) Based on the information in sub-regulations (1) and (2), a risk assessment must consider-

(a) the likelihood of the risks being realised;

(b) the severity of the risks and consequences of the realisation of the risks for other species, habitats and ecosystems;

(c) the potential costs associated with the control of the species to minimise harm to biodiversity; and

(d) options for minimising the potential risks

Table S1.2: Aspects not covered in the Risk Analysis Framework which deal with the restricted activity regarding the permit application and are suggested to be requested for permit applications in a separate document (from NEMBA A&IS Regulations; DEA 2014)

14.	**Risk assessment framework**
	(1) A risk assessment must consider- (b) information regarding the restricted activity, in respect of which the permit is sought, including- (i) the nature of the restricted activity; (ii) the reason for the restricted activity; (iii) the location where the restricted activity is to be carried out; (iv) the number and, where applicable, the gender of the specimens of the species involved; and (v) the intended destination of the specimens, if they are to be translocated; and (c) information regarding the receiving environment, including- (i) climate match; (ii) habitat; (iii) disturbance regimes; (iv) the presence of natural enemies, predators and competitors; and (v) the presence of potentially reproductive compatible species.
	(2) A risk assessment carried out in terms of sub-regulation (1) must identify- (a) the probability that the species will naturalise in the area in which the restricted activity is to be carried out or in any other area elsewhere in the Republic; (b) the possible impact of the species on the biodiversity and sustainable use of natural resources of- (i) the area in which the restricted activity is to be carried out; and (c) the risks of the specimen serving as a vector through which specimens of other alien species may be introduced; (d) the risks of the method by which a specimen is to be introduced or the restricted activity carried out serving as a pathway through which specimens of other alien species may be introduced; and (e) any measures proposed in order to manage the risks.
	(3) Based on the information in sub-regulations (1) and (2), a risk assessment must consider- (a) the likelihood of the risks being realised; (b) the severity of the risks and consequences of the realisation of the risks for other species, habitats and ecosystems; (c) the potential costs associated with the control of the species to minimise harm to biodiversity; and (d) options for minimising the potential risks.

Supplementary Material 2

Appendix S2: Risk Analysis for Alien Taxa framework, adapted to South African NEMBA A&IS Regulations (v.1.2)

Version history

v1.0: Kumschick, S., Wilson, J. R., Foxcroft, L.C. (2017) Guidelines for conducting risk analyses under the NEM:BA Alien and Invasive Species Regulations of 2014. Submitted to the South African Department of Environmental Affairs, March 2017.

v1.1: Kumschick, S.; Wilson, J.R.; Foxcroft, L.C. (2018) Framework and guidelines for conducting risk analyses for alien species. Preprints 2018, 2018110551, http://dx.doi.org/10.20944/preprints201811.0551.v1

v1.2 (and future version): to be available from Zenodo. [DOI 10.5281/zenodo.3760907]

Risk analysis framework

The questions are described here in detail. For each question, a section in the Answer sheet needs to be filled in, generally consisting of Response, Confidence, Comments/Rationale and References. Unless otherwise stated, all these sections need to be filled in. A glossary of terms used in the framework is provided in Annexure S2.

1) Background

The background gives important information on the assessor, the *Area* and the *Taxon*.

BAC1 Name of assessor(s)
Give the full name and surname of the main assessor and any additional assessors. The lead assessor takes responsibility for the assessment and is the author/assessor for correspondence. Add more lines if more assessors were involved.

BAC2 Contact details of assessor(s)
Add more lines if more assessors were involved.

BAC3 Name(s) and contact details of expert(s) consulted
This can include internal (within same organisation or group of assessors) or external (including international) experts or reviewers, who influenced, commented or amended the document before submission. In the comments, outline the kind of contribution these experts made. Add additional lines if several experts were consulted.

BAC4 Scientific name of Taxon *under assessment*
The biological entity under consideration. The full scientific (binomial) name as well as taxonomic authority is required. In most cases, this will be a species, but it could be another taxonomic level (e.g. genus or sub-species). Mention the taxonomic level under comments. The organism under assessment will be called the "*Taxon*" in the rest of the document. Check ITIS (http://www.itis.gov/) or a taxon specific taxonomic database for the correct nomenclature and note the validity of the name

under comments. Note in the references which database was used for the species identification/name.

BAC5 Synonym(s) considered
List synonyms of the scientific (Latin) name of the *Taxon* which were considered for this assessment. Only list names included in the literature search, not synonyms which were not considered. Check for synonyms in ITIS (http://www.itis.gov/) or a taxon specific taxonomic database. Note in the references which database was considered.

BAC6 Common name(s) considered
List common names of the *Taxon* which were considered for this assessment. Only list names included in the literature search, not all recorded common names. In the comments, indicate where the common names are used and which languages were considered.

BAC7 What is the native range of the Taxon*?*
The *Taxon's* biogeographic distribution provides useful context for understanding the actual and potential range of the *Taxon*. Here, a description in words is required, which can aid the literature search. If the *Taxon's* native range includes the *Area* or part of the *Area*, see BAC12.
A map of the native range should be provided, if possible. If the map is available in a file, please insert a low res copy (< 1 MB) as an appendix to the Answer sheet and provide the file name and (if possible) a link to a higher resolution copy.

BAC8 What is the global alien range of the Taxon*?*
This includes the *Taxon's* global alien range, including the range within the *Area*. The distribution of the *Taxon's* introduced range provides useful context for understanding the actual and potential range of the *Taxon* and provides guidance for the literature search. For example, we are only interested in negative impacts caused in the alien range for the impact scoring and classification, even though some species also have undesirable effects in the native range under certain conditions.
A map of the alien range should be provided, if possible. If the map is available in a file, please insert a low res copy (< 1 MB) as an appendix to the Answer sheet and provide the file name and (if possible) a link to a higher resolution copy.

BAC9 Geographic scope = the Area *under consideration*
Specify the geographic entity under consideration, i.e. the geographic scope of the assessment. In most cases this will be the whole of South Africa, but can also be only a part of the country; for example, a single province, a national park or a river catchment. The region under assessment will hereafter be referred to as the "*Area*". The *Taxon* should generally only be assessed in its alien range.

BAC10 Is the Taxon *present in the* Area*?*
Note if the Taxon is present anywhere in the Area. In the case where the presence of the species is not confirmed, but a record has been noted, include field visits, as appropriate.

BAC11 Availability of physical specimen
In the Response, state if a physical sample was collected in the *Area* (yes/no). The name of the herbarium/museum and its accession number/record of the *Taxon* in the *Area* should be provided in the respective section. The record should have been checked by a national and/or international taxonomic expert and the person at the herbarium/museum who identified the sample and date should also be given.
If the *Taxon* has not previously been reported as present in the *Area* and the identity is not certain OR if no herbarium or museum record is available, contact a relevant specialist. Record all information that can be obtained from the specialist; including a reference to some herbarium or museum, so that in the future, if need be, it will be possible to determine what the *Taxon's* identity was compared to at the initial identification, i.e. if it turns out, in future, that the identification could be wrong, we need to be able to understand why it was identified as that particular *Taxon*.

BAC12 Is the Taxon *native to the* Area *or part of the* Area*?*

Indicate whether the *Taxon* is native or alien and select one of the answers provided for each (yes, no or don't know). If native to parts of the *Area*, specify its native and alien range in the Comments. If alien to the whole or parts of the *Area*, clarify under BAC7 that only alien ranges are considered for this assessment. If the *Taxon* is native to the whole of the *Area*, it should not be considered for listing under the NEMBA A&IS Regulations in that *Area* and does not go through the assessment process. For species native to the mainland, but alien on the off-shore islands, listing should only be considered for the islands, i.e. the *Area* (as specified under BAC7) should be the islands.

BAC13 What is the Taxon's *introduction status in the* Area*?*

If the *Taxon* is present in the *Area*, define its introduction status as follows (according to Blackburn et al. 2011):

- alien in cultivation/captivity: individuals transported beyond the limits of its native range and in captivity, quarantine or cultivation, i.e. individuals provided with conditions suitable for them, but explicit measures of containment or explicit measures to prevent spread are in place
- alien outside of cultivation/captivity: individuals transported beyond the limits of native range and directly released into the new environment or individuals escaped from cultivation/captivity, but incapable of surviving for a significant period or, if surviving in the wild, no reproduction or, if reproduction occurring, population not self-sustaining
- established: individuals surviving outside of cultivation/captivity in locations where introduced, reproduction occurring and population self-sustaining
- invasive: self-sustaining populations outside of cultivation/captivity with individuals surviving and reproducing a significant distance from the original point of introduction, i.e. dispersal happening.

Give information on each step in the invasion continuum and select one of the answers provided for each (yes, no or don't know).

BAC14 Primary (introduction) pathways

List historical, currently known and potential future entry pathways for the *Taxon* in the *Area* and other introduced ranges. The pathway classification is based on the one accepted by the Convention on Biological Diversity (CBD) (see also Essl et al. 2011). Provide information on all categories and, if available, on the sub-categories in the Response.

2) Likelihood

This section deals with the likelihood of the *Taxon* to enter (LIK1 & LIK2), establish (LIK3 & LIK4) and spread (LIK5 & LIK6) in the *Area*, which is representing the steps alien taxa need to take in order to become invasive. This section, therefore, assesses the likelihood of the *Taxon* becoming invasive. The timeframe to be considered for these questions is 10 years. In other words, we are assessing the likelihood of these events to occur within the next 10 years.
All the answers are described in scenarios for each level separately, with each level being an order of magnitude more likely than the next lower level. If the answer is unknown, it is set as p = 1, due to the precautionary principle (i.e. a high likelihood is assumed if not known).
Generally, all the answers in this section are structured in the same way and they follow the logic described here:

- Extremely unlikely (p = 0.000001): as likely as winning the lottery if you play it once
- Very unlikely (p = 0.0027): as likely as a new person you meet having their birthday on the same day as yours
- Unlikely (p = 0.027): as likely as rolling 2 sixes when playing dice
- Fairly probable (p = 0.5): as likely as getting heads when flipping a coin, i.e. fifty-fifty

- Probable (p = 1 for calculation purposes): more likely to happen than not

The probability levels p represent the likelihood of an event happening and will be used to calculate a final likelihood of an invasion to occur (see Figure S2 and Table S2).

The questions in this section represent the invasion process, with two questions for each step in the process (i.e. entry, establishment and spread). Each answer to the questions in this section is attached to a probability value p as indicated in brackets in the response options (i.e. Extremely unlikely: p = 0.000001; Very unlikely: p = 0.0027; Unlikely: p = 0.027; Fairly probable: p = 0.5; Probable: p = 1; Don't know: p = 1).

Figure S2 illustrates how to calculate a final Likelihood score from the answers provided in LIK1-LIK6. Subsequently, this value can be transcribed into a Likelihood description as in Table S2, which feeds into the Risk assessment (Table S3).

