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The balance of trade in alien species between South Africa and the rest of Africa

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Background: Alien organisms are not only introduced from one biogeographical region to another but also spread within regions. As South Africa shares land borders with six countries, multiple opportunities exist for the transfer of alien species between South Africa and other African countries; however, the direction and importance of intra-regional spread is unclear.

Objectives: The aim of this study was to gain a greater understanding of the introduction of alien species into Africa and the spread of species between South Africa and other African countries.

Method: We developed scenarios that describe the routes by which alien species are introduced to and spread within Africa and present case studies for each. Using data from literature sources and databases, the relative importance of each scenario for alien birds and insect pests of eucalypts was determined, and the direction and importance of intra-regional spread was assessed.

Results: Alien species from many taxonomic groups have, through various routes, been introduced to and spread within Africa. For birds and eucalypt insect pests, the number of species spreading in the region has recently increased, with South Africa being a major recipient of birds (14 species received and 5 donated) and a major donor of eucalypt insect pests (1 species received and 10 donated). For both groups, many introduced species have not yet spread in the region.

Conclusion: The intra-regional spread of alien species in Africa represents an important and possibly increasing threat to biosecurity. To address this threat, we propose a framework that details how African countries could cooperate and develop a coordinated response to alien species introductions.

Introduction

The movement of goods and people around the world is facilitating the introduction of organisms to regions where they are not native. Although many alien organisms are introduced directly from one biogeographical region to another ('inter-regional introduction'), the spread of species within biogeographical regions also contributes to biological invasions ('intra-regional spread') (Chiron, Shirley & Kark 2010; Hurley et al. 2016; Jaksic et al. 2002; Roques et al. 2016 in this article, the biogeographical region of interest is continental Africa). Relatively high propagule pressure [i.e. the number of individuals introduced and the number of introduction events for a specific species (Lockwood, Cassey & Blackburn 2005)] and short geographical distances mean that once an organism has been introduced to a region, further natural or human-aided spread is likely (Garnas et al. 2016; Hurley et al. 2016; Jaksic et al. 2002; Roques et al. 2016). Furthermore, organisms that are native to a biogeographical region might spread within the region, either naturally or with the aid of humans, to areas where they are not native (Chiron et al. 2010).

The intra-regional spread of species is often asymmetrical [i.e. one country donates more species than it receives (Ferus et al. 2015; Jaksic et al. 2002)] and, under some circumstances, introductions through intra-regional spread may be more common than those that occur through inter-regional introduction (Chiron et al. 2010). However, such patterns are the result of historical economic and socio-political processes and so can vary over time (Chiron et al. 2010; Essl et al. 2011; Roques et al. 2016). Furthermore, as properties linked with invasion success (e.g. likelihood of enemy release and propagule pressure) vary across dispersal pathways (e.g. extreme long-distance or leading-edge dispersal; see Wilson et al. 2009), whether an organism is introduced through inter-regional

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introduction or intra-regional spread can have consequences for its invasion success. To develop and improve efforts aimed at preventing or mitigating the introduction of invasive species, it is therefore important to identify the types of introduction within a region and determine their relative importance and direction [also see the Convention on Biological Diversity's Aichi Target 9 (UNEP 2011)].

Many organisms have been directly introduced to South Africa from other continents [e.g. the Sirex woodwasp (*Sirex noctilio*), which is native to Eurasia and northern Africa, was introduced to South Africa from Oceania and South America (Boissin et al. 2012), and the harlequin ladybird (*Harmonia axyridis*), which is native to Asia, was introduced to South Africa from North America (Lombaert et al. 2010)]. Given that South Africa shares land borders with six other African countries, multiple opportunities exist for species to spread between South Africa and other African countries, either through natural dispersal or with the aid of various human-related transport vectors (e.g. air, sea and land transport vectors). However, the relative importance of inter-regional introduction and intra-regional spread is currently not clear, and whether South Africa is primarily a donor or recipient of alien species is also unknown.

In an effort to gain a greater understanding of the movements of alien species into and within Africa, we aimed to (1) develop introduction route scenarios that describe how alien species might have been introduced to the region and spread between South Africa and elsewhere in Africa; (2) demonstrate these scenarios using case studies; (3) use the scenarios to quantify, for selected groups, the importance and direction of intra-regional spread; (4) determine if these patterns have changed through time; and (5) propose a framework for trans-boundary collaboration in biosecurity that could address the threat posed to Africa by the intra-regional spread of alien species.

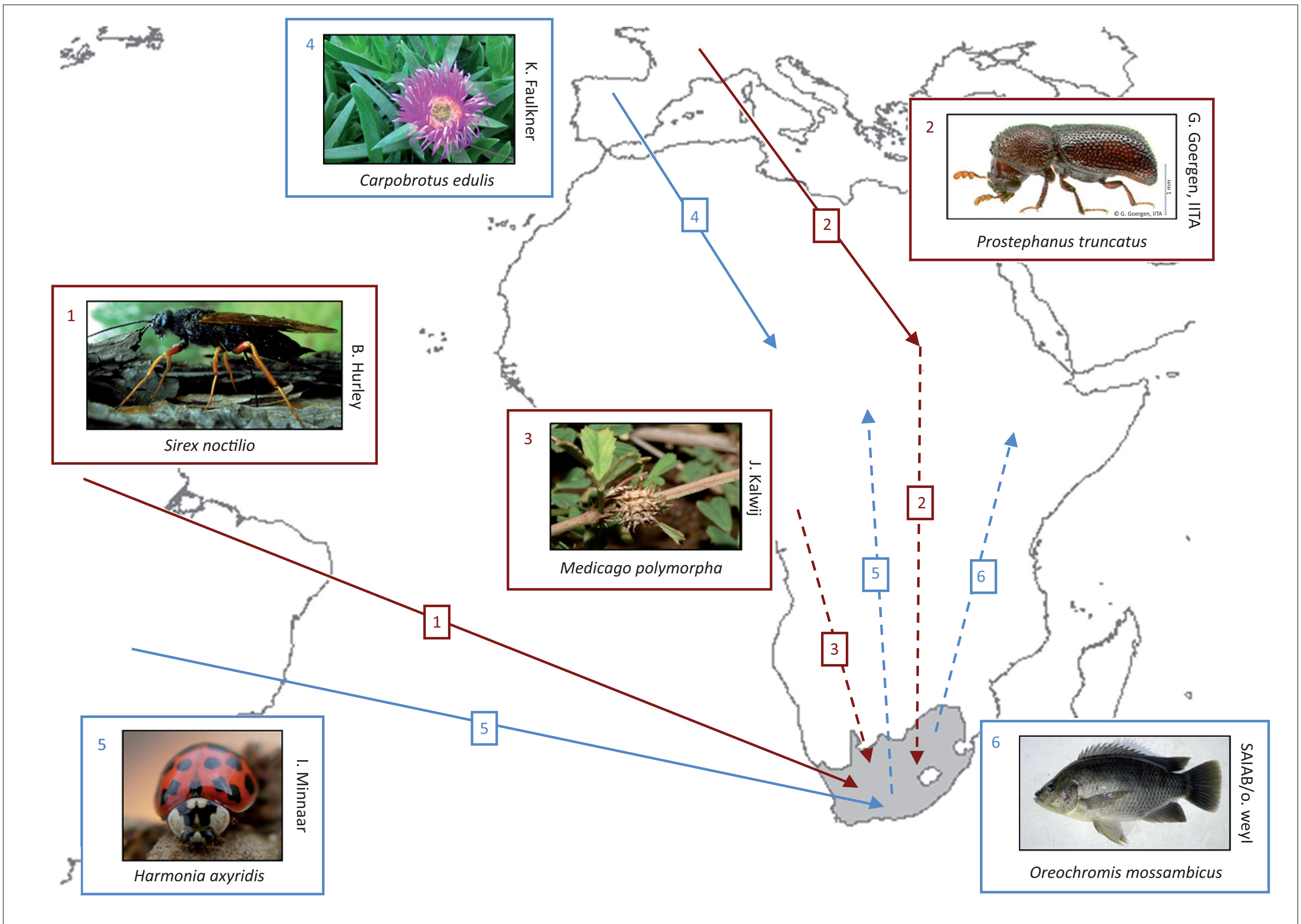
Research method and design

Introduction route scenarios

Six introduction route scenarios that describe how alien species might have been introduced to the region and spread between continental South Africa (SA) and elsewhere in continental Africa (AF) were developed and examples identified. In these scenarios, both natural dispersal and the human-aided movement of species within the continent were considered as intra-regional spread. Furthermore, although introduction and spread through all human-related transport vectors were considered (i.e. land, air and sea transport vectors), these vectors were not discriminated in the scenarios. The scenarios describe introduction routes where species have been introduced to SA or AF from other regions, and consider whether subsequent intra-regional spread between SA and AF occurred. Also described are instances where species that are native to either SA or AF have spread between the subregions to areas where they are not native. Details on the introduction route scenarios and examples of species for each scenario are shown in Figure 1, and the details for each example are provided in Appendix 2, Figure 1-A2 to Figure 6-A2.

