




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



Authors:

Katelyn T. Faulkner^{1,2}
 Brett P. Hurley^{3,4} 
 Mark P. Robertson²
 Mathieu Rouget⁵ 
 John R.U. Wilson^{1,6} 

Affiliations:

¹Invasive Species Programme, South African National Biodiversity Institute, Kirstenbosch Research Centre, South Africa

²Centre for Invasion Biology, Department of Zoology and Entomology, University of Pretoria, South Africa

³Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa

⁴Department of Zoology and Entomology, University of Pretoria, South Africa

⁵Centre for Invasion Biology, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, South Africa

⁶Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, South Africa

Corresponding author:

Katelyn Faulkner,
 katelynfaulkner@gmail.com

Dates:

Received: 30 Aug. 2016

Accepted: 01 Dec. 2016

Published: 31 Mar. 2017

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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

How to cite this article: Faulkner, K.T., Hurley, B.P., Robertson, M.P., Rouget, M. & Wilson, J.R.U., 2017, 'The balance of trade in alien species between South Africa and the rest of Africa', *Bothalia* 47(2), a2157. <https://doi.org/10.4102/abc.v47i2.2157>

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Note: This paper was initially delivered at the 43rd Annual Research Symposium on the Management of Biological Invasions in South Africa, Goudini Spa, Western Cape, South Africa on 18-20 May 2016.

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

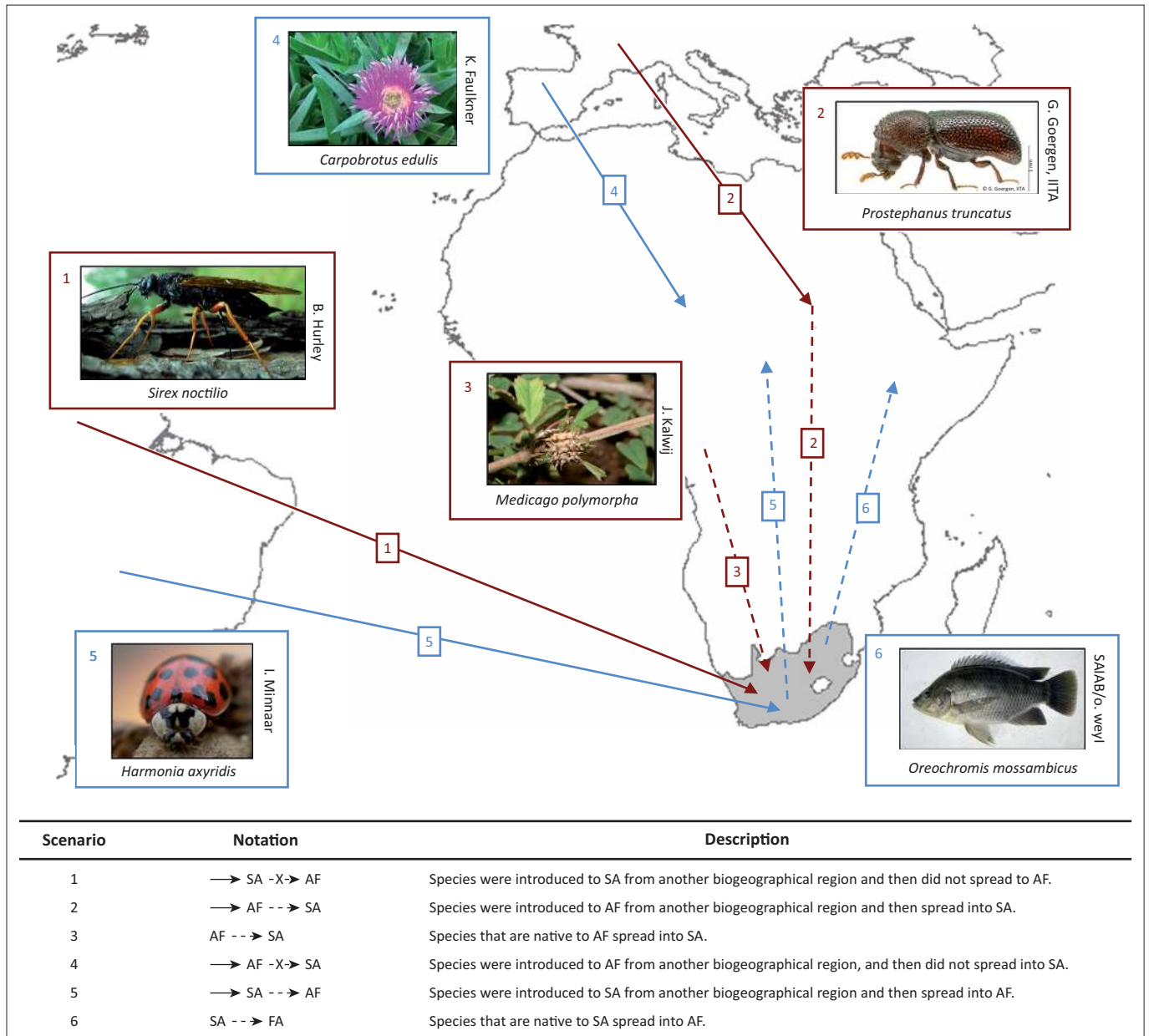
Introduction route scenarios

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 guinea fowl (*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



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.

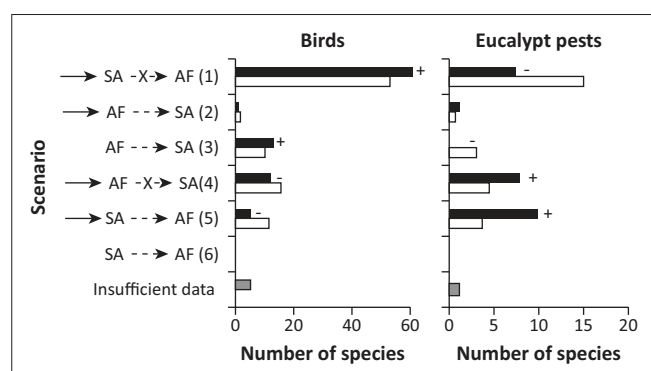
A generalised linear model (Poisson error distribution and log link) was used to analyse a two-way contingency table of species counts (Crawley 2007) and test the association between organism type (birds and eucalypt insect pests) and scenario. The relative importance of inter-regional introduction and 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: $\chi^2 = 30.6$, $d.f. = 5$, $p < 0.001$). 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

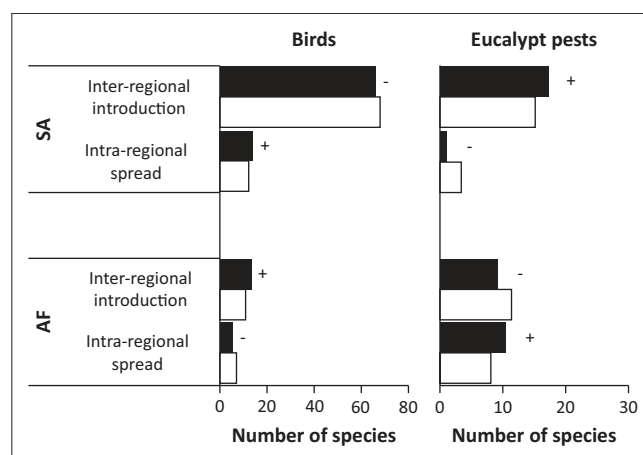


Details of the scenarios are provided in Figure 1. In white are the expected values for each scenario. Species with insufficient data (shown in grey) were not included in the statistical analysis. Plus and minus signs indicate species counts that were significantly higher or lower than what was expected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