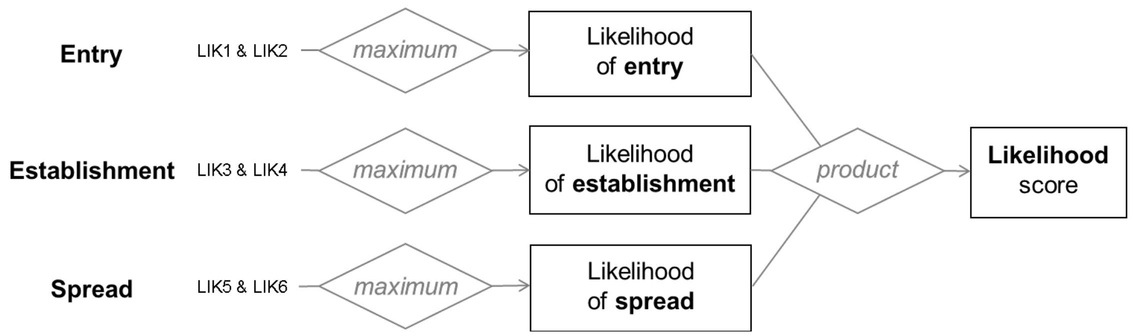

Figure S2 The calculation of a final likelihood score from the likelihood questions LIK1-LIK6. The likelihood descriptions to extract a Risk score for the Risk assessment in Table S3 can then be found in Table S2.

Table S2: Transcription of Likelihood scores into descriptions for the Risk score in Table S3. The Likelihood score is calculated as in Figure S2.

Likelihood score	Likelihood (description)
p ≤ 0.000001	Extremely unlikely
0.000001 < p ≤ 0.0027	Very unlikely
0.0027 < p ≤ 0.027	Unlikely
0.027 < p ≤ 0.5	Fairly probable
p > 0.5	Probable

LIK1 Likelihood of entry via unaided primary pathways

If the *Taxon* is present in the *Area* (see BAC10), the probability of entry should be set as 1. Still fill in this section as if the Taxon were not present and give details on pathways, as this can provide information for risk management and the feasibility to stop future immigration. However, for the calculations, use the probability of 1.
Estimate the probability that the *Taxon* enters the *Area* from outside the *Area* through unaided pathways within the timespan of a decade. Consider the unaided pathways mentioned under BAC14. Features of the *Taxon* which favour unaided entry include presence in neighbouring countries and regions, water or wind dispersed propagules (e.g. floating propagules), the ability to fly long distances, the ability for fish to move from one river catchment where introduced, to another via connected waterways. Animal dispersal is also considered here, except domestic and farm animals which are

included under LIK2. The following factors can aid entry via animals: edible parts (e.g. fruits) which are eaten by animals, propagules with spines/barbs/sticky substances which can attach to animals, very small propagules which can get stuck in fur and feathers, pests attached to plants or animals. List the pathways and corresponding likelihoods in the comments section. In the response, give the highest likelihood for any pathway. The assessment should be based on the likelihood of entry, based on current and future pathways.

Response options:

Extremely unlikely (p = 0.000001): the *Taxon* and its propagules are highly sessile and are known never to disperse on its own – proof is required for inability to move, otherwise classify as "Very unlikely".

Very unlikely (p = 0.0027): the *Taxon* and its propagules are sessile and do not usually disperse on their own

Unlikely (p = 0.027): the *Taxon* is sessile, but it can disperse during one specific life stage, dispersal capabilities are slow and over short distances

Fairly probable (p = 0.5): the *Taxon* is highly mobile during at least one of its life stages and can reach a high dispersal capability during one of its life stages

Probable (p = 1): highly mobile *Taxon* with dispersal capability fast and over large distances

Don't know (p = 1): no information is available on the unaided pathways available to the *Taxon*

LIK2 Likelihood of entry via human aided primary pathways

If the *Taxon* is present in the *Area* (see BAC10), the probability of entry should be set as 1. Still fill in this section as if the Taxon were not present and give details on pathways, as this can provide information for risk management and the feasibility to stop future immigration. However, for the calculations, use the probability of 1.

Estimate the probability that the *Taxon* enters the *Area* from outside the *Area* through the pathways mentioned under BAC14 which are human-mediated (as opposed to unaided, which are covered in LIK1) within the timespan of a decade. List the pathways and corresponding likelihoods in the comments section. This also includes entry from neighbouring countries (consider it could in future be introduced into neighbouring countries). In the response, give the highest likelihood for any pathway. The assessment should be based on the likelihood of introductions, based on current and future pathways. For taxa which are already present in the *Area*, mainly focus on unintentional pathways.

Response options:

Extremely unlikely (p = 0.000001): There is currently no human aided entry pathway available/in use for the *Taxon* and no future pathway is expected to arise

Very unlikely (p = 0.0027): There is currently a human aided entry pathway available/in use, but the *Taxon* is highly sensitive to movement and is unlikely to arrive alive at any life stage

Unlikely (p = 0.027): There is a human aided entry pathway available/in use which is infrequently used and/or future new pathways are expected to arise; also, the *Taxon* is not expected to arrive in high numbers

Fairly probable (p = 0.5): Several human aided entry pathways are available/in use, but not regularly used and/or some potentially lead to a high number of introductions

Probable (p = 1): Several human aided entry pathways available and regularly used for the *Taxon* and high numbers of individuals expected.

Don't know (p = 1): no information is available on the human aided pathways used by the *Taxon*

LIK3 Habitat suitability

Indicate the likelihood of the *Taxon* to find suitable habitats in the *Area* for survival and reproduction. Habitat includes the presence of suitable food items, hosts, pollinators, seed dispersers and other biotic conditions. If the *Area* encompasses multiple habitats, consider those that are most likely suited and mention in the comments section which habitats were assessed. Thus also take the habitat specificity of the *Taxon* into account. Artificial habitats include, for example, (with increasing degree of artificiality) gardens, zoos, greenhouses, indoor habitats.

Response options:

Extremely unlikely (p = 0.000001): the *Taxon* is extremely specialised and there is no suitable habitat in the *Area*, none of the key conditions for the *Taxon's* survival is met

Very unlikely (p = 0.0027): the *Taxon* is highly specialised, but there is reason to assume that it might adapt to some biotic habitat conditions; only highly artificial habitats which are rare or difficult to maintain are suitable.
Unlikely (p = 0.027): the *Area* provides habitat that is only partly suitable to the *Taxon*; certain artificial habitats are suitable
Fairly probable (p = 0.5): the key conditions are met, but only in a marginal part of the *Area*; also non-artificial habitats suitable.
Probable (p = 1): all key biotic habitat conditions are met in a large part of the *Area*.
Don't know (p = 1): no information is available on habitat requirements of the *Taxon*

LIK4 Climate suitability

Indicate the likelihood of the *Taxon* to find suitable climate in the *Area* for survival and reproduction. Use the native and alien ranges as references for the *Taxon's* distribution, as obtained in BAC7 and BAC8. As a minimum standard, use published maps of climate zones to check whether the climate in the *Area* is suitable for the *Taxon*. Such maps include the following:
- Koeppen-Geiger climate zones, updated by Peel et al. (2007)
- Richardson and Thuiller (2007) maps of global locations that match South African climates.

Climate models are more desirable and lead to a higher confidence in the assessment.
If the *Area* encompasses multiple climate zones, consider those that are most likely suited and mention in the comments section which climatic zones were assessed. For species already present in the *Area*, the answer cannot be "extremely unlikely".

Response options:
Extremely unlikely (p = 0.000001): The *Area* provides no suitable climate (including artificially created environments)
Very unlikely (p = 0.0027): The *Area* provides no suitable climate, but suitable climate can be artificially created in small (< 5%) parts of the *Area*.
Unlikely (p = 0.027): The *Area* provides little (< 5%) climatic overlap with the known distribution of the Taxon, excluding artificially created suitable habitats.
Fairly probable (p = 0.5): The main climatic requirements are met in a marginal (> 5% but < 20% - one fifth) part of the *Area*.
Probable (p = 1): The main climatic requirements are met in a larger part (> 20%) of the *Area*.
Don't know (p = 1): no information is available on the climatic requirements of the *Taxon*

LIK5 Unaided secondary (dispersal) pathways

This includes the unaided pathways currently or potentially bringing the *Taxon* from the occupied regions to elsewhere within the *Area*. It excludes unaided pathways bringing propagules from areas outside of the *Area* into the *Area* (covered in LIK1). Indicate the probability that the *Taxon* disperses naturally from a population within the *Area* to currently unoccupied regions and habitats. Mention details of the expected dispersal pathways and mechanisms in the comments section. More precisely, try to estimate the probability that the *Taxon* can disperse > 50 km in a decade. Features of the *Taxon* which favour unaided dispersal include water or wind dispersed propagules (e.g. floating propagules), the ability to fly long distances, the ability for fish to move from one river catchment where introduced, to another via connected waterways. Animal dispersal is also considered here, except domestic and farm animals which are included under LIK6. The following factors can aid dispersal by animals: edible parts (e.g. fruits) which are eaten by animals, propagules with spines/barbs/sticky substances which can attach to animals, very small propagules which can get stuck in fur and feathers, pests attached to plants or animals.

Response options:
Extremely unlikely (p = 0.000001): the *Taxon* and its propagules are highly sessile and are known never to disperse on their own – proof is required for inability to move, otherwise classify as "Very unlikely".
Very unlikely (p = 0.0027): the *Taxon* and its propagules are sessile and do not usually disperse on their own.
Unlikely (p = 0.027): the *Taxon* is sessile, but it can disperse during one specific life stage, dispersal capabilities are slow and short distance (< 50 km in 10 years).
Fairly probable (p = 0.5): the *Taxon* is mobile and can reach a high dispersal capability during one of its life stages.

Probable (p = 1): highly mobile *Taxon* with dispersal capability fast and over large distances.
Don't know (p = 1): no information is available on unaided dispersal pathways used by the *Taxon.*

LIK6 Human aided secondary (dispersal) pathways

This includes the human aided pathways currently or potentially bringing the *Taxon* from the occupied regions and habitats elsewhere within the *Area*. This question does not include dispersal from outside of the *Area* to the *Area* as this is covered in LIK2. Indicate the probability that the *Taxon* gets dispersed from a population within the *Area* to uninvaded habitats. Intentional and unintentional pathways need to be considered. Mention details of the expected pathways in the comments section. The likelihood score relates to the proximity of the *Taxon* to human and domestic/farm animals and frequency of contact, which allows it to be dispersed in these kinds of dispersal pathways, as well as traits and features of the *Taxon* which facilitate for it to be moved around.
More precisely, try to estimate the probability that human-mediated dispersal takes (propagules of) the *Taxon* > 50 km in a decade.
Features of the *Taxon* which favour human aided dispersal include edible parts (e.g. fruits), propagules with spines/barbs/sticky substances which can attach to clothing, vehicles and boats, building materials, very small propagules which can get stuck in clothing/shoes or with movement of ornamental plants and be transported unnoticed. Dispersal by domestic and farm animals is included here.

