Chapter 12

South Africa's Pathways of Introduction and Dispersal and How They Have Changed Over Time

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Abstract Alien taxa have been introduced to South Africa through a wide variety of pathways, and have subsequently been intentionally or accidentally dispersed across the country. While many introductions to South Africa have been intentional, alien

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taxa have also been accidentally introduced, or have spread unaided into the country from neighbouring countries where they have previously been introduced. Similar to other regions, organisms of different types have been introduced to South Africa through different pathways, and some pathways have introduced more taxa that have become invasive than others. Changing socio-economic factors have played an important role in shaping the pathways of introduction and dispersal for South Africa. The first known introductions to South Africa were mostly intentional introductions from Africa for agriculture and medicine. However, as a result of increasing and geographically expanding trade and transport, the development of new technologies, and changing human interests and attitudes, over time, new pathways of introduction and dispersal developed, and the importance of existing pathways changed. Control measures have been put in place to manage some of the pathways, but despite these measures introductions continue to occur at an increasing rate. It is likely that these trends will persist into the future, and in particular, accidental introductions are likely to increase with increasing trade. Due to new legislation, the risks posed by legal intentional introductions should be reduced, but technological and political developments mean that it is becoming increasingly difficult to manage the pathways and enforce existing regulations. To better inform management, further research into the pathways of introduction and dispersal is required.

12.1 Introduction

Since the 1500s there has been a dramatic increase in the volume of goods and the number of people being moved around the world (Harrari 2015). Consequently, there has been, and continues to be, an increase in the number of organisms being transported and introduced to regions where they are not native (Hulme 2009; Seebens et al. 2017). Pathways of introduction are the processes that lead to the movement of alien taxa from one geographical location to another (Richardson et al. 2011), and include both the vector on or within which the organism is transported (e.g. ship, aeroplane) and the route followed (Essl et al. 2015). These pathways not only facilitate the movement of alien taxa between countries, but also the transportation of taxa

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within countries. There are a wide range of pathways through which alien taxa are either intentionally or accidentally introduced (Hulme et al. 2008). Alien taxa are intentionally transported and introduced for many uses, including for agriculture, horticulture, angling, medicinal purposes and as pets. But organisms are also often accidentally introduced when their hosts (such as plants or animals, or parts thereof such as wood or fruit) are intentionally transported between regions, or when they 'hitchhike' on or in transport vessels (including ships and aeroplanes).

Because some alien taxa become invasive and have negative environmental or socio-economic impacts where introduced, it is vital that these taxa are managed (Pimentel et al. 2001; Blackburn et al. 2011; Simberloff et al. 2013). Often the most efficient and cost-effective way to manage biological invasions is to prevent the introduction of taxa that are likely to cause harm (Leung et al. 2002; Puth and Post 2005; Simberloff et al. 2013). Most efforts to achieve this only focus on a few taxa that have a history of invasion elsewhere (Early et al. 2016; Grosholz 2018). Unfortunately, this strategy is ineffective in preventing the introduction of taxa with no invasion history or those that are accidentally introduced (Hulme 2006; Seebens et al. 2017, 2018; Grosholz 2018). Strategies that aim to identify and prioritise important pathways of introduction are more appropriate in these instances (Hulme 2006). These strategies aim to prevent invasions by reducing the propagule pressure [the number of individuals introduced or number of introduction events for a specific taxon (Lockwood et al. 2005)] and colonisation pressure [the number of species introduced (Lockwood et al. 2009)] associated with priority pathways, and these efforts have been shown in some instances to be highly effective (Bailey et al. 2011; Sikes et al. 2018). For example, enacted policies that require foreign vessels entering the Laurentian Great Lakes to exchange and/or flush their ballast tanks with mid-ocean saltwater have markedly reduced the risk of introductions mediated by the release of ballast water by ships (Bailey et al. 2011).

The importance of managing the pathways of introduction is widely recognised, and has been included in the Aichi Biodiversity targets set by the Convention on Biological Diversity (CBD). In order to meet Aichi Biodiversity Target 9, the countries that are party to the CBD, including South Africa, must identify and prioritise their pathways of introduction, and manage those pathways to prevent the introduction of invasive taxa (UNEP 2011). It is, therefore, not surprising that the pathways of introduction have been studied in many regions [e.g. Czech Republic (Pyšek et al. 2011) and China (Xu et al. 2006)] and at various spatial scales [e.g. global (Kraus 2007; Hulme et al. 2008), continental (Katsanevakis et al. 2013) and sub-continental (Zieritz et al. 2017)]. These studies have demonstrated that the pathways that are important for the introduction of alien taxa vary across regions and spatial scales, but also across taxonomic groups, environments and over time (Hulme et al. 2008; Pyšek et al. 2011; Katsanevakis et al. 2013; Essl et al. 2015; Faulkner et al. 2016; Zieritz et al. 2017). The pathways also vary in the degree to which they are associated with taxa that become invasive and/or have negative impacts (Wilson et al. 2009; Pyšek et al. 2011; Faulkner et al. 2016; Pergl et al. 2017), and in their relative importance in facilitating initial introduction and subsequent dispersal (Padayachee et al. 2017). Species traits, the environment and trends in socio-economic factors (like the volume and type of goods imported, economics,

changing fashions and management interventions) interact to shape these patterns and determine not only how the pathways of introduction change over time (Hulme et al. 2008; Essl et al. 2011, 2015; Ojaveer et al. 2017; Saul et al. 2017; Seebens et al. 2017; Zieritz et al. 2017), but also the likelihood that the introduced taxa will become invasive and have negative impacts in their new range (Cassey et al. 2004; Lambdon et al. 2008; Lockwood et al. 2009; Wilson et al. 2009; Pyšek et al. 2011; Essl et al. 2015).

Such variations, along with the vast number of potential pathways and economic globalisation have made it difficult to implement pathway-centred legislation and prevention strategies. To overcome these obstacles, efforts have been made to classify or aggregate pathways into categories and in so doing facilitate assessments of their relative importance (Hulme et al. 2008; Essl et al. 2015). Various classifications have been developed (see Hulme et al. 2008; Wilson et al. 2009) and used in assessments (e.g. Pyšek et al. 2011; Measey et al. 2017), with one of these, developed by Hulme et al. (2008), being modified to form the hierarchical pathway classification scheme that has been adopted by the CBD (CBD 2014). This scheme classifies pathways, based on their attributes (e.g. degree of human assistance, means of transport and subsequent introduction), into six main pathway categories (see Table 12.1 for explanations and examples of the categories) and 44 subcategories (Fig. 12.1). The detail required for pathway management depends on the management goal (Essl et al. 2015), and the information provided by the hierarchical scheme can inform management at a number of levels. The six main categories provide sufficient detail to develop overarching legislation [and also facilitate analyses that compare trends across regions, taxonomic groups and environments (Hulme et al. 2008)], while the high level of detail provided by the subcategories allows for decision makers to be better informed, and for tailored regulations and interventions to be developed and implemented (Essl et al. 2015; Saul et al. 2017).