Importance of introductions into Africa versus spread within Africa

For alien species in SA and AF, information on their native and introduced range (in Africa and elsewhere in the world), descriptions of introduction and spread as well as introduction data (introduction source, number of introductions, pathway of introduction and date of introduction or first record) were used to categorise species in terms of the most likely introduction route scenario that resulted in introduction. As detailed species-level introduction data are often lacking (Faulkner et al. 2015), we focused on two groups for which these data could be obtained: birds and insect pests of *Eucalyptus* trees (see Tables 1-A1 and 2-A1 for species lists). For birds, data were extracted from South African (i.e. Dean 2000; Peacock, van Rensburg & Robertson 2007; Picker & Griffiths 2011; van Rensburg et al. 2011) and global sources (i.e. CAB International 2016; Lever 1987, 2005; Long 1981). For each eucalypt insect pest in South Africa, date of first record for southern African countries was obtained from Bush et al. (2016), Wingfield et al. (2008) and local authorities, and other data were extracted from South African (i.e. Picker & Griffiths 2011) and global information sources (i.e. CAB International 2016). Re-introductions [e.g. helmeted guineafowl (*Numida meleagris*) in South Africa (Lever 1987; Long 1981)] and extralimital populations [species that have been translocated within the subregion where they are native to parts of that subregion where they are not native; e.g. red-eyed dove (*Streptopelia semitorquata*) in South Africa (Lever 1987; Long 1981)] were not included. For species that have been introduced to the region multiple times, all applicable scenarios were recorded (and therefore the total count of species for the scenarios can be larger than the total number of species investigated). Furthermore, this means that although a species might not have spread between the two subregions, as a result of independent introductions it might still occur in both SA and AF. For some introductions, it was clear which scenario was applicable [e.g. scenario 5 is clearly applicable for the common starling (*Sturnus vulgaris*) which was introduced in the 1800s from the United Kingdom to SA and then spread into neighbouring countries, i.e. AF], but for others this was not the case [e.g. the Indian subspecies of the rose-ringed parakeet (*Psittacula krameri*) was introduced to SA in the 1800s and then later to Egypt (i.e. AF), it is likely that these introductions were independent (i.e. both scenarios 1 and 4 are applicable); however, it is possible that the birds in Egypt came from SA (i.e. scenario 5)]. In an effort to account for this uncertainty, we categorised each introduction according to the most likely scenario (i.e. scenario 5 for *S. vulgaris* and scenarios 1 and 4 for *P. krameri*) and then rated our confidence in each designation as high or low. A high confidence rating was assigned when the scenario was clear (e.g. for *S. vulgaris*), and low confidence was assigned when more than one scenario was possible (e.g. for *P. krameri*). For some species, there were insufficient data to make a designation, for example, the common pigeon (*Columba livia*) is native to parts of North Africa and has also been introduced



Scenario	Notation	Description
1	→ SA -X→ AF	Species were introduced to SA from another biogeographical region and then did not spread to AF.
2	→ AF - -→ SA	Species were introduced to AF from another biogeographical region and then spread into SA.
3	AF - -→ SA	Species that are native to AF spread into SA.
4	→ AF -X→ SA	Species were introduced to AF from another biogeographical region, and then did not spread into SA.
5	→ SA - -→ AF	Species were introduced to SA from another biogeographical region and then spread into AF.
6	SA - -→ FA	Species that are native to SA spread into AF.

South Africa is shown in grey, arrows with solid lines indicate introductions from other biogeographical regions (inter-regional introductions) and arrows with dashed lines indicate spread within the region (intra-regional spread). In dark red are scenarios where SA is the final recipient of the alien species and in light blue are scenarios where AF is the final recipient. Introduction or spread may be facilitated intentionally or unintentionally by humans, or may be as a result of natural dispersal by the organism.

FIGURE 1: Introduction route scenarios (indicated using numbers) for alien species in South Africa (SA) and in other parts of Africa (AF), and examples of species which conform to each scenario.

widely on the continent; however, details are imprecise for many of these introductions and thus multiple, equally likely scenarios are possible (Lever 2005). These species were recorded as having insufficient data, and they were not assigned an introduction route scenario.

While some of the scenarios involve only inter-regional introductions or intra-regional spread, others involve combinations of the two introduction types (i.e. a species is introduced to AF or SA and also spreads between SA and AF; see Figure 3). Therefore, the results for a number of the scenarios had to be combined to determine the relative importance of the two types of introduction. For instance, to determine the total number of species introduced from another biogeographical region to SA, results for scenarios 1 and 5 had to be combined (Figure 3). However, as the six scenarios provide useful details that are lost when combined (e.g. whether the species is native or alien to the region), we evaluated alien species movements in terms of both the scenarios and the types of introduction.

A generalised linear model (Poisson error distribution and log link) was used to analyse a two-way contingency table of species counts (Crawley 2007) and test the association between organism type (birds and eucalypt insect pests) and scenario. The relative importance of inter-regional introduction and intra-regional spread between SA and AF was assessed by calculating the number of bird and eucalypt insect pest species directly introduced from another region to SA (sum of the counts for scenarios 1 and 5) and AF (sum of the counts for scenarios 2 and

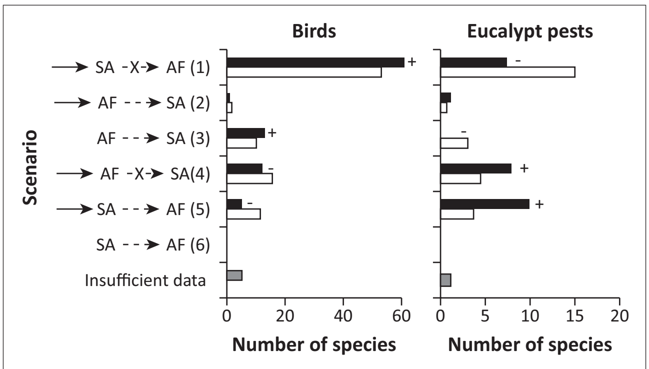
4), and the number of species that spread into SA from AF (sum of the counts for scenarios 2 and 3) and vice versa (sum of the counts for scenarios 5 and 6). A generalised linear model (Poisson error distribution and log link) was used to analyse a three-way contingency table of species counts and test the association between organism type (birds and eucalypt insect pests), recipient subregion (SA and AF) and introduction type (inter-regional introduction and intra-regional spread). To evaluate whether the relative importance of inter-regional introduction and intra-regional spread has varied over time, date of introduction or first record data were used to designate introductions into 50-year time periods, and for each period, the number of birds and eucalypt insect pests introduced to SA and AF through inter-regional introduction and intra-regional spread was determined. All generalised linear models were checked for overdispersion (Crawley 2007; Zuur et al. 2009), but no instances were noted. Counts that were significantly different from what might be expected based on chance alone were identified by calculating the standardised adjusted residuals and comparing these values to the critical values of the normal distribution (Bewick, Cheek & Ball 2004; Everitt 1977). In an effort to determine the influence of uncertainty on results, analyses were performed twice: using all the data and using a subset with only designations made with high certainty.

Results

Importance of introductions into Africa versus spread within Africa

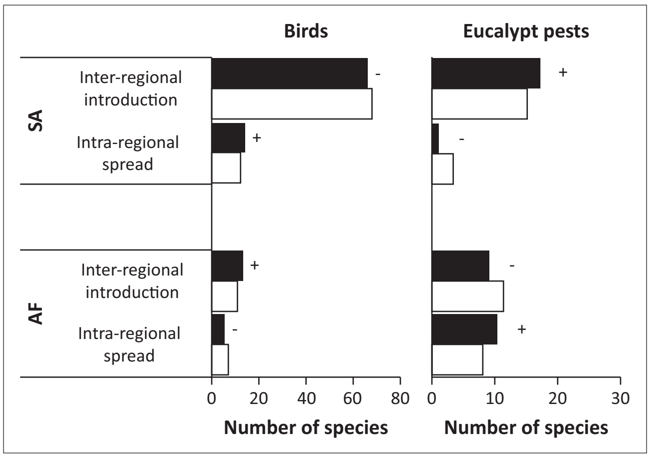
Birds and eucalypt insect pests have been introduced through various introduction routes (Tables 3-A1 and 4-A1), but different scenarios were common for the two groups (significant association between scenario and organism type: χ^2 = 30.6, *d.f.* = 5, $p < 0.001$). Many bird species that have been introduced to SA from another biogeographical region did not spread to AF (scenario 1, see Figure 2); however, four of these species have been independently introduced to AF (scenario 4). While the number of bird species for which scenario 1 was applicable was significantly higher than expected by chance, so too was the number of bird species that are native to AF that spread into SA (scenario 3, see Figure 2). For eucalypt insect pests, most species, and a significantly higher number than expected, were introduced to SA from another region and then subsequently spread into AF (scenario 5, see Figure 2). A significantly higher number of eucalypt insect pests than expected by chance were also directly introduced to AF from another region and then did not spread into SA (scenario 4, see Figure 2). However, all of these species have also been introduced to SA (scenario 1). Multiple scenarios were applicable for eight bird and eight eucalypt insect pest species. There were few instances of insufficient data (3% for birds and 4% for eucalypt insect pests, see Figure 2). For birds, 68% of the scenario designations were made with high certainty, but for eucalypt insect pests, this was only the case for 26% of designations. Consequently, the results of the statistical analysis differed when only scenario designations with high certainty were included (the association between scenario and organism type was no longer significant), but for birds, the identified pattern (i.e. scenario 1 dominated, but for many species scenario 3 was applicable) remained the same (Figure 1-A1).

The relative importance of inter-regional introduction and intra-regional spread differed for birds and eucalypt insect pests and also varied based on the recipient subregion (Figure 3; significant association between introduction type, organism type and recipient subregion: χ^2 = 4.3, *d.f.* = 1, p = 0.04). Based on the species for which the date of introduction data were available (75% for birds and 89% for eucalypt insect pests), it appears that for alien birds and eucalypt insect pests in SA and AF, the relative importance of inter-regional introduction and intra-regional spread changed over time (Figure 4). Although most alien bird species in SA were introduced from other regions, this number was significantly lower than expected by chance, and the number that spread from AF into SA was significantly higher than expected (Figure 3). Additionally, since 2000, more species have spread from AF to SA than have been introduced from other regions (Figure 4). For eucalypt insect pests in SA, a significantly higher number than expected have been introduced from other regions (Figure 3), but since