Response options:
Extremely unlikely (p = 0.000001): the *Taxon* is not present in places accessible by humans, domestic and/or farm animals.
Very unlikely (p = 0.0027): the *Taxon* is only present in places humans, domestic and/or farm animals can reach with difficulty and/or has no features which make it likely to be dispersed human aided.
Unlikely (p = 0.027): the *Taxon* is present in places where humans, domestic and/or farm animals occasionally occur and/or has features which make it possible to be dispersed human aided, but only in exceptional cases.
Fairly probable (p = 0.5): the *Taxon* is present in places easily accessible by humans and/or it or its propagules are easily moved, i.e. it possesses some feature mentioned above.
Probable (p = 1): the *Taxon* is present in a place frequented by humans and it or its propagules are easily and regularly moved due to features mentioned above.
Don't know (p = 1): no information is available on the human aided pathways used by the *Taxon.*

3) Consequences

In this section, all evidence of impacts in the global alien range (including the *Area*) available for the *Taxon* needs to be collated and scored for environmental impacts and socio-economic impacts. Data on the impacts of the *Taxon* itself from the *Area* or other alien regions are the most desirable (CON1a)-k) and CON2a)-f)). Only if no data are available on the *Taxon* in any alien range globally should it be classified as Data Deficient (DD) under CON1 and CON2.
If this is the case, i.e. no data are available for the Taxon on impacts anywhere in its global alien range, look for data of congeners or other closely related species with similar life history traits and fill in CON3 and CON4.
Additionally, consider data in the native range of the *Taxon* and/or estimate the magnitude of impact possible for the *Taxon* in the *Area,* based on biological, ecological and behavioural traits in CON5. This needs to be filled in regardless of whether information on CON1 and CON2 is available, but can lead to similar results if the impact of the *Taxon* has been well studied.
The environmental impact (CON1) is based on the Environmental Impact Classification of Alien Taxa (EICAT) system by Blackburn et al. (2014), IUCN (2020

a & b) and the socio-economic rating (CON2), based partly on the Socio-Economic Impact Classification for Alien Taxa (SEICAT) by Bacher et al. (2017).
For a measure of future potential and currently unrecorded impact of the *Taxon* in the *Area*, CON5 includes considerations on the *Taxon*'s traits, behaviour and ecology and considers impacts recorded in the native range.

Fill all results as described below from CON1-5 into Figure S3 below and in the answer sheet to calculate maximum impact levels for the *Taxon*. For the consequence score, the maximum impact level should be taken between all the impact measures (CON1-5). This impact level is then used to calculate the risk score, as described in Table S3.

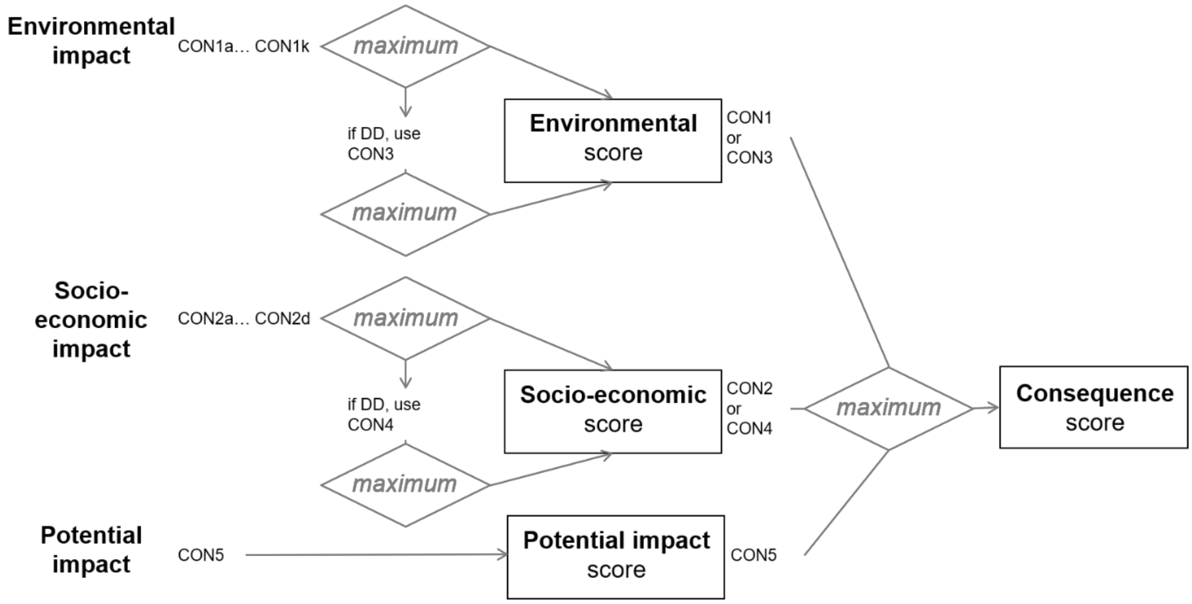

Figure S3: Consequences in terms of impact scores

CON1 Environmental impact

The consequence assessment is based on the Environmental Impact Classification of Alien Taxa (EICAT) scheme. EICAT classifies taxa into minimal concern (MC), minor (MN), moderate (MO), major (MR), massive (MV) according to the magnitude of impact they cause. Detailed descriptions of all the impact levels are given in CON1a)-CON1k) below.
Fill in the Answer sheet for each of the mechanisms as described below (CON1a-CON1k). Then use the scheme provided in Figure S3 to calculate the environmental impact score (CON1), which is basically the maximum of all the mechanisms. Report on the maximum impact found in any of the mechanisms for the global alien range in the Response for CON1 and the main mechanism affected in the Rationale, but provide information on all the sectors and impact scores in CON1a)-CON1k), including detailed information on the references used for the assessments. If impact assessments have been conducted previously for the *Taxon* and are available in literature, information can be extracted from there and no detailed search is needed.
If no data on impact are available for the *Taxon* anywhere in the global alien range for any of the mechanisms described, mark the *Taxon* as Data Deficient (DD) here and additionally fill in CON3, i.e. consider information on closely related taxa.

CON1a Competition

What is the evidence in the global alien range of the *Taxon* for impact through competition?
Does the *Taxon* compete with native taxa for resources (e.g. food, water, space), leading to deleterious impact on native taxa somewhere in its global alien range?
Classify the Taxon in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Competition resulting in replacement or local extinction of one or several native taxa; changes are irreversible	Competition resulting in local population extinction of at least one native taxon, but changes are reversible when the alien taxon is no longer present	Competition resulting in a decline of population size of at least one native taxon, but no local population extinction	Competition affects performance of native individuals without decline of their populations	Negligible level of competition with native taxa; reduction of performance of native individuals is not detectable

CON1b Predation

This consists of the *Taxon* preying on native taxa somewhere in its global alien range and includes direct effects leading to deleterious impact on native taxa.
Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Predation results in local extinction of one or several native taxa; changes are irreversible	Predation results in local population extinction of at least one native taxon; reversible when the alien taxon is no longer present	Predation results in a decline of population size of at least one native taxon, but no local population extinction	The alien taxon preys on native taxa, without leading to a decline in their populations	Not applicable; predation on native taxa is classified at least as MN.

CON1c Hybridisation

The *Taxon* hybridises with native species somewhere in its global alien range, leading to deleterious impact on native species.
Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Hybridisation between the alien taxon and native taxa leading to the loss of at least one pure native population (genomic extinction); pure native taxa cannot be recovered even if the alien and hybrids are no longer present	Hybridisation between the alien taxon and native taxa leading to the loss of at least one pure native population (genomic extinction); reversible when the alien taxon and hybrids are no longer present	Hybridisation between the alien taxon and native taxa is regularly observed in the wild; local decline of populations of at least one pure native taxon, but pure native taxa persist	Hybridisation between the alien taxon and native taxa is observed in the wild, but rare; no decline of pure local native populations	No hybridisation between the alien taxon and native taxa observed in the wild (prezygotic barriers), hybridisation with a native taxon is possible in captivity

CON1d Transmission of disease

The *Taxon* transmits diseases to native species somewhere in its global alien range, leading to deleterious impact on native species.

Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Transmission of disease to native taxa resulting in local extinction of at least one native taxon; changes are irreversible	Transmission of disease to native taxa resulting in local population extinction of at least one native taxon; reversible when the alien taxon is no longer present	Transmission of disease to native taxa resulting in a decline of population size of at least one native taxon, but no local population extinction; disease is severely affecting native taxa, including mortality of individuals, and it has been found in native and alien co-occurring individuals (same time and space)	Transmission of disease to native taxa affects performance of native individuals without leading to a decline of their populations; alien taxon is a host of a disease which has also been detected in native taxa and affects the performance of native taxa	The alien taxon is a host or vector of a disease transmissible to native taxa but disease not detected in native taxa; reduction in performance of native individuals is not detectable

CON1e Parasitism

The *Taxon* parasitises native species somewhere in its global alien range, leading directly or indirectly (e.g. through apparent competition) to deleterious impact on native species.
Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Parasites or pathogens directly result in local extinction of one or several native taxa; changes are irreversible	Parasites or pathogens directly result in local population extinction of at least one native taxon, but changes are reversible when the alien taxon is no longer present	Parasites or pathogens directly result in a decline of population size of at least one native taxon, but no local population extinction	Parasites or pathogens directly affect performance of native individuals without decline of their populations	Negligible level of parasitism or disease incidence (pathogens) on native taxa, reduction in performance of native individuals is not detectable

CON1f Poisoning/toxicity

The *Taxon* is toxic or allergenic by ingestion somewhere in its global alien range, inhalation or contact with wildlife or allelopathic to plants, leading to deleterious impact on native species.
Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
The alien taxon is toxic/allergenic by ingestion, inhalation or contact with wildlife or allelopathic to plants, resulting in local extinction of at least one native taxon; changes are irreversible	The alien taxon is toxic/allergenic by ingestion, inhalation or contact with wildlife or allelopathic to plants, resulting in local population extinction of at least one native taxon, but changes are reversible when the alien taxon is removed	The alien taxon is toxic/allergenic by ingestion, inhalation or contact with wildlife or allelopathic to plants, resulting in a decline of population size of at least one native taxon, but no local population extinction	The alien taxon is toxic/allergenic by ingestion, inhalation or contact with wildlife or allelopathic to plants, affecting performance of native individuals without decline of their populations	The alien taxon is toxic/allergenic/ allelopathic, but the level is very low, reduction of performance of native individuals is not detectable

CON1g Bio-fouling or other direct physical disturbance

The accumulation of individuals of the *Taxon* on wetted surfaces leads to deleterious impact on native species somewhere in its global alien range.

Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Bio-fouling or other direct physical disturbance resulting in local extinction of one or several native taxa; changes are irreversible	Bio-fouling or other direct physical disturbance resulting in local population extinction of at least one native taxon, but changes are reversible when the alien taxon is no longer present	Bio-fouling or other direct physical disturbance resulting in a decline of population size of at least one native taxon, but no local population extinctions	Bio-fouling or other direct physical disturbance affects performance of native individuals without decline of their populations	Negligible level of bio-fouling or direct physical disturbance on native taxa; reduction in performance of native individuals is not detectable

CON1h Grazing/herbivory/browsing

Grazing, herbivory or browsing by the *Taxon* leads to deleterious impact on native plant species somewhere in its global alien range.

Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Herbivory/grazing/browsing resulting in local extinction of one or several native taxa; changes are irreversible	Herbivory/grazing/browsing resulting in local population extinction of at least one native taxon, but changes are reversible when the alien taxon is no longer present	Herbivory/grazing/browsing resulting in a decline of population size of at least one native taxon, but no local population extinction	Herbivory/grazing/browsing affects performance of individuals of native taxa without decline of their populations	Negligible level of herbivory/grazing/browsing on native taxa, reduction in performance of native taxa is not detectable

CON1i Chemical, physical or structural impact on ecosystem

The *Taxon* causes changes to either: the chemical, physical and/or structural biotope characteristics of the native environment; nutrient and/or water cycling; disturbance regimes; or natural succession, leading to deleterious impact on native species somewhere in the *Taxon's* global alien range.

Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Changes in chemical, physical, and/or structural biotope characteristics; or changes in nutrient and water cycling; or disturbance regimes; or changes in natural succession, resulting in local extinction of at least one native taxon; changes are irreversible	Changes in chemical, physical, and/or structural biotope characteristics; or changes in nutrient cycling; or disturbance regimes; or changes in natural succession, resulting in local extinction of at least one native species, changes are reversible when the alien taxon is no longer present	Changes in chemical, physical, and/or structural biotope characteristics; or changes in nutrient cycling; or disturbance regimes; or changes in natural succession, resulting in a decline of population size of at least one native taxon, but no local population extinction	Changes in chemical, physical, and/or structural biotope characteristics; or changes in nutrient cycling; or disturbance regimes; or changes in natural succession detectable, affecting performance (e.g., growth, reproduction, defence, immunocompetence) of native individuals without decline of their populations	Small changes in chemical, physical, and/or structural biotope characteristics; or changes in nutrient cycling; or disturbance regimes; or changes in natural succession detectable, but no reduction of performance of native individuals

CON1k Indirect impacts through interactions with other species

The *Taxon* interacts with other (native or alien) taxa (e.g. through pollination, seed dispersal, habitat modification, mesopredator release), facilitating deleterious impact on native species somewhere in its global alien range.
Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Interaction of an alien taxon with other taxa leading to indirect impacts (e.g., pollination, seed dispersal, habitat modification, apparent competition) causing local extinction of one or several native taxa, leading to irreversible changes that would not have occurred in the absence of the alien taxon	Interaction of an alien taxon with other taxa leading to indirect impacts (e.g., pollination, seed dispersal, habitat modification, apparent competition) causing local population extinction of at least one native taxon; changes are reversible but would not have occurred in the absence of the alien taxon	Interaction of an alien taxon with other taxa leading to indirect impacts (e.g., pollination, seed dispersal, habitat modification, apparent competition) causing a decline of population size of at least one native taxon, but no local population extinction; impacts would not have occurred in the absence of the alien taxon	Interaction of an alien taxon with other taxa leading to indirect impacts (e.g., pollination, seed dispersal, apparent competition) affecting performance of native individuals without decline of their populations; impacts would not have occurred in the absence of the alien taxon	Interaction of an alien taxon with other taxa leading to indirect impacts (e.g., pollination, seed dispersal, apparent competition) but reduction in performance of native individuals is not detectable

CON2 Socio-economic impact

Assess the socio-economic impact of the *Taxon* in its global alien range (i.e. everywhere it has been introduced outside of its native range). Perform a SEICAT assessment on the *Taxon* as described in Bacher et al. 2017 and in CON2a) to CON2d) below. This concerns impacts on the following constituents of human well-being:
(a) safety
(b) material and immaterial assets
(c) health
(d) social, spiritual and cultural relations

Fill in the Answer sheet for each of the constituents of human well-being (CON2a-CON2d) and use Figure S3 to calculate the main socio-economic impact score. Report on the maximum impact found in any of the constituents of human well-being and any alien range in the Response to CON2 and the main sector affected in the Rationale, but provide information on all the sectors and impact scores in CON2a)-2d), including detailed information on the references used for the assessments.
If no data on impact are available for the *Taxon* in any part of its alien range globally on any of the sectors described below, mark the *Taxon* as Data Deficient (DD) here and additionally fill in CON4.

CON2a Safety

This concerns impacts on human well-being affecting activities related to safety, for example personal safety, secure resource access, security from disasters. Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
Local disappearance of an activity from all or part of the area invaded by the alien taxon affecting aspects of human safety. Change is likely	Local disappearance of an activity from all or part of the area invaded by the alien taxon affecting aspects of human safety. Collapse of the	Negative effects on well-being leading to changes in activity size, fewer people participating in an activity, but the activity is still	Negative effect on peoples' well-being, such that the alien taxon makes it difficult for people to participate in their normal	No deleterious impacts reported despite availability of relevant studies with regard to its impact on human well-being. Taxa that have been	There is no information to classify the taxon with respect to its impact, or insufficient time has elapsed since introduction for

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
to be permanent and irreversible for at least a decade after removal of the alien taxon, due to fundamental structural changes of socio-economic community or environmental conditions ("regime shift")	specific social activity, switch to other activities, or abandonment of activity without replacement, or emigration from region. Change is likely to be reversible within a decade after removal or control of the alien taxon. "Local disappearance" does not necessarily imply the disappearance of activities from the entire region assessed, but refers to the typical spatial scale over which social communities in the region are characterised (e.g. a human settlement)	carried out. Reductions in activity size can be due to various reasons, e.g. moving the activity to regions without the alien taxon or to other parts of the area less invaded by the alien taxon; partial abandonment of an activity without replacement by other activities; or switch to other activities while staying in the same area invaded by the alien taxon. Also, spatial displacement, abandonment or switch of activities does not increase human well-being compared to levels before the alien taxon invaded the region (no increase in opportunities due to the alien taxon)	activities. Individual people in an activity suffer regarding safety. Reductions of well-being can be detected through e.g. income loss, health problems, higher effort or expenses to participate in activities, increased difficulty in accessing goods, disruption of social activities, induction of fear, but no change in activity size is reported, i.e. the number of people participating in that activity remains the same	evaluated under the SEICAT process but for which impacts have not been assessed in any study should not be classified in this category, but rather should be classified as data deficient	impacts to have become apparent

CON2b Material and immaterial assets

This concerns impacts on human well-being affecting activities leading to changes in the availability and quality of material and immaterial assets, for example, adequate livelihoods, sufficient nutritious food, shelter, access to goods. Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
Local disappearance of an activity from all or part of the area invaded by the alien taxon. Change is likely to be permanent and irreversible for at least a decade after removal of the alien taxon, due to fundamental structural changes of socio-economic community or environmental	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Collapse of the specific social activity, switch to other activities, or abandonment of activity without replacement, or emigration from region. Change is likely to be reversible within a decade after removal or	Negative effects on well-being leading to changes in activity size, fewer people participating in an activity, but the activity is still carried out. Reductions in activity size can be due to various reasons, e.g. moving the activity to regions without the alien taxon or to other parts of the area less	Negative effect on peoples' well-being, such that the alien taxon makes it difficult for people to participate in their normal activities. Individual people in an activity suffer in at least one constituent of well-being (i.e. security; material and non-material assets; health; social, spiritual	No deleterious impacts reported despite availability of relevant studies with regard to its impact on human well-being. Taxa that have been evaluated under the SEICAT process but for which impacts have not been assessed in any study should not be classified in this category, but rather should be classified as data	There is no information to classify the taxon with respect to its impact, or insufficient time has elapsed since introduction for impacts to have become apparent

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
conditions (“regime shift”)	control of the alien taxon. “Local disappearance” does not necessarily imply the disappearance of activities from the entire region assessed, but refers to the typical spatial scale over which social communities in the region are characterised (e.g. a human settlement)	invaded by the alien taxon; partial abandonment of an activity without replacement by other activities; or switch to other activities while staying in the same area invaded by the alien taxon. Also, spatial displacement, abandonment or switch of activities does not increase human well-being compared to levels before the alien taxon invaded the region (no increase in opportunities due to the alien taxon)	and cultural relations). Reductions of well-being can be detected through e.g. income loss, health problems, higher effort or expenses to participate in activities, increased difficulty in accessing goods, disruption of social activities, induction of fear, but no change in activity size is reported, i.e. the number of people participating in that activity remains the same	deficient	

CON2c Health

This includes impacts on human well-being affecting their health, including strength, feeling well, access to clean air and water. Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
Local disappearance of an activity from all or part of the area invaded by the alien taxon. Change is likely to be permanent and irreversible for at least a decade after removal of the alien taxon, due to fundamental structural changes of socio-economic community or environmental conditions (“regime shift”)	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Collapse of the specific social activity, switch to other activities, or abandonment of activity without replacement, or emigration from region. Change is likely to be reversible within a decade after removal or control of the alien taxon. “Local disappearance” does not necessarily imply the disappearance of activities from the entire region assessed, but	Negative effects on well-being leading to changes in activity size, fewer people participating in an activity, but the activity is still carried out. Reductions in activity size can be due to various reasons, e.g. moving the activity to regions without the alien taxon or to other parts of the area less invaded by the alien taxon; partial abandonment of an activity without replacement by other activities; or switch to other activities while staying in the	Negative effect on peoples’ well-being, such that the alien taxon makes it difficult for people to participate in their normal activities. Individual people in an activity suffer in at least one constituent of well-being (i.e. security; material and non-material assets; health; social, spiritual and cultural relations). Reductions of well-being can be detected through e.g. income loss, health problems, higher effort or expenses to participate in	No deleterious impacts reported despite availability of relevant studies with regard to its impact on human well-being. Taxa that have been evaluated under the SEICAT process but for which impacts have not been assessed in any study should not be classified in this category, but rather should be classified as data deficient	There is no information to classify the taxon with respect to its impact, or insufficient time has elapsed since introduction for impacts to have become apparent

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
	refers to the typical spatial scale over which social communities in the region are characterised (e.g. a human settlement)	same area invaded by the alien taxon. Also, spatial displacement, abandonment or switch of activities does not increase human well-being compared to levels before the alien taxon invaded the region (no increase in opportunities due to the alien taxon)	activities, increased difficulty in accessing goods, disruption of social activities, induction of fear, but no change in activity size is reported, i.e. the number of people participating in that activity remains the same		

CON2d Social, spiritual and cultural relations

This concerns impacts on human well-being affecting social, spiritual and cultural relations, for example, social, spiritual and cultural practice, mutual respect, friendship. Classify the *Taxon* in an impact level according to the descriptions below. If no data are available, the Response is Data Deficient (DD).

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
Local disappearance of an activity from all or part of the area invaded by the alien taxon. Change is likely to be permanent and irreversible for at least a decade after removal of the alien taxon, due to fundamental structural changes of socio-economic community or environmental conditions (“regime shift”)	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Collapse of the specific social activity, switch to other activities, or abandonment of activity without replacement, or emigration from region. Change is likely to be reversible within a decade after removal or control of the alien taxon. “Local disappearance” does not necessarily imply the disappearance of activities from the entire region assessed, but refers to the typical spatial scale over which social communities in the region are characterised (e.g. a human settlement)	Negative effects on well-being leading to changes in activity size, fewer people participating in an activity, but the activity is still carried out. Reductions in activity size can be due to various reasons, e.g. moving the activity to regions without the alien taxon or to other parts of the area less invaded by the alien taxon; partial abandonment of an activity without replacement by other activities; or switch to other activities while staying in the same area invaded by the alien taxon. Also, spatial displacement, abandonment or switch of activities does not increase human well-being compared to	Negative effect on peoples’ well-being, such that the alien taxon makes it difficult for people to participate in their normal activities. Individual people in an activity suffer in at least one constituent of well-being (i.e. security; material and non-material assets; health; social, spiritual and cultural relations). Reductions of well-being can be detected through e.g. income loss, health problems, higher effort or expenses to participate in activities, increased difficulty in accessing goods, disruption of social activities, induction of fear, but no change in activity size is reported, i.e. the number of people	No deleterious impacts reported despite availability of relevant studies with regard to its impact on human well-being. Taxa that have been evaluated under the SEICAT process but for which impacts have not been assessed in any study should not be classified in this category, but rather should be classified as data deficient	There is no information to classify the taxon with respect to its impact, or insufficient time has elapsed since introduction for impacts to have become apparent

Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)	Data Deficient (DD)
		levels before the alien taxon invaded the region (no increase in opportunities due to the alien taxon)	participating in that activity remains the same		

CON3 Closely related taxons' environmental impact

This section is only considered if the Response is Data Deficient (DD) in CON1.
Consider here data of congeners or other closely related taxa with similar life history traits and their environmental impacts in their global alien range. In detail, perform a classification of impacts as described in CON1a-CON1k for closely related and similar taxa. Note which taxon(a) was/were considered in the Rationale and report on the details of the different impact mechanisms on the Answer sheet. In the Response to CON3, note the maximum impact found in any mechanism.