As biological invasions have major impacts in South Africa (van Wilgen et al. 2001), information on the country's pathways of introduction is required not only to meet Aichi Biodiversity Target 9, but also to inform strategies that aim to prevent invasions by managing introduction pathways. A dataset containing historical introduction data for South Africa was collated during an assessment of South African alien species databases (Faulkner et al. 2015). The dataset includes information, for taxa introduced to South Africa, on taxonomy, and date and pathway of introduction, with the pathway of introduction data classified using the scheme developed by Hulme et al. (2008) (see Faulkner et al. 2015, 2016 for details on the methodology followed). The dataset has been used in previous published assessments of South Africa's pathways of introduction (see Faulkner et al. 2016), but has been subsequently updated (see van Wilgen and Wilson 2018) using the pathway classification scheme adopted by the CBD. This update was necessary to assess the status of South Africa's pathways of introduction using recently developed indicators for national level assessments of biological invasions (Wilson et al. 2018). The indicators, however, not only consider the role the pathways play in introducing alien taxa, but also their prominence or socio-economic importance. Therefore, in order to populate the indicators for South Africa, socio-economic data and socio-economic forecasts for the pathways were also obtained from a variety of sources (see van

Table 12.1 The six main pathway of introduction categories of the hierarchical pathway classification scheme adopted by the Convention on Biological Diversity (CBD 2014), with an explanation of each category and examples

Pathway category	Explanation	Examples
Release in nature	The intentional introduction of an alien organism into the natural environment for human use	Biological control agents to control the spread of alien plants and fish for angling
Escape from confinement	The movement of an alien organism kept in confinement into the natural environment, includes both the accidental and irresponsible release of live organisms	Both escaped and unwanted pets, plants that have escaped from gardens
Transport—contaminant	The unintentional introduction of an alien organism with an intentionally imported commodity	Pests on imported food, animals or plants
Transport—stowaway	The introduction of an alien organism attached to transport vessels or their associated equipment and media	Marine organisms introduced through biofouling or with the release of ballast water by ships, and hitchhikers in aeroplanes
Corridor	The spread of alien organisms into a new region through human-constructed transport infrastructure that connects previously unconnected regions, and without which spread would not have been possible	The movement of organisms through international canals that connect previously unconnected seas
Unaided	The unaided spread of an alien organism from a region where it was previously introduced to another region where it is not native	Any alien organism capable of dispersal

Fig. 12.1 The current and forecasted status of the pathways of introduction. The number of taxa introduced (No. taxa); changes to the rate of introduction in the last full decade in comparison to that of the previous decade (NK, not known; up arrow, increase; down arrow, decrease; dash symbol, minimal change; times symbol, no introductions); the socio-economic importance of the pathways (NK, not known; PNP, pathway not present; Min, minimal; Mod, moderate; Maj, major) and forecasted changes to socio-economic importance (NK, not known; up arrow, increase; down arrow, decrease; dash symbol, minimal change; up arrow / down arrow, increase or decrease). The pathways were categorised using the scheme adopted by the Convention on Biological Diversity (CBD 2014). See van Wilgen and Wilson (2018) for information on data sources and the methodology followed (redrawn from Faulkner and Wilson 2018)

Wilgen and Wilson 2018 for the raw data and details on the methodology followed). In this chapter, we present these historical and socio-economic data as well as additional information, and discuss how alien taxa have been introduced to and dispersed within (referred to in this chapter as ‘pathways of dispersal’) South Africa. We demonstrate how these pathways have changed over time and discuss the socio-economic factors that have driven these changes. The pathways that are currently facilitating the introduction and within-country dispersal of alien taxa are addressed, and how the pathways might change in the future are discussed. While the pathways of introduction and dispersal are discussed broadly, more detail is provided for some pathways that demonstrate important aspects or trends.

12.2 How Have Taxa Been Introduced to and Dispersed Within South Africa?

12.2.1 Importance of the Pathways of Introduction and Dispersal

Alien taxa have been introduced to South Africa through a wide variety of pathways (Fig. 12.1). Many plant taxa have been intentionally imported by the ornamental plant trade, or have been introduced for agriculture (Fig. 12.1). These plants have subsequently escaped from gardens or cultivation, and many have become invasive (Faulkner et al. 2016). Several vertebrates have been imported intentionally and released for purposes like fishing (Figs. 12.1 and 12.2, also see Box 12.1; Weyl et al. 2020, Chap. 6), and most of these introductions have resulted in invasions (Faulkner et al. 2016). A large number of invertebrates have been released as biological control agents (Figs. 12.1 and 12.2; Hill et al. 2020, Chap. 19), and none of the agents released to control alien plants in South Africa in the last 100 years have been reported to cause negative impacts (Moran et al. 2013). While many alien taxa have been intentionally imported into the country, alien organisms have also entered the country accidentally (Fig. 12.2). For example, as contaminants on imported goods like plants or parts thereof (e.g. wood or fruit), or as stowaways on transport vessels such as ships (Fig. 12.1). The majority of taxa that are known to have been accidentally introduced are invertebrates (Fig. 12.2), and several of these taxa have subsequently become invasive (Faulkner et al. 2016). Some organisms that have been introduced to neighbouring countries have also spread unaided into South Africa; however, no alien taxa are known to have spread into the country through human-built corridors that connect previously unconnected regions (Fig. 12.2). Information on the pathways of introduction for many of the taxa introduced to South Africa is not available (Fig. 12.2), with these data more likely available for taxa that are well known or widespread and those that are intentionally introduced (Faulkner et al. 2016). Additionally, there may be many taxa that have been introduced but that have not been recorded (McGeoch et al. 2012). It is likely

Fig. 12.2 The number of invertebrates, plants and vertebrates introduced to South Africa through the pathways of introduction [categorised into the main categories of the scheme adopted by the Convention on Biological Diversity (CBD 2014)], and the number of taxa for which pathway of introduction was unknown. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

that many of these introductions were accidental, particularly for invertebrates, and so the importance of stowaway and contaminant introductions may be underestimated (Faulkner et al. 2015, 2016; Janion-Schepers and Griffiths 2020, Chap. 7, Sect. 7.3).

Once introduced, alien taxa have also dispersed within South Africa through numerous pathways. However, native taxa are also being transported from their native range and are being introduced elsewhere in the country where they are alien [referred to as ‘extralimital species’ (Measey et al. 2017)] (Faulkner and Wilson 2018). Alien and native taxa have been traded and transported all over South Africa by the public [e.g. plants in the aquatic plant trade (Martin and Coetzee 2011) and medicinal plant trade (Byrne et al. 2017)], or have been intentionally transported to new regions and released [e.g. release of fish in new river systems for angling (see Box 12.1)] (Faulkner and Wilson 2018). These taxa have also been accidentally transported within South Africa as contaminants of transported goods or as stowaways on transport vehicles (e.g. ships, aeroplanes and cars), while many alien taxa have spread throughout the country unaided [e.g. *Sturnus vulgaris* (European Starling)] (Faulkner and Wilson 2018). In contrast to introductions to the country, some taxa have dispersed within the country along human-built corridors to regions where they previously did not occur [see Box 12.2 for an example] (Faulkner and Wilson 2018).