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

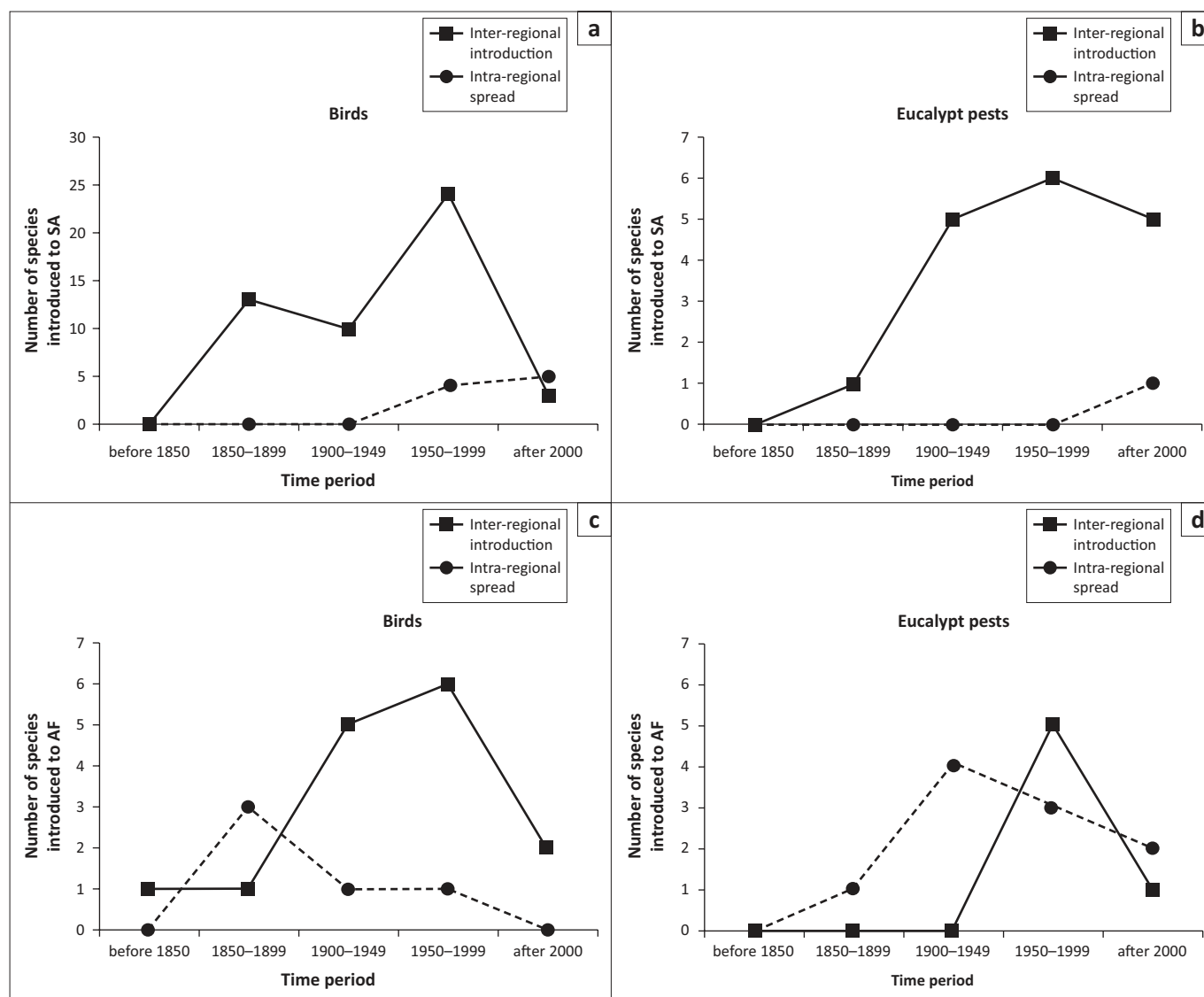
introduced to SA from another region and then subsequently spread into AF (scenario 5, see Figure 2). A significantly higher number of eucalypt insect pests than expected by chance were also directly introduced to AF from another region and then did not spread into SA (scenario 4, see Figure 2). However, 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: $\chi^2 = 4.3$, $d.f. = 1$, $p = 0.04$). 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



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.

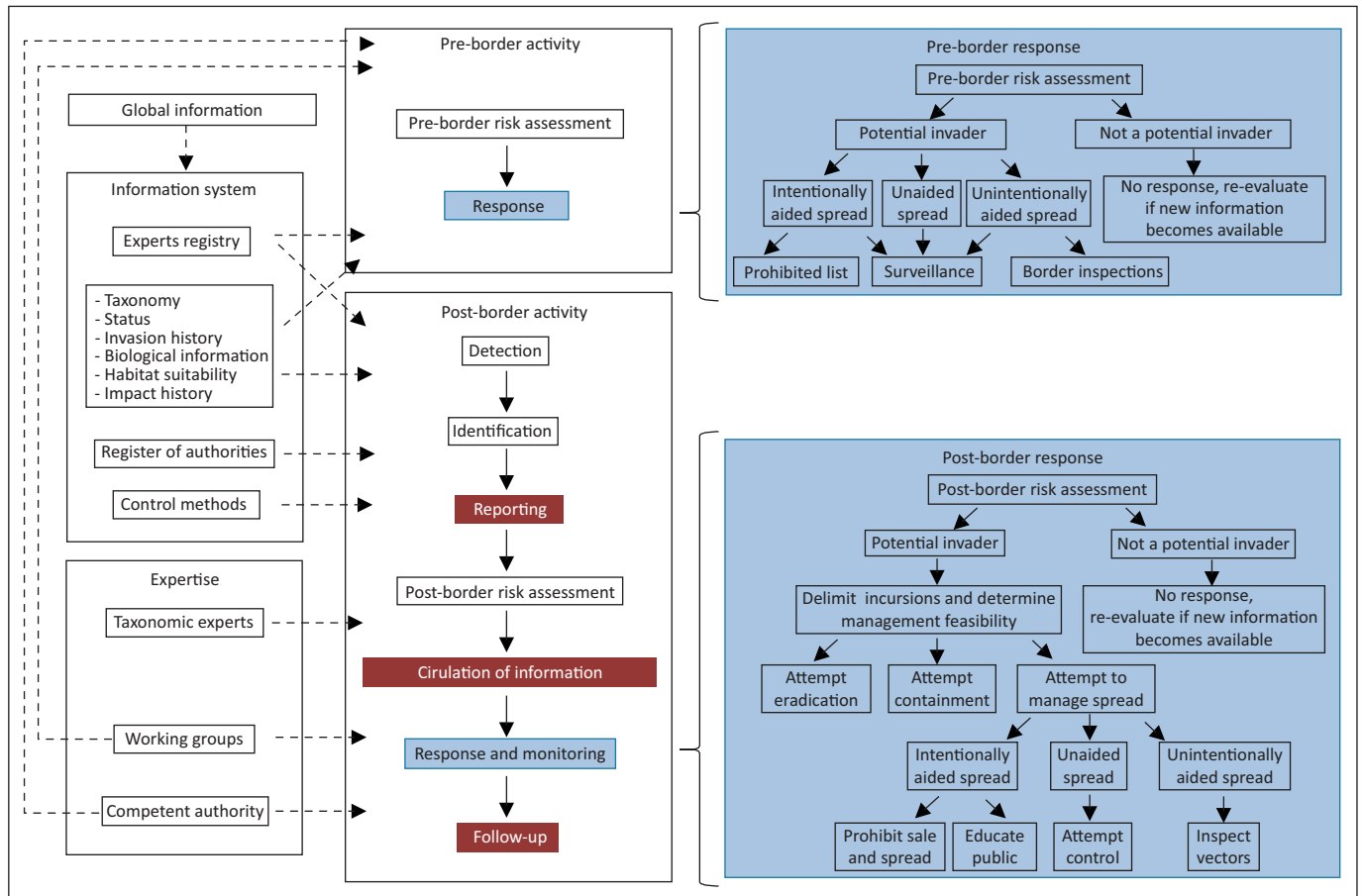
The increasing number of species that have spread between South Africa and the rest of Africa highlights that current efforts in South Africa to prevent or reduce introductions from other African countries are likely insufficient. This potential weakness in South Africa's biosecurity deserves consideration 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.

