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Research Article

Argument maps can support decisions to declare the presence of alien species: South Africa as a case study

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Abstract

Accurate alien species lists are essential for effective biodiversity policy and regulation. However, the evidence that a species is present at a site can be weak. In South Africa, of the 560 taxa listed under invasive species regulations, at least 11 taxa (~2%) are assumed present based on anecdotal or outdated evidence. This study introduces a structured argument mapping approach to evaluate whether an alien species should be considered present. Argument maps display the inferential connections between reasons and objections, and the logical connections between them, to judge the validity of the premises of an argument. We applied this approach to three South African case studies—the Chilean black urchin (*Tetrapygus niger*), heather (*Calluna vulgaris*), and leafy spurge (*Euphorbia esula*)—evaluating the available evidence in terms of its credibility, specificity, sensitivity, and quantity. The method enabled a concise classification of presence (*T. niger* not present with high confidence, *C. vulgaris* present with medium confidence, and *E. esula* not present with medium confidence) and informed recommendations for regulation and research. By providing a systematic method to incorporate multiple data types and make reasoning explicit, argument maps can support decisions regarding the presence of an alien species when evidence is conflicting, sparse or questionable.

Key words: Absence evaluation, evidence assessment, evidence-based decision-making, invasive species, invasive species management, non-native species, presence status, risk analysis, species listing

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Introduction

Biological invasions are one of the leading threats to biodiversity (Bellard et al. 2022; Roy et al. 2023). In the coming decades, it is anticipated that the international exchange of alien species due to human activities will continue to increase (Seebens et al. 2021). The probability of an introduced alien species becoming invasive, however, is generally low (Smith et al. 1999). Most introductions either fail to establish or, if they do establish, struggle to form invasive populations (Blackburn et al. 2011; Simberloff 2013). Moreover, invasive populations can, and do, disappear (Simberloff and Gibbons 2004). This dynamic nature of invasions calls for transparent, up-to-date and evidence-based alien species lists to support appropriate and effective management (Roy et al. 2023).

Maintaining alien species lists is challenging as lists are often based on inconsistent or incomplete evidence, and rapidly become outdated (McGeoch et al. 2012;

Pyšek et al. 2012). Misidentifications and false presences can lead to underestimations or inflated species counts (McGeoch et al. 2012), affecting policy and resource allocation (Pyšek et al. 2012; McGeoch et al. 2016). These issues arise both when listing new species and when evaluating whether previously recorded species are still present. In some cases, species are listed as invasive but are either no longer detectable, or were never introduced (Simberloff and Gibbons 2004). Conversely, some alien species not currently listed may be incorrectly assumed to be absent (McGeoch et al. 2012). For instance, a thorough revision of alien species in the Mediterranean resulted in the exclusion of 73 species previously considered established (Zenetos et al. 2017). However, the premature removal of species from lists can result in missed opportunities for eradication and long-term control efforts (Nishimoto et al. 2021). These issues highlight the importance of careful evaluation before changing the listing of an alien species, particularly in cases where presence is uncertain.

Increasing transparency in the listing process and improving detection efforts can help address the uncertainties and enhance the value and reliability of alien species lists for policymakers and managers (Burgman 2001; Butchart et al. 2010). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has identified knowledge gaps in alien species lists, particularly in the Global South where data are often limited or insufficient (Seebens et al. 2023). This is often due to limited geographical coverage and insufficient long-term monitoring (Vicente et al. 2022). To address this, well-documented and standardised assessment methods are needed to support reliable listing decisions based on strong evidence and a clear rationale (Burgman 1981; Keller and Springborn 2014; Schmiedel et al. 2016; Karasawa and Nakata 2018).

In South Africa, a regulatory framework for managing invasive plants was established under the Conservation of Agricultural Resources Act (CARA) of 1983. This was later replaced by the National Environmental Management: Biodiversity Act (NEM:BA) of 2004, which included all taxa. The initial NEM:BA lists of regulated alien species were published in 2014 and updated in 2020, with 560 valid taxa listed as present and 'invasive' in the country [note, 'invasive' is defined in NEM:BA in regulatory terms rather than based on impact or biogeography, see Wilson and Kumschick (2024) for details of South Africa's regulatory lists]. Concerns have been raised regarding the actual presence of several listed 'invasive' species within South Africa. The issue partly stems from the initial listings being based on expert opinion and perceived threat, without comprehensive, verifiable evidence of presence (McGeoch et al. 2012; Wilson and Kumschick 2024). As a first step to address these concerns, a review of the 560 taxa listed as 'invasive' under NEM:BA (DFFE 2020; Wilson 2025) was done to identify cases where presence in South Africa was uncertain (see Suppl. material 1: note 1 for full methodology). This assessment found that at least 11 species (~2%) are listed as present, despite weak, ambiguous or outdated occurrence records (Suppl. material 1: table S1). While this situation may apply to a relatively small proportion of listed taxa, these cases are often the most difficult to resolve and can have significant implications for management. Moreover, additional cases are likely to emerge as analyses are conducted more systematically and in a structured way [e.g., by following the Risk Analysis for Alien Taxa (RAAT) framework (Kumschick et al. 2020, 2025)]. While risk analysis and risk assessment frameworks typically require some evaluation of the presence of a taxon in a country, as far as we know there is no transparent and standardised process for addressing cases where the evidence is conflicting.

