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Global environmental and socio-economic impacts of selected alien grasses as a basis for ranking threats to South Africa

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Abstract

Decisions to allocate management resources should be underpinned by estimates of the impacts of biological invasions that are comparable across species and locations. For the same reason, it is important to assess what type of impacts are likely to occur where, and if such patterns can be generalised. In this paper, we aim to understand factors shaping patterns in the type and magnitude of impacts of a subset of alien grasses. We used the Generic Impact Scoring System (GISS) to review and quantify published impact records of 58 grass species that are alien to South Africa and to at least one other biogeographical realm. Based on the GISS scores, we investigated how impact magnitudes varied across habitats, regions and impact mechanisms using multiple regression. We found impact records for 48 species. *Cortaderia selloana* had the highest overall impact score, although in contrast to five other species (*Glyceria maxima*, *Nassella trichotoma*, *Phalaris aquatica*, *Polypogon monspeliensis*, and *Sorghum halepense*) it did not score the highest possible impact score for any specific impact mechanism. Consistent with other studies, we found that the most frequent environmental impact was through competition with native plant species (with 75% of cases). Socio-economic impacts were recorded more often and tended to be greater in magnitude than environmental impacts, with impacts recorded particularly often on agricultural and animal production (57% and 51% of cases respectively). There was variation across different regions and habitats in impact magnitude, but the differences were not statistically significant. In conclusion, alien grasses present in South Africa have caused a wide range of negative impacts across most habitats and regions of the world. Reviewing impacts from around the world has provided important information for the management of alien grasses in South Africa, and, we believe, is an important component of management prioritisation processes in general.

Keywords
alien grasses, environmental impact, GISS, impact assessment, impact magnitude, impact mechanism, socio-economic impact.

Introduction

Grasses (family Poaceae) are among the most introduced species around the world; they occur on every continent and in various habitat types (Linder et al. 2018, van Kleunen et al. 2015, Visser et al. 2016). Alien grasses are often introduced for their high economic value. They are the source for the most consumed staple foods in the world (cereal grains) (Prescott-Allen and Prescott-Allen 1990), pasturage for livestock in agriculture (Boval and Dixon 2012), energy through biofuels (Pimentel and Patzek 2005), and they are used in alcoholic beverages such as beer and whisky (Solange et al. 2014). Alien grasses have also, however, been introduced to new areas as transport contaminants and stowaways. For example, a study by Whinam et al. (2005) found that the major source of alien grass (such as *Agrostis stolonifera*) introductions into sub-Antarctic islands was the transport used for ship to shore food transfers.

Whether such introductions were accidental or deliberate, and regardless of the many benefits they provide, the introduction of alien grasses can result in invasions that cause substantial negative environmental and socio-economic impacts (Early et al. 2016, D'Antonio and Vitousek 1992, Driscoll et al. 2014). Grasses such as *Andropogon gayanus* have been reported to increase fire frequencies and intensity in fire-prone ecosystems (Rossiter-Rachor et al. 2004, Rossiter-Rachor et al. 2009, Setterfield et al. 2010). Arundo donax is known to change community structure, thereby causing habitat loss for birds and small mammals in the USA (Bell 1997). And in China, *Avena fatua* is reported to cause economic losses of US$500 million annually by invading agricultural land and reducing crop yields (Willenborg et al. 2005).

Less is known about how these impacts vary across different introduced ranges, but it has been suggested that some introduced ranges experience fewer recorded impacts from alien grasses due to context-dependent factors (Hulme et al. 2013); e.g. the level of grass invasions might track variation in fire regimes, or might be an artifact of how well studied invasions are (Visser et al. 2016). Either way, impacts of alien grasses are most likely still increasing due to factors such as climate change and propagule pressure (Chuine et al. 2012, Fensham et al. 2013). We therefore need to understand these impacts and take precautionary measures in order to prevent or reduce them (Hulme 2003, 2006, Keller and Perrings 2011). Impact assessments are cost-effective tools used to estimate the impacts of alien species and help in the decision-making process during the prioritization of limited resources (Jeschke et al. 2014, Kumschick et al. 2012, Kumschick and Richardson 2013). Impact assessments have also been used to try to identify factors that predict impacts. Studies have found that traits such as a high fecundity, a habitat generalist strategy, a wide native range, a large body size and a large clutch size are associated with high environmental impacts for mammals, birds, and amphibians (Kumschick et al. 2013, Measey et al. 2016), and traits such as height, life form and life history are associated with greater impacts for plant species (Pyšek et al. 2012, Rumlerová et al. 2016). However, traits have generally been much more successful in predicting invasion success than in predicting impact magnitude. Moreover, impact magnitude has been found to be independent of invasion success (Ricciardi and Cohen 2007).