Acknowledgements

We thank Georg Goergen, Jesse Kalwij, Ingrid Minnaar and Olaf Weyl for providing photos of example species. We also thank Donald Chungu (Copperbelt University, Zambia), Tembani Mduduzi (Forest Research Centre, Zimbabwe), Peter Kiwuso (Forest Research Institute, Uganda), Gerald Meke (FRIM, Malawi) and Eston Mutitu (KEFRI, Kenya) for providing information on the detection date of eucalypt insect pests in their respective countries.

This work was supported by the South African National Department of Environment Affairs through its funding of the South African National Biodiversity Institute's Invasive Species Programme. Additional funding was provided by the DST-NRF Centre for Invasion Biology. M.R. acknowledges funding from the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation of South Africa.

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 1

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

No	Family	Species	Synonym	Common name
1	Alaudidae	<i>Melanocorypha bimaculata</i>		Bimaculated lark
2	Anatidae	<i>Aix galericulata</i>		Mandarin duck
3	Anatidae	<i>Aix sponsa</i>		Wood duck
4	Anatidae	<i>Anas acuta</i>		Northern pintail
5	Anatidae	<i>Anas clypeata</i>		Northern shoveler
6	Anatidae	<i>Anas discors</i>		Blue-winged teal
7	Anatidae	<i>Anas platyrhynchos</i>		Mallard
8	Anatidae	<i>Anas querquedula</i>		Garnaney
9	Anatidae	<i>Anas rubripes</i>	<i>Anas obscura</i>	American black duck
10	Anatidae	<i>Aythya ferina</i>		Common pochard
11	Anatidae	<i>Aythya fuligula</i>		Tufted duck
12	Anatidae	<i>Aythya nyroca</i>		Ferruginous duck
13	Anatidae	<i>Cairina moschata</i>		Muscovy duck
14	Anatidae	<i>Callonetta leucophrys</i>		Ringed teal
15	Anatidae	<i>Cygnus atratus</i>		Black swan
16	Anatidae	<i>Cygnus olor</i>		Mute swan
17	Anatidae	<i>Dendrocygna autumnalis</i>		Black-bellied whistling duck
18	Anatidae	<i>Netta rufina</i>		Red-crested pochard
19	Anatidae	<i>Oxyura jamaicensis</i>		Ruddy duck
20	Anatidae	<i>Tadorna tadorna</i>		European shelduck
21	Cacatuidae	<i>Cacutua sulphurea</i>		Yellow-crested cockatoo
22	Cacatuidae	<i>Nymphicus hollandicus</i>		Cockatiel
23	Columbidae	<i>Columba livia</i>		Common pigeon
24	Columbidae	<i>Columbina inca</i>	<i>Scardafella inca</i>	Inva dove
25	Columbidae	<i>Geopelia cuneata</i>		Diamond dove
26	Columbidae	<i>Streptopelia decaoto</i>		Eurasian collared dove
27	Columbidae	<i>Streptopelia turtur</i>		European turtle dove
28	Columbidae	<i>Zenaida macroura</i>		Mourning dove
29	Coraciidae	<i>Coracias cyanogaster</i>		Blue-bellied roller
30	Corvidae	<i>Corvus frugilegus</i>		Rook
31	Corvidae	<i>Corvus monedula</i>		Jackdaw
32	Corvidae	<i>Corvus splendens</i>		House Crow
33	Corvidae	<i>Dendrocitta vagabunda</i>		Rufous treepie
34	Emberizidae	<i>Paroaria coronata</i>	<i>Paroaria dominicana</i>	Red-crested Cardinal
35	Estrildidae	<i>Amandava amandava</i>	<i>Estrilda amandava</i>	Red Avadavat
36	Estrildidae	<i>Estrilda melpoda</i>		Orange-cheeked waxbill
37	Estrildidae	<i>Euodice cantans</i>	<i>Lonchura cantans</i>	African silverback
38	Estrildidae	<i>Lonchura oryzivora</i>	<i>Padda oryzivora</i>	Java Sparrow
39	Estrildidae	<i>Taeniopygia guttata</i>		Zebra finch
40	Falconidae	<i>Falco columbarius</i>		Merlin
41	Fringillidae	<i>Carduelis carduelis</i>		Goldfinch
42	Fringillidae	<i>Fringilla coelebs</i>		Common chaffinch
43	Leiothrichidae	<i>Leiothrix argenteauris</i>		Silver-eared mesia
44	Meropidae	<i>Merops malimbicus</i>		Rosy beeater
45	Muscicapidae	<i>Luscinia megarhynchos</i>		Nightingale
46	Musophagidae	<i>Crinifer piscator</i>		Western gray plain-tain-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	<i>Criniferoides leucogaster</i>		White-bellied-go-away-bird
48	Musophagidae	<i>Musophaga violacea</i>		Violet turaco
49	Passeridae	<i>Passer domesticus</i>		House sparrow
50	Phasianidae	<i>Alectoris chukar</i>	<i>Alectoris graeca</i>	Chukar partridge
51	Phasianidae	<i>Alectoris melanocephalus</i>		Arabian chukar
52	Phasianidae	<i>Chrysolophus pictus</i>		Golden pheasant
53	Phasianidae	<i>Colinus virginianus</i>		Bobwhite quail
54	Phasianidae	<i>Coturnix chinensis</i>		Asian blue quail
55	Phasianidae	<i>Gallus gallus</i>		Red jungle fowl
56	Phasianidae	<i>Lophortyx californicus</i>		California quail
57	Phasianidae	<i>Lophura nycthemera</i>		Silver pheasant
58	Phasianidae	<i>Pavo cristatus</i>		Common peacock
59	Phasianidae	<i>Phasianus colchicus</i>		Common pheasant
60	Ploceidae	<i>Ploceus nigerrimus</i>		Vieillot's black weaver
61	Psittacidae	<i>Agapornis cana</i>	<i>Agapornis canus</i>	Madagascar lovebird
62	Psittacidae	<i>Amazona aestiva</i>		Blue-fronted parrot
63	Psittacidae	<i>Aratinga jandaya</i>		Jandaya conure
64	Psittacidae	<i>Aratinga pertinax</i>		Brown-throated conure
65	Psittacidae	<i>Aratinga weddellii</i>		Dusky-headed conure
66	Psittacidae	<i>Cyanoliseus patagonus</i>		Patagonian conure
67	Psittacidae	<i>Forpus passerinus</i>		Blue-winged parrotlet
68	Psittacidae	<i>Melopsittacus undulatus</i>		Budgerigar
69	Psittacidae	<i>Myiopsitta monachus</i>		Monk parakeet
70	Psittacidae	<i>Nandayus nenday</i>		Black-hooded conure
71	Psittacidae	<i>Poicephalus rueppellii</i>		Ruppell's parrot
72	Psittacidae	<i>Poicephalus rufiventris</i>		African orange-bellied parrot
73	Psittacidae	<i>Psittacula krameri</i>		Rose-ringed parakeet
74	Psittacidae	<i>Pyrrhura rupicola</i>		Black-capped conure
75	Psittaculidae	<i>Psittacula cyanocephala</i>		Plum-headed parakeet
76	Pycnonotidae	<i>Pycnonotus jocosus</i>		Red-whiskered bulbul
77	Rallidae	<i>Fulica Americana</i>		American coot
78	Rallidae	<i>Gallinula comeri</i>		Gough moorhen
79	Rallidae	<i>Gallinula nesiotis</i>		Tristan moorhen
80	Sturnidae	<i>Acridotheres tristis</i>		Common myna
81	Sturnidae	<i>Lamprotornis iris</i>		Emerald starling
82	Sturnidae	<i>Lamprotornis purpuropterus</i>	<i>Lamprotornis purpuroptera</i>	Ruppells long-tailed starling
83	Sturnidae	<i>Lamprotornis superbus</i>		Superb starling
84	Sturnidae	<i>Sturnus vulgaris</i>		Common starling
85	Threskiornithidae	<i>Eudocimus ruber</i>		Scarlet ibis
86	Turdidae	<i>Turdus merula</i>		Blackbird
87	Turdidae	<i>Turdus philomelos</i>		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	<i>Pineus boernerii</i>	Pine woolly aphid
2	Aphididae	<i>Cinara cronartii</i>	Black pine aphid
3	Aphididae	<i>Eulachnus rileyi</i>	Pine needle aphid
4	Cerambycidae	<i>Phoracantha recurva</i>	Eucalyptus longhorn beetle
5	Cerambycidae	<i>Phoracantha semipunctata</i>	Eucalyptus longhorn beetle
6	Chrysomelidae	<i>Trachymela tincticollis</i>	Eucalyptus tortoise beetle
7	Curculionidae	<i>Gonipterus scutellatus</i>	Eucalyptus snout beetle
8	Curculionidae	<i>Pissodes nemorensis</i>	Pine weevil
9	Eulophidae	<i>Leptocybe invasa</i>	Bluegum chalcid
10	Eulophidae	<i>Ophelimus maskelli</i>	Eucalyptus gall wasp