Argument maps and their potential application in decisions about alien species presence

Argument maps have been used in critical thinking courses and textbooks since the 1950s (e.g., Beardsley 1950; Toulmin 1958; Scriven 1976; LeBlanc 1998). This approach is a graphical way to represent the structure of an argument (Butchart et al. 2009) providing a logical way to organise uncertainties based on qualitative information and evidence that supports an estimate. Argument maps are centred on a claim, which is supported by reasons or challenged by objections each of which must be supported by evidence with sources (Okada 2008; Keith et al. 2017). By mapping out the reasons and objections, experts can estimate the subjective probabilities that the claim is true, which then allows for the calculation of an overall probability (Keith et al. 2017). An argument map presents different lines of evidence that users can evaluate for an informed judgement.

The argument map is based on a probabilistic statement. Here, argument maps were used to evaluate the claim that species X is not present in site Y, particular in cases where the presence of an alien species was uncertain, contested or based on limited or inconsistent evidence. In the argument map, four sections, made up of reasons and objections, are considered to support the claim of an alien species not being present in a given area (Fig. 1; Table 1). Each step provides a logical checkpoint in the evaluation process. All available evidence is outlined and biological understanding is used to evaluate the evidence in determining whether the claim is supported or not. Evidence sources included published data, ecological measurements, observations, location records, scientific literature, and expert opinion. These sources are identified and documented, and their reliability is assessed based on criteria such as peer-reviewed status, methodological rigour, and the source of information. Each piece of evidence is then scored for credibility, specificity, sensitivity, and quantity (Table 2), with informal observations or expert opinions assigned a baseline weight or flagged for verification.

Although the approach shares similarities with decision trees, which have been applied in invasive species management prioritisation and pathway analysis (Padayachee 2017; Clarke 2021), there are important differences. Decision trees typically guide users through a sequence of branching yes/no questions that lead to a management outcome or classification, whereas argument maps explicitly set out the structure of reasoning around a claim, including supporting reasons, counterarguments, and the evidence underpinning them. Decision trees tend to simplify complexity by using categorical pathways, while argument maps retain complexity by making assumptions, uncertainties, and objections transparent. As such, argument maps complement rather than replace decision-tree approaches, offering a more detailed and transparent framework for situations where the evidence is disputed or lacking.

The argument map approach aims to reduce subjective bias, inconsistencies, vagueness, and other uncertainties by requiring clear documentation of the evidence and a structured scoring of the quality of the source. It acknowledges that judgements based solely on personal observations or expert opinions retain inherent bias (Keith et al. 2017), with each reason supported by a set of considerations and tested against plausible objections. This logical structure underpins the argument map and promotes consistent decision-making under uncertainty. The following steps describe how evidence is identified, evaluated, and scored to guide the application of the argument map in practice.

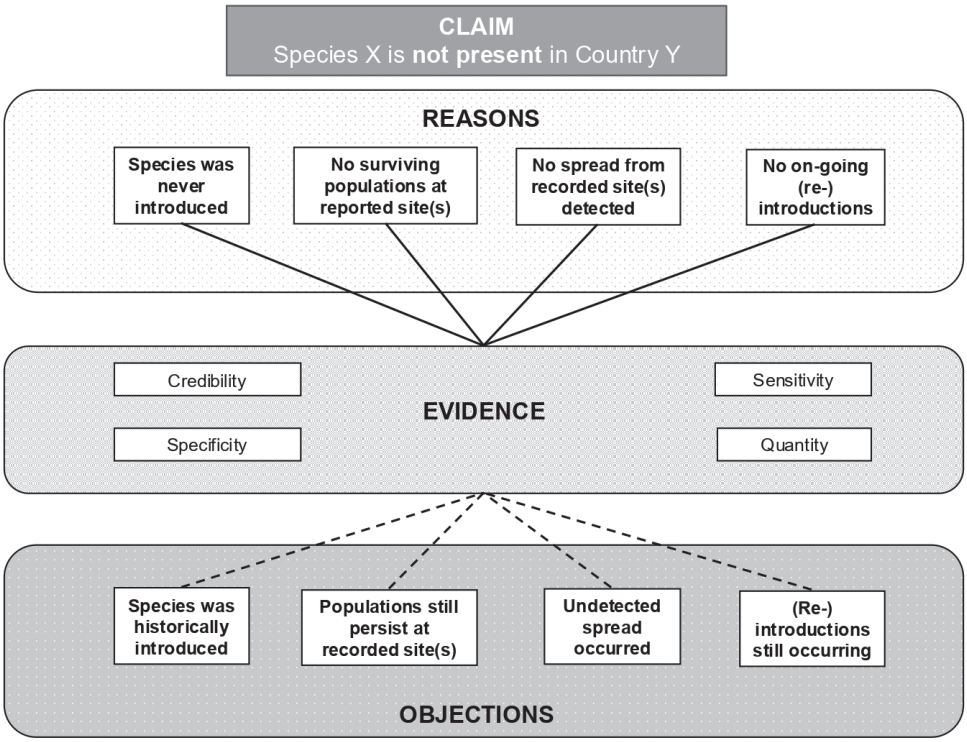


Figure 1. Argument map for systematically evaluating the presence of an alien species in a country. Solid lines represent reasons supporting the claim. Dashed lines indicate evidence that supports counter arguments or objections. Explanations for each element in the argument map (e.g. claims, reasons, objections, and evidence) are provided in Table 1. Although the reasons are partially hierarchical (if a species was never introduced there should be no sites to evaluate), given the uncertainties involved it is prudent to complete the full argument map in all cases.