Fig. 12.3 The number of new taxa introduced to South Africa through the pathways of introduction [categorised into the main categories of the scheme adopted by the Convention on Biological Diversity (CBD 2014)] each decade since 1650. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

12.2.2 *Changes Over Time to the Pathways of Introduction and Dispersal*

Based on the available data, it appears that most of the taxa introduced to South Africa could have been intentionally imported and then were released or escaped from confinement. However, the pathways through which alien taxa have been introduced to and dispersed within the country have changed over time (Fig. 12.3). An understanding of these changes and their socio-economic drivers is vital to inform the management of pathways. Below we discuss the introduction and dispersal of alien taxa during four phases of introduction [the pre-colonial period (before 1650), the colonial period (1650–1910), the post-colonial period (1910–1994), and the period following South Africa’s democratisation (1994–2018)], and we give suggestions on potential future trends.

Box 12.1 Releases for Fishing

Angling for recreation and food has been a major pathway for the introduction of alien fish globally and in South Africa. Thirteen alien fish species have been intentionally introduced to South Africa since 1859 to provide opportunities for sport fishing (figure below). Initially, the dissatisfaction of British colonists with the lack of ‘suitable’ native angling fish resulted in the introduction and subsequent establishment of *Cyprinus carpio* (Common Carp) in 1859,

(continued)

Box 12.1 (continued)

Salmo trutta (Brown Trout) in 1890, *Salvelinus fontinalis* (Brook Trout) in 1890, *Oncorhynchus mykiss* (Rainbow Trout) in 1894 and *Salmo salar* (Atlantic Salmon) in 1896 (Ellender and Weyl 2014). Later, other globally prized sport fish species were also introduced, such as *Micropterus salmoides* (North American Largemouth Bass) in 1928 and *Micropterus dolomieu* (Smallmouth Bass) in 1937.

The number of alien taxa introduced to South Africa for fishing each decade since 1800. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

Multiple introductions (figure below), which ensured high propagule pressure, combined with climate matching maximised the chances of establishment, and only a few species (e.g. Atlantic Salmon and Brook Trout) failed to establish. A massive recreational fishery developed around alien fish and with the help of acclimatisation societies and state supported formal stocking programs, popular angling species were spread throughout South Africa and in some cases further into Africa (Weyl et al. 2017). For instance, the first successful African introductions of Brown Trout were from Scotland to KwaZulu-Natal (in 1890) and England to the Western Cape (in 1892). The establishment of hatcheries in KwaZulu-Natal (1890), the Western Cape (1894), and the Eastern Cape (1897) facilitated the distribution of Brown Trout within South Africa and then as a bridgehead into other African countries (1907–1964) and even Marion Island in the sub-Antarctic (see Measey et al. 2020, Chap. 27, Sect. 27.3.4; Weyl et al. 2017).

(continued)

Box 12.1 (continued)

Major introduction routes of *Salmo trutta* (Brown Trout) from Britain, France, South Africa and Kenya into other African countries: Britain to (A) KwaZulu-Natal (1890) and (B) the Western Cape (1892) of South Africa, (E) Malawi (1906) and (F) Kenya (1905). From South Africa to (C) other localities in South Africa, (D) Lesotho (approx. 1907–14), (H) Swaziland (1914), (G) Zimbabwe (1907), (E) Malawi (1932–34), (J) Tanzania (1934) and (K) Marion Island (1964). From France to (I) Madagascar (1926) and from (F) Kenya to (L) Ethiopia (1967) (redrawn from Weyl et al. 2017)

(continued)

Box 12.1 (continued)

As alien sport fishes are widely dispersed within the country, demand for new species for fishing is low, and as a result no new alien fish have been introduced to South Africa for fishing since the 1980s. Due to this and as legislation exists to regulate their introduction, new alien fish are unlikely to be introduced to South Africa for fishing in the future. However, and despite the legislation in place, alien fish are still intentionally dispersed within the country for angling.

12.2.2.1 Pre-colonial Period (Before 1650)

The first known deliberate introductions to South Africa occurred around 2000 years ago when small groups of hunter-herders infiltrated the country from further north in Africa (Deacon 1986; Sadr 2015). At the time, there were few pathways of introduction, and most of the alien taxa known to have been introduced during this time were intentionally transported into the country from elsewhere in Africa for agricultural and medicinal purposes (Deacon 1986; Henderson 2006; Sadr 2015). The first taxa known to be introduced to South Africa included *Ovis aries* (Sheep), *Bos taurus* (Cattle), *Capra hircus* (Goats) and *Canis familiaris* (Dogs), however, as farmed animals were highly valued and were targeted by predators, these organisms were unlikely to escape and establish (Deacon 1986; Thompson 2000). Cereals and other food crops (like Sorghum and Millet) were introduced around 250 AD (Deacon 1986), while other early intentional introductions included plants for medicinal purposes like *Catharanthus roseus* (Madagascar Periwinkle) (Henderson 2006) and *Ricinus communis* (Castor-oil Plant), which was possibly introduced more than 1200 years ago (Henderson 2006; but see Deacon 1986). The movement of people and animals during this period also facilitated accidental introductions. *Medicago polymorpha* (Bur Clover), for example, has a long association with humans in Africa with archaeological evidence of the species in South Africa from around 760 AD (Deacon 1986; Henderson 2006). As the prickly burs of this plant (Fig. 12.4) get entangled in wool it is possible that the plant was introduced along with sheep (Deacon 1986). Accidental introductions were also facilitated by early trade, and *Rattus rattus* (House Rat) was likely introduced in 700–800 AD by Arab traders moving along the east coast of Africa (Deacon 1986; Richardson et al. 2003; Measey et al. 2020, Chap. 5, Sect. 5.3.1).

Although during this period some introduced organisms could have dispersed unaided within the country, the dispersal of most introduced taxa would have largely depended on human movements and, therefore, would have been limited. It is therefore unlikely that major invasions occurred and although some of the taxa introduced during this period have become invasive (e.g. *R. communis* and *R. rattus*), these invasions may have been driven or influenced by processes that have subsequently occurred. For example, *R. rattus* has been introduced multiple times to the country, including through shipping (Aplin et al. 2011; Bastos et al.

Fig. 12.4 *Medicago polymorpha* (Bur Clover) could have been introduced to South Africa as early as around 760 AD, possibly entangled in the wool of sheep brought into the country from elsewhere in Africa (Deacon 1986) (photograph courtesy of J.M. Kalwij)

2011; Measey et al. 2020, Chap. 5, Sect. 5.3.1), and new genetic material introduced with more recent introductions could have increased the species' invasiveness (Richardson et al. 2003; Wilson et al. 2009; Garnas et al. 2016).