CON4 Closely related taxons' socio-economic impact

This section is only considered if the Response is Data Deficient (DD) in CON2.
Consider here data of congeners or other closely related taxa with similar life history traits and their socio-economic impacts in their global alien range. More specifically, perform a classification of impacts as described in CON2a-CON2d for closely related and similar taxa. Note which taxon(a) was/were considered in the Rationale and report on the details of the different sectors on the Answer sheet. In the Response to CON4, note the maximum impact found on any sector.

CON5 Potential impact

This is filled in for all taxa regardless of whether information on the other impact questions (CON1-4) is available. Ideally, experiments should be performed on impacts of taxa for which no information is available regarding consequences of invasions, but this is hardly feasible for all taxa. Therefore, if no data are available on impacts in any introduced region of the *Taxon* and any closely related taxon, use data from the native range of the *Taxon* and/or estimate the magnitude of impact possible for the *Taxon* in the *Area,* based on its life history traits and trait-based models for other taxa.
In detail, estimate the potential of the *Taxon* to cause any impact in the magnitude as described under CON1 and CON2 in the *Area*, including impacts for which no evidence has been recorded yet. Assume the *Taxon* is established and abundant in the *Area* and consider the highest impact possible under any of the mechanisms and to any sector. Here we consider the life history traits of the *Taxon* which could lead to impact, including undesirable traits, as well as the recipient systems, meaning the recipient habitat and community. In some cases, impacts caused in the native range can be useful indicators of impact; for example, impacts on agriculture.
Undesirable traits include (but do not exclusively consist of): produces spines, thorns or burrs, allelopathic, parasitic, unpalatable to grazing animals, toxic to animals, host for recognised pests and pathogens, causes allergies or is otherwise toxic to humans, creates a fire hazard in natural ecosystems, grows on infertile soils, shade-tolerant plant at some stage of its life cycle.
Consider here also feeding habits, novelty aspects, functional traits and studies performed on other groups and taxa considering trait-impact relationships.

Impact levels	Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)

Impact levels	Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal Concern (MC)
Environmental impact	Causes local extinction of at least one native taxon (i.e. taxa vanish from communities at sites where they occurred before the alien arrived), which is irreversible; even if the alien taxon is no longer present, the native taxon cannot recolonise the area	Causes local or sub-population extinction of at least one native taxon (i.e. taxa vanish from communities at sites where they occurred before the alien arrived); which is reversible if the alien taxon is no longer present	Causes population declines in at least one native taxon, but no local population extinctions	Causes reductions in individual performance (e.g. growth, reproduction, defence, immunocompetence), but no declines in local native population sizes	Negligible level of impacts; no reduction in performance (e.g. growth, reproduction, defence, immunocompetence) of individuals of native taxa
Socio-economic impact	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Change is likely to be permanent and irreversible for at least a decade after removal of the alien taxon, due to fundamental structural changes of socio-economic community or environmental conditions ("regime shift")	Local disappearance of an activity from all or part of the area invaded by the alien taxon. Collapse of the specific social activity, switch to other activities or abandonment of activity without replacement or emigration from region. Change is likely to be reversible within a decade after removal or control of the alien taxon	Negative effects on well-being leading to changes in activity size, fewer people participating in an activity, but the activity is still carried out	Negative effect on peoples' well-being, such that the alien taxon makes it difficult for people to participate in their normal activities. Individual people suffer in at least one constituent of well-being (i.e. security; material and non-material assets; health; social, spiritual and cultural relations)	No deleterious impacts reported despite availability of relevant studies with regard to its impact on human well-being
Potential impact	The *Taxon* is a transformer in its native range, has ecosystem engineering properties or possesses other traits which suggest irreversible impacts on the community composition in the *Area* to occur. The *Taxon* is a pest of agricultural production in the native range and has the potential to cause irreversible losses of activities	The *Taxon* has traits which suggest major impacts on native communities in the *Area*, but these impacts are likely to be reversible. The *Taxon* has traits which can lead to losses of activities	The *Taxon* possesses several undesirable traits. Due to the traits of the *Taxon* and/or its behaviour, it is expected to reduce population sizes of at least one native species, and/or human well-being leading to people changing their activities	The *Taxon* does not possess any traits which could lead to effects on native species population sizes, but reduction in native individuals' performance is expected; and/or it could lead to loss in individual peoples' well-being and increased difficulties to perform normal activities. No changes to activity sizes	Due to the traits of the *Taxon* no effect on native individuals' performance is expected. No effects on human well-being are expected. The *Taxon* does not possess any undesirable traits

Risk assessment

The risk posed by an alien *Taxon* is the likelihood that the *Taxon* will become an invader and the consequences in terms of impact resulting from the introduction of the *Taxon*. The Likelihood for the risk assessment is derived from LIK1-LIK6 as described in Figure S2 and Table S2. Consequences are derived from CON1-CON5, as summarised in Figure S3. Table S3 summarises how risk scores are derived from Consequences and Likelihood.

If the risk of the *Taxon* to become a harmful invader is medium or high (according to Table S3), the management options section needs to be assessed. If the risk is low, the *Taxon* does not need to be listed, but under certain circumstances could be monitored in the region it occurs. The Risk assessment therefore provides the evidence base for or against the listing of a *Taxon* under the NEMBA A&IS Regulations, whereas the Risk management section helps to decide which listing status could be considered (Figure S4).

4) Management

A decision on the listing *status*, i.e. whether a taxon should be listed as prohibited, Category 1a, 1b, 2 or 3 as outlined in the NEM:BA A&IS Regulations, is not only based on scientific evidence, but often relies on the value of the *Taxon*, besides some inherent features which make it more or less difficult to control. Therefore, risk management considerations describing whether and how risks can be managed apply, including benefits (Table S4 and MAN questions).

MAN1 What is the feasibility to stop future immigration?

Assess here if future immigration of the *Taxon* into the *Area* can be prevented. If the *Taxon* is already present as an alien in the *Area* (see BAC10), this is needed to determine whether eradication is a feasible goal. If the *Taxon* is not yet in the *Area,* this determines whether prevention is a feasible goal. Based on the pathways identified in BAC14 and the answers provided in LIK1 and LIK2, estimate the feasibility to stop propagules from entering the *Area*.

High: The *Taxon* is introduced into the *Area* intentionally with pathways which are easy to regulate and control.
Low: The Taxon is introduced into the *Area* unintentionally, for example, as contaminant and stowaway and/or is present in neighbouring countries and areas and is entering the *Area* unaided.

***MAN2 Benefits of the* Taxon**

Taxa with significant benefits and significant costs are sometimes termed conflict species. The benefits might be in terms of either socio-economy or the environment. Crucially the benefits of an introduction are often spatially and temporally separated from the costs of an invasion. This section (MAN2a & MAN2b) aims at assessing current socio-economic and environmental benefits to highlight potential conflicts of interest. Stakeholders might need to be consulted to answer these questions (see also Novoa et al. 2018). Summarise the current benefits using the maximum of both, socio-economic and environmental benefits as outlined below. Keep in mind that conflicts are expected, especially if socio-economic benefits are significant. If relevant, mention potential benefits here, but base your response on actual, current benefits.

MAN2a Socio-economic benefits of the Taxon

Socio-economic benefits, if appropriate, should be described to ensure an objectivity and recognition of the services that may be provided by the *Taxon*. Under Rationale and comments, list the benefits and the significance of each. Include here if the *Taxon* is used for any of the following: as pet, in horticulture, for fencing, shading, dune stabilisation, firewood, building material, hunting, fishing, human food, animal feed and fodder, fabric production etc. Benefits are rated as of high or low significance, based on the criteria outlined below. Details of the benefits and why they are rated in the respective level need to be provided in the Rationale.

High: Significant benefits are expected if the *Taxon* provides a service or makes an activity possible which is not available without the *Taxon*, i.e. which is not provided by the native species in the *Area*. Covered here are also services provided by the *Taxon* which are essential for security, adequate livelihoods, sufficient nutritious food, access to clean air and water and food.

Low: List benefits which can be relatively easily replaced by another (native or non-harmful alien) taxon, for example pets, trees providing firewood, game for hunting, horticultural plants, trees for shade, cacti for fencing. Depending on the size of the affected industry, conflicts are still possible, therefore it is important to outline these benefits regardless. Covered here are also services provided by the *Taxon* which affect aspects of human well-being related to social, spiritual and cultural relations, for example, friendship and spiritual practices.

MAN2b Environmental benefits of the Taxon

Here, benefits to the natural environment and native species in the *Area* are assessed. Benefits are rated as of high or low significance, based on the criteria outlined below. Details of the benefits and why they are rated in the respective level need to be provided in the Rationale.

High: High benefits are expected if the *Taxon* provides a crucial habitat or food source to an environment. These functions might be replaceable over time by native taxa, but it indicates that current control would be detrimental to conservation or ecosystem functioning. Significant benefits are also noted if the *Taxon* provides resources which are not or no longer available without the *Taxon* present to native species, especially to rare, endemic or threatened species.

Low: Benefits to native species and ecosystems which can be relatively easily replaced by another (native or non-harmful alien) taxon.

MAN3 Ease of management

Some invasions are notoriously difficult to control and this influences both the decisions concerning risk management and how the risks should be communicated. Values as described in MAN3a-MAN3d are assigned for situations where the *Taxon* has been detected, not where it could be found, in the *Area*. This is only relevant if the *Taxon* is present in the *Area* (BAC10). Provide detailed answers to MAN3a-MAN3d in the Answer sheet and use Table S4 to calculate the ease of management, i.e. the sum of the answers.

Response options (after calculating sum in Table S4):

> 5: Difficult. Generally difficult to manage (e.g. specialist equipment or techniques are required/ multiple approaches are needed for control to be effective/management is an expensive operation over several seasons)

3–5: Medium. Some aspects make it difficult to manage

< 3: Easy. Management is relatively straightforward (e.g. can be achieved without substantial training or repeated control efforts)

MAN3a How accessible are populations?

Rate how easily accessible the populations of the *Taxon* are in the *Area*. Base your response on the most difficult to access. Moderately accessible will include regions that pose some operational difficulty, but that might not necessarily require specialised teams (e.g. a riparian area) and private gardens. To be rated as difficult to access, the *Taxon's* distribution must involve at least some sites that are very difficult to access (e.g. a ravine).

Response options:
0 for easy access
1 for moderately accessible
2 for difficult to access; or don’t know

MAN3b Is detectability critically time-dependent?
Assess if the Taxon is easily detectable during the year (response: no) or if it is only detectable during certain seasons or time-periods (response: yes). The objective of this question is to distinguish taxa that are readily detectable throughout the year from those that might be detectable only for short periods (e.g. following the production of new foliage or as dispersing adults). If the *Taxon* is detectable relatively briefly, it provides only small windows for control prior to reproductive events.

Response options:
0 for no
2 for yes; or don’t know

MAN3c Time to reproduction
Assess the time the *Taxon* takes from being juvenile to a reproductive stage (e.g. for animals how long does it take from being born to reproducing?). It will be more difficult to prevent reproduction of a *Taxon* that reproduces quickly than those that have extended juvenile periods. Default value (i.e. if unknown) is 1.

Response options:
0 for > 3 years
1 for 1–3 years; or don’t know
2 for < 1 year

MAN3d Propagule persistence
Describe here how long resting stages, seeds, spores, fragments, eggs or other parts of the *Taxon* can stay/persist in an environment before they die and are not able to progress to adult stages. Propagule persistence is often one of the most important impedance factors, since it sets the minimum duration for an eradication programme. Default value if unknown is 1.