11	Psyllidae	<i>Blastopsylla occidentalis</i>	Eucalyptus psyllid
12	Psyllidae	<i>Ctenarytaina eucalypti</i>	Bluegum psyllid
13	Psyllidae	<i>Glycaspis brimblecombei</i>	Redgum lerp psyllid
14	Psyllidae	<i>Spondylaspis c.f. plicatulooides</i>	Shell lerp psyllid
15	Scolytidae	<i>Hylastes angustatus</i>	Pine bark beetle
16	Scolytidae	<i>Hylurgus ligniperda</i>	Red-haired pine bark beetle
17	Scolytidae	<i>Orthotomicus erosus</i>	Mediterranean pine engraver beetle
18	Siricidae	<i>Sirex noctilio</i>	Sirex woodwasp
19	Thaumastocoridae	<i>Thaumastocoris peregrinus</i>	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
<i>Cygnus olor</i>	Mute swan	1	High
<i>Lophortyx californicus</i>	California quail	1	High
<i>Gallus gallus</i>	Red jungle fowl	1	High
<i>Agapornis cana</i>	Madagascar Lovebird	1	High
<i>Melopsittacus undulatus</i>	Budgerigar	1	High
<i>Fringilla coelebs</i>	Common Chaffinch	1	High
<i>Paroaria coronata</i>	Red-crested Cardinal	1	High
<i>Pavo cristatus</i>	Common peacock	1	High
<i>Lophura nycthemera</i>	Silver pheasant	1	High
<i>Phasianus colchicus</i>	Common pheasant	1	High
<i>Coturnix chinensis</i>	Asian blue quail	1	High
<i>Dendrocygna autumnalis</i>	Black-bellied whistling duck	1	High
<i>Cygnus atratus</i>	Black swan	1	High
<i>Aix galericulata</i>	Mandarin duck	1	High
<i>Aix sponsa</i>	Wood duck	1	High
<i>Anas discors</i>	Blue-winged teal	1	High
<i>Cacutia sulphurea</i>	Yellow-crested cockatoo	1	High
<i>Nymphicus hollandicus</i>	Cockatiel	1	High
<i>Geopelia cuneata</i>	Diamond dove	1	High
<i>Zenaidura macroura</i>	Mourning dove	1	High
<i>Taeniopygia guttata</i>	Zebra finch	1	High
<i>Chrysolophus pictus</i>	Golden pheasant	1	High
<i>Aratinga pertinax</i>	Brown-throated conure	1	High
<i>Nandayus nenday</i>	Black-hooded conure	1	High
<i>Forpus passerinus</i>	Blue-winged parrotlet	1	High
<i>Amazona aestiva</i>	Blue-fronted parrot	1	High
<i>Psittacula cyanocephala</i>	Plum-headed Parakeet	1	High
<i>Pycnonotus jocosus</i>	Red-whiskered bulbul	1	High
<i>Gallinula nesiotis</i>	Tristan moorhen	1	High
<i>Eudocimus ruber</i>	Scarlet ibis	1	High
<i>Tadorna tadorna</i>	European shelduck	1	High
<i>Callonetta leucophrys</i>	Ringed teal	1	High
<i>Anas rubripes</i>	American black duck	1	High
<i>Aythya nyroca</i>	Ferruginous duck	1	High
<i>Columbina inca</i>	Inva dove	1	High
<i>Dendrocitta vagabunda</i>	Rufous treepie	1	High
<i>Leiothrix argentauris</i>	Silver-eared mesia	1	High
<i>Pyrrhura rupicola</i>	Black-capped conure	1	High
<i>Aratinga jandaya</i>	Jandaya conure	1	High
<i>Aratinga weddellii</i>	Dusky-headed conure	1	High
<i>Cyanoliseus patagonus</i>	Patagonian conure	1	High
<i>Fulica Americana</i>	American coot	1	High
<i>Gallinula comeri</i>	Gough moorhen	1	High
<i>Psittacula krameri</i>	Rose-ringed Parakeet	1	Low
<i>Luscinia megarhynchos</i>	Nightingale	1	Low
<i>Turdus merula</i>	Blackbird	1	Low
<i>Turdus philomelos</i>	Song Thrush	1	Low
<i>Amandava amandava</i>	Red Avadavat	1	Low
<i>Lonchura oryzivora</i>	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
<i>Carduelis carduelis</i>	Goldfinch	1	Low
<i>Netta rufina</i>	red-crested Pochard	1	Low
<i>Aythya ferina</i>	Common pochard	1	Low
<i>Aythya fuligula</i>	Tufted duck	1	Low
<i>Cairina moschata</i>	Muscovy duck	1	Low
<i>Corvus frugilegus</i>	Rook	1	Low
<i>Streptopelia decaocto</i>	Eurasian collared dove	1	Low
<i>Melanocorypha bimaculata</i>	Bimaculated lark	1	Low
<i>Falco columbarius</i>	Merlin	1	Low
<i>Anas clypeata</i>	Northern shoveler	1	Low
<i>Anas acuta</i>	Northern pintail	1	Low
<i>Anas querquedula</i>	Garnaney	1	Low
<i>Corvus splendens</i>	House Crow	2	High
<i>Coracias cyanogaster</i>	Blue-bellied roller	3	High
<i>Criniferoides leucogaster</i>	White-bellied-go-away-bird	3	High
<i>Crinifer piscator</i>	Western gray plain-tain-eater	3	High
<i>Musophaga violacea</i>	Violet turaco	3	High
<i>Ploceus nigerrimus</i>	Viellot's black weaver	3	High
<i>Poicephalus rufiventris</i>	African orange-bellied parrot	3	High
<i>Poicephalus rueppellii</i>	Ruppell's parrot	3	High
<i>Lamprotornis iris</i>	Emerald starling	3	High
<i>Lamprotornis purpuropterus</i>	Ruppells long-tailed starling	3	High
<i>Lamprotornis superbus</i>	Superb starling	3	High
<i>Merops malimbicus</i>	Rosy beeater	3	High
<i>Estrilda melpoda</i>	Orange-cheeked waxbill	3	Low
<i>Euodice cantans</i>	African silverback	3	Low
<i>Alectoris melanocephalus</i>	Arabian Chukar	4	High
<i>Corvus splendens</i>	House Crow	4	High
<i>Corvus monedula</i>	Jackdaw	4	High
<i>Passer domesticus</i>	House Sparrow	4	High
<i>Lanchura oryzivora</i>	Java Sparrow	4	High
<i>Oxyura jamaicensis</i>	Ruddy duck	4	High
<i>Myiopsitta monachus</i>	Monk parakeet	4	High
<i>Anas platyrhynchos</i>	Mallard	4	Low
<i>Psittacula krameri</i>	Rose-ringed Parakeet	4	Low
<i>Acridotheres tristis</i>	Common Myna	4	Low
<i>Amandava amandava</i>	Red Avadavat	4	Low
<i>Cairina moschata</i>	Muscovy duck	4	Low
<i>Sturnus vulgaris</i>	Common starling	5	High
<i>Acridotheres tristis</i>	Common Myna	5	High
<i>Passer domesticus</i>	House Sparrow	5	High
<i>Anas platyrhynchos</i>	Mallard	5	Low
<i>Alectoris chukar</i>	Chukar partridge	5	Low
<i>Colinus virginianus</i>	Bobwhite quail	Insufficient data	
<i>Columba livia</i>	Common pigeon	Insufficient data	
<i>Streptopelia turtur</i>	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
<i>Pissodes nemorensis</i>	Pine weevil	1	High
<i>Trachymela tincticollis</i>	Eucalyptus tortoise beetle	1	High
<i>Sirex noctilio</i>	Sirex woodwasp	1	High
<i>Spodilyaspis c.f. plicatuloides</i>	Shell lerp psyllid	1	High
<i>Ctenarytaina eucalypti</i>	Bluegum psyllid	1	Low
<i>Blastopsylla occidentalis</i>	Eucalyptus psyllid	1	Low
<i>Ophelimus maskelli</i>	Eucalyptus gall wasp	1	Low
<i>Leptocybe invasa</i>	Bluegum chalcid	2	High
<i>Phoracantha recurva</i>	Eucalyptus longhorn beetle	4	Low
<i>Phoracantha semipunctata</i>	Eucalyptus longhorn beetle	4	Low
<i>Ctenarytaina eucalypti</i>	Bluegum psyllid	4	Low
<i>Cinara cronartii</i>	Black pine aphid	4	Low
<i>Pineus boernerii</i>	Pine woolly aphid	4	Low
<i>Blastopsylla occidentalis</i>	Eucalyptus psyllid	4	Low
<i>Glycaspis brimblecombei</i>	Redgum lerp psyllid	4	Low
<i>Ophelimus maskelli</i>	Eucalyptus gall wasp	4	Low
<i>Gonipterus scutellatus</i>	Eucalyptus snout beetle	5	High
<i>Hylastes angustatus</i>	Pine bark beetle	5	High
<i>Hylurgus ligniperda</i>	Red-haired pine bark beetle	5	Low
<i>Phoracantha recurva</i>	Eucalyptus longhorn beetle	5	Low
<i>Phoracantha semipunctata</i>	Eucalyptus longhorn beetle	5	Low
<i>Orthotomicus erosus</i>	Mediterranean pine engraver beetle	5	Low
<i>Cinara cronartii</i>	Black pine aphid	5	Low
<i>Pineus boernerii</i>	Pine woolly aphid	5	Low
<i>Thaumastocoris peregrinus</i>	Bronze bug	5	Low
<i>Glycaspis brimblecombei</i>	Redgum lerp psyllid	5	Low
<i>Eulachnus rileyi</i>	Pine needle aphid	Insufficient data	