Evidence compilation and confidence rating

The first step in the assessment involves collating and organising all available evidence and assigning confidence ratings based on four key criteria: credibility, specificity, sensitivity, and quantity (Table 2, Suppl. material 1: table S2). These criteria reflect principles drawn from structured evidence evaluation frameworks used in scientific decision-making (Aguayo-Albasini et al. 2014; Dicks et al. 2014; EFSA Scientific Committee et al. 2016, 2017). Each piece of evidence is assessed against all four criteria. For each criterion, the evidence is assigned a confidence level (low, medium or high) based on how well it meets the relevant standards. These individual ratings help determine how much weight to place on each piece of evidence when linked to a reason or objection within an argument map.

Evaluating competing arguments

Once evidence is linked to specific reasons and objections, each line of reasoning is evaluated by comparing the cumulative confidence ratings of the supporting evidence. This evaluation follows a weight-of-evidence approach commonly applied in scientific assessments (EFSA 2017). Confidence is assigned based on established criteria, ensuring that the credibility, specificity, sensitivity, and quantity of each piece of evidence are considered systematically. Lines of reasoning supported by direct, high-quality, and verifiable evidence, such as peer-reviewed studies, systematic records, or structured survey data, carry more weight than those based on low-confidence evidence, absence of evidence or speculative claims (EFSA 2017; Pan et al. 2018; Kumschick et al. 2020). This structured comparison helps ground

Table 1. The four sections of the generic argument map used to evaluate alien species occurrence status under conditions of uncertainty.

Evaluation	Reason	Objection	Details/considerations
Was the species ever introduced?	Species was never introduced	Species was historically introduced	• Evaluate historical records, herbarium/ physical specimens, import/ export data bases, and published literature for documented presence • Review grey literature, expert knowledge, and citizen science observations (e.g., iNaturalist) • Investigate potential for accidental or deliberate introductions not recorded in formal datasets • Evaluate the geographical precision and temporal relevance of reported records • Verify species identification accuracy (e.g., morphological ambiguity, genetic confirmation) • Consider whether evidence may be mislabelled or outdated
Does it still exist at known site(s)?	No surviving populations at reported site(s)	Populations still persist at recorded site(s)	• Examine historical records, population surveys, and control measures • Review outcomes of field surveys, eradication reports, and habitat assessments at previous reported locations • Assess the frequency, methodology, and spatial extent of surveys • Investigate whether the habitat at the reported location remained suitable for the species (e.g., considering land use changes, hydrology, and fire history) • Consider whether eradication or control efforts were implemented effectively and followed up over sufficient timeframes • Consider the reproductive capacity and detectability of individuals or propagules, especially for taxa with long-lived seedbanks or dormant life stages
Has it spread to other locations?	No spread from recorded site(s) detected	Undetected spread occurred	• Track back from the site to potential sources of introductions based on putative introduction and dispersal pathways • Track forward from known sites to potential sites via putative dispersal pathways (e.g., rivers, roads, and trade routes) • Consider survey methodology, intensity, spatial coverage, and frequency • Identify gaps where spread could have occurred unnoticed • Consider species-specific traits that may influence detectability or dispersal (e.g., spread, dispersal, and unnoticed life stages) • Consider observer expertise, sampling limitations, and whether monitoring was active or passive
Are new (re-) introductions occurring?	No on-going (re-) introductions	(Re-) introductions still occurring	• Identify all putative historical, current, and potential future pathways of introduction • Specifically evaluate whether the putative original introduction pathway remains active (e.g., aquaculture, ornamental or pet trade, and contaminated equipment) and survey potential sites of introduction (i.e., develop risk maps and use them to guide surveys as above) • Assess management of key pathways

conclusions in the quality and consistency of the available information, rather than the number of sources or persuasive language, aligning with international best practices in risk evaluation (Mastrandrea et al. 2010; IUCN 2020).

Constructing the argument map from rated evidence

Following the evaluation of evidence, an argument map is constructed for the study species (based on Fig. 1) using the outcomes recorded. Each line of reasoning in the map is based on evidence that has been systematically rated, ensuring transparency and consistency across the assessment. This approach allows for a clear visualisation of how individual pieces of evidence support or challenge the central claim. While expert opinion and informal observations can offer valuable insights, they are more susceptible to bias and uncertainty and are therefore treated with appropriate caution in the argument mapping process (Keith et al. 2017).

Table 2. Evidence-rating rubric used to assess evidence supporting claims about the presence of a species at a site.