Box 12.2 Human Built Corridors That Connect River Basins

South Africa is arid, with many areas receiving less than 500 mm of rainfall each year. For this reason there are few permanent rivers and the Orange River, which drains an area of almost 1 million km², accounts for 85 % of the fresh water flow. To stabilise water supply for human and agricultural use in arid areas, 26 major inter-basin water transfer schemes have been constructed in South Africa (Slabbert 2007). These schemes connect previously isolated catchments and create continuous dispersal opportunities for many aquatic organisms (Rahel 2007). For example, the Orange-Fish-Sundays inter-basin water transfer scheme (figure below), which was completed in 1978, has resulted in the dispersal of Orange River fishes, including *Labeobarbus aeneus* (Smallmouth Yellowfish), *Clarias gariepinus* (African Sharptooth Catfish) and *Labeo capensis* (Orange River Mudfish), into the Great Fish and Sundays Rivers. Known impacts of these introductions include competition with and predation on native biota (Ellender and Weyl 2014; Weyl et al. 2016) and hybridisation between the Orange River Labeo and Eastern Cape populations of the closely related Moggel *L. umbratus* (Ramoejane et al. 2019).

(continued)

Box 12.2 (continued)

The Orange-Great Fish-Sundays River inter-basin water transfer scheme resulted in the extra-limital introduction of *Labeo capensis* (Orange River Mudfish), *Labeobarbus aeneus* (Smallmouth Yellowfish), *Clarias gariepinus* (African Sharptooth Catfish) and *Austroglanis sclateri* (Rock Catfish) into the Great Fish and Sundays Rivers (redrawn from Ramoejane et al. 2019)

12.2.2.2 Colonial Period (1650–1910)

The colonial period was characterised by waves of human immigration, with each additional influx of immigrants bringing with them new alien taxa. At the end of the fifteenth century, in an effort to discover a sea route from Europe to Asia, the Portuguese circumnavigated the Cape of Good Hope (Davenport and Saunders 2000; Thompson 2000; Ross 2012). By the end of the sixteenth century this sea route was used by merchant mariners from various European countries and ships would regularly stop at the Cape Peninsula to obtain fresh water and barter with local pastoralists for Sheep and Cattle (Thompson 2000; Ross 2012). Spurred by the high sickness and mortality rates of sailors, caused by their limited shipboard diet, the Dutch East India Company (the Vereenigde Oostindische Compagnie or VOC) established a small, permanent settlement in the Cape in 1652 (Davenport and Saunders 2000). The VOC intended to produce fresh fruit, vegetables and grains for their passing ships (Karsten 1951), and thus many of the taxa introduced at the time were for agriculture (Deacon 1986). However, plants were also introduced by the VOC for medicinal purposes (Scott and Hewett 2008), including Scurvy Grass (*Cochlearia* sp.), which was introduced in 1656 to treat scurvy, a condition affecting many sailors because their shipboard diet lacked vitamin C (Karsten 1951). According to Jan van Riebeeck's (Commander of the Cape from 1652 to 1662) journal and letters, approximately 100 plants were introduced and tested for cultivation in the Western Cape (Table 12.2). During this period, plants were also introduced for horticultural purposes (Table 12.2) and, for example, the ornamental plant *Oenothera biennis* (Common Evening Primrose) was introduced in 1772 (Henderson 2001; Bromilow 2010). Although the Dutch introduced relatively few alien taxa (Fig. 12.5; also see Deacon 1986), these taxa originated from a wider range of locations than previous introductions, including from Europe [e.g. *Quercus robur* (English Oak) and *Pinus pinaster* (Cluster Pine)] and North America [e.g. *Opuntia ficus-indica* (Mission Prickly Pear)] (Henderson 2006). See Measey et al. (2020, Chap. 5, Sect. 5.3) for introductions of mammals and birds during this period.

During this period, transport infrastructure was limited to small streets in Cape Town and tracks that led to restricted parts of the country (Mitchell 2014a). Extensive exploratory journeys were undertaken inland, but such movements were hindered by the country's adverse geographical and topographic features [e.g. no navigable rivers (Mitchell 2014a)]. As a consequence, introductions were limited to the Western Cape (Deacon 1986), and there was probably little human-assisted dispersal of alien taxa.

Globally, the rate at which alien taxa were introduced to new regions remained low until the 1800s, when the industrial revolution, an increase in international trade, and the colonisation of new regions by millions of Europeans, resulted in a steady increase in the rate of introduction (Hulme 2009; Seebens et al. 2017). These global socio-economic trends also influenced introductions in South Africa, and while the rate of introduction increased slightly following the arrival of the Dutch, it began to dramatically increase in the early 1800s when the British colonised the country

Table 12.2 Plants introduced to the Western Cape under the commandership of Jan van Riebeeck (1652–1662). The common names as recorded by van Riebeeck are provided

Plant type	Introduced plants
Vegetables	Artichokes; asparagus; beans [broad, horse, dutch (brown and white), rouan and turkish]; beet; beetroot; cabbage (red and white); carrots; cauliflower; cucumbers; endives; horse-radish; various kinds of Indian beans collectively called “Katjang boonijies”; leek; lettuce; onions; parsnip; peas (green, grey, blue and white); radish; spinach; sweet potato; turnips; savoy cabbage
Fruit and nuts	Apples; bananas; cherries; chestnuts; currants; coconuts; gooseberries; hazelnuts; Indian fruit trees (no species mentioned in journal, but some letters requested guavas, pomegranate and pawpaw); lemons; melons; oranges; pomelo; pears; pineapples; plums; pumpkin; quince; strawberries; vines (grapes); walnut; watermelon; almonds; apricots; elder berries; figs; mulberries; morellos; peaches; raspberries
Herbs and medicinal plants	Aniseed; chervil; fennel; garlic; linseed; mustard seed; parsley; purslane; scurvy plant; tobacco; wormwood; rosemary; bay-trees; sage; savory; pimpinell; caper (nasturtium)
Grains, fodder and utilities	Barley; buckwheat; clover; cress; hemp; maize; oats; rice; rye; wheat; bamboo; hop; indigo; rape-seed
Ornamental plants	Roses; alders; hawthorn; tulip; oaks

Data obtained from Karsten (1951)

Fig. 12.5 The number of new taxa introduced to South Africa every decade since 1650. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

(Fig. 12.5). The growing number of goods and people transported to South Africa at the time likely caused some existing pathways of introduction to increase in importance (Fig. 12.3). However, during this period alien taxa were also introduced for a wider variety of purposes, new technologies were developed and, as a consequence, important new pathways of introduction arose (Fig. 12.3). Although intentional introductions for purposes such as agriculture, horticulture and medicine continued, alien taxa began to be intentionally introduced for other purposes, including for forestry, fishing (see Box 12.1) and to ‘improve’ the local fauna and flora (introductions for aesthetic reasons to ‘improve’ the local biota or to augment local species with organisms that were familiar to settlers). Additionally, accidental introductions through new pathways, such as biofouling on ships (see Box 12.3), began to be recorded. For previously existing pathways, there was also an increase in the sources from which alien taxa were introduced. For example, indentured labourers drafted from India (in the 1860s), China (from 1904 to 1908) and elsewhere in southern Africa [from 1890 (Callinicos 1987; Flint 2006)] introduced new medicinal systems, such as Indian Ayurvedic medicine, and as a result medicinal plants such as Ginger, Turmeric, Fennel and Camphor, along with new undocumented species, were introduced from these regions (Wojtasik 2013).