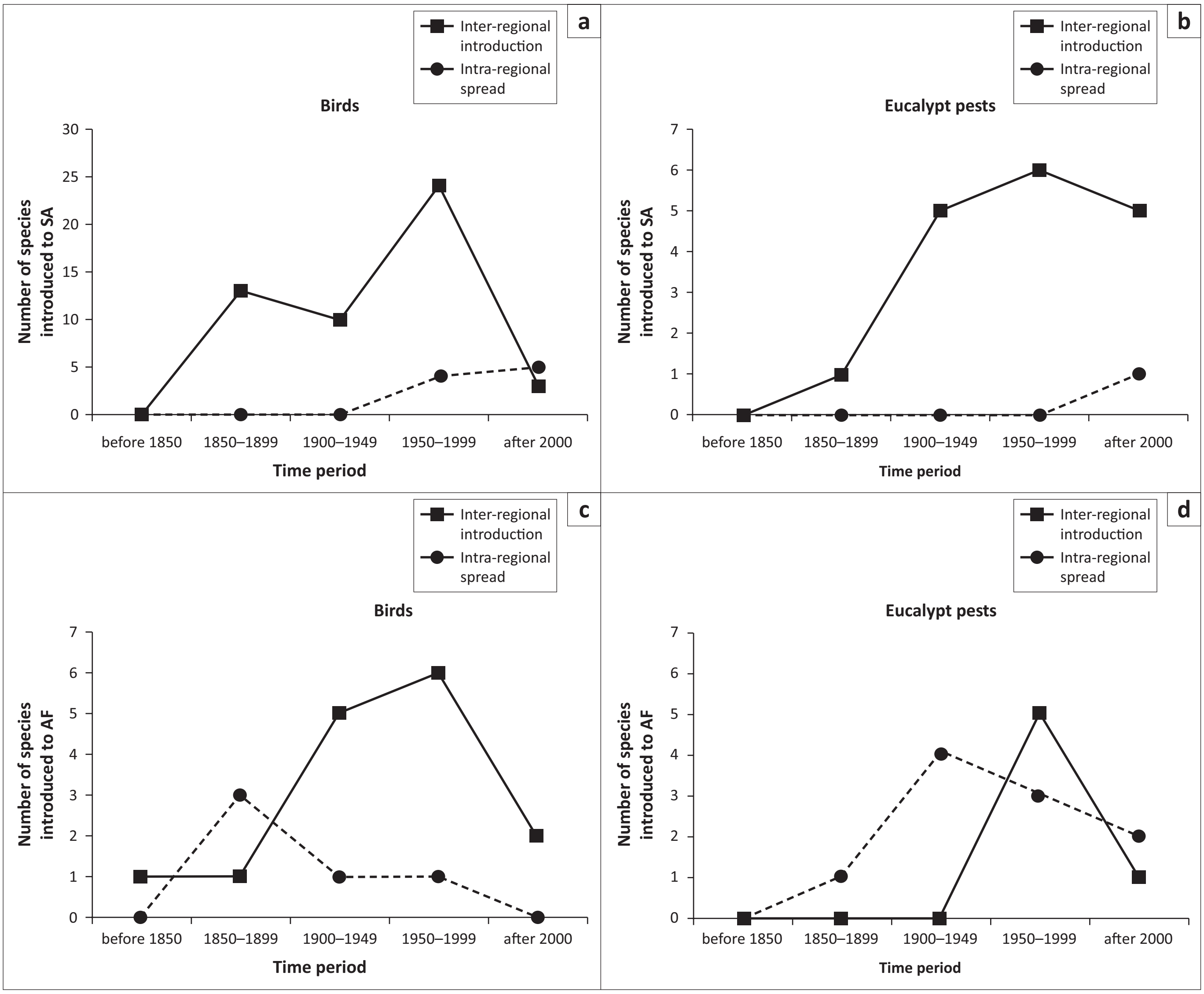
Details of the scenarios are provided in Figure 1. In white are the expected values for each scenario. Species with insufficient data (shown in grey) were not included in the statistical analysis. Plus and minus signs indicate species counts that were significantly higher or lower than what was expected by chance.

FIGURE 2: The number of alien bird and eucalypt insect pest species for which each introduction route scenario was applicable (in black).



Expected values are shown in white. Plus and minus signs indicate numbers of species that were significantly higher or lower than what was expected by chance. Although the observed and expected values did not differ greatly, these differences were significant.

FIGURE 3: The number of alien bird and eucalypt insect pest species (in black) in South Africa (SA) and elsewhere in Africa (AF) that were introduced through a direct introduction from another region (inter-regional introduction) or through spread between the two subregions (intra-regional spread).



Please note the differing scales of the y-axes.

FIGURE 4: Temporal changes in the number of alien bird and eucalypt insect pest species in South Africa (a and b) and elsewhere in Africa (c and d) that were introduced through a direct introduction from another region (inter-regional introduction) or through spread between the two subregions (intra-regional spread).

2000, one species has also spread from AF to SA (Figure 4). A significantly higher number of bird species were introduced from other regions to AF than was expected (Figure 3), with this number being higher, for all time periods since 1900, than the number that have spread from SA into AF (Figure 4). The number of eucalypt insect pests that spread from SA to AF was significantly higher than that expected by chance (Figure 3), with more species spreading from SA to AF since 2000 than the number introduced from other regions (Figure 4). In the spread of alien species between SA and AF, SA was the major recipient of birds but the major donor of eucalypt insect pests (Figure 3). When only designations with high certainty were included in the analysis, the statistical results changed (the association between introduction type, organism type and recipient subregion was no longer significant), but the identified patterns were the same (i.e. most birds and eucalypt insect pests in SA and birds in AF were inter-regional introductions, but most eucalypt insect pests in AF spread in from SA, and SA was a major recipient of birds but a major donor of eucalypt insect pests; Figure 2-A1).

Discussion

The patterns of movement of alien species are often complex (Hurley et al. 2016) and, in line with this, our case studies and results show that alien organisms in Africa have been introduced through various introduction routes (e.g. see Measey et al. 2017 for a discussion on amphibians; and Visser et al. 2017 for grasses). Although many species are introduced to the continent directly from other regions, species are also spreading within Africa, with the relative importance and direction of spread varying across organisms and over time. This poses a challenge to biosecurity that needs to be addressed (see Keller & Kumschick 2017).

Importance of introductions to Africa versus spread within Africa

Many birds and eucalypt insect pests have been introduced to either SA or AF but have not yet spread between the two subregions. Similarly, many alien species in other regions [e.g. plants (Lambdon et al. 2008), birds (Chiron et al. 2010) and insects (Roques et al. 2016) in Europe] have not spread from the country where they were introduced. The spread of these species might be limited by a variety of factors, including the environment and their dispersal capabilities (Roques et al. 2016), but in many cases, it might simply be a matter of time before they spread across national boundaries. Most bird species that were introduced to SA and subsequently spread into AF were introduced over 100 years ago, while those species that have not yet spread tend to have been introduced during or after the 1970s. The future spread of these species likely represents a major invasion debt (Rouget et al. 2016).

Although introductions from other regions dominated in most cases, the spread of species between SA and AF has recently increased in importance. This trend might be driven by recent growth in trade between these two subregions (Figure 3-A1). The link between socio-economic factors and the introduction and spread of alien species is well documented (Essl et al. 2011) and, for example, political and economic changes in Europe (e.g. the cold war and the later opening of borders to movement and trade) have influenced the spread of alien bird and insect species in the region (Chiron et al. 2010; Roques et al. 2016).

South Africa is one of a few countries that serve as major introduction points for eucalypt insect pests (Hurley et al. 2016). Additionally, South Africa currently exports more goods to other African countries than it imports (Figure 4-A1). Thus, it is not surprising that South Africa appears to be a major donor in the intra-regional spread of eucalypt insect pests. Contrary to the dominant direction of trade, South Africa is the major recipient in the intra-regional spread of birds. However, as birds are often introduced intentionally, their movement patterns might be less likely than those of eucalypt insect pests (usually introduced accidentally), to reflect coarse trends in trade (but, see Seebens et al. 2015 for predictors of global flows of naturalised plants).

The results discussed above are based on only two groups for which some historical data could be obtained. Because of data quality issues, using historical data to determine the introduction routes of alien species can lead to imprecise inferences (for information on genetic techniques, see Estoup & Guillemaud 2010). For example, countries differ with regard to their surveillance and monitoring activities (Latombe et al. in press), and as a consequence, species that have been recorded in South Africa first might not have been introduced directly from another region, but might instead have spread into the country from elsewhere in Africa where their introduction was not detected. To get an indication of how data quality impacted our results, we conducted the analysis on the full dataset and on a subset in which we had high confidence. Although the results of these analyses differed, the overall conclusions were the same (i.e. that inter-regional introductions dominate but that intra-regional spread is important, and that South Africa is a major donor for eucalypt insect pests but a major recipient for birds). Furthermore, by focusing on birds and eucalypt insect pests, we were able to highlight that organisms are being introduced to and are spreading within Africa, a pattern which, we show using our case studies, is true for a wide variety of organisms.

Intra-African spread as a biosecurity threat

Although inter-regional introductions and intra-regional spread may, in general, be increasing as a result of increased global travel and trade (Hurley et al. 2016), an increase in the number of species spreading within Africa (as shown here for birds and eucalypt insect pests) might pose a particularly high biosecurity threat. Shorter geographical distances, and higher propagule pressure and environmental similarity mean that the chances of naturalisation might be higher for species spreading within a region than for those introduced directly from other regions (van Kleunen et al. 2015). In keeping with this, for many regions (including Africa), a higher number of plant species than expected are native to a part of the region but have been introduced to and have become naturalised in other parts of the region where they are not native (van Kleunen et al. 2015). Furthermore, as many alien species present in Africa may still establish and spread (i.e. establishment and spread debt, see Rouget et al. 2016), it is likely that the biosecurity threat posed by intra-African spread will continue to increase.