Criterion	High	Medium	Low
Credibility Reliability of the data, based on expertise, transparency, and methodological rigour[1,2,4]	Peer-reviewed research, verified databases, government or academic reports with clear methods	Grey literature, well-documented expert opinion, standardised field surveys with some uncertainty	Unpublished observations, anecdotal accounts, or sources lacking clear details of the method used
Specificity How directly the evidence relates to the species and location in question [1,2,4]	Directly addresses the species and specific area under consideration (coordinates, habitat)	Relevant to either the species or the area, but not both	Generalised or indirect reference with unclear geographic/species relevance
Sensitivity The capacity of detection methods to identify the species and minimise false negatives[1,2,3]	Uses detection methods known to identify the species effectively. Several surveys conducted. Very unlikely that the target species would be confused with any species in the specific area	Detection methods with limited frequency or coverage AND/OR some potential species present in the specific area that are morphologically similar	Detection methods likely to miss key life stages, not conducted during appropriate times, or that are unlikely to distinguish the species of interest from other species in the specific area
Quantity The volume of independent, corroborative evidence [4,5]	Multiple, independent, AND/OR recent lines of evidence	Several sources but not all recent or up to date	Very few, isolated, or outdated sources

[1]Aguayo-Albasini et al. 2014; [2]Keith et al. 2017; [3]Saltelli et al. 2013; [4]Suter et al. 2017; [5]Suter et al. 2017a.

Determining occurrence status and assigning confidence

Once the argument map is constructed and the quality of evidence evaluated, a conclusion must be drawn as to whether the species is considered present in the study area. This decision should be based on how the available evidence supports or challenges the central claim, as reflected in the logical structure of the argument map. Each decision must be accompanied by a corresponding confidence rating, which indicates the level of certainty based on the quality and consistency of the evidence (Zengeya et al. 2025: occurrenceStatus). The decision on occurrence status must be justified by a clear explanation, referencing supporting evidence and any assumptions involved. If the overall confidence is medium or low, recommendations should be provided for targeted surveys or further data collection to increase the confidence in future assessments (cf. Zengeya et al. 2025).

Case studies from South Africa

The argument map method was applied to three case studies from South Africa, namely the Chilean black urchin (*Tetrapygus niger*) and two plant species, heather (*Calluna vulgaris*) and leafy spurge (*Euphorbia esula*). These three species were selected because they represent different taxonomic groups and illustrate a range of evidentiary challenges: *T. niger* as a marine invertebrate with a putative but unconfirmed introduction pathway, *C. vulgaris* as a cultivated ornamental with scattered historical records, and *E. esula* as a species that was possibly misidentified. Collectively, they demonstrate some of the most common uncertainties that arise when assessing alien species presence (Mabin et al. 2015; Magona et al. 2018), illustrate different initial assumptions about their presence, while providing diverse scenarios to demonstrate the application of argument mapping.

A risk analysis was first conducted or consulted (where already completed) for each case study species following the RAAT framework v2.0 (Kumschick et al. 2025). As part of this process, a literature review was conducted to create a historical account of each species occurrence, distribution, and introduction pathways, including any past or ongoing management efforts. Detailed information was

gathered from herbarium records, scientific peer-reviewed and grey literature, and biodiversity databases such as the Global Biodiversity Information Facility (GBIF) (www.data.gbif.org), the on-line spotter network iNaturalist (www.iNaturalist.org) (restricted to research-grade observations), GenBank (https://www.ncbi.nlm.nih.gov/genbank/), SANBI's National Herbarium Database (NEWPOSA) (www.newposa.sanbi.org), Web of Science, and Google Scholar using the species name and 'South Africa' as search terms. Searches included the species names as listed in the Alien and Invasive Species Regulations of 2020, as well as accepted names and synonyms (cross-checked using global taxonomic backbones such as GBIF and Plants of the World Online) to ensure taxonomic accuracy and completeness.

Each piece of evidence was organised on the evidence evaluation table (Suppl. material 1: table S2). Each piece of evidence was scored as either high, medium, or low confidence and an argument map was drawn up thereafter using the gathered and evaluated evidence. Based on this, a conclusion was drawn for each species on whether it should be considered present or not present, with an associated confidence rating (low, medium, or high), justification for the rating, and recommendations for management (cf. Suppl. material 1: tables S3, S4).

Case Study 1: *Tetrapygus niger*: formerly present, the population was extirpated and is now considered not present

There is strong evidence (high confidence) that *T. niger* was present in South Africa (Haupt et al. 2010). Animals were recorded in 2007 at an aquaculture facility in Alexander Bay, with museum specimens collected, and the account published (Haupt et al. 2010; Mabin et al. 2015). However, follow-up systematic surveys found no living individuals at the only known site and surrounding areas (Mabin et al. 2015). Only empty shells were observed and no evidence of spread was detected.

The known habitat (a dam used for oyster aquaculture) had dried up and suitable similar habitats in the region yielded no new detections (Mabin et al. 2015). It was considered likely that the *T. niger* would have been detected if it had persisted or spread to the kelp-dominated ecosystem given there should be visible signs of grazing typical of urchin presence (none were recorded). No credible sightings have been recorded since 2007 and the original pathway of introduction (via oyster spat imports) was confirmed to be inactive at the Alexander Bay facility (Haupt et al. 2010; Mabin et al. 2015). However, since oyster farming continues at other sites in South Africa the pathway remains active and poses a risk of new introductions. Nonetheless, given the taxon is highly distinctive, if the urchin is (or had been) present at other aquacultural facilities, it would likely have been detected and reported.

In the argument map (Fig. 2; Suppl. material 1: table S5), all strong reasons for absence outweighed the few unsupported objections. Based on the weight of evidence and associated confidence ratings, it was concluded that *T. niger* is not present in South Africa, with high confidence. All four reasons supporting this conclusion were underpinned by strong, well-documented sources such as peer-reviewed studies and structured field surveys, and were assigned a high overall confidence (Fig. 2). Additionally, the two objections were speculative, lacked direct evidence, and were rated low in confidence.