Box 12.3 Stowaways Introduced Through Ballast Water and Hull Fouling

Many alien marine organisms have been transported to South Africa by ships, either attached to the hulls and submerged niche areas of ships (termed ‘biofouling’ or ‘hull fouling’) or within the ballast water used to adjust the stability of ships (figure below). Following the establishment of the Dutch colony in 1652, many ships began to visit South Africa. However, it was only

(continued)

Box 12.3 (continued)

in 1852 that the first marine alien species [the bryozoan *Virididentula dentata* (previously known as *Bugula dentata*)] was recorded (Busk 1852). At the time, wooden ships were in use and dry ballasts (e.g. rocks and sand) were used for stability (Griffiths et al. 2009). As a consequence, the first marine introductions included fouling organisms (e.g. bryozoans and barnacles), wood-boring organisms [e.g. shipworms like *Teredo navalis* (Noble 1886)] and intertidal species that were accidentally loaded with dry ballast. During this time, Table Bay, Port Elizabeth and Durban harbours were the primary ports (Mitchell 2014c) and these, along with the naval harbour at Simon's Town [where the shipworm *Lyrodus pedicellatus* was detected (Moll and Roch 1931)], probably played an important role in early marine introductions.

The number of alien taxa introduced to South Africa through hull fouling and the release of ballast water each decade since 1800. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

In the 1900s, increasing trade resulted in an increase in the number of ships visiting South Africa, new harbours were developed (e.g. Richards Bay and Saldanha Bay in the 1970s), existing harbours were improved (e.g. Cape Town and Durban) (Griffiths et al. 2009; Mitchell 2014c), and larger, faster steel vessels, using ballast water for stability, began to frequent South African waters (Warren 1998; Richardson et al. 2003; Griffiths et al. 2009). Together, these developments resulted in an increase in the number of shipping facilitated introductions (figure above). Additionally, the change to metal hulls and the use of ballast water meant that while fouling organisms were still being transported, wood-boring organisms were not, and the introduction of benthic and planktonic organisms, as well as organisms with planktonic larval stages, became more common (Griffiths et al. 2009).

(continued)

Box 12.3 (continued)

Currently, South Africa has eight major maritime ports (Richards Bay, Durban, East London, Ngqura, Port Elizabeth, Mossel Bay, Table Bay and Saldanha Bay), which were visited in 2016 by more than 8000 ocean going vessels (Transnet National Ports Authority 2017). Globally, efforts have been made to prevent ballast water and biofouling introductions. Introductions associated with ballast water are being addressed through the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention), which was adopted in 2004 (IMO 2004), but only entered into force in September 2017 (IMO 2017). While ships are often coated with anti-fouling paint, currently no international agreement deals with biofouling and many anti-fouled vessels can still transport alien taxa (Moser et al. 2017). Although biofouling appears to be playing an important role in the dispersal of marine alien taxa to (Griffiths et al. 2009; Mead et al. 2011; Peters and Robinson 2017) and within South Africa [particularly on recreational yachts (Peters and Robinson 2017; Peters et al. 2019)], there are currently no plans in place to manage biofouling introductions (figure below).

Introduced marine organisms attached to the hull of a yacht in a South African marina (photograph courtesy of K. Peters)

Due to the BWM Convention, in the future there could be a reduction in the number of introductions associated with ballast water. However, with the continuous increase in trade and future harbour developments [all major ports, except Mossel Bay, will be upgraded and expanded in the future (Transnet National Ports Authority 2014)], without management intervention, biofouling is likely to remain an important pathway for the introduction and within-country dispersal of marine alien taxa.

Following British occupation, the country's population expanded and settlements developed in what are now the Eastern Cape and KwaZulu-Natal (Deacon 1986). With the discovery of diamonds (1867) and gold (1870), the population expanded further and moved into the interior of the country (Deacon 1986). Roads were built to link the mines to main ports and the large-scale construction of railways began (Mitchell 2014a, b). The development of settlements in new areas and the building of transport infrastructure meant that the introduction of alien taxa was no longer confined to the Western Cape, and the increased movement of goods and people around the country likely facilitated the within-country dispersal of alien taxa (see Box 12.1 for an example).

Many of the taxa introduced through the pathways that arose, or became more important during this period, have become invasive and have had major impacts. For example, *Opuntia ficus-indica*, which was introduced by the Dutch (Henderson 2006), as well as many of the taxa introduced for forestry [like *Acacia mearnsii* (Black Wattle), *Hakea drupacea* (Sweet Hakea) and *Pinus halepensis* (Aleppo Pine) (Richardson et al. 2003)], horticulture [like *Lantana camara* (Lantana) (Henderson 2001; Bromilow 2010)], fishing [like *Salmo trutta* (Brown Trout) (Weyl et al. 2017)] and to 'improve' the local flora and fauna [like *Sturnus vulgaris* (European Starling) and *Sciurus carolinensis* (Grey Squirrel) (see Measey et al. 2020, Chap. 5, Sect. 5.3)].

12.2.2.3 Post-colonial Period (1910–1994)

Global trade continued to increase gradually in the first half of the twentieth century, but from 1950 began to accelerate (Hulme 2009). This increase was facilitated by important technological developments, including containerisation and aviation, which allowed for increasing amounts of goods and people to be rapidly transported around the world (Hulme 2009). Globalisation and the increasing intensity and speed of trade and travel had a large impact on the introduction of alien taxa (Hulme 2009). Although during the first half of the twentieth century the global rate of introduction gradually increased, with temporary declines during the world wars, after 1950 there was an exponential increase in the rate at which alien taxa were introduced around the world (Seebens et al. 2017). Similar to what was seen globally, and mirroring trends in South Africa's commodity imports (Fig. 12.6), the rate at which taxa were introduced to South Africa increased during the twentieth century, with a particularly large increase after 1950 (Fig. 12.5). Technological developments also affected the pathways through which taxa were introduced to South Africa (for an example see Box 12.3). Further development of transport networks, and increasing traffic along them, led to some existing pathways becoming more important in the introduction of alien taxa. These pathways included those that facilitate the introduction of stow-away and contaminant organisms (Fig. 12.3). For instance, *Mytilus galloprovincialis* (Mediterranean Mussel), a widespread marine invasive species, was detected in the late 1970s and was likely introduced as a stowaway by ships, either through biofouling or in ballast water (Branch and Nina Steffani 2004; Robinson et al. 2020, Chap. 9). However, new technologies also led to the development of new

Fig. 12.6 The value of South African merchandise imports. Data for 1908–1959 were obtained from the United Nations (1962), and data for 1960–2012 were obtained from The World Bank (2014). All import values were converted to 2010 US dollars

pathways of introduction. For example, particularly short-lived taxa began to be transported accidentally to South Africa by hitchhiking on aeroplanes. These taxa include the blow-fly *Calliphora vicina* (European Bluebottle), which was first reported in the country in 1965 near what is now OR Tambo International Airport in Johannesburg (Picker and Griffiths 2011).