Similar to the 'invasive elsewhere' strategy of predicting invasion (Gordon et al. 2010), is the use of records of 'impact elsewhere' to quantify the potential impacts of alien species (Kumschick et al. 2015, Ricciardi 2003). This approach can be useful in predicting the impacts of species such as grasses with biased impact records, i.e. uneven research effort across their introduced ranges. This is because it allows species with limited information to be assessed, compared against other species, and be included in management strategies. Furthermore, the approach also facilitates the search for patterns related to the impact mechanisms and magnitudes, which can ultimately lead to a more predictive understanding of invasions.

Here we assess the environmental and socio-economic impacts of selected alien grasses occurring in South Africa by consolidating their impact records across their introduced ranges (e.g. see Kumschick et al. 2015 for examples of this for alien plants and animals in Europe, and Measey et al. 2016 for amphibians). We do this with the aim of providing quantitative estimates in order to determine which alien grasses have the greatest impacts, and to therefore assist decision makers when prioritising which alien grasses to manage. Furthermore, in order to improve our understanding of the likely impacts, we assess which factors contribute to an increased magnitude of impact in alien grasses by investigating habitats impacted by the species across different regions and determining the mechanisms through which impacts occur.

Methods

Species selection

There are approximately 256 alien grasses introduced into South Africa (Visser et al. 2017). Of these, we assessed impacts for the 58 species that occur as aliens in at least one of the other following regions: Australia, Chile, Europe or the USA. We adopted this approach because: (i) there is a limited number of studies of grass impacts in South Africa; (ii) these regions have a relatively large literature on alien grasses; and (iii) the regions are assumed to be representative of different major biogeographical realms across the world (Visser et al. 2016).

Literature search

We searched for relevant literature on the impacts caused by the selected alien grasses up to June 2016 using the Web of Science, Google Scholar, as well as biological invasion websites and databases such as Centre for Agriculture and Biosciences International (CABI) Invasive Species Compendium (www.cabi.org/isc), Invasive Species Specialist Group (ISSG) Global Invasive Species Database (www.iucngisd.org/gisd), Hawaiian Ecosystems at Risk project (HEAR) (www.hear.org), California Invasive Plant Council Inventory (www.cal-ipc.org). The grass species' scientific binomial names were used as search terms. We used synonyms and previous species names obtained from the Integrated Taxonomic Information System (ITIS) (www.itis.gov) as search terms for species with no literature record. We then selected relevant publications from the search results based on the titles and abstract content.

We used primary literature when possible, otherwise, we referred to the literature's reference list to acquire the cited literature, and the full reference to the cited literature was searched in Google Scholar. If we were still unable to access the primary literature, we noted this and recorded the primary literature as it is cited by the secondary source.

A total of 1300 published sources including >100 websites and databases were reviewed; 352 published references and 98 websites and databases were considered for the impact assessment (Appendix 1).

Impact scoring

Different methods have been developed to quantify the environmental and socio-economic impacts of alien species, with recent notable schemes including the Environmental Impact Classification for Alien Taxa (EICAT) (Hawkins et al. 2015) and the Socio-Economic Impact Classification for Alien Taxa (SEICAT) (Bacher et al. 2018). In this study, however, we chose to use the Generic Impact Scoring System (GISS) (Nentwig et al. 2016) (see Hagen and Kumschick 2018 for a comparison of the EICAT, SEICAT, and GISS schemes) as the GISS has been used widely to assess impacts of different species, and we wanted to relate our results with other previous assessments. The GISS classifies impacts into two major classes, namely (1) environmental and (2) socio-economic, with six impact mechanisms assigned for each impact class: (1.1) impacts on native plants or vegetation through mechanisms other than competition; (1.2) impacts on animals through predation, parasitism, or intoxication; (1.3) impacts on native species through competition; (1.4) impacts through transmission of diseases or parasites to native species; (1.5) impacts through hybridisation; (1.6) impacts on ecosystems (which includes changes in nutrient pools and fluxes, habitat modifications and changes in disturbance regimes); (2.1) impacts on agricultural production; (2.2) animal production; (2.3) forestry production; (2.4) human health; (2.5) human infrastructure and administration; and (2.6) human social life (Nentwig et al. 2016). For each impact mechanism a six-point ranked scale is used, ranging from zero (no impact detectable) to five (highest impact possible at a site) (Kumschick et al. 2015). The GISS contains definitions and descriptions for the impact mechanisms and the impact scores within them. We assigned an impact mechanism and score to every recorded impact obtained according to the definitions and descriptions of the GISS. Scores can be summed over mechanisms to get a total score per species, with a maximum overall impact score of 60 (12 categories * a maximum impact score of 5 in each category—see details on the scoring system in Kumschick et al. 2015, Nentwig et al. 2016). In this study, we used the maximum impact score recorded per mechanism of each species for both environmental and socio-economic impacts to rank species (see Table 1). This method of aggregating only the maximum impacts per species per mechanism was used by Kumschick et al. (2015); we also adopted it in order to make our results comparable.