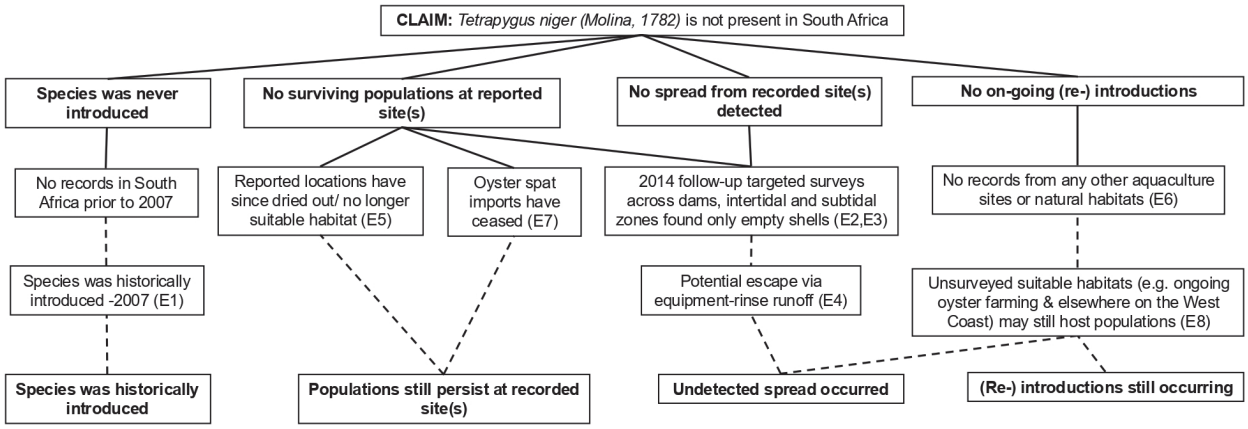
A resurvey of the original introduction site does not seem necessary at present. However, targeted surveys should be reinstated if trade pathways reopen (see recommendations in Fig. 2). Continued monitoring of oyster spat imports is

recommended and other aquaculture sites could be evaluated as a precaution. As per a risk analysis conducted previously (SANBI unpublished), it is recommendation that the listing of the taxon in South Africa is changed from 1a to prohibited, and the taxon is added to a watch list. The taxon should be considered as A1 under the adapted unified framework for biological invasions (Groom et al. 2019).

Case Study 2: *Calluna vulgaris*: regulated as if it were not present, discovered and extirpated, but it is likely still present.

Calluna vulgaris was listed as prohibited under the NEM:BA A&IS Lists of 2014 and 2016, implying that it was not present in South Africa but posed a high risk (the NEM:BA A&IS Lists 2020 did not included a prohibited list). However, a single population was discovered and removed, and it is likely that *C. vulgaris* is still present in South Africa based on a historical herbarium specimen (1987), research grade iNaturalist observations (2008, 2021), and ecological inferences (Fig. 3).

No evidence was found to suggest *C. vulgaris* was formally stocked or traded within the commercial horticultural industry, and it is not included in a comprehensive review of cultivated plants of southern Africa (Glen 2002). However, the species is presumed to have been cultivated informally in private gardens and possibly shared as an ornamental plant. The confidence was scored as medium



Element	Outcome	Justification	Recommendations
Presence status	Not present	*Tetrapygus niger* has not been detected in any recent surveys of the original introduction site and surrounding sites. The only verified record dates to 2007 and was a single introduction event, with no evidence of persistence or spread. Subsequent surveys found only empty shells and no live individuals have been reported since. The original site is now dry and the historical introduction pathway (oyster spat imports) is no longer active at that site.	Importations of oyster spat to South Africa should be monitored for *T. niger*. Include *T. niger* on the prohibited list. Encourage public reporting of any potential reintroduction by including *T. niger* on a watch list.
Confidence in conclusion	High	Recent, peer-reviewed surveys and official reports show no live detections. All evidence rated high in credibility, specificity, and sensitivity. While some objections referenced surveyed areas, these lacked empirical support, and were rated low in confidence (i.e., it is unlikely that there are undetected populations given the ecological characteristics of the habitat and species and survey effort). The weight of reliable evidence strongly supports the outcome.	Given the high confidence, *T. niger* should be considered not and listed as prohibited under regulatory frameworks to prevent future introductions. Targeted surveys should be reinstated if trade pathways reopen.

Figure 2. Argument map and corresponding decision regarding the presence of *Tetrapygus niger* in South Africa. Boxes represent individual pieces of evidence. Solid lines indicate reasons supporting the central claim. Dashed lines represent objections that challenge the claim or its supporting reasons. For details of the underlying evidence (E1–8), see Suppl. material 1: table S5. The claim was supported—it is recommended that *T. niger* be regulated as not present in South Africa.