During this period, the pathways of introduction were also influenced by other, shifting socio-economic factors. Changing human interests probably caused the importance of some pathways to decline and others to increase. For example, introductions to ‘improve’ the local fauna and flora stopped due to a shift in societal norms (Seebens et al. 2017), but introductions for the pet trade increased (see Box 12.4). An increasing awareness of the impacts of biological invasions also affected the pathways of introduction (see Box 12.5). The desire to control alien taxa perceived as pests led to the intentional import and release of beneficial alien taxa as biological control agents. The first biological control agent introduced against an alien plant in South Africa (*Dactylopius ceylonicus*) was released in 1913 to control the spread of *Opuntia monacantha* (Drooping Prickly Pear) (Moran et al. 2013; Janion-Scheepers and Griffiths 2020, Chap. 7; Hill et al. 2020, Chap. 19). Following this very successful programme, the rate at which alien taxa were introduced for biological control increased until the 1980s, after which there was a decline (see Appendix 2 in van Wilgen and Wilson 2018). The decline in the release of agents to control invasive plants was due to improved release standards combined with regulatory and bureaucratic complications (Klein 2011; Klein et al. 2011). Increased research efforts to understand the ecology and hosts of agents led to a decline in the number of agents released to control insect pests (Cock et al. 2016). During the 1900s, international agreements (for an example see Box 12.5) and national legislation [e.g. Conservation of Agricultural Resources Act (Act No. 43 of 1983), Agricultural Pests Act (Act No. 36 of 1983), and Animal Diseases Act (Act No. 35 of 1984)] related to the movement and introduction of harmful alien taxa

were also initiated. The implementation of control measures related to these instruments might have reduced introductions through some pathways (for examples see Boxes 12.1 and 12.5), however, this is difficult to prove and changing fashions or other socio-economic factors could have played a role (see Box 12.1).

Box 12.4 Escaped Pets

More than a billion ornamental fish are traded as pets globally each year (Whittington and Chong 2007), while the trade in other animals is dominated by birds, reptiles and relatively fewer mammals (Bush et al. 2014). The pet trade is known to have caused some important and high impact invasions globally. This can occur when the pet itself is released or escapes from captivity; examples include *Python bivittatus* (Burmese Python) in the Everglades in Florida (e.g. Dove et al. 2011); *Felis catus* (Domestic Cat), which is generally regarded as one of the worst invaders globally but which has been most devastating on islands (e.g. Nogales et al. 2004); and *Carassius auratus* (Goldfish), which is an aquatic ecosystem engineer that can increase turbidity and nutrient loading in rivers and lakes (Crooks 2002). However, the pet trade can also contribute to invasions when the organisms that are associated with some pets are introduced alongside them [for example, amphibians that are infected with the devastating chytrid fungus (Scheele et al. 2019)] or when associated organisms are sold [e.g. plants sold, often with fish, in the aquarium trade (Martin and Coetzee 2011)].

The pet trade in South Africa consists of many vertebrates, of which fish, amphibians and reptiles have been studied in the greatest detail (van Wilgen et al. 2008; van der Walt et al. 2017), but also invertebrates like tarantulas [~200 species (Shivambu 2018)], insects, scorpions and gastropods [~35 species (Nelufule 2018)]. For some groups the number of individuals and species imported for the pet trade has increased over time (van Wilgen et al. 2010), and there has been an increase in the number of pet taxa that have escaped or have been released from captivity (first figure below). Given the high impacts caused by some introduced pets elsewhere in the world, it seems surprising that the importance of the pet trade as a source for major invaders seems to be relatively minor in South Africa, besides the classical examples of Cats and Dogs that have caused massive impacts on local fauna where they have been introduced (Hagen and Kumschick 2018). Many vertebrates and invertebrates in the pet trade (e.g. second figure below) have not established populations outside of captivity or are not (yet) problematic (van Wilgen et al. 2008; Measey et al. 2020, Chap. 5, Sect. 5.2). For example, *Psittacula krameri* (Rose-ringed Parakeet), is known to cause high impacts in other areas where introduced, but has only recently established populations in Durban (Hart and Downs 2014) and Johannesburg (Measey et al. 2020, Chap. 5, Sect. 5.3.2).

(continued)

Box 12.4 (continued)

The number of alien pet taxa in South Africa that escaped or were released each decade since 1650. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

A tarantula sold in the pet trade in South Africa (photograph courtesy of C. Shivambu)

(continued)

Box 12.4 (continued)

If the new NEM:BA regulations are followed, no new taxa should be introduced through the pet trade without a risk assessment that shows that they are not a threat to the country. However, illegal trade in pets is fairly common (Rosen and Smith 2010) and online trade poses a considerable risk for the importation of potentially invasive taxa (Derraik and Phillips 2010). A further challenge for managing the pet trade is that animals may be incorrectly labelled or misidentified, with the result being that the true identity of these taxa remains unknown (Collins et al. 2012). The main risks therefore currently stem from pets which are already present in captivity, and those established in the wild which might become invasive given enough time and opportunity (e.g. van Wilgen et al. 2008).

Many of the socio-economic factors (e.g. the development of new technologies) that influenced the introduction of alien taxa during this period also played a role in within-country dispersal. The advent of the internal combustion engine and the development of motor vehicles spurred the construction of a road network in South Africa in the first half of the twentieth century (Mitchell 2014a). This development, as well as many others [e.g. the further expansion of the harbour system (see Box 12.3)] probably facilitated the intentional and accidental dispersal of alien taxa within the country. For instance, the within-country dispersal of *Corvus splendens* (House Crow) was probably aided by ships travelling along the coast (Dean 2000; Lever 2005; Measey et al. 2020, Chap. 5, Sect. 5.3.2), while inter-basin water transfer schemes constructed during this period facilitated the dispersal of fish to new river systems (see Box 12.2; Weyl et al. 2020, Chap. 6).

Box 12.5 Contaminants on Imported Plants and Plant Products

Plants and their products have a long history of being moved around the world by humans, and along with these plants, terrestrial invertebrates have been accidentally transported and introduced to regions where they are not native (figure below). One of the first known plant contaminant introductions to South Africa occurred in 1886, when *Daktulosphaira vitifoliae* (Grape Phylloxera) was imported along with grapevine planting material (de Klerk 1974). As this species had devastating impacts in Europe, its introduction initiated the development and implementation of South Africa's first plant quarantine measures.