Because scores are based on published research, species that receive more research attention might be expected to have higher scores (Pyšek et al. 2008). Therefore, we tested the relationship between the species' overall impact scores and the number of published papers used per species using a Pearson correlation test (Kumschick et al. 2017). We also tested whether there is a correlation between the species' overall and maximum impact score in any one impact mechanism using a Kendall's tau correlation test.

Impacts across habitat types and regions

For each impact reference, we recorded the habitats where the impacts were said to occur, using the habitats classified according to the first level of the International Union for the Conservation of Nature (IUCN) Red List Habitat Classification Scheme (Version 3.1) (www.iucnredlist.org). In cases where the study was not in a natural habitat (e.g. greenhouse or laboratory) or the habitat was not stated, we recorded the habitat as 'not specified'.

We also noted the country where the impacts occurred for each impact recorded and determined whether the grass species was native or alien in that specific country. Impact records from the native range were excluded from further analyses. We did, however, retain cases where the country was not specified but the grass species was referred to as "alien", "introduced", or "non-native". We assigned each record to one of eight regions based on the location of the country in which the impacts were recorded. We used a Kendall's tau test to determine the correlation between the maximum impact of alien grasses in South Africa and the maximum impact elsewhere.

Statistical analysis

In contrast to the approach taken above to rank species, when testing the relationship between impact and habitats and region, we used the raw data on impact scores (i.e. each impact record was considered as a separate datum). The impact scores analysed here are therefore ordinal variables in which the scores are ordered (but which closely resemble a logarithmic scale). As such, we used a cumulative link mixed-effects model in the R package 'ordinal' (Christensen 2015) to test whether habitats and regions influ-

Table 1. Grasses alien to South Africa and one other region (Chile, Europe, Australia and the USA) ranked according to impacts. The numbers under environmental and socio-economic impacts are the respective sums of the maximum impact scores per impact mechanism of a species. Species that score a maximum of 5 in any one impact mechanism are highlighted in bold. NA indicates no impact found for that species, hence not applicable. Total impact represents the overall sum of the environmental and socio-economic impacts. Species marked with an asterisk* have impacts recorded in South Africa. Literature used and detailed maximum scores per mechanism are available in the Supporting Information (Appendix S1 and Table S1).

Species name	Environmental impacts	Socio-economic impacts	Total impact
*Cortaderia selloana**	7	11	18
*Arundo donax**	10	7	17
*Avena fatua**	10	7	17
*Elymus repens**	10	7	17
Festuca arundinacea	8	9	17
Nassella trichotoma*	**6**	**9**	**15**
Sorghum halepense*	**6**	**8**	**14**
Bambusa vulgaris	8	5	13
*Bromus tectorum**	7	8	13
Cortaderia jubata	7	8	13
Paspalum notatum	3	10	13
*Bromus rubens**	9	3	12
Glyceria maxima*	**4**	**8**	**12**
Brachypodium distachyon	9	2	11
Vulpia myuros	2	9	11
Holcus lanatus	7	3	10
*Hordeum murinum**	7	3	10
Paspalum dilatatum	2	8	10
Phalaris aquatica	**5**	**5**	**10**
*Agrostis stolonifera**	6	3	9
Arrhenatherum elatius	5	4	9
Bromus rigidus	2	7	9
Dactylis glomerate	3	6	9
Hordeum jubatum	4	5	9
*Poa annua**	5	4	9
Polypogon monspeliensis	**2**	**7**	**9**
Vulpia bromoides	5	4	9
Bromus madritensis	5	3	8
Lolium multiflorum	4	4	8
Aira caryophyllea	4	3	7
Avena barbata	6	1	7
*Bromus catharticus**	6	1	7
Lolium perenne	2	5	7
Poa pratensis	5	2	7
Briza maxima	6	NA	6
Bromus diandrus	NA	6	6
Digitaria sanguinalis	3	3	6
Lolium temulentum	2	4	6