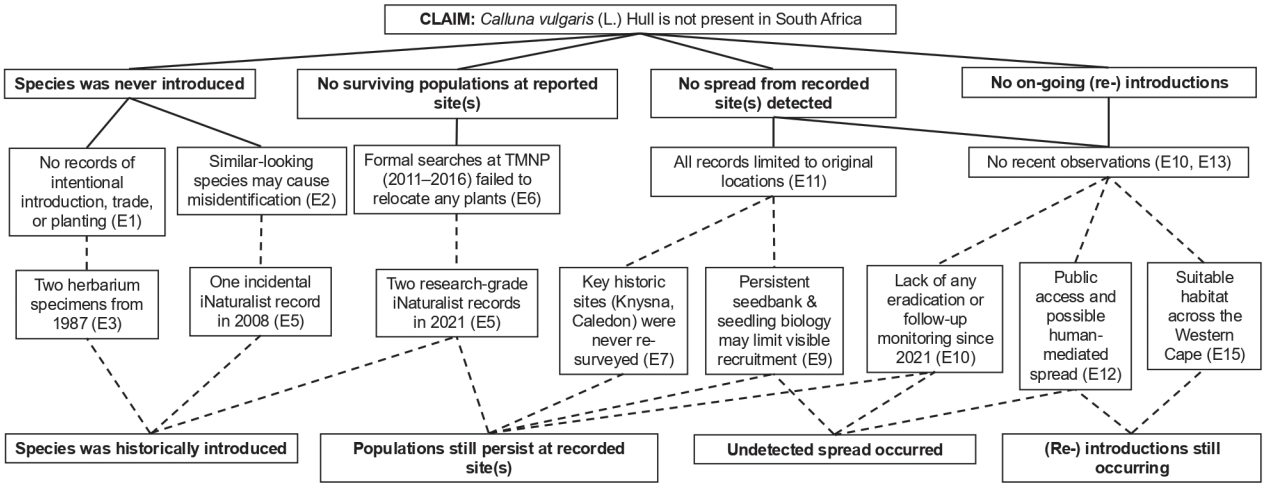
based on the quality of the evidence and arguments. High credibility sources, such as herbarium records, supported the claim of presence, while the lack of recent formal surveys and limited follow-up, reduced overall confidence. Although no widespread establishment or formal introduction was recorded, multiple verified records and ecological reasoning pointed to past and potentially ongoing presence. Confidence was medium due to limited recent detections and scattered survey coverage, but individual sources were generally high in credibility and specificity.

Based on the risk analysis conducted for *C. vulgaris* (Suppl. material 1: table S7), the recommendation, as for all taxa listed as prohibited that are subsequently found to be present (Wilson and Kumschick 2024), is that *C. vulgaris* should be regulated as a category 1a taxon pending an assessment of the feasibility of nation-wide eradication. Targeted surveys are recommended in areas where past records originated, including the Knysna and Caledon districts. Particular attention is advised for regions with suitable habitat and high human activity, where unintentional introduction or spread may have occurred. The potential for undetected dispersal and persistence due to the ability of *C. vulgaris* to form long-lived seedbanks further contributed to uncertainty. These gaps in monitoring and survey coverage supported a classification of medium confidence. In terms of the invasion status, it is suggested the taxon is classified as C1 under the adapted unified framework for biological invasions (Groom et al. 2019).

Case Study 3: *Euphorbia esula*: a case of mistaken identity?

A single, unverified record of *Euphorbia esula* was reported in a reputable database in 2006 [observation #58885 in the Southern African Plant Invaders Atlas (SAPIA); see Henderson (1998) for details of SAPIA]; however, no supporting physical evidence (e.g., herbarium specimens or photographs) were available to validate the observation. Multiple extensive field surveys have been conducted at and around the original reported location (Cindi et al. 2015, 2016; Henderson and Wilson 2017). No individuals of *E. esula* were detected during these surveys. However, a congener, *Euphorbia terracina*, which is also alien to South Africa, was found within the same region as the reported location of *E. esula* (iNaturalist 2025c, d). Given the relative similarity in morphology between *E. esula* and *E. terracina*, and the lack of additional confirmations, it was considered likely that the original sighting was misidentified.

Based on the available evidence (Suppl. material 1: table S8), *E. esula* was assessed as not present in South Africa, with medium confidence (Fig. 4). Although the original report was submitted to a reputable data base by a credible observer, it remained unverified and lacked physical evidence. Furthermore, no herbarium records, introduction pathways or additional reports were identified. The medium confidence rating was assigned due to the high quality and specificity of the negative survey data, despite the ongoing uncertainty stemming from the lack of formal eradication and the potential for overlooked individuals. Additionally, based on the risk analysis (Suppl. material 1: table S9), it is recommended that the listing of *E. esula* be changed from category 1a to prohibited (i.e., it is not present in the country but poses a high risk). No further active surveillance for the species seems warranted. Given the lack of evidence of introductions, it is suggested the taxon is classified as A0 under the adapted unified framework for biological invasions (Groom et al. 2019). See Fig. 4 for the resulting argument map for *E. esula*, with the full evidence set out in Suppl. material 1: table S7.