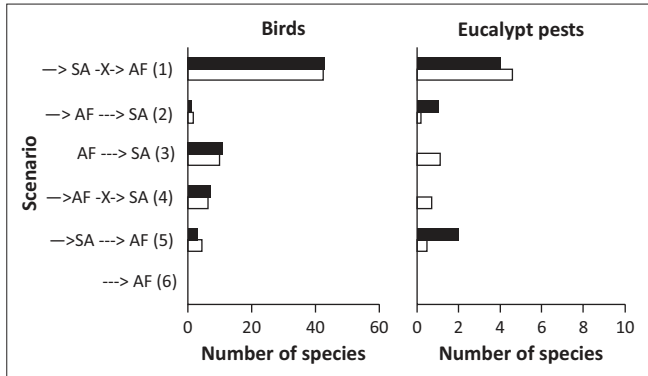


FIGURE 1-A1: The number of alien bird and eucalypt insect pest species for which each introduction route scenario was applicable (in black). Scenario designations with only high certainty were included. Details of the scenarios are provided in Figure 1. Expected values were not significant: $\chi^2 =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

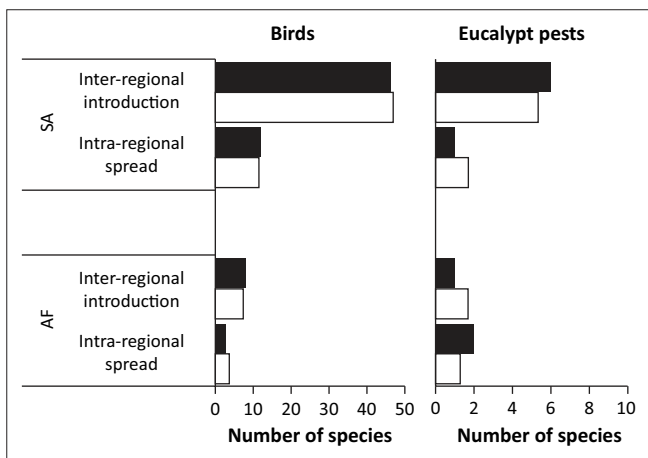


FIGURE 2-A1: The number of alien bird and eucalypt insect pest species (black) in South Africa (SA) and elsewhere in Africa (AF) that were introduced through a direct introduction from another region (inter-regional introduction) or through spread between the two subregions (intra-regional spread). Scenario 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: $\chi^2 = 1.5, df = 1, p = 0.2$.

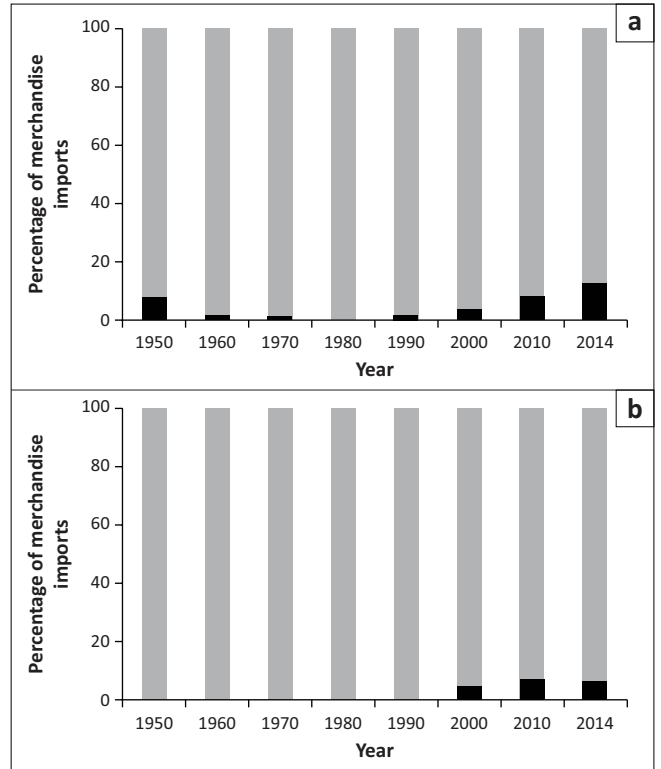


FIGURE 3-A1: Direction of trade statistics from the International Monetary Fund showing temporal changes in the contribution of (a) Africa (black) and other regions (grey) to South African imports and (b) South Africa (black) and other regions (grey) to African imports.