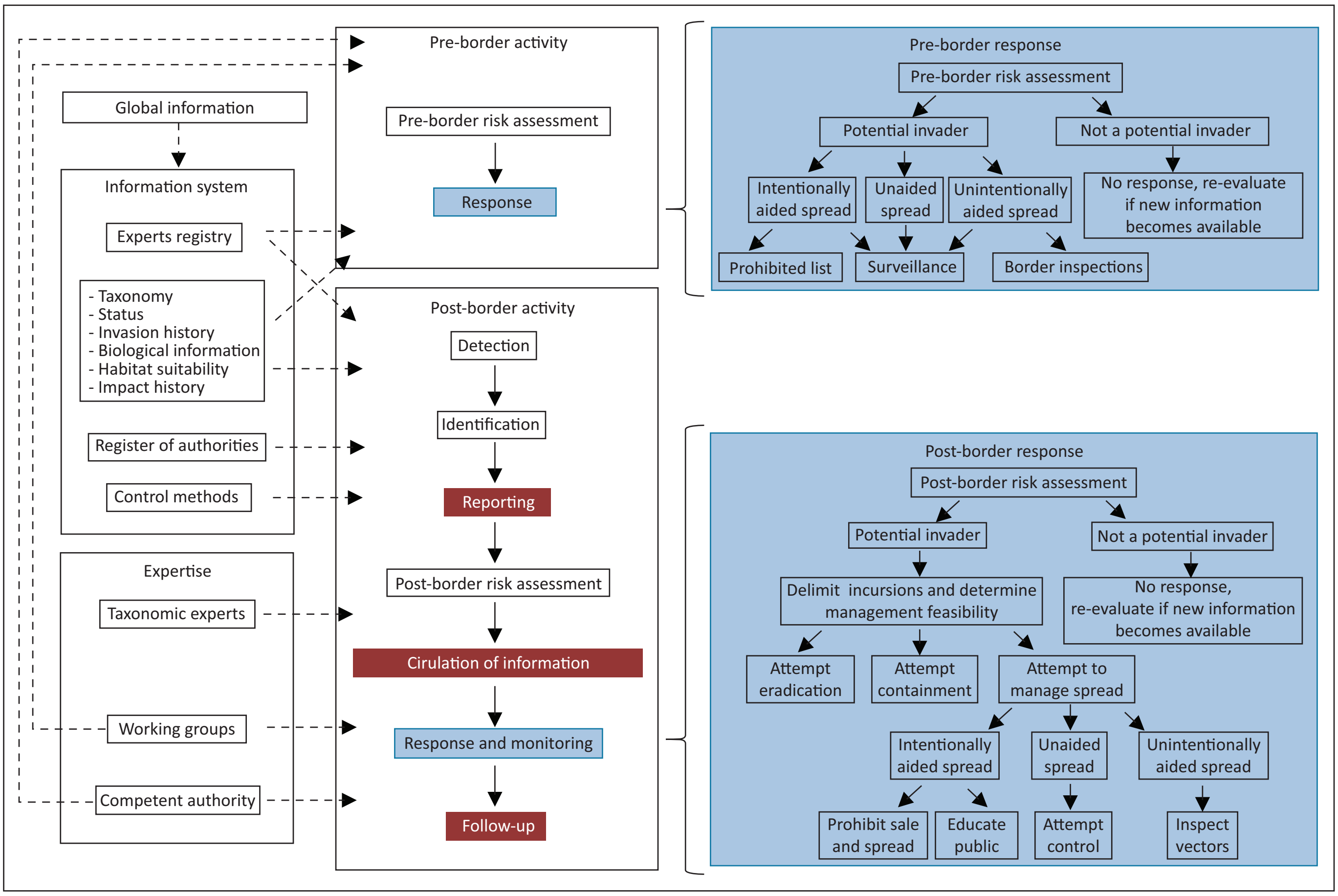
The increasing number of species that have spread between South Africa and the rest of Africa highlights that current efforts in South Africa to prevent or reduce introductions from other African countries are likely insufficient. This potential weakness in South Africa's biosecurity deserves consideration in the first National Status Report on Biological Invasions, and in any future plans to manage South Africa's pathways of introduction (Wilson et al. 2017).

Unfortunately, preventing intra-regional spread is particularly difficult. Organisms from outside Africa can only be transported directly to South Africa by air or sea, and thus to prevent their introduction, border control only needs to be implemented at 18 official ports of entry (Table 1). In contrast, species in Africa can spread into South Africa through natural dispersal or with the aid of land, sea or air

TABLE 1: The modes of transportation, the types of introduction they could facilitate, the number of ports of entry for South Africa and the relative ease of managing introductions.

Mode of transport	Type of introduction	Ports of entry	Management ease
Sea	Intra-regional spread and inter-regional introduction	8	High
Air	Intra-regional spread and inter-regional introduction	10	Medium
Land	Intra-regional spread	54	Low
Natural dispersal	Intra-regional spread	Anywhere along the 4862-km-long land border	Extremely low

Only ports of entry where individuals may officially enter or exit the country were considered. Details on the ports of entry were obtained from the website of the South African Department of Home Affairs.



Source: Based on a framework for Europe (Genovesi et al. 2010)

Pre- and post-border response activities are in light blue, and details of these responses are presented in the light blue boxes, activities involving the sharing of information between countries are in dark red, and all other activities are in white. The stippled arrows demonstrate the type of information and expertise required for pre- or post-border activities.

FIGURE 5: Framework for a coordinated response to alien species introductions in Africa.

transportation (Table 1). Thus, to prevent organisms from spreading into the country, not only does border control need to be implemented at 73 official ports of entry, but South Africa's 4862-km-long land boundary (Central Intelligence Agency 2015) also needs to be managed (Table 1).

To overcome this problem, and better manage biological invasions in the region, a coordinated regional response is needed. Attempts have been made in other regions to achieve this and, for example, the Chilean and Argentinian governments have developed joint research and control programmes for alien mammals (Jaksic et al. 2002), while an early warning and response framework has been developed for Europe (Genovesi et al. 2010). Based on the European system, we have developed a framework, shown in Figure 5, to coordinate the response of African countries to alien species introductions. The framework details the activities that countries should perform before (i.e. pre-border activities) and after (i.e. post-border activities) an alien species is detected; highlights when communication and information sharing between countries is required (e.g. report the detection of an alien species); and details how countries should respond to the introduction of a potential invader based on its type of spread (i.e. unaided or intentionally or unintentionally aided by humans). To achieve these actions, various types of information (e.g. the status of a species and its invasion history) and expertise (e.g. taxonomic experts for identifications) are required. As data availability on alien species varies across countries (McGeoch et al. 2010), we recommend that the required data should be maintained in a regional information system, which is regularly updated and to which information from global databases contributes [e.g. CABI's Invasive Species Compendium and the Global Invasive Species Information Network (GISIN), also see Lucy et al. 2016]. Such a database would improve not only the availability of alien species data but also, if standards are put in place, the quality of the data. Finally, it is unlikely that all of the required expertise will be available in every African country, for example, no country will have taxonomic experts for every taxonomic group (Klopper, Smith & Chikuni 2002). Regional cooperation, particularly in the training of personnel and the exchange of experts, is therefore required. In an effort to achieve this for taxonomy, regional networks [e.g. SABONET (Willis & Huntley 2001), which came to a close in 2005] and international initiatives [e.g. the Global Taxonomy Initiative (Secretariat of the Convention on Biological Diversity 2010)] have already been established.

Conclusion

A wide variety of alien species have been introduced to Africa and have spread within the region, with the movement patterns of these species varying across organisms and over time. Although direct introductions from other regions remain a concern, the number of species spreading within the region appears to be increasing, and these species probably pose a particularly high biosecurity threat. As preventing the intra-African spread of species is at best difficult, African countries need to cooperate and coordinate their responses. Achieving this requires communication, the development and implementation of standardised methods and systems, and political will. As the efficacy of a country's biosecurity greatly influences that of its neighbours, such an endeavour would benefit all of the countries involved.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Author(s) contributions

K.T.F., M.P.R. and J.R.U.W. developed the scenarios. K.T.F. identified the examples. K.T.F. and B.P.H. collected the data. K.T.F. analysed the data. K.T.F., B.P.H., M.P.R., M.R. and J.R.U.W. wrote the manuscript.

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Appendix starts on the next page →

Appendix 1

Table 1-A1: Bird species introduced to South Africa and/or other parts of Africa.

No	Family	Species	Synonym	Common name
1	Alaudidae	*Melanocorypha bimaculata*		Bimaculated lark
2	Anatidae	*Aix galericulata*		Mandarin duck
3	Anatidae	*Aix sponsa*		Wood duck
4	Anatidae	*Anas acuta*		Northern pintail
5	Anatidae	*Anas clypeata*		Northern shoveler
6	Anatidae	*Anas discors*		Blue-winged teal
7	Anatidae	*Anas platyrhynchos*		Mallard
8	Anatidae	*Anas querquedula*		Garnaney
9	Anatidae	*Anas rubripes*	*Anas obscura*	American black duck
10	Anatidae	*Aythya ferina*		Common pochard
11	Anatidae	*Aythya fuligula*		Tufted duck
12	Anatidae	*Aythya nyroca*		Ferruginous duck
13	Anatidae	*Cairina moschata*		Muscovy duck
14	Anatidae	*Callonetta leucophrys*		Ringed teal
15	Anatidae	*Cygnus atratus*		Black swan
16	Anatidae	*Cygnus olor*		Mute swan
17	Anatidae	*Dendrocygna autumnalis*		Black-bellied whistling duck
18	Anatidae	*Netta rufina*		Red-crested pochard
19	Anatidae	*Oxyura jamaicensis*		Ruddy duck
20	Anatidae	*Tadorna tadorna*		European shelduck
21	Cacatuidae	*Cacutua sulphurea*		Yellow-crested cockatoo
22	Cacatuidae	*Nymphicus hollandicus*		Cockatiel
23	Columbidae	*Columba livia*		Common pigeon
24	Columbidae	*Columbina inca*	*Scardafella inca*	Inva dove
25	Columbidae	*Geopelia cuneata*		Diamond dove
26	Columbidae	*Streptopelia decaoto*		Eurasian collared dove
27	Columbidae	*Streptopelia turtur*		European turtle dove
28	Columbidae	*Zenaida macroura*		Mourning dove
29	Coraciidae	*Coracias cyanogaster*		Blue-bellied roller
30	Corvidae	*Corvus frugilegus*		Rook
31	Corvidae	*Corvus monedula*		Jackdaw
32	Corvidae	*Corvus splendens*		House Crow
33	Corvidae	*Dendrocitta vagabunda*		Rufous treepie
34	Emberizidae	*Paroaria coronata*	*Paroaria dominicana*	Red-crested Cardinal
35	Estrildidae	*Amandava amandava*	*Estrilda amandava*	Red Avadavat
36	Estrildidae	*Estrilda melpoda*		Orange-cheeked waxbill
37	Estrildidae	*Euodice cantans*	*Lonchura cantans*	African silverback
38	Estrildidae	*Lonchura oryzivora*	*Padda oryzivora*	Java Sparrow
39	Estrildidae	*Taeniopygia guttata*		Zebra finch
40	Falconidae	*Falco columbarius*		Merlin
41	Fringillidae	*Carduelis carduelis*		Goldfinch
42	Fringillidae	*Fringilla coelebs*		Common chaffinch
43	Leiothrichidae	*Leiothrix argentauris*		Silver-eared mesia
44	Meropidae	*Merops malimbicus*		Rosy beeater
45	Muscicapidae	*Luscinia megarhynchos*		Nightingale
46	Musophagidae	*Crinifer piscator*		Western gray plaintain-eater

Table 1-A1 continues →

Table 1-A1 (Continues): Bird species introduced to South Africa and/or other parts of Africa.