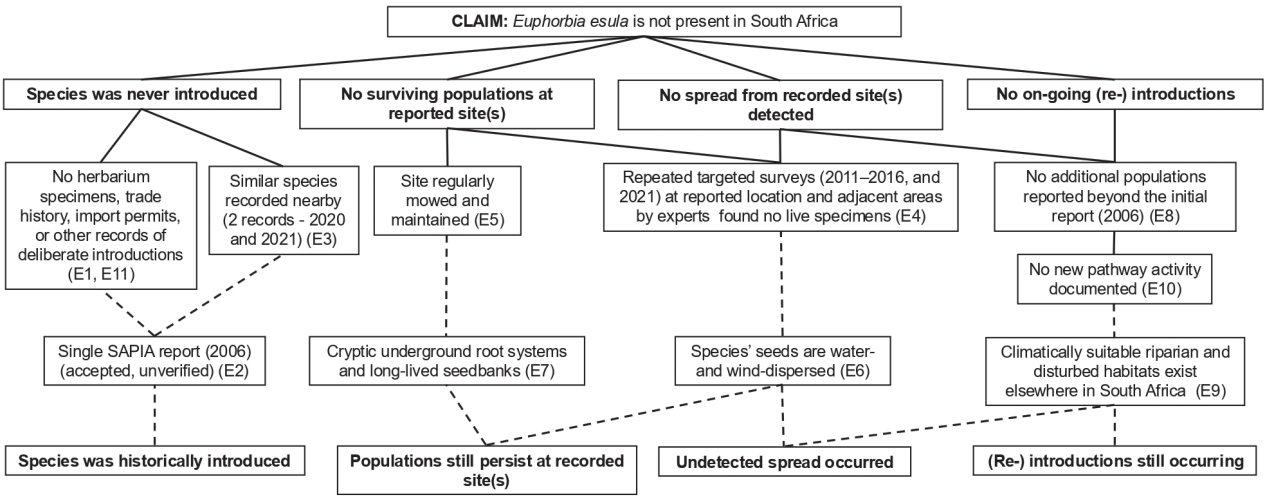
Element	Outcome	Justification	Recommendations
Presence status	Present	The evidence supports that *C. vulgaris* is present in South Africa, based on herbarium records (1987), iNaturalist observations (2008, 2021), and ecological evidence. These records suggest past introductions and potential persistence.	Periodic surveys and targeted monitoring efforts are needed for observations to be confirmed, particularly in regions where herbarium specimens and observations were recorded and other suitable habitats. Garden clubs in the Western Cape could be surveyed to establish if there any plants in cultivation.
Confidence in conclusion	Medium	The evidence is a mix of high credibility and medium confidence. Gaps in surveys and the potential for undetected spread result in medium confidence.	Evidence gaps should be addressed by prioritising surveys in unsurveyed areas, such as the Knysna and Caledon districts. Given the medium confidence in spread, monitoring for potential dispersal should be considered in susceptible areas, especially where human activity is high.

Figure 3. Argument map and corresponding decision regarding the presence of *Calluna vulgaris* in South Africa. Boxes represent individual pieces of evidence. Solid lines indicate reasons supporting the central claim, while dashed lines represent objections that challenge the claim or its supporting reasons. For details of the underlying evidence (E1–15), see Suppl. material 1: table S6. The claim was not supported—it is recommended that *C. vulgaris* be regulated as present in South Africa.

Discussion and conclusion

The use of argument maps provide a structured way to organise uncertainties and synthesise evidence in cases where doubts exist about the presence of an alien species within a country. In all three case studies presented here, argument maps visually represented the reasons and objections alongside supporting evidence and the logical flow of the argument led to a clearly justified conclusion supported by an associated confidence rating.

The reliability of outcomes derived from argument maps is strongly dependent on the availability and quality of evidence. In the case studies, constraints such as inadequate long-term monitoring, poor geographic coverage, and limited data availability were found to hinder the assessment process. For example, although the presence of *C. vulgaris* was supported by five verified records and reliable evidence for the most recent record (Fig. 5A), the lack of recent targeted surveys in all known locations and absence of post-2021 monitoring lowered the confidence rating in the conclusion. These limitations, however, were highlighted by the structured argument mapping process, which helped identify priorities for future research and monitoring. Evaluating and weighing evidence from sources with varying levels of credibility (e.g., expert opinion, physical samples, and citizen science identification platforms) remained complex and somewhat subjective. The argument map approach allowed



Element	Outcome	Justification	Recommendations
Presence status	Not present	A single unverified record was submitted to a reputable database in 2006; however, it lacked physical evidence such as herbarium specimens or photographs. Multiple structured surveys at the reported location failed to detect *E. esula.* The original record is likely a misidentification of *E. terracina*.	No further surveys are currently recommended unless new evidence emerges. List as absent from South Africa and add to the prohibited list.
Confidence in conclusion	Medium	The confidence rating is due to high quality, specificity and sensitivity of the negative survey data. Although the original record remains unverified and no corroborating evidence exists, the conclusion is supported by repeated surveys over time and the lack of introduction pathways.	No additional surveys are necessary at this stage.

Figure 4. Argument map supporting the absence of *Euphorbia esula* in South Africa. Boxes represent individual pieces of evidence. Solid lines indicate reasons supporting the central claim, while dashed lines represent objections that challenge the claim or its supporting reasons. For details of the underlying evidence (E1–E11), see Suppl. material 1: table S9. The claim was supported—it is recommended that *E. esula* be regulated as absent from South Africa.

these differences to be addressed systematically and transparently by assessing each source in terms of credibility, specificity, sensitivity, and quantity.

Species that persist in low densities, exhibit cryptic life stages, or closely resemble native or other alien species pose challenges to detection and identification. These traits can lower confidence scores and risk the inclusion of false positives in alien species lists (McGeoch et al. 2012). This was particularly evident for *E. esula* and *C. vulgaris*. In the case of *E. esula*, a single unverified record was likely a misidentification of *E. terracina* (Fig. 5B), a morphologically similar species. Similarly, some records of *C. vulgaris* from citizen science platforms may have reflected confusion with native species (*Erica* spp. in particular). Historical nomenclatural issues add to this uncertainty: for example, the name *Erica glabra* was once applied to both a native *Erica* species in the Cape of Good Hope and to *C. vulgaris* in Europe (The Heather Society 2017). While this does not indicate that *C. vulgaris* was present, it highlights how taxonomic ambiguities and misapplied names can complicate the interpretation of records. These cases highlighted the importance of verifying records through multiple, independent lines of evidence wherever possible.