(continued)

Box 12.5 (continued)

The number of alien taxa introduced to South Africa as plant contaminants each decade since 1650. For details on the compilation of this dataset see Faulkner et al. (2015, 2016) and Faulkner and Wilson (2018)

Over time, there has been an increase in the quantity of plants and plant products imported into South Africa—including live plants for horticulture, agriculture or forestry, and plant products for consumption (e.g. fruit). In an effort to prevent the accidental introduction of plant contaminants, legislation and biosecurity measures have been implemented at national and international levels. For example, the International Plant Protection Convention (IPPC) was developed in 1952, and South Africa enacted the Agricultural Pests Act in 1983. Based on these regulations, a permit is required to import any unprocessed plants and plant products into South Africa, with these permits also usually stipulating that a phytosanitary inspection must be performed upon arrival in South Africa (figure below). Additionally, to reduce the within-country dispersal of plant contaminants, the transportation of certain plants within the country is restricted [e.g. citrus propagation material to prevent the spread of *Candidatus Liberibacter africanus* (Citrus Greening Disease) and its vector, *Trioza erytreae* (African Citrus Psyllid) (DAFF 2018)]. While South Africa has a good track record of intercepting contaminant organisms on agricultural imports (Saccaggi and Pieterse 2013), and as a consequence remains free of a number of widely distributed agricultural pests [e.g. *Hypothenemus hampei* (Coffee Berry Borer) (CAB International 2018) and *Aculus schlechtendali* (Apple Rust Mite) (Plantwise Knowledge Bank 2018)], biosecurity is not infallible and incursions do occur [e.g. *Bactrocera dorsalis* (Oriental Fruit Fly) in 2010 (Manrakhan et al. 2015)]. Furthermore, while the movement of certain plants within the country is restricted (DAFF 2018), implementation of the regulations is problematic and spread of contaminant organisms is difficult to control.

(continued)

Box 12.5 (continued)

Arthropods detected on imported Kiwifruit (*Actinidia deliciosa*) in South Africa. Anti-clockwise from top: *Frankliniella intonsa* (Thripidae), *Tuckerella japonica* (Tuckerellidae), *Brevipalpus* sp. (Tenuipalpidae) and Oribatida (two species) (photograph courtesy of D. Saccaggi)

Plant imports are largely driven by consumer demand and, therefore, the volume and diversity of these imports to South Africa is likely to continue to increase in the future. As a consequence of this, as well as technological (e.g. e-commerce) and political developments, implementing phytosanitary regulations is becoming increasingly challenging (Saccaggi et al. 2016). The proposed free trade zone within Africa [African Continental Free Trade Area (AfCTFA)], for example, is likely to pose a particular challenge. If implemented, goods will be freely transported within the region and phytosanitary regulations will only be applied at the first point of entry. The development of a clear phytosanitary framework that is consistently implemented across the entire region would be essential to address this challenge.

12.2.2.4 Post-democratisation Period (1994–2018)

After South Africa's democratisation in 1994, commodity imports increased further (Fig. 12.6), the country's trading partners expanded (Ahwireng-Obeng and McGowan 1998), and new infrastructure was developed [e.g. the harbour at Ngqura

Fig. 12.7 South African ports of entry. Any person wishing to enter into or depart from South Africa can only legally do so through these points. Information was obtained from the South African Department of Home Affairs (2017) (redrawn from Faulkner and Wilson 2018)

near Port Elizabeth was built in the 2000s (Mitchell 2014c)]. Today, people, goods and transport vessels can enter South Africa through 72 official ports of entry, including eight maritime ports, ten airports and 54 land border posts (Fig. 12.7, and see Faulkner and Wilson 2018). Over time, the number of people entering South Africa has increased, and over 21 million people, including over 10 million tourists (World Tourism and Travel Council 2017), entered the country in 2016 (Fig. 12.8, and see Faulkner and Wilson 2018). The contribution the tourism and travel industry makes to South Africa's Gross Domestic Product has increased over time (Fig. 12.9, see Faulkner and Wilson 2018). As alien taxa are often transported within the luggage of tourists, this pathway is an example of many socio-economically important pathways that are increasing in their importance (Fig. 12.1) and that, as a result, could be playing an increasing role in facilitating introductions (Faulkner and Wilson 2018).

It is, therefore, not surprising that many pathways are facilitating the introduction of alien taxa to South Africa, and that for many pathways (see Boxes 12.3, 12.4 and 12.5) the rate of introduction has recently increased or remained constant (Fig. 12.1, see Faulkner and Wilson 2018). As an example, hunting generates a total estimated revenue of ZAR 2.61 billion, and the hunting market in South Africa has increased

Fig. 12.8 The number of people arriving in South Africa by air, road and sea transport in 2006 and 2016. Data were obtained from Statistics South Africa (2017). Note the differing y-axes (redrawn from Faulkner and Wilson 2018)

Fig. 12.9 The contribution of travel and tourism to South Africa's Gross Domestic Product (GDP) every year since 1995, and the predicted contribution in future years (shaded in grey). Data were obtained from the World Tourism and Travel Council (2017) (redrawn from Faulkner and Wilson 2018)

over time (Taylor et al. 2015). Alien taxa are introduced to game farms to increase the attractiveness of the property to both tourists and hunters (Taylor et al. 2015; Faulkner and Wilson 2018), and eleven new alien taxa were introduced to South Africa for hunting between 2000 and 2011 (see Appendix 2 in van Wilgen and Wilson 2018). Organisms are, however, not only being introduced through some pathways at an increasing rate, but some taxa are being introduced repeatedly and in some instances from multiple sources. For example, hundreds of medicinal plants, most of which are alien to South Africa, are imported into the country by immigrants from China, India, Nigeria, Ghana, Somalia, Ethiopia, Eritrea and the Democratic Republic of Congo (Byrne et al. 2017; Burness 2019). Many of these plants are imported in the form of viable propagules, with multiple immigrant groups importing the same medicinal plants, but from different parts of the world (Fig. 12.10). The repeated introduction

Fig. 12.10 The introduction routes of alien plants imported for medicine by immigrant groups living in South Africa (Burness 2019)

of propagules from multiple sources increases propagule pressure and the potential for introducing high genetic diversity, which in turn increases the likelihood of successful establishment and, in some instances, invasion (Wilson et al. 2009).

Unfortunately, some of the pathways that are important for the introduction of alien taxa are difficult to manage, or are becoming increasingly difficult to manage (for an example see Box 12.5). There has been a recent increase in trade between South Africa and other African countries (Ahwireng-Obeng and McGowan 1998), which means that there has likely been an increase in the movement of alien taxa from these countries to South Africa. Indeed within a year (July 2016–February 2017), three agriculturally important alien pest species [*Raoiella indica* (Red Palm Mite), *Tuta absoluta* (Tomato Leaf Miner), and *Spodoptera frugiperda* (Fall Armyworm)] dispersed into South Africa from other African countries (International Plant Protection Convention 2016; Agricultural Research Council-Plant Protection Research Institute 2017; Visser et al. 2017a). Alien organisms that disperse unaided into the country can enter South Africa anywhere along the 4862 km land borderline, while those transported intentionally or accidentally by humans could enter the country at 54 land border posts. It is, therefore, extremely difficult to prevent alien organisms from dispersing into South Africa from neighbouring countries (Faulkner et al. 2017a). The development of e-commerce has also made it very easy to find and purchase alien ornamental plants and pets, and many taxa that are prohibited for import into South Africa, or that have already been introduced to the country and are invasive or harmful, are sold online by South African traders (Martin and Coetzee 2011). Such online commerce is difficult to control, because improved transport and packaging technology has made it easy to move taxa purchased online between countries, and made it very difficult to enforce regulations (Martin and Coetzee 2011) (also see Boxes 12.4 and 12.5). As a consequence, the rate of introduction continues to increase (Fig. 12.5) despite existing control measures (Faulkner and Wilson 2018).