No	Family	Species	Synonym	Common name
47	Musophagidae	*Criniferoides leucogaster*		White-bellied-go-away-bird
48	Musophagidae	*Musophaga violacea*		Violet turaco
49	Passeridae	*Passer domesticus*		House sparrow
50	Phasianidae	*Alectoris chukar*	*Alectoris graeca*	Chukar partridge
51	Phasianidae	*Alectoris melanocephalus*		Arabian chukar
52	Phasianidae	*Chrysolophus pictus*		Golden pheasant
53	Phasianidae	*Colinus virginianus*		Bobwhite quail
54	Phasianidae	*Coturnix chinensis*		Asian blue quail
55	Phasianidae	*Gallus gallus*		Red jungle fowl
56	Phasianidae	*Lophortyx californicus*		California quail
57	Phasianidae	*Lophura nycthemera*		Silver pheasant
58	Phasianidae	*Pavo cristatus*		Common peacock
59	Phasianidae	*Phasianus colchicus*		Common pheasant
60	Ploceidae	*Ploceus nigerrimus*		Vieillot's black weaver
61	Psittacidae	*Agapornis cana*	*Agapornis canus*	Madagascar lovebird
62	Psittacidae	*Amazona aestiva*		Blue-fronted parrot
63	Psittacidae	*Aratinga jandaya*		Jandaya conure
64	Psittacidae	*Aratinga pertinax*		Brown-throated conure
65	Psittacidae	*Aratinga weddellii*		Dusky-headed conure
66	Psittacidae	*Cyanoliseus patagonus*		Patagonian conure
67	Psittacidae	*Forpus passerinus*		Blue-winged parrotlet
68	Psittacidae	*Melopsittacus undulatus*		Budgerigar
69	Psittacidae	*Myiopsitta monachus*		Monk parakeet
70	Psittacidae	*Nandayus nenday*		Black-hooded conure
71	Psittacidae	*Poicephalus rueppellii*		Ruppell's parrot
72	Psittacidae	*Poicephalus rufiventris*		African orange-bellied parrot
73	Psittacidae	*Psittacula krameri*		Rose-ringed parakeet
74	Psittacidae	*Pyrrhura rupicola*		Black-capped conure
75	Psittaculidae	*Psittacula cyanocephala*		Plum-headed parakeet
76	Pycnonotidae	*Pycnonotus jocosus*		Red-whiskered bulbul
77	Rallidae	*Fulica Americana*		American coot
78	Rallidae	*Gallinula comeri*		Gough moorhen
79	Rallidae	*Gallinula nesiotis*		Tristan moorhen
80	Sturnidae	*Acridotheres tristis*		Common myna
81	Sturnidae	*Lamprotornis iris*		Emerald starling
82	Sturnidae	*Lamprotornis purpuropterus*	*Lamprotornis purpuroptera*	Ruppells long-tailed starling
83	Sturnidae	*Lamprotornis superbus*		Superb starling
84	Sturnidae	*Sturnus vulgaris*		Common starling
85	Threskiornithidae	*Eudocimus ruber*		Scarlet ibis
86	Turdidae	*Turdus merula*		Blackbird
87	Turdidae	*Turdus philomelos*		Song thrush

Table 2-A1: Insect pests of *Eucalyptus* trees introduced to South Africa and other parts of Africa.

No	Family	Species	Common name
1	Adelgidae	*Pineus boerneri*	Pine woolly aphid
2	Aphididae	*Cinara cronartii*	Black pine aphid
3	Aphididae	*Eulachnus rileyi*	Pine needle aphid
4	Cerambycidae	*Phoracantha recurva*	Eucalyptus longhorn beetle
5	Cerambycidae	*Phoracantha semipunctata*	Eucalyptus longhorn beetle
6	Chrysomelidae	*Trachymela tincticollis*	Eucalyptus tortoise beetle
7	Curculionidae	*Gonipterus scutellatus*	Eucalyptus snout beetle
8	Curculionidae	*Pissodes nemorensis*	Pine weevil
9	Eulophidae	*Leptocybe invasa*	Bluegum chalcid
10	Eulophidae	*Ophelimus maskelli*	Eucalyptus gall wasp
11	Psyllidae	*Blastopyslla occidentalis*	Eucalyptus psyllid
12	Psyllidae	*Ctenarytaina eucalypti*	Bluegum psyllid
13	Psyllidae	*Glycaspis brimblecombei*	Redgum lerp psyllid
14	Psyllidae	*Spondyliaspis c.f. plicatuloides*	Shell lerp psyllid
15	Scolytidae	*Hylastes angustatus*	Pine bark beetle
16	Scolytidae	*Hylurgus ligniperda*	Red-haired pine bark beetle
17	Scolytidae	*Orthotomicus erosus*	Mediterranean pine engraver beetle
18	Siricidae	*Sirex noctilio*	Sirex woodwasp
19	Thaumastocoridae	*Thaumastocoris peregrinus*	Bronze bug

Table 3-A1: Bird species introduced to South Africa and/or other parts of Africa categorised in terms of the most likely introduction route scenario that resulted in introduction, and our confidence in each designation. For some species data were insufficient to make a designation.

Species	Common name	Scenario	Confidence
Cygnus olor	Mute swan	1	High
Lophortyx californicus	California quail	1	High
Gallus gallus	Red jungle fowl	1	High
Agapornis cana	Madagascar Lovebird	1	High
Melopsittacus undulatus	Budgerigar	1	High
Fringilla coelebs	Common Chaffinch	1	High
Paroaria coronata	Red-crested Cardinal	1	High
Pavo cristatus	Common peacock	1	High
Lophura nycthemera	Silver pheasant	1	High
Phasianus colchicus	Common pheasant	1	High
Coturnix chinensis	Asian blue quail	1	High
Dendrocygna autumnalis	Black-bellied whistling duck	1	High
Cygnus atratus	Black swan	1	High
Aix galericulata	Mandarin duck	1	High
Aix sponsa	Wood duck	1	High
Anas discors	Blue-winged teal	1	High
Cacutua sulphurea	Yellow-crested cockatoo	1	High
Nymphicus hollandicus	Cockatiel	1	High
Geopelia cuneata	Diamond dove	1	High
Zenaida macroura	Mourning dove	1	High
Taeniopygia guttata	Zebra finch	1	High
Chrysolophus pictus	Golden pheasant	1	High
Aratinga pertinax	Brown-throated conure	1	High
Nandayus nenday	Black-hooded conure	1	High
Forpus passerinus	Blue-winged parrotlet	1	High
Amazona aestiva	Blue-fronted parrot	1	High
Psittacula cyanocephala	Plum-headed Parakeet	1	High
Pycnonotus jocosus	Red-whiskered bulbul	1	High
Gallinula nesiotis	Tristan moorhen	1	High
Eudocimus ruber	Scarlet ibis	1	High
Tadorna tadorna	European shelduck	1	High
Callonetta leucophrys	Ringed teal	1	High
Anas rubripes	American black duck	1	High
Aythya nyroca	Ferruginous duck	1	High
Columbina inca	Inva dove	1	High
Dendrocitta vagabunda	Rufous treepie	1	High
Leiothrix argentauris	Silver-eared mesia	1	High
Pyrrhura rupicola	Black-capped conure	1	High
Aratinga jandaya	Jandaya conure	1	High
Aratinga weddellii	Dusky-headed conure	1	High
Cyanoliseus patagonus	Patagonian conure	1	High
Fulica Americana	American coot	1	High
Gallinula comeri	Gough moorhen	1	High
Psittacula krameri	Rose-ringed Parakeet	1	Low
Luscinia megarhynchos	Nightingale	1	Low
Turdus merula	Blackbird	1	Low
Turdus philomelos	Song Thrush	1	Low
Amandava amandava	Red Avadavat	1	Low
Lonchura oryzivora	Java Sparrow	1	Low

Table 3-A1 continues on the next page →

Table 3-A1 (Continues): Bird species introduced to South Africa and/or other parts of Africa categorised in terms of the most likely introduction route scenario that resulted in introduction, and our confidence in each designation. For some species data were insufficient to make a designation.