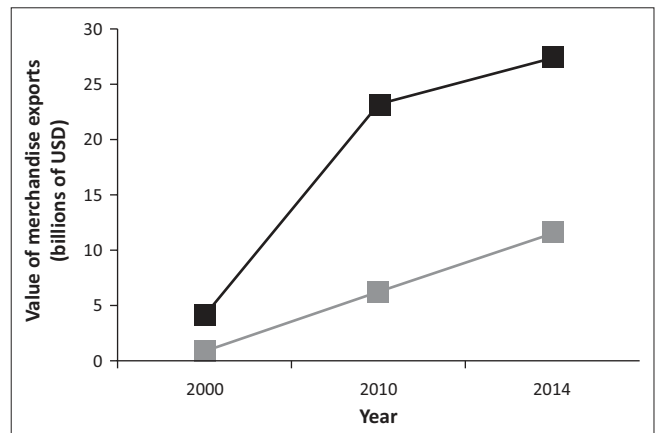


FIGURE 4-A1: Recent temporal changes in the value of merchandise exports from South Africa to elsewhere in Africa (black) and from elsewhere in Africa to South Africa (grey). Data were obtained from the International Monetary Fund.

Appendix 2

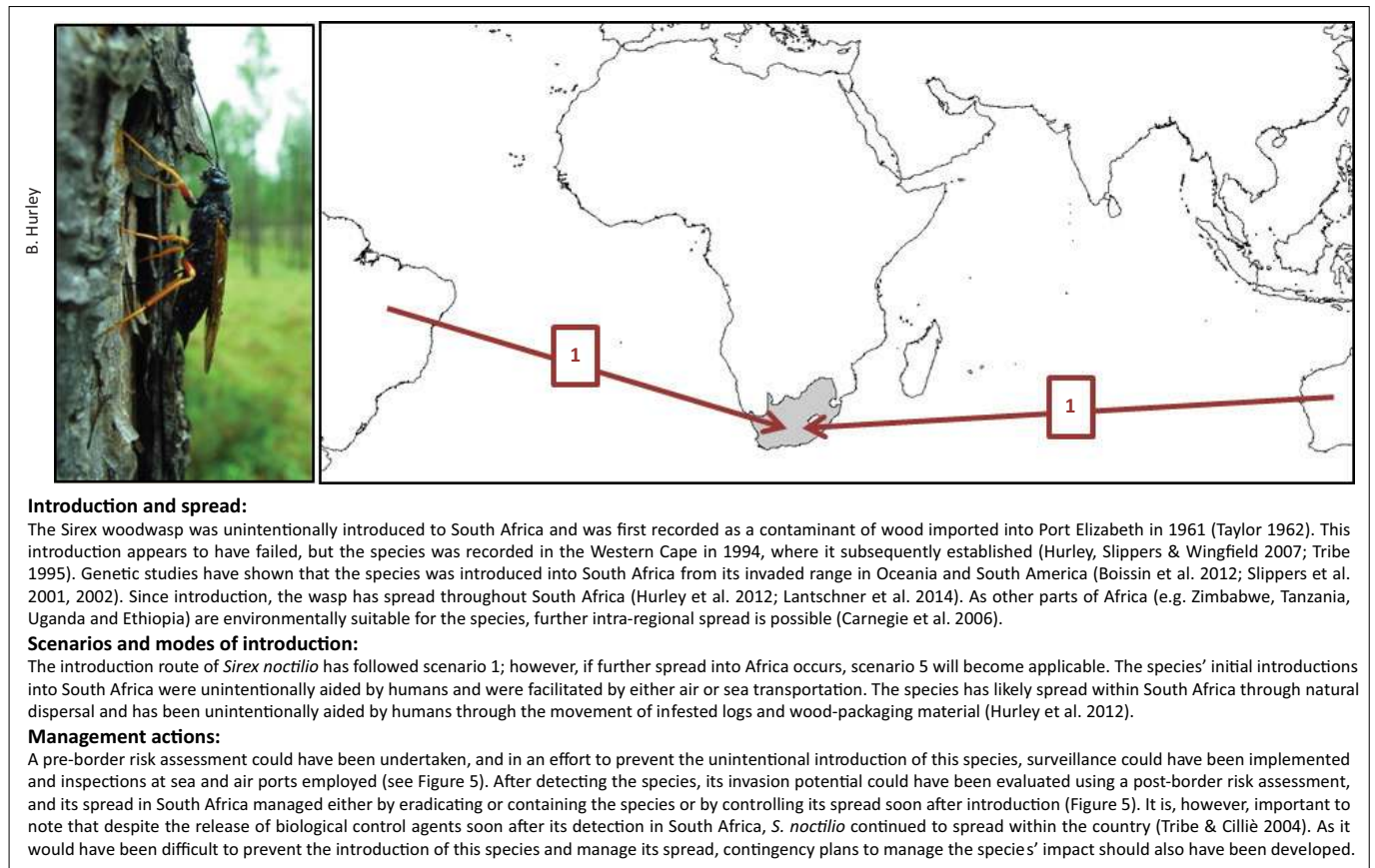


FIGURE 1-A2: Details on the introduction and spread of *Sirex noctilio*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

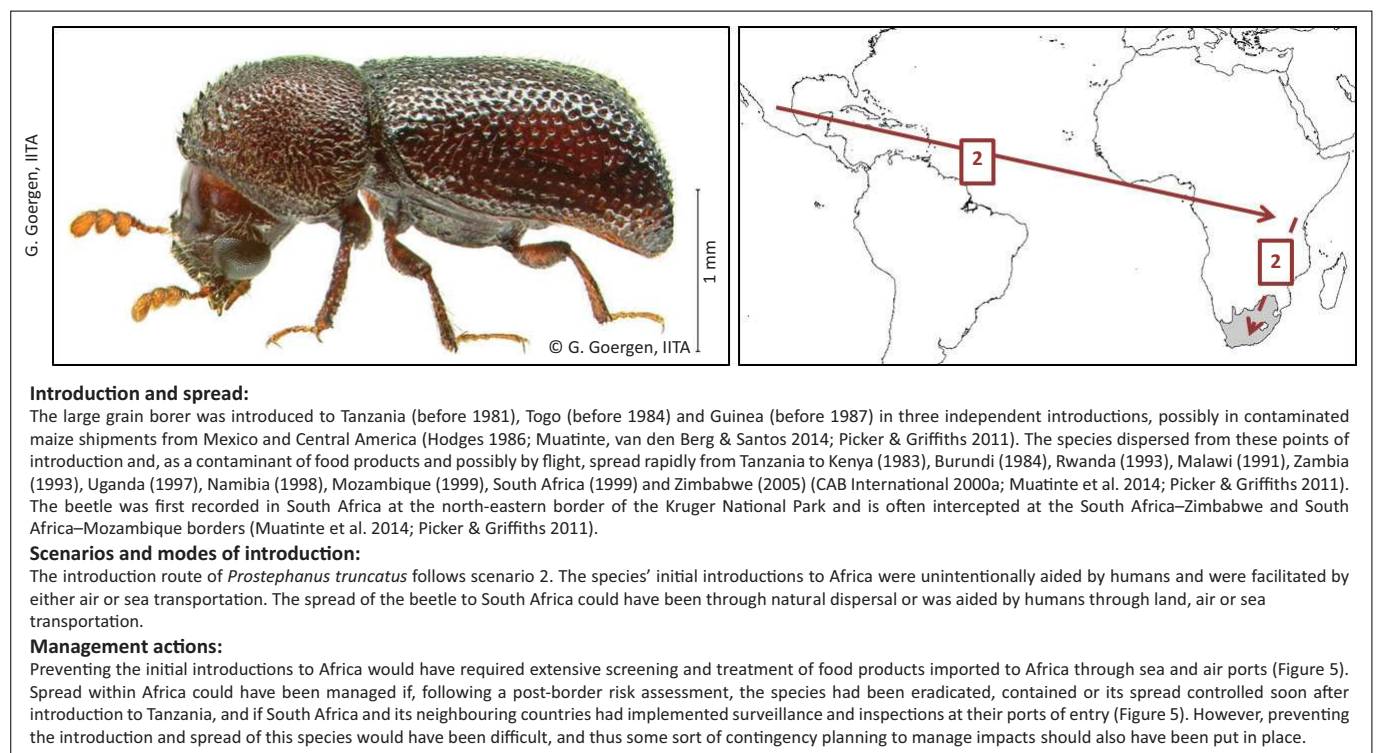


FIGURE 2-A2: Details on the introduction and spread of *Prostephanus truncatus*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