Response options:
0 for < 1 year
1 for 1–5 years; or don’t know
3 for > 5 years

MAN4 Has the feasibility of eradication been evaluated?
Assess if an eradication feasibility study has been performed for the *Taxon* in the *Area* specifically. Determining whether eradication is a feasible goal is a process in and of itself requiring some of the information that is used elsewhere in this framework [e.g. whether it is feasible to stop future immigration (MAN1) and the overall ease of management (MAN3)], but also much more. Most of this information will only become available as control efforts are piloted (see Wilson et al. 2017 for detailed guidelines for evaluating eradication feasibility and monitoring progress). A detailed evaluation of eradication feasibility will at a minimum include: explicit delimitation of populations, trial management, an assessment of current status, a risk map, a bioeconomic/decision support model showing costs and potential success of different control scenarios (e.g. Moore et al. 2011) and a proposed management strategy with time-lines and specific goals.
Given there is often a short temporal window during which eradication is feasible (and after which the *Taxon* has become too widespread and numerous in the *Area*), it is important that control efforts are not delayed until a regulatory decision has been finalised. Therefore, under this framework, a recommendation is not dependent on whether the feasibility of eradication has been evaluated or not.

However, only if there has been a specific and detailed evaluation, should eradication be set as the management goal in the regulations. If the pilot management achieves eradication before formal regulatory confirmation of an eradication attempt, then it will in no way limit future options (unlikely delaying eradication until it is too late).

Response options:

Yes: there has been a detailed evaluation of eradication feasibility in the *Area* that has been documented (e.g. in a journal article).

No: there has been no evaluation of eradication or the evaluation is not detailed or it is for a different region (i.e. not the *Area* for which the risk is analysed)

MAN5 Control options and monitoring approaches available for the Taxon

Describe here management actions taken and control options available for the *Taxon*. If known, add information on eradication and control attempts in the *Area*, number of populations, distribution in hectares and other information which can feed into control plans and/or eradication feasibility studies for the *Area*. Include measures taken in the *Area* currently and historically and elsewhere. Include ongoing or future plans for biocontrol, herbicides registered, control trials etc. Include information on the success of each method, if known. Use the following guidance based on the ones developed for the Global Invasive Species Database (GISD) and give more detail, if known.

Management goals and actions for alien taxa, adapted from GISD.

<table>
<tr><th>Management goals</th><th>Definition</th><th>Actions / approaches</th></tr>
<tr><td>Prevention</td><td>Measures taken to stop the Taxon from entering the Area</td><td>Risk assessment
Legal Status (restrictions)
Best practices
Cultural methods
Management at port of departure
Management of vectors
Management at point of entry (e.g. at-border inspections)</td></tr>
<tr><td>Eradication</td><td>Actions taken to eliminate all occurrences of the Taxon from the Area. Long term, on-going eradication projects are included in this category.</td><td rowspan="3">(for eradication, containment, or impact reduction)
Quarantine areas
Inspection
Shooting
Trapping
Hand removal
Pesticides or herbicides
Poisoning or toxicants
Others (disease, fumigants, draining...)
Physical-Mechanical (manual)
Chemical
Biological
Cultural approaches
Land management
Utilisation
Integrated methods</td></tr>
<tr><td>Containment</td><td>Measures taken to stop or reduce the spread of the Taxon</td></tr>
<tr><td>Impact reduction</td><td>Measures taken to reduce the Taxon or biomass (control), to keep the Taxon in a defined area (containment) and/or to reduce harmful effects of the Taxon (mitigation).</td></tr>
<tr><td>None</td><td>No management goal has been specified for the Taxon in the Area</td><td>NA</td></tr>
<tr><td>Unknown</td><td>It is not clear if a management goal has been set</td><td>NA</td></tr>
</table>

Consider also the best methods to evaluate the distribution, expansion and/or density of the *Taxon*. These might include dedicated species-specific surveys; general surveys for invasions as part of atlassing projects; remote-sensing; and the collection of data using citizen science schemes (e.g. iNaturalist).

MAN6 Any other management considerations to highlight?

If yes, fill in details of the consideration in appendix MAN6 (note the inclusion of an appendix is optional). These might include considerations of whether existing exemptions (e.g. for sterile cultivars or particular contexts) are appropriate or exemptions could be considered and whether and what permit conditions might be appropriate. This is intended to support those tasked with decision-making, so a critical evaluation of options (including those that are not suitable) is useful, but it should ideally be backed up with appropriate referencing. It might also include information useful for management prioritisation or that might ultimately end up in a species-specific management plan (and so not necessarily directly influence the wording in the regulatory lists).

Response options:
Yes: details are provided in appendix
No: no appendix is provided

5) Recommendations and reporting

Based on the information in the risk assessment and management sections, we consider several broad recommendations for the regulation of an alien *Taxon* (Figure S4). These differ based on whether the *Taxon* is already present in the *Area*, whether prevention or eradication are feasible management goals and whether the *Taxon* has benefits to the *Area,* such that it might be a conflict species that could be allowed under permit in certain conditions (Figure S4). Figure S4 describes how to arrive at certain recommendations for Risk management and listing from the answers provided in the Risk analysis.
For an easily digestible overview of the analysis, a summary sheet including the conclusions from each table should be provided, with short descriptions on the *Taxon* itself, impacts, risks, management options and benefits. An example is given in the Supplementary Material Appendix S3, based on the Reporting template in the Answer sheet. The full risk analysis with each question answered and all references, including detailed information on assessors, reviewers, *Taxon* and *Area* and maps should be provided as well.

References

Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Mrugała A, Marková Z, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, Wilson JRU, Winter M, Genovesi P & Bacher S (2014) A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology 12(5): e1001850

Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP, et al. (2011) A proposed unified framework for biological invasions. Trends in Ecology and Evolution 26: 333–339.

Department of Environmental Affairs (2014) National Environmental Management: Biodiversty Act 2004 (Act No. 10 of 2004) Alien and Invasive Species Regulations, 2014. Government Gazette Vol. 590, No. 37885

Essl F, Nehring S, Klingenstein F, Milasowszky N, Nowack C & Rabitsch W (2011) Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information system (GABLIS). Journal for Nature Conservation 19: 339-350.

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Kumschick S, Bacher S, Marková Z, Pergl J, Pyšek P, Vaes-Petignat S, van der Veer G, Vilà M & Nentwig W (2015) Comparing impacts of alien plants and animals using a standard scoring system. Journal of Applied Ecology 52: 552-561

Moore JL, Runge MC, Webber BL & Wilson JRU (2011) Contain or eradicate? Optimizing the management goal for Australian acacia invasions in the face of uncertainty. Diversity and Distributions 17: 1047-1059.

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Panetta FD & Timmins SM (2004) Evaluating the feasibility of eradication for terrestrial weed invasions. Plant Protection Quarterly 19: 5-11.

Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Koppen-Geiger climate classification. Hydrology and Earth System Sciences 11: 1633-1644

Richardson DM and Thuiller W (2007) Home away from home – objective mapping of high-risk source areas for plant introductions. Diversity and Distributions 13: 299-312

Wilson JR, Panetta FD & Lindgren C (2017) *Detecting and responding to alien plant incursions*. Cambridge University Press.

Risk Analysis Report

(the following summary sheet is to be completed once all the other sections are completed, but will appear at the front of the report, keep to one page and do not reduce the size of the text to get it to fit. Please delete all this annotated text in brackets.)

<table>
<tr><td>Taxon:
(as in BAC4)</td><td colspan="2">Area:
(as in BAC9)</td></tr>
<tr><td>Compiled by:
(from BAC1)</td><td colspan="2">Approved by:
(leave empty)</td></tr>
<tr><td>Picture of Taxon</td><td colspan="2">Alien distribution map (BAC8)</td></tr>
<tr><td colspan="2">Risk Assessment summary:
(Summarise here the answers to questions under section 2) LIK and section 3) CON and from Table S3. Emphasise the situation in the Area, if such information is available and distinguish information from elsewhere.)</td><td>Risk score:
(from Table S3)</td></tr>
<tr><td colspan="2">Management options summary:
(Report on the main findings from section 4) MAN, which includes benefits and questions on the ease of control. Mention if an eradication feasibility study was done or is recommended and give some information on control options available.)</td><td>Ease of management:
(Easy, Medium, Difficult)</td></tr>
<tr><td colspan="2" rowspan="2">Recommendations:
(Outline the recommendation and reasons for arriving at this, i.e. why something came out as it did in the decision tree as presented in Figure S4. This should also include recommendations on further studies needed, management plans, stakeholder engagement etc. Note what the current listing category is under the NEMBA A&IS Regulations and discuss if the recommendation is to change from this)</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2016:
(check the regulations)</td></tr>
<tr><td>Recommended listing category:
(as in Figure S4)</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)		
Name of lead assessor		
Additional assessor (1)		
Additional assessor (2)		
BAC2 Contact details of assessor (s)		
Lead assessor	Organisational affiliation:	
	email:	
	Phone:	
Additional assessor (1)	Organisational affiliation:	
	email:	
	Phone:	
Additional assessor (2)	Organisational affiliation:	
	email:	
	Phone:	
BAC3 Name(s) and contact details of expert(s) consulted		
Expert (1)	Name:	
	email:	
	Phone:	
Expert (2)	Name:	
	email:	
	Phone:	
Comments:		
BAC4 Scientific name of *Taxon* under assessment		
Taxon name:		Authority:
Comments:		
References:		
BAC5 Synonym(s) considered		
Synonyms:		
Comments:		
References:		
BAC6 Common name(s) considered		
Common names:		
Comments:		
References:		
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)		
Response:		Confidence:
Comments:		
References:		
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)		
Response:		Confidence:
Comments:		
References:		
BAC9 Geographic scope = the *Area* under consideration		
Area of assessment:		
Comments:		
BAC10 Is the *Taxon* present in the *Area*?		
Response:		Confidence:

Comments:		
References:		
BAC11 Availability of physical specimen		
Response:		Confidence in ID:
Herbarium or museum accession number:		
References:		
BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	Yes / No / Don't know	Confidence:
The *Taxon* is alien in (part of) the *Area*.	Yes / No / Don't know	Confidence:
Comments:		
References:		
BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Yes / No / Don't know	Confidence:
The *Taxon* is present outside of cultivation/containment.	Yes / No / Don't know	Confidence:
The *Taxon* has established/naturalised.	Yes / No / Don't know	Confidence:
The *Taxon* is invasive.	Yes / No / Don't know	Confidence:
Comments:		
References:		
BAC14 Primary (introduction) pathways		
Release		Confidence:
Escape		Confidence:
Contaminant		Confidence:
Stowaway		Confidence:
Corridor		Confidence:
Unaided		Confidence:
Comments:		
References:		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response:	Confidence:
Rationale:	
References:	

LIK2 Likelihood of entry via human aided primary pathways	
Response:	Confidence:
Rationale:	
References:	

LIK3 Habitat suitability	
Response:	Confidence:
Rationale:	
References:	

LIK4 Climate suitability	
Response:	Confidence:
Rationale:	
References:	

LIK5 Unaided secondary (dispersal) pathways	
Response:	Confidence:
Rationale:	
References:	