Species	Common name	Scenario	Confidence
Carduelis carduelis	Goldfinch	1	Low
Netta rufina	red-crested Pochard	1	Low
Aythya ferina	Common pochard	1	Low
Aythya fuligula	Tufted duck	1	Low
Cairina moschata	Muscovy duck	1	Low
Corvus frugilegus	Rook	1	Low
Streptopelia decaoto	Eurasian collared dove	1	Low
Melanocorypha bimaculata	Bimaculated lark	1	Low
Falco columbarius	Merlin	1	Low
Anas clypeata	Northern shoveler	1	Low
Anas acuta	Northern pintail	1	Low
Anas querquedula	Garnaney	1	Low
Corvus splendens	House Crow	2	High
Coracias cyanogaster	Blue-bellied roller	3	High
Criniferoides leucogaster	White-bellied-go-away-bird	3	High
Crinifer piscator	Western gray plaintain-eater	3	High
Musophaga violacea	Violet turaco	3	High
Ploceus nigerrimus	Vieillot's black weaver	3	Hig h
Poicephalus rufiventris	African orange-bellied parrot	3	High
Poicephalus rueppellii	Ruppell's parrot	3	High
Lamprotornis iris	Emerald starling	3	High
Lamprotornis purpuropterus	Ruppells long-tailed starling	3	High
Lamprotornis superbus	Superb starling	3	High
Merops malimbicus	Rosy beeater	3	High
Estrilda melpoda	Orange-cheeked waxbill	3	Low
Euodice cantans	African silverback	3	Low
Alectoris melanocephalus	Arabian Chukar	4	High
Corvus splendens	House Crow	4	High
Corvus monedula	Jackdaw	4	High
Passer domesticus	House Sparrow	4	High
Lonchura oryzivora	Java Sparrow	4	High
Oxyura jamaicensis	Ruddy duck	4	High
Myiopsitta monachus	Monk parakeet	4	High
Anas platyrhynchos	Mallard	4	Low
Psittacula krameri	Rose-ringed Parakeet	4	Low
Acridotheres tristis	Common Myna	4	Low
Amandava amandava	Red Avadavat	4	Low
Cairina moschata	Muscovy duck	4	Low
Sturnus vulgaris	Common starling	5	High
Acridotheres tristis	Common Myna	5	High
Passer domesticus	House Sparrow	5	High
Anas platyrhynchos	Mallard	5	Low
Alectoris chukar	Chukar partridge	5	Low
Colinus virginianus	Bobwhite quail	Insufficient data	
Columba livia	Common pigeon	Insufficient data	
Streptopelia turtur	European turtle dove	Insufficient data	

Table 4-A1: Insect pests of *Eucalyptus* trees introduced to South Africa and other parts of Africa categorised in terms of the most likely introduction route scenario that resulted in introduction, and our confidence in each designation. For some species data were insufficient to make a designation.

Species	Common name	Scenario	Confidence
Pissodes nemorensis	Pine weevil	1	High
Trachymela tincticollis	Eucalyptus tortoise beetle	1	High
Sirex noctilio	Sirex woodwasp	1	High
Spondyliaspis c.f. plicatuloides	Shell lerp psyllid	1	High
Ctenarytaina eucalypti	Bluegum psyllid	1	Low
Blastopyslla occidentalis	Eucalyptus psyllid	1	Low
Ophelimus maskelli	Eucalyptus gall wasp	1	Low
Leptocybe invasa	Bluegum chalcid	2	High
Phoracantha recurva	Eucalyptus longhorn beetle	4	Low
Phoracantha semipunctata	Eucalyptus longhorn beetle	4	Low
Ctenarytaina eucalypti	Bluegum psyllid	4	Low
Cinara cronartii	Black pine aphid	4	Low
Pineus boerneri	Pine woolly aphid	4	Low
Blastopyslla occidentalis	Eucalyptus psyllid	4	Low
Glycaspis brimblecombei	Redgum lerp psyllid	4	Low
Ophelimus maskelli	Eucalyptus gall wasp	4	Low
Gonipterus scutellatus	Eucalyptus snout beetle	5	High
Hylastes angustatus	Pine bark beetle	5	High
Hylurgus ligniperda	Red-haired pine bark beetle	5	Low
Phoracantha recurva	Eucalyptus longhorn beetle	5	Low
Phoracantha semipunctata	Eucalyptus longhorn beetle	5	Low
Orthotomicus erosus	Mediterranean pine engraver beetle	5	Low
Cinara cronartii	Black pine aphid	5	Low
Pineus boerneri	Pine woolly aphid	5	Low
Thaumastocoris peregrinus	Bronze bug	5	Low
Glycaspis brimblecombei	Redgum lerp psyllid	5	Low
Eulachnus rileyi	Pine needle aphid	Insufficient data	

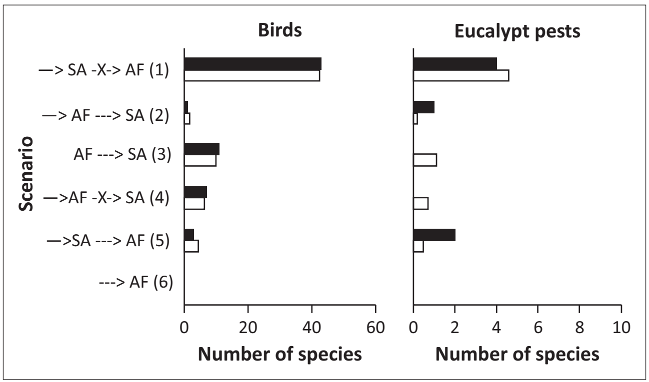


FIGURE 1-A1: The number of alien bird and eucalypt insect pest species for which each introduction route scenario was applicable (in black). Scenario designations with only high certainty were included. Details of the scenarios are provided in Figure 1. Expected values are shown in white. The association between scenario and organism type was not significant: $\chi^2 = 0.06$, *d.f.* = 5, $p = 0.1$.

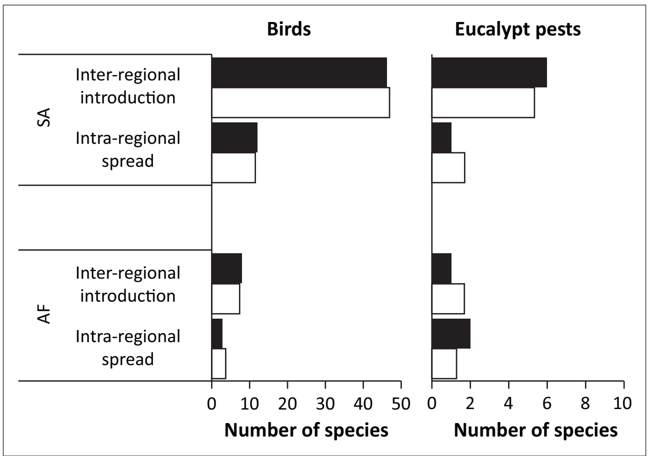


FIGURE 2-A1: The number of alien bird and eucalypt insect pest species (black) in South Africa (SA) and elsewhere in Africa (AF) that were introduced through a direct introduction from another region (inter-regional introduction) or through spread between the two subregions (intra-regional spread). Scenario designations with only high certainty were included and expected values are shown in white. The association between introduction type, organism type and recipient sub-region was not significant: $\chi^2 = 1.5$, *d.f.* = 1, $p = 0.2$.

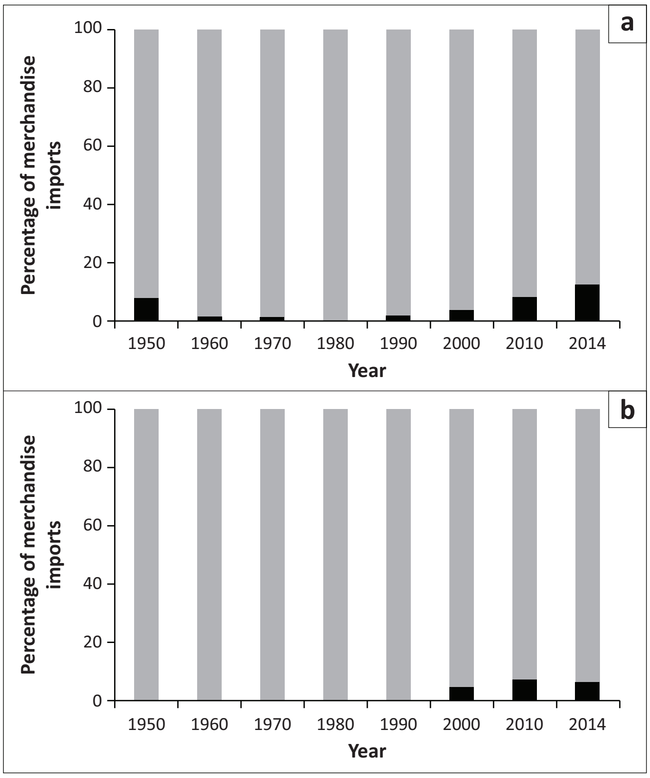


FIGURE 3-A1: Direction of trade statistics from the International Monetary Fund showing temporal changes in the contribution of (a) Africa (black) and other regions (grey) to South African imports and (b) South Africa (black) and other regions (grey) to African imports.

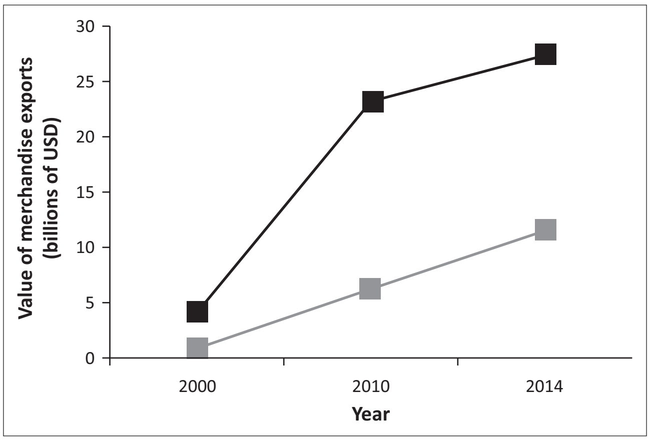
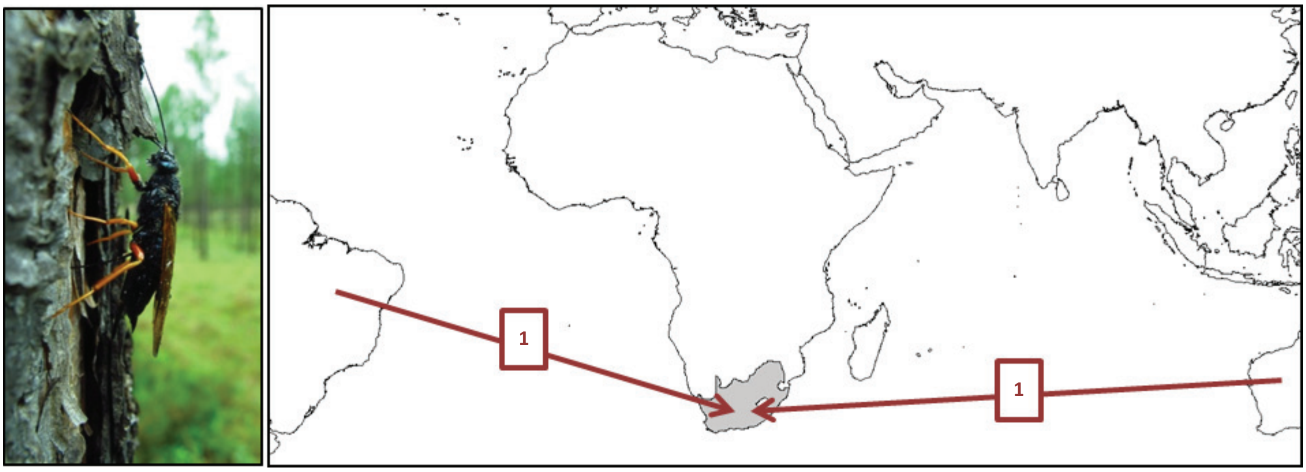


FIGURE 4-A1: Recent temporal changes in the value of merchandise exports from South Africa to elsewhere in Africa (black) and from elsewhere in Africa to South Africa (grey). Data were obtained from the International Monetary Fund.