South Africa's extensive transport networks (Fig. 12.11) facilitate the transportation of a high and increasing volume of goods and number of people and, for instance, there has been a recent increase in the number of domestic airline passengers (Fig. 12.12, see Faulkner and Wilson 2018). Alien and native taxa are currently dispersed within the country through a wide range of pathways, and these transport networks often facilitate these movements. For example, taxa are sold (e.g. on web-sites like EBay) and transported throughout the country by the public (Martin and Coetzee 2011; van Rensburg et al. 2011; Taylor et al. 2015), marine alien taxa [such as *Caprella mutica* (Japanese Skeleton Shrimp) (Peters and Robinson 2017)] are unintentionally transported along the coast attached to the hulls and niche areas of vessels (see Box 12.3) and, despite existing control measures (see Box 12.5), pests of agriculture or forestry are often transported around the country in infested plant material (Faulkner and Wilson 2018) [like *Sirex noctilio* (Sirex Woodwasp) (Picker and Griffiths 2011; Hurley et al. 2012) and the recently introduced *Euwallacea fornicatus* (Polyphagous Shot Hole Borer) and its fungal symbiont *Fusarium euwallaceae* (Eatough Jones and Paine 2015; International Plant Protection Convention 2018)] (see Box 11.3 in Potgieter et al. 2020, Chap. 11).

Fig. 12.11 The South African (a) road and (b) rail networks. Major roads are motorways, primary and secondary roads. Data were obtained from © OpenStreetMap contributors, (available under the Open Database License; see <https://www.openstreetmap.org/copyright>) and are available at <https://www.openstreetmap.org> (redrawn from Faulkner and Wilson 2018)

Fig. 12.12 The total number of scheduled commercial domestic flights (in black) and passengers (in grey) for each financial year since 2012/2013 (note neither axis starts at zero). These data were obtained from Airports Company South Africa (2017) (redrawn from Faulkner and Wilson 2018)

12.2.2.5 The Future

While it is difficult to forecast how the pathways of introduction and dispersal will change in the future, some predictions can be made based on recent or forecasted changes to the socio-economic importance of these pathways (see Appendix 2 in van Wilgen and Wilson 2018 for the data and sources used in these assessments). Intentional introductions for some purposes are likely to increase in the future. For example, recently there has been an increase in biological control research and implementation (Zachariades et al. 2017; Faulkner and Wilson 2018), there is considerable interest in new agricultural opportunities [e.g. the introduction of grasses for biofuels (Visser et al. 2017b)], and there is continuing demand from consumers for new varieties of ornamental plants (Middleton 2015; Faulkner and Wilson 2018). Therefore, in the future the release of biological control agents could continue to increase, and there could also be an increase in the introduction of new taxa for agriculture and horticulture (Faulkner and Wilson 2018). Socio-cultural resistance, however, could influence introductions through some pathways. The hunting industry, for instance, may benefit from a decline in the hunting opportunities available in other countries, but could be negatively affected by increasing global anti-hunting sentiment and publicity (Fig. 12.1; also see Taylor et al. 2015). It is, therefore, uncertain whether introductions for hunting will continue at an increasing rate. Under the recently promulgated Alien and Invasive Species Regulations of the National Environmental Management: Biodiversity Act (NEM:BA, Act No. 10 of 2004), a permit is required to intentionally import a new alien taxon into South Africa. Such a permit is only approved by the Department of Environment, Forestry and Fisheries if a risk assessment, performed by a professional scientist, shows the risk of invasion to be low. Therefore, while new alien taxa will continue to be intentionally introduced through some pathways, these organisms

Fig. 12.13 Trends in imports to mainland African countries (excluding South Africa). **(a)** The value of merchandise imports to mainland African countries, and **(b)** the percentage change in the volume of goods imported into this region, with predictions for the upcoming years (in grey). Data were obtained from the World Trade Organisation (2017) and International Monetary Fund (2016) (redrawn from Faulkner and Wilson 2018)

should not pose a threat. However, it is important to note that compliance with and enforcement of the regulations could be problematic [e.g. for aquarium plants (Martin and Coetzee 2011) and ornamental plants (Cronin et al. 2017)].

In the next few decades unintentional introductions to South Africa are likely to continue at an increasing rate (Faulkner and Wilson 2018). A number of pathways whereby alien organisms are accidentally introduced as stowaways on transport vectors are predicted to increase in socio-economic importance in the future (Fig. 12.1, see Faulkner and Wilson 2018). For instance, shipping intensity (see Box 12.3) and the contribution of travel and tourism to South Africa's Gross Domestic Product are expected to increase (Figs. 12.1 and 12.9). Unfortunately, for most of these pathways no measures are in place to prevent the introduction of alien species (for an example see Box 12.3), and unless this changes [as has recently been done at a global level for ballast water (see Box 12.3)] their predicted increase in socio-economic importance might result in an increase in the rate at which alien taxa are introduced (Faulkner and Wilson 2018). Changes at regional and global scales (e.g. changes to climate and trade agreements) will also affect South Africa's pathways of introduction in the future. As an example, the quantity of goods imported by mainland African countries is predicted to increase over the next few years (Fig. 12.13). As a consequence of this and the proposed free trade zone within Africa [African Continental Free Trade Area (AfCTFA)], there could be an increase in the number of taxa being introduced to other African countries and then dispersing either unaided or with the help of humans into South Africa (Fig. 12.1; also see Box 12.5). As it is extremely difficult to prevent these introductions, stronger regional co-operation will be required (Faulkner et al. 2017a).

12.3 Conclusion

Many alien taxa have been intentionally and accidentally introduced to South Africa, and have subsequently become widely dispersed. Over time, increasing travel and trade, the development of new technologies, and changing human interests and attitudes have greatly influenced South Africa's pathways of introduction and dispersal. Consequently, the relative importance of existing pathways has changed over time and new pathways have developed. Currently, alien taxa are being introduced to and dispersing within South Africa through a wide variety of pathways, with introductions occurring at an increasing rate. While there have been attempts to manage some pathways, many pathways are becoming increasingly difficult to manage, and for some pathways management plans have not been implemented. To better inform management, a good understanding of the pathways of introduction and dispersal is required. Unfortunately, for many taxa information on pathways of introduction is not available (Faulkner et al. 2015). This could have large consequences as uncertainties regarding pathway importance could influence the prioritisation of pathways for management, and lead to the ineffective allocation of resources. Furthermore, while there have been broad studies of South Africa's pathways of introduction (e.g. Faulkner et al. 2016, 2017a), and some specific pathways have received research attention [e.g. medicinal plant trade (Byrne et al. 2017; Burness 2019), aquatic plant trade (Martin and Coetzee 2011), shipping (Faulkner et al. 2017b), pet trade (Nelufule 2018; Shivambu 2018), recreational boating (Peters et al. 2019), and contaminants on imported plants (Saccaggi and

Pieterse 2013)], many pathways are understudied. Further research is, therefore, required to better inform management, especially on the pathways that facilitate within-country dispersal and those that involve the accidental introduction of alien taxa.

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