The value of field verification is clear. For *T. niger*, detailed surveys described in Mabin et al. (2015) found no live specimens and identified a highly plausible reason for the extirpation of the population. For *C. vulgaris*, the localities available were too vague to target, one record from Table Mountain provided sufficient detail for a site visit: this location was surveyed and one individual was detected. For *E. esula*, only a single locality was reported; this site and its surrounding area were surveyed, and nothing was



Figure 5. Evidence from surveys conducted in 2021 by author. **A.** Verified flowering *Calluna vulgaris* individual (within image, with small, pale purple/pink flower spikes) found on Table Mountain; **B.** *Euphorbia terracina* in flower in South Africa (foreground, with narrow leaves and yellow-green floral structures; the prominent purple flowers in the background belong to a different species); **C.** Location along the Hennops River in Pretoria, Gauteng, where *Euphorbia esula* was reported being mowed as part of land maintenance (photos by Chelsey Matthys 2021).

found. This highlights that while published and curated records are central to the argument mapping approach, the feasibility and resolution of field verification may vary across species. Incorporating targeted field surveys would help strengthen confidence levels, especially in cases where the evidence base is sparse, outdated or of low quality.

More generally, the argument maps helped clarify where confidence was lacking and where further evidence would be most useful. In the case of *C. vulgaris*, the final status was classified as present with medium confidence, reflecting the weight of historical evidence alongside gaps in recent data. In contrast, *E. esula* was assessed as not present, also with medium confidence, due to repeated expert-led surveys, a lack

of introduction pathways and the unverified nature of the original record. Regular mowing and land maintenance at the reported site likely further contributed to the absence of detectable individuals, potentially eliminating any above-ground presence if the species had ever been introduced (Fig. 5C). Although based on personal communication, this context-specific information supported the conclusion and highlighted how local land use practices can influence detection outcomes.

The argument maps present the reasons and objections informed by ecological or detection-related uncertainties. Nonetheless, a lack of systematic surveys of potentially suitable sites is a limitation. This concern was particularly relevant for *T. niger*, where strong evidence supported its extirpation but the possibility it is present at other aquaculture facilities remained.

Beyond evaluating individual pieces of evidence, consistency across the evidence base played an important role in reaching final conclusions. For instance, in the case of *E. esula*, the absence of herbarium specimens, trade history, or confirmed sightings was consistent with the repeated failure to detect the species during targeted surveys. This coherence across multiple independent lines of evidence strengthened confidence in the assessment, even though the confidence in each line of evidence alone was limited. In contrast, for *C. vulgaris*, inconsistent information, such as recent citizen science records alongside a lack of survey coverage, resulted in medium confidence. Recognising and explicitly considering the level of consistency across types of evidence is another strength of the argument map approach.

Beyond assessing species presence, argument mapping could be adapted to support other management decisions for invasive alien species. For example, it could be used to structure evidence around the feasibility of eradication efforts, the likelihood of containment success, or the prioritisation of management actions when resources are limited. By making assumptions, uncertainties, and objections explicit, the approach could help managers and policy makers see the trade-offs more clearly and make decisions with a clearer appreciation of the risks involved.

Although this study focused on South Africa as a case study, similar uncertainties in alien species listings exist globally. For instance, in North America, species such as *Fallopia japonica* have posed longstanding questions around presence, spread, and management thresholds (Gillies et al. 2016; Fennell et al. 2018). Argument mapping could provide a consistent framework for handling such contested cases, thereby complimenting existing risk assessment and policy tools across different jurisdictions. The main value of this argument mapping approach lies in its transparency, traceability, and adaptability. It provides a way to structure and weigh individual pieces of evidence. The intention is that this method is incorporated into the RAAT framework (Kumschick et al. 2025) to address situations where the evidence of presence is weak or contested (i.e., medium or low confidence), with decisions being incorporated into South Africa's list of alien taxa (Zengeya et al. 2025). As such, the approach can support evidence-based decision-making for regulatory listings and contribute meaningfully to reporting progress towards Target 6 of the Global Biodiversity Framework (Convention on Biological Diversity 2022).

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Additional information

Conflict of interest

JW was part of the editorial team for the special issue 'Developing lists of alien taxa in the Global South: workflows, protocols, processes, and experiences', but took no part in the peer review and decision-making process for this paper.

Ethical statement

No ethical statement was reported.

Use of AI

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Risk analyses

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Data type: docx

Explanation note: table S1: Alien species listed under South African regulations for which the occurrence status is uncertain; table S2: Generic evidence evaluation table; table S3: Guidance for assigning occurrence status and confidence ratings; table S4: Occurrence assessment outcome and supporting justification; table S5: Evidence evaluation table for *Tetrapygus niger*; table S6: Evidence evaluation table for *Calluna vulgaris*; table S7: Risk Analysis for *Calluna vulgaris*; table S8: Evidence evaluation table for *Euphorbia esula*; table S9: Risk Analysis for *Euphorbia esula*.

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