Appendix 2



Introduction and spread:

The Sirex woodwasp was unintentionally introduced to South Africa and was first recorded as a contaminant of wood imported into Port Elizabeth in 1961 (Taylor 1962). This introduction appears to have failed, but the species was recorded in the Western Cape in 1994, where it subsequently established (Hurley, Slippers & Wingfield 2007; Tribe 1995). Genetic studies have shown that the species was introduced into South Africa from its invaded range in Oceania and South America (Boissin et al. 2012; Slippers et al. 2001, 2002). Since introduction, the wasp has spread throughout South Africa (Hurley et al. 2012; Lantschner et al. 2014). As other parts of Africa (e.g. Zimbabwe, Tanzania, Uganda and Ethiopia) are environmentally suitable for the species, further intra-regional spread is possible (Carnegie et al. 2006).

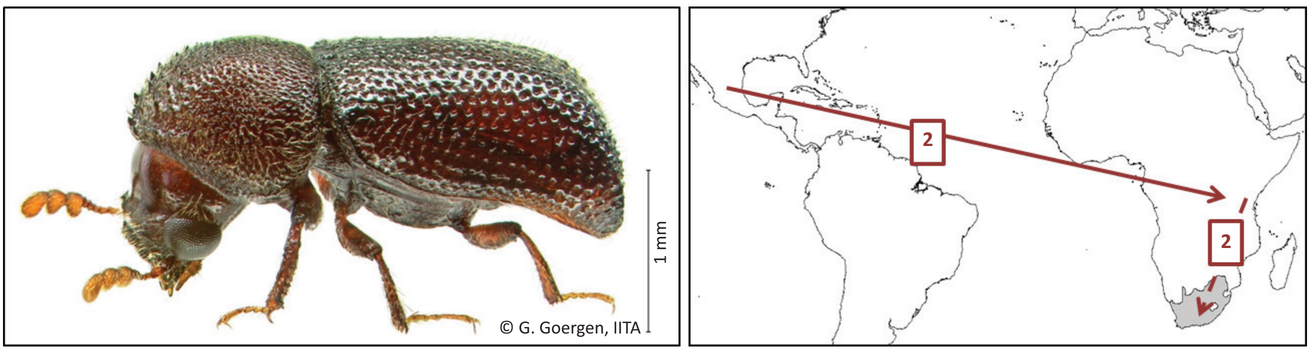
Scenarios and modes of introduction:

The introduction route of *Sirex noctilio* has followed scenario 1; however, if further spread into Africa occurs, scenario 5 will become applicable. The species' initial introductions into South Africa were unintentionally aided by humans and were facilitated by either air or sea transportation. The species has likely spread within South Africa through natural dispersal and has been unintentionally aided by humans through the movement of infested logs and wood-packaging material (Hurley et al. 2012).

Management actions:

A pre-border risk assessment could have been undertaken, and in an effort to prevent the unintentional introduction of this species, surveillance could have been implemented and inspections at sea and air ports employed (see Figure 5). After detecting the species, its invasion potential could have been evaluated using a post-border risk assessment, and its spread in South Africa managed either by eradicating or containing the species or by controlling its spread soon after introduction (Figure 5). It is, however, important to note that despite the release of biological control agents soon after its detection in South Africa, *S. noctilio* continued to spread within the country (Tribe & Cillié 2004). As it would have been difficult to prevent the introduction of this species and manage its spread, contingency plans to manage the species' impact should also have been developed.

FIGURE 1-A2: Details on the introduction and spread of *Sirex noctilio*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.



Introduction and spread:

The large grain borer was introduced to Tanzania (before 1981), Togo (before 1984) and Guinea (before 1987) in three independent introductions, possibly in contaminated maize shipments from Mexico and Central America (Hodges 1986; Muatinte, van den Berg & Santos 2014; Picker & Griffiths 2011). The species dispersed from these points of introduction and, as a contaminant of food products and possibly by flight, spread rapidly from Tanzania to Kenya (1983), Burundi (1984), Rwanda (1993), Malawi (1991), Zambia (1993), Uganda (1997), Namibia (1998), Mozambique (1999), South Africa (1999) and Zimbabwe (2005) (CAB International 2000a; Muatinte et al. 2014; Picker & Griffiths 2011). The beetle was first recorded in South Africa at the north-eastern border of the Kruger National Park and is often intercepted at the South Africa–Zimbabwe and South Africa–Mozambique borders (Muatinte et al. 2014; Picker & Griffiths 2011).

Scenarios and modes of introduction:

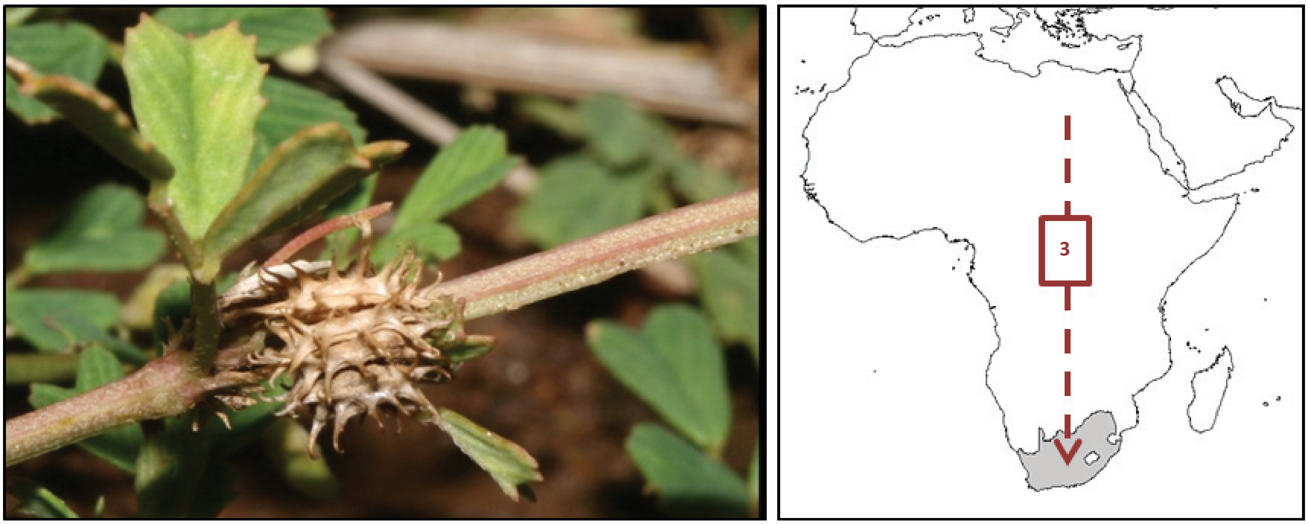
The introduction route of *Prostephanus truncatus* follows scenario 2. The species' initial introductions to Africa were unintentionally aided by humans and were facilitated by either air or sea transportation. The spread of the beetle to South Africa could have been through natural dispersal or was aided by humans through land, air or sea transportation.

Management actions:

Preventing the initial introductions to Africa would have required extensive screening and treatment of food products imported to Africa through sea and air ports (Figure 5). Spread within Africa could have been managed if, following a post-border risk assessment, the species had been eradicated, contained or its spread controlled soon after introduction to Tanzania, and if South Africa and its neighbouring countries had implemented surveillance and inspections at their ports of entry (Figure 5). However, preventing the introduction and spread of this species would have been difficult, and thus some sort of contingency planning to manage impacts should also have been put in place.

FIGURE 2-A2: Details on the introduction and spread of *Prostephanus truncatus*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

J. Kalwij



Introduction and spread:

The bur clova, which is native to much of Eurasia and North Africa, has been unintentionally (transport of spiny seeds) and intentionally (as a fodder plant) introduced to many parts of the world, including to South Africa where this species is now widespread (Bromilow 2010; CAB International 2000b; Small 2011; Wells et al. 1986). Based on historical evidence, it has been suggested that this plant was introduced to South Africa by British immigrants (CAB International 2000b) and that the species has been in South Africa for at least 130 years (Bromilow 2010; Deacon 1986). However, archaeological evidence indicates that the bur clova might have been introduced to South Africa by 760 AD (Deacon 1986). As the burs of this species become entangled in sheep wool, it is possible that the plant was unintentionally introduced along with domesticated sheep by the ancestors of the Khoi (Deacon 1986).