LIK6 Human aided secondary (dispersal) pathways	
Response:	Confidence:
Rationale:	
References:	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response:	Confidence:
Rationale:	
References:	
CON1b: Predation	
Response:	Confidence:
Rationale:	
References:	
CON1c: Hybridisation	
Response:	Confidence:
Rationale:	
References:	
CON1d: Transmission of disease	
Response:	Confidence:
Rationale:	
References:	
CON1e: Parasitism	
Response:	Confidence:
Rationale:	
References:	
CON1f: Poisoning/toxicity	
Response:	Confidence:
Rationale:	
References:	
CON1g: Bio-fouling or other direct physical disturbance	
Response:	Confidence:
Rationale:	
References:	
CON1h: Grazing/herbivory/browsing	
Response:	Confidence:
Rationale:	
References:	
CON1i: Chemical, physical or structural impact on ecosystem	
Response:	Confidence:
Rationale:	
References:	
CON1k: Indirect impacts through interactions with other species	
Response:	Confidence:
Rationale:	
References:	
CON1 Maximum environmental impact (Figure S3)	
Response:	Confidence:
Rationale:	
References:	

CON2 Socio-economic impact	
CON2a: Safety	
Response:	Confidence:
Rationale:	
References:	
CON2b: Material and immaterial assets	
Response:	Confidence:
Rationale:	

References:	
CON2c: Health	
Response:	Confidence:
Rationale:	
References:	
CON2d: Social, spiritual and cultural relations	
Response:	Confidence:
Rationale:	
References:	
CON2 Maximum socio-economic impact (Figure S3)	
Response:	Confidence:
Rationale:	
References:	

CON3 Closely related species' environmental impact	
Response:	Confidence:
Rationale:	
References:	

CON4 Closely related species' socio-economic impact	
Response:	Confidence:
Rationale:	
References:	

CON5 Potential impact	
Response:	Confidence:
Rationale:	
References:	

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response:	Confidence:
Rationale:	
References:	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response:	Confidence:
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response:	Confidence:
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response:	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response:	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response:	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response:	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response:	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response:	Confidence:
Rationale:	
References:	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood =
(fill in numbers in table below)

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1		P(entry) =	P (invasion) =
LIK2			
LIK3		P(establishment) =	
LIK4			
LIK5		P (spread) =	
LIK6			

Consequence =
(fill in the responses)

Parameter	**Mechanism/sector**	**Response**
CON1a	Competition	
CON1b	Predation	
CON1c	Hybridisation	
CON1d	Disease transmission	
CON1e	Parasitism	
CON1f	Poisoning/toxicity	
CON1g	Bio-fouling or other direct physical disturbance	
CON1h	Grazing/herbivory/browsing	
CON1i	Chemical, physical, structural impact	
CON1k	Indirect impacts through interactions with other species	
CON1	**Maximum environmental impact**	
CON2a	Safety	
CON2b	Material and immaterial assets	
CON2c	Health	
CON2d	Social, spiritual and cultural relations	
CON2	**Maximum socio-economic impact**	
CON3	Environmental impact of closely related taxa (only score if CON1a-k are all DD, otherwise NA)	
CON4	Socio-economic impact of closely related taxa (only score if CON2a-g are all DD, otherwise NA)	
CON5	Potential impact based on traits, experiments or models	

Table S3: Risk score
(highlight the respective fields)

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management
(fill in numbers in table below)

Parameter	**Question**	**Response**
MAN3a	How accessible are populations?	
MAN3b	Is detectability critically time-dependent?	
MAN3c	Time to reproduction	
MAN3d	Propagule persistence	
MAN3	**SUM**	

Appendix BAC7: Provide here a map of the native range, if possible. If the map is available in a file, please insert a low res copy (< 1 MB) and provide the file name and (if possible) a link to a higher resolution copy below.

Appendix BAC8(a): Provide here a map of the global alien range if possible. If the map is available in a file, please insert a low res copy (< 1 MB) and provide the file name and (if possible) a link to a higher resolution copy below.

Appendix BAC8(b): Provide here a map of the alien range in the *Area* if possible. If the map is available in a file, please insert a low res copy (< 1 MB) and provide the file name and (if possible) a link to a higher resolution copy below.

Appendix MAN6: An optional section, where other management considerations that might affect the recommendations and that are not covered in MAN5 or elsewhere, can be discussed. These might include the potential for exemptions (of particular sexes, genotypes, phenotypes or context) or of the sorts of issues specific to the Taxon that would need to be considered under which permits might be granted. Please include relevant references. This is not intended to be a section for broad speculation, so if in doubt, leave out.

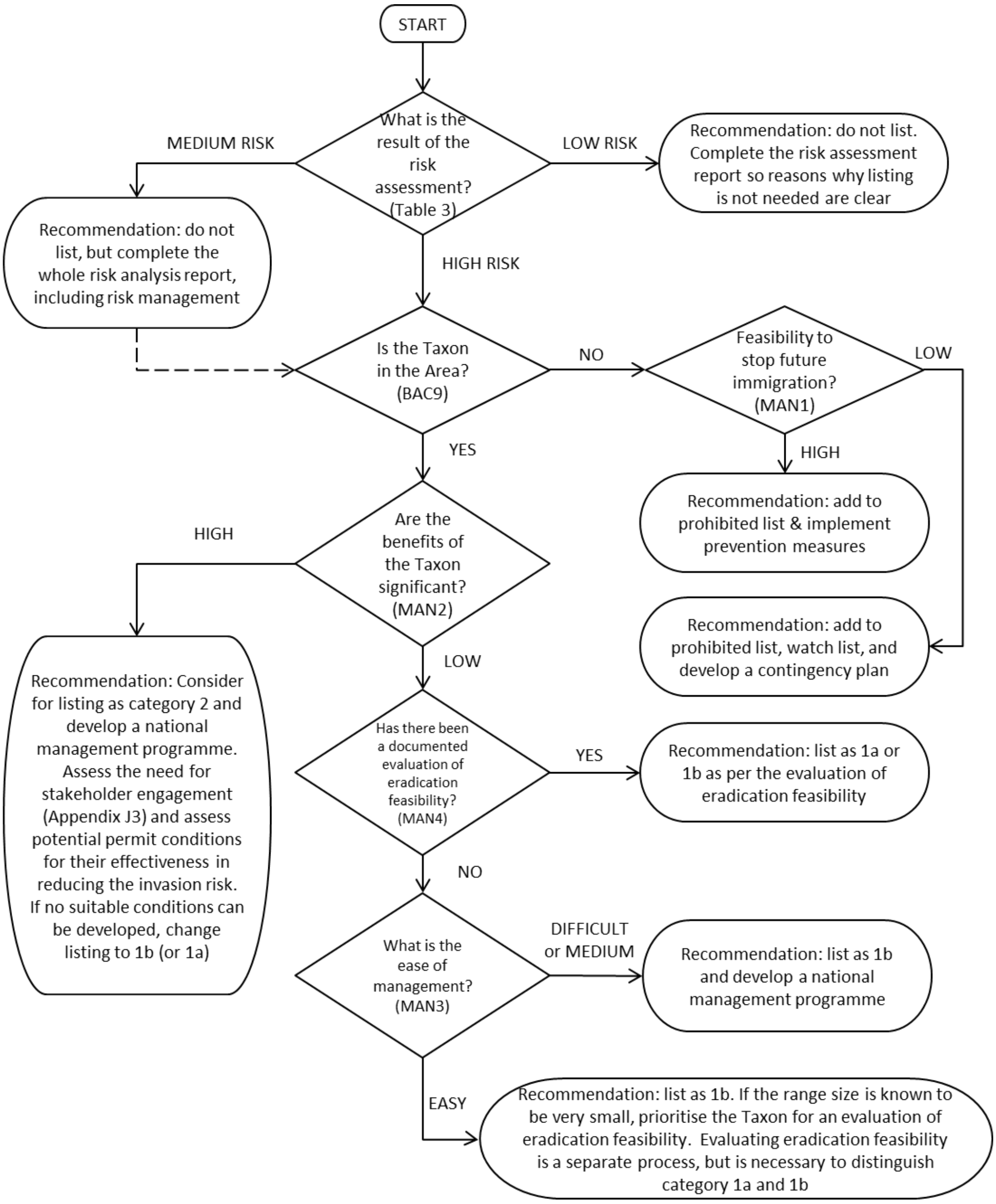


Figure S4. A decision tree for determining the appropriate risk management response. The listing categories (1a, 1b, 2) are as per South Africa's NEMBA A&IS Regulations.

Annexure S2: Glossary

NEMBA A&IS Regulations: The National Environmental Management: Biodiversity Act (NEMBA, Act 10 of 2004) Alien and Invasive Species Regulations (Department of Environmental Affairs 2014)

Alien taxon: A taxon in a given area whose presence there is due to intentional or accidental introduction as a result of human activity. Taxa that have part of their native range in a given country, but whose presence in another part of the same country is attributable to human actions that enabled the taxon to overcome fundamental biogeographical barriers, are also referred to as alien here.

Area: The area of assessment for the risk analysis. Specify the geographic entity under consideration, i.e. the geographic scope of the assessment. In most cases, this will be the whole of South Africa, but can also be only a part of the country, for example, a single province, a national park or a river catchment. The region under assessment will be referred to as the Area in the framework.

Extralimital: A taxon that has part of its native range in a given country, but whose presence in another part of the same country is attributable to human actions that enabled the taxon to overcome fundamental biogeographical barriers

Introduction status: Whether a taxon is found in an area to which it is not native (alien), and how far along the introduction-naturalisation-invasion continuum it has reached. Ideally as per the Blackburn et al. (2011) framework.

Invasive taxon: A taxon which is alien to an area and which has self-sustaining populations there with propagules spreading from the initial site of introduction.

Pathway: The processes by which taxa are moved between areas.

Primary (introduction) pathway: The combined processes by which taxa are introduced from one geographical location to another (cf. Vector). Classified into categories and sub-categories.

Propagule: Any spore, seed, fruit, fragment or other part of an organism capable of reproduction by sexual or asexual means

Secondary (dispersal) pathway: The processes by which taxa disperse or are dispersed from one area of introduction to another.

Risk analysis: The process of identifying and assessing the likelihood and consequence of an event, as well as considerations as to manage and communicate the risks.

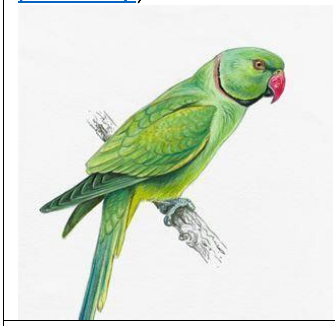
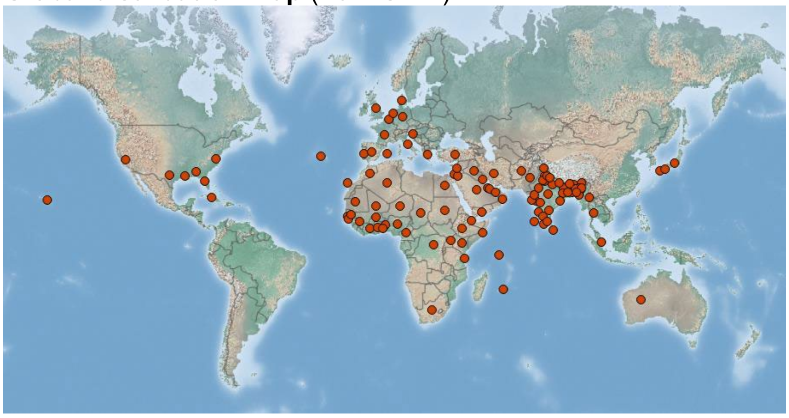
Risk assessment: The process of evaluating the likelihood and consequence of an event taking place. In this document, such an event would be an alien taxon becoming a harmful invasive species. Risk assessment is part of risk analysis. Risk analysis is comprised of risk assessment, risk management and risk communication.