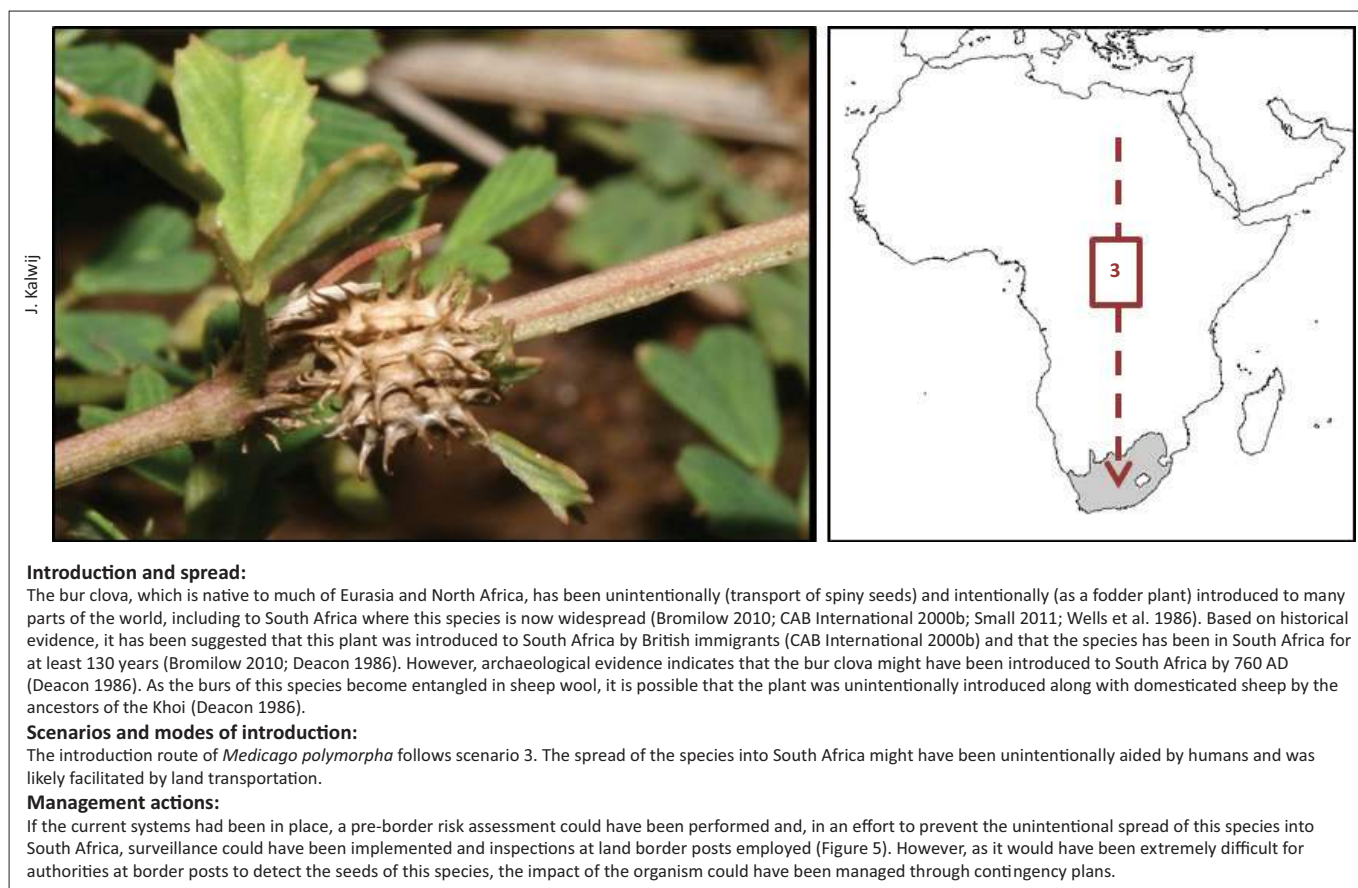


FIGURE 3-A2: Details on the introduction and spread of *Medicago polymorpha*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

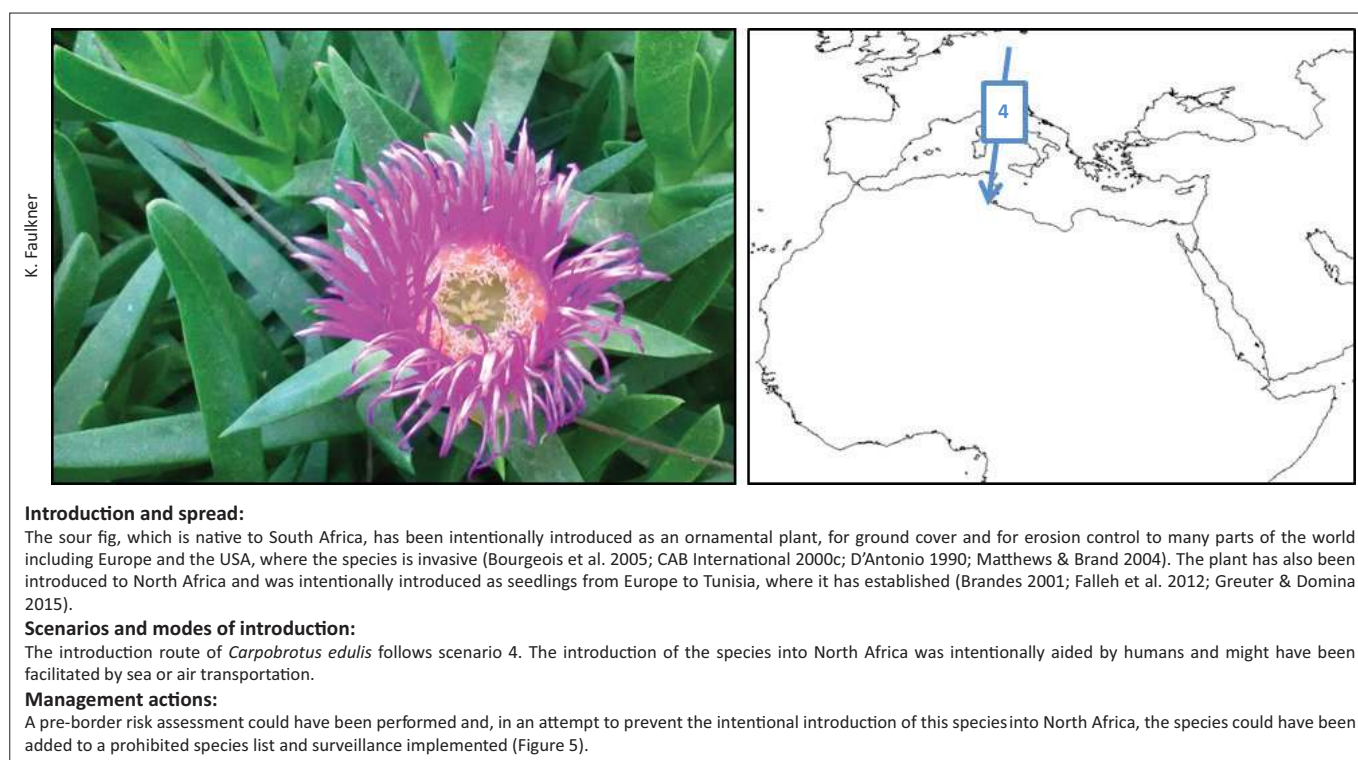


FIGURE 4-A2: Details on the introduction and spread of *Carpobrotus edulis*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