Scenarios and modes of introduction:

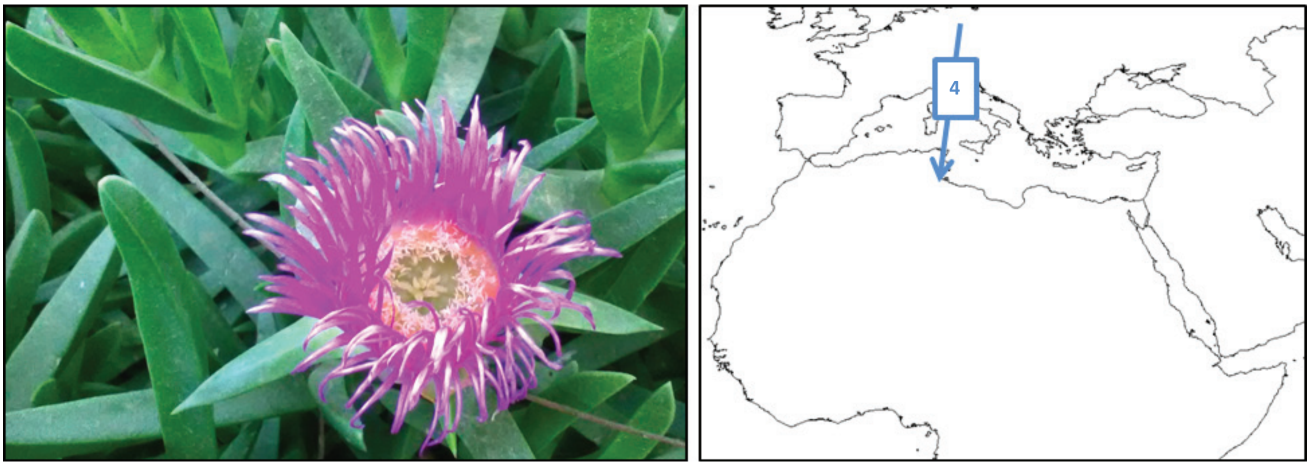
The introduction route of *Medicago polymorpha* follows scenario 3. The spread of the species into South Africa might have been unintentionally aided by humans and was likely facilitated by land transportation.

Management actions:

If the current systems had been in place, a pre-border risk assessment could have been performed and, in an effort to prevent the unintentional spread of this species into South Africa, surveillance could have been implemented and inspections at land border posts employed (Figure 5). However, as it would have been extremely difficult for authorities at border posts to detect the seeds of this species, the impact of the organism could have been managed through contingency plans.

FIGURE 3-A2: Details on the introduction and spread of *Medicago polymorpha*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

K. Faulkner



Introduction and spread:

The sour fig, which is native to South Africa, has been intentionally introduced as an ornamental plant, for ground cover and for erosion control to many parts of the world including Europe and the USA, where the species is invasive (Bourgeois et al. 2005; CAB International 2000c; D'Antonio 1990; Matthews & Brand 2004). The plant has also been introduced to North Africa and was intentionally introduced as seedlings from Europe to Tunisia, where it has established (Brandes 2001; Falleh et al. 2012; Greuter & Domina 2015).

Scenarios and modes of introduction:

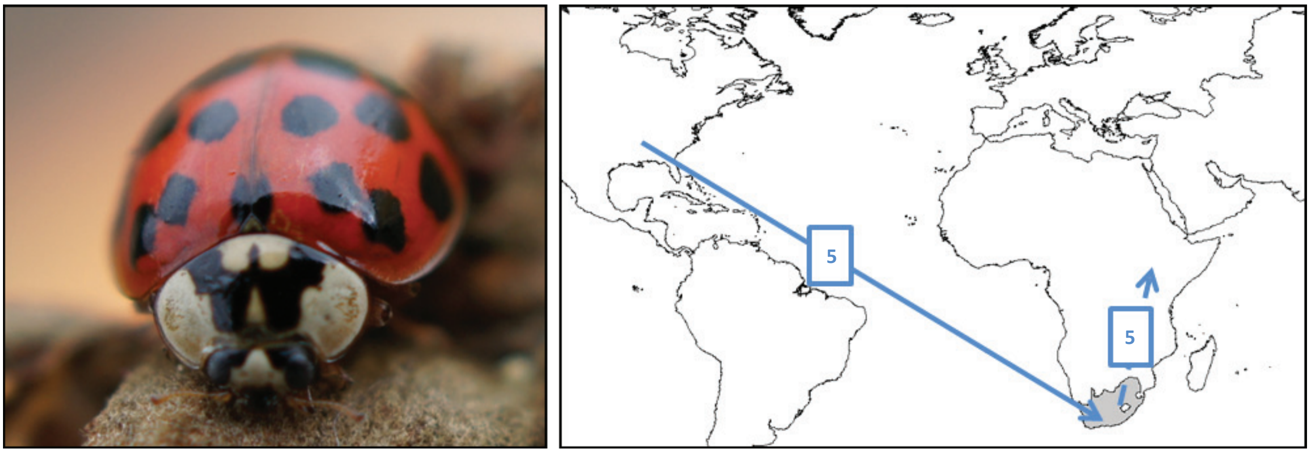
The introduction route of *Carpobrotus edulis* follows scenario 4. The introduction of the species into North Africa was intentionally aided by humans and might have been facilitated by sea or air transportation.

Management actions:

A pre-border risk assessment could have been performed and, in an attempt to prevent the intentional introduction of this speciesinto North Africa, the species could have been added to a prohibited species list and surveillance implemented (Figure 5).

FIGURE 4-A2: Details on the introduction and spread of *Carpobrotus edulis*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

I. Minnaar



Introduction and spread:

Harlequin ladybird individuals, sourced in the USA but originating from Japan, were intentionally introduced to South Africa for biological control in ~1980, but the introduction failed (Roy et al. 2016). However, the beetle appears to have been accidentally introduced from the USA to South Africa (Lombaert et al. 2010), where it was recorded from the Western Cape in 2001 (Stals 2010; Stals & Prinsloo 2007). The species subsequently spread in South Africa and has been recorded in Lesotho (2008) and Swaziland (2013) (Roy et al. 2016; Stals 2010). Elsewhere in Africa, the species was intentionally introduced to Egypt (before 2000) and Tunisia (~1990) and was unintentionally introduced to Kenya (2010) and Zanzibar (2014) (Brown et al. 2011; Roy et al. 2016). The species may spread through natural dispersal, as a contaminant of plant material or as a stowaway on transport vectors (Brown et al. 2011). As much of southern and central Africa are environmentally suitable for the species, further spread is likely (Poutsma et al. 2008).

Scenarios and modes of introduction:

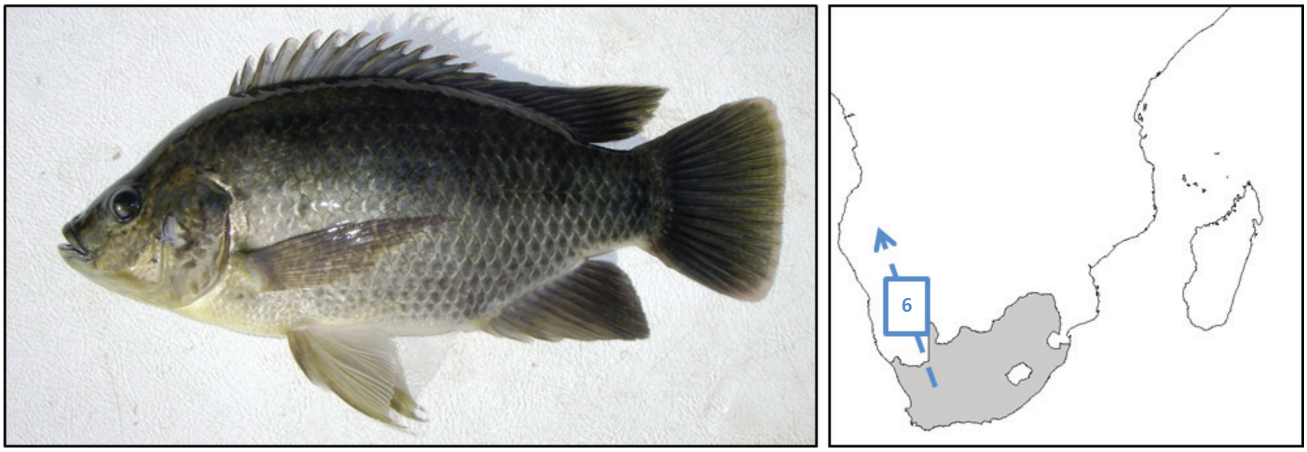
One of the introduction routes of *Harmonia axyridis* follows scenario 5. The species' initial introductions to South Africa were intentionally and unintentionally aided by humans and were facilitated by either air or sea transportation. The spread of the species in South Africa and into other southern African countries might have been through natural dispersal or may have been unintentionally aided by humans through land, air or sea transportation.

Management actions:

In an effort to prevent the unintentional introduction to South Africa, surveillance and inspections at sea and air ports could have been implemented following a pre-border risk assessment (see Figure 5). Following introduction, a post-border risk assessment could have been performed and spread in South Africa managed by either eradicating or containing the species, or controlling its spread soon after introduction. Spread into South Africa's neighbouring countries could have been managed, following a pre-border risk assessment, by implementing surveillance and inspections at ports of entry (Figure 5). As preventing the introduction of this species and controlling its spread would have been difficult [biological control for this species is still under investigation (Kenis et al. 2008)] to limit the impact of this beetle, contingency plans could have been developed.

FIGURE 5-A2: Details on the introduction and spread of *Harmonia axyridis*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

SAIAB/o.weyl



Introduction and spread:

The Mozambique tilapia is native to rivers on the east coast of southern Africa, including those of South Africa (de Moor & Bruton 1988; Picker & Griffiths 2011; Skelton 1993). This fish has been introduced to many parts of the world for biological control (for insects and aquatic weeds) and aquaculture, and as an aquarium or bait fish (Canonico et al. 2005). In South Africa, this species has been intentionally and widely transported for angling and as a fodder fish for bass (de Moor & Bruton 1988; Picker & Griffiths 2011). Consequently, extralimital populations in South Africa now occur inland and in southern and west coastal rivers, as well as in Namibia, where this species is not native (de Moor & Bruton 1988; Picker & Griffiths 2011; Skelton 1993).

Scenarios and modes of introduction:

The introduction route of *Oreochromis mossambicus* follows scenario 6. Spread in South Africa and into Namibia was intentionally aided by humans and was likely facilitated by land transportation.

Management actions:

The spread of this species into Namibia could have been prevented if, following a pre-border risk assessment, the species had been added to a prohibited species list and surveillance for the species had been implemented (Figure 5).

FIGURE 6-A2: Details on the introduction and spread of *Oreochromis mossambicus*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.