Risk management: The process of assessing options by which the risks of an event (its likelihood and/or consequence) can be reduced or mitigated.

Vector: A mechanism responsible for the transport of species to new areas where they did not previously occur. A pathway (for example shipping) could have several vectors associated with it (for example in cargo, in passenger luggage, on passengers or crew themselves, in ballast water or attached to the hull).

Supplementary Material 3

Appendix S3: Example of a reporting sheet for the risk analysis of *Psittacula krameria* in South Africa. Note: this has been updated to the most recent format and is slightly different from the approved version.

Taxon: *Psittacula krameri* (Scopoli 1769)	***Area:*** South Africa
Approved by: South African Alien Species Risk Analysis Review Panel on 18 May 2018	
Picture of *Taxon* (from https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/ring-necked-parakeet/) 	**Global distribution map** (from CABI) 
Risk Assessment summary: There is a high likelihood of entry, establishment and further spread in the Area where *Psittacula krameria* is already present in several locations. The environmental impact (i.e. on natural biodiversity) is moderate through competition with native species—there is room for more research in the Area as the information on impact was found elsewhere. Socio-economic impacts are moderate to major, given the situation in the native range and other alien ranges. This leads to a high risk.	**Risk score:** High
Management options summary: The benefits were rated as low, as it is only used as a pet and has no other beneficial uses—however, there is a substantial amount of breeding and trade around this species in the Area. The species could be replaced by another parrot species with less invasive tendencies. Management would be tricky as it is a charismatic species which is mainly present in urban areas. People like the species and any control attempt will lead to a public outcry, if not handled correctly. As a communally roosting species, it provides unique opportunities for control and several methods are available.	**Ease of management:** Medium
Recommendations: Listing under the NEM:BA A&IS regulations as 1b is recommended, based on the high risk and relatively low benefits and the availability of many other, less invasive parrot species in the pet trade. Stakeholder engagement is crucial for any measures taken, as it is a charismatic species and one of the most common pet birds. However, if it is allowed under permit conditions, i.e. listed as Category 2, it needs to be ensured that measures to prevent invasiveness and impacts are taken, also preventing the species' movement and reproduction, as it is hard to control the release and escape of this pet due to people's behaviour. Either way, an invasive species management programme must be developed in terms of section 75(4) of NEM:BA.	**Listing under NEM:BA A&IS lists of 2014 as amended 2016:** 2 **Recommended listing category:** 1b

Suggested citation: SANBI (unpublished) Risk analysis of *Psittacula krameri* (Scopoli 1769) for South Africa as per the risk analysis of alien taxa framework v1.0, approved by the South African Alien Species Risk Analysis Review Panel on 18 May 2018, pp XX. (there is no doi for this report, but the link would be provided here in the general form http://dx.doi.org/10.5281/zenodo.XXXX)

Supplementary Material 4

Appendix S4: List of contributors to the risk analysis process in South Africa 2018, 2019. Only people involved in risk analyses where the recommendation has been approved are noted here; there are many others who are currently involved as assessors, experts or reviewers, but they have not yet been involved in an approved risk analysis. Many other people were involved prior to 2018 (in particular the panel was set up and initially chaired by Philip Ivey), but the risk analysis framework had not been implemented at that stage. A 'Member' is someone who served on the Alien Species Risk Analysis Review Panel (with ex-officio members indicated with an asterisk); an 'Assessor' is someone who conducted a risk analysis; an 'Expert' is a person who is an Assessor and listed as someone who was formally consulted during the development of their risk analysis report; a 'Reviewer' is someone who reviewed a risk analysis report at the bequest of an ASRARP member (i.e. independent from the Assessor). In addition, Khensani Nkuna and Viwe Balfour assisted as part of the ASRARP Secretariat. It is intended that an updated list will be published annually on SANBI's website, but it can also be provided on request.

Year	Role	Name
2018	Member	Essa Suleman
2018	Member	Graham Alexander
2018	Member	*John Wilson
2018	Member	Julie Coetzee
2018	Member	Lynn Jackson
2018	Member	Mandisa Poswa
2018	Member	Mark Robertson
2018	Member	Musa Mlambo
2018	Member	Olaf Weyl
2018	Member	Owen Horwood
2018	Member	Ryan Blanchard
2018	Member	Sabrina Kumschick
2018	Member	*Sebataolo Rahlao
2018	Member	Sheunesu Ruwanza
2018	Member	Thabiso Mokotjomela
2018	Member	Tshifhiwa Matamela
2018	Member	*Tsungai Zengeya
2018	Member	Unathi Heshula
2018	Member	Willem de Lange
2018	Assessor	Emily Jones
2018	Assessor	Katelyn Faulkner
2018	Assessor	Khensani Nkuna
2018	Assessor	Lynn Jackson
2018	Assessor	Olaf Weyl
2018	Assessor	Sabrina Kumschick
2018	Assessor	Tumeka Mbobo
2018	Expert	Bruce Ellender
2018	Expert	Charles Griffiths
2018	Expert	Colleen Downs
2018	Expert	Craig Whittington-Jones
2018	Expert	Dave Goodenough
2018	Expert	David Gwynne-Evans
2018	Expert	David Pearton
2018	Expert	Etienne Branquart
2018	Expert	Grace Marais
2018	Expert	Grant Aggett-Cox
2018	Expert	Grant Martin
2018	Expert	Johan Baard
2018	Expert	Khathutshelo Nelukalo
2018	Expert	Lesley Henderson
2018	Expert	Michael Cheek
2018	Expert	Neil Crouch
2018	Expert	Nicholas Mandrak
2018	Expert	Rob Little
2018	Expert	Sigrun Ammann
2018	Expert	Sonia Vanderhoeven
2018	Expert	Sue Jackson
2018	Expert	Tammy Robinson
2018	Expert	Theo Nel
2018	Expert	Tsungai Zengeya
2018	Reviewer	Christian Berg
2018	Reviewer	Dean Impson
2018	Reviewer	Ewald Weber
2018	Reviewer	Jana Mullerova
2018	Reviewer	Lorinda Hart
2018	Reviewer	Mandisa Poswa
2018	Reviewer	Nicholas Mandrak
2018	Reviewer	Philippe Goulettquer
2018	Reviewer	Ronell Klopper
2018	Reviewer	Ryan Blanchard
2018	Reviewer	Sabrina Kumschick
2018	Reviewer	Sheunesu Ruwanza
2019	Member	Buyisile Makhubo
2019	Member	Essa Suleman
2019	Member	Graham Alexander
2019	*Member	John Wilson

2019	Member	Lynn Jackson
2019	Member	Mandisa Poswa
2019	Member	Mark Robertson
2019	Member	Musa Mlambo
2019	Member	Olaf Weyl
2019	Member	Owen Horwood
2019	Member	Ryan Blanchard
2019	Member	Sabrina Kumschick
2019	*Member	Sebataolo Rahlao
2019	Member	Sheunesu Ruwanza
2019	Member	Tshifhiwa Matamela
2019	Member	Unathi Heshula
2019	Member	Willem de Lange
2019	Assessor	Anja le Grange
2019	Assessor	Arunova Data
2019	Assessor	Avril-Castelle Subramoney
2019	Assessor	Dikobe Molepo
2019	Assessor	Ingrid Nanni
2019	Assessor	Inshaaf Layloo
2019	Assessor	Joyce Ntuli
2019	Assessor	Kanyisa Jama
2019	Assessor	Katelyn Faulkner
2019	Assessor	Menzi Msizi Nxumalo
2019	Assessor	Musandiwa Liada
2019	Assessor	Nolwethu Tshali
2019	Assessor	Ntombifuthi Shabalala
2019	Assessor	Siyasanga Miza
2019	Assessor	Susan Canavan
2019	Assessor	Takalani Nelufule
2019	Assessor	Thulisile Jaca
2019	Expert	Adriaan Engelbrecht
2019	Expert	Anthony Forbes
2019	Expert	Colleen Downs
2019	Expert	Craig Whittington-Jones
2019	Expert	Derek Daly
2019	Expert	Ed Backer
2019	Expert	Eddie Ueckermann
2019	Expert	George M. Branch
2019	Expert	Grace Marais
2019	Expert	Grant Aggett-Cox
2019	Expert	Grant Martin
2019	Expert	Khathutshelo Nelukalo
2019	Expert	Lesley Henderson
2019	Expert	Llewelyn Jacobs
2019	Expert	Michael Cheek
2019	Expert	Nokuthula Mbanyana
2019	Expert	Rob Little
2019	Expert	Ruan Veldtman
2019	Expert	Sean Fennessy
2019	Expert	Sonam Yonten
2019	Expert	Stephen Boatwright
2019	Expert	Tammy Robinson-Smythe
2019	Expert	Theo Nel
2019	Expert	Tony Palmer
2019	Reviewer	Alan Wood

2019	Reviewer	Angela Bownes
2019	Reviewer	Anthony King
2019	Reviewer	Bruce Auld
2019	Reviewer	Christopher McQuaid
2019	Reviewer	Emma Sandenbergh
2019	Reviewer	Fritz Heystek
2019	Reviewer	Iain Bickerton
2019	Reviewer	Iain Paterson
2019	Reviewer	John Measey
2019	Reviewer	Lenin Chari
2019	Reviewer	Llewellyn Foxcroft
2019	Reviewer	Lynn Jackson
2019	Reviewer	Melissa Smith
2019	Reviewer	Mike Allsopp
2019	Reviewer	Nicola Bredenkamp
2019	Reviewer	Quentin Groom
2019	Reviewer	Ruan Veldtman
2019	Reviewer	Sabrina Kumschick
2019	Reviewer	Samella Ngxande-Koza
2019	Reviewer	Tshifhiwa Matamela
2019	Reviewer	Vernon Visser

Supplementary Material 5

Appendix S5: Guidance regarding the use of the confidence rating (taken from Hawkins et al. 2015, modified from the EPPO pest risk assessment decision support scheme (Alan MacLeod 09/03/2011; revised 28/04/2011; copied from CAPRA, version 2.74; 2)).

Confidence level	Examples
High (approx. 90% chance of assessment being correct)	There is direct relevant observational evidence to support the assessment; *and* Impacts are recorded at the typical spatial scale over which original native communities can be characterized; *and* There are reliable/good quality data sources on impacts of the taxa; *and* The interpretation of data/information is straightforward; *and* Data/information are not controversial or contradictory.
Medium (approx. 65-75% chance of assessment being correct)	There is some direct observational evidence to support the assessment, but some information is inferred; *and/or* Impacts are recorded at a spatial scale which may not be relevant to the scale over which original native communities can be characterised, but extrapolation or downscaling of the data to relevant scales is considered reliable or to embrace little uncertainty; *and/or* The interpretation of the data is, to some extent, ambiguous or contradictory.
Low (approx. 35% chance of assessment being correct)	There is no direct observational evidence to support the assessment, for example, only inferred data have been used as supporting evidence; *and/or* Impacts are recorded at a spatial scale which is unlikely to be relevant to the scale over which original native communities can be characterised and extrapolation or downscaling of the data to relevant scales is considered unreliable or to embrace significant uncertainties. *and/or* Evidence is poor and difficult to interpret, for example, because it is strongly ambiguous. *and/or* The information sources are considered to be of low quality or contain information that is unreliable.