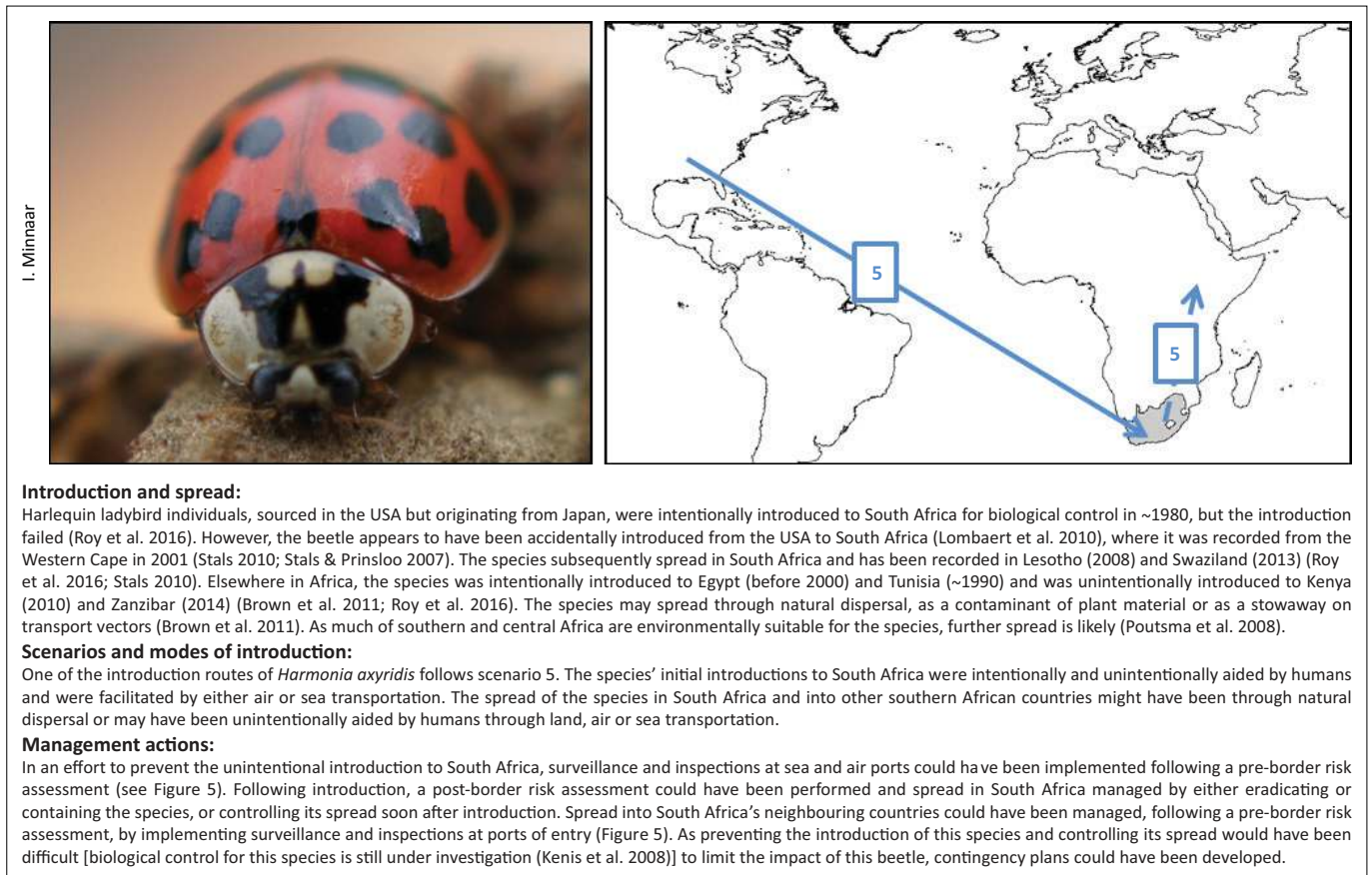


FIGURE 5-A2: Details on the introduction and spread of *Harmonia axyridis*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.

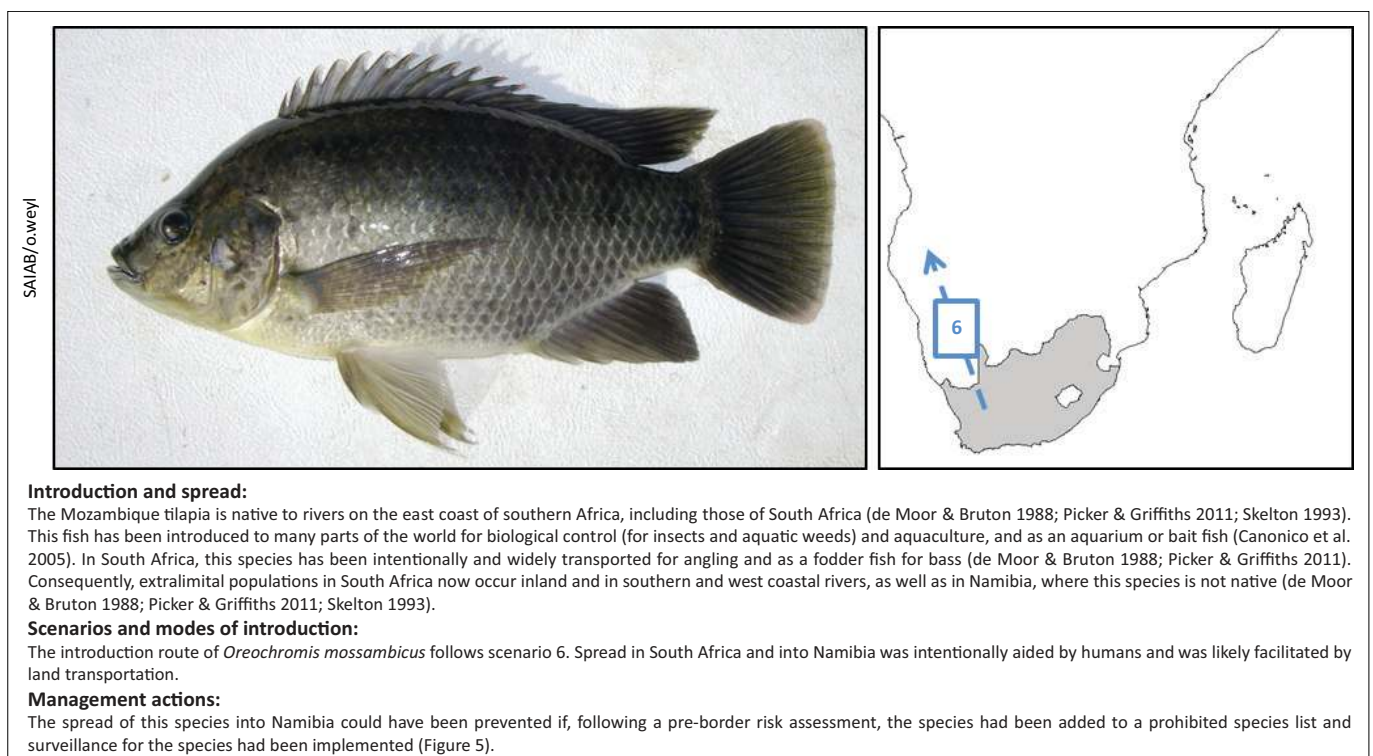


FIGURE 6-A2: Details on the introduction and spread of *Oreochromis mossambicus*, the relevant introduction route scenario and modes of transport, and the management actions that could have prevented or mitigated the invasion.