Species name	Environmental impacts	Socio-economic impacts	Total impact
Paspalum urvillei	4	2	6
*Pennisetum setaceum**	5	1	6
Cenchrus spinifex	2	2	4
Cynosurus echinatus	4	NA	4
*Paspalum quadrifarium**	3	1	4
Avena sterilis	NA	3	3
Bromus hordeaceus	3	NA	3
Oryza sativa	2	NA	2
Panicum miliaceum	NA	2	2
*Pennisetum villosum**	1	1	2

ence impact magnitude. Since we found multiple studies that assess the same impacts for the same species in the same region or habitat, we included species identity, as well as mechanism nested in impact type (environmental or socio-economic) as random factors and impact mechanism, habitat type, and region as fixed effects. We also tested a model in which mechanism nested within impact type was included as a fixed effect but found this made no difference to the results. We did not investigate interactions among predictors because of the limited number of observations. To determine the goodness of fit for the model we calculated pseudo R^2 by fitting a null model with no predictor variables and compared it against the full model using the 'nagelkerke' function within the R package 'rcompanion' (Mangiafico 2016). We tested the significance of fixed effects using analysis of deviance of single-term deletion models tested against the full model using a chi-squared distribution from the 'drop1' command. We used least-squares means with P values adjusted using the Tukey method, to determine significant differences between the levels of each predictor (mechanism, habitat and region).

All statistical analyses were performed using R version 3.4.4 (R Core Team, 2018).

Results

Grasses ranked by impact

Of the 58 alien grasses selected for impact assessment, we found records of impact for 48 species, i.e. 10 species (Suppl. material 1: Table S1) were data deficient with no record of impact. The species with the highest overall impact score was *Cortaderia selloana* (impact magnitude = 18), followed by *Arundo donax*, *Avena fatua*, *Elymus repens*, and *Festuca arundinacea* (all with impacts of 17, Table 1). However, a different set of species scored the maximum possible impact of five on any one particular impact mechanism, namely, *Glyceria maxima* (animal production), *Nassella trichotoma* (animal production), *Phalaris aquatica* (predation or parasitism or intoxication and animal production), *Polypogon monspeliensis* (animal production), and *Sorghum halepense* (agricultural production) (see Suppl. material 1: Table S1).

Table 2. Cumulative link mixed effects model estimating the effect of habitat, region and impact mechanism on overall impact magnitude of the studied alien grasses (m1). The significance of predictor variables was determined using single-term (predictor) deletion models tested against the full model. Models were run with species identity, and mechanism nested within mechanism type (environmental or socio-economic) as random factors. AIC is the Alkaike's Information Criterion, and P is the chi-squared p-value.

Model	Df	AIC	P
m1		2203.4	
Habitats	9	2193.8	0.49
Regions	8	2202.5	0.06
Mechanisms	11	2219.3	< 0.001

We used a total of 352 published literature sources; however, the literature was highly skewed, ranging from one to 23 publications per species. Some literature sources reported on more than one species. We found a significant positive correlation (tau = 0.48, P = 0.006) between the overall impact scores per species and the number of publications used to score the impacts. However, this potentially only affects the relative rankings of species according to impact scores (Table 1), because for the mixed effect model analyses, we did not aggregate maximum records of the species and used each paper as a separate record.

Impact magnitudes across mechanisms

We found that three-quarters (36 out of 48) of alien grass species have records of causing environmental impacts through competition with native species, and half (24 out of 48) of the species have records of causing impacts on ecosystems (Figure 1). We found the fewest records and the lowest overall impact through the 'plants or vegetation' mechanism, which according to the GISS includes allelopathy or the release of plant exudates (Nentwig et al. 2016). Most socio-economic impacts are caused through agricultural and animal production, with 29 and 26 cases respectively, while forestry production was represented by few species (Figure 1). The maximum impact possible (5), was recorded for impacts on animals through predation or parasitism, animal production and agricultural production. When comparing scores between impact types, greater impact magnitudes of 4 and 5 were obtained for socio-economic than environmental impacts.

The effects of impact mechanisms, impacted regions, and habitat types on impact magnitude

We found that impact mechanism is the only statistically significant predictor of impact magnitude (P < 0.001, Table 2). Results from the model show that alien grasses have a lower impact magnitude through the transmission of diseases or parasites to native species and greater impacts on native animals through food availability or palatability and intoxication (Figure 2). There is a trend towards greater impact magnitude in Antarctica (Suppl. material 1: Figure S1); however, differences across regions are not significant (P = 0.057, Table 2). We found nine habitats impacted by alien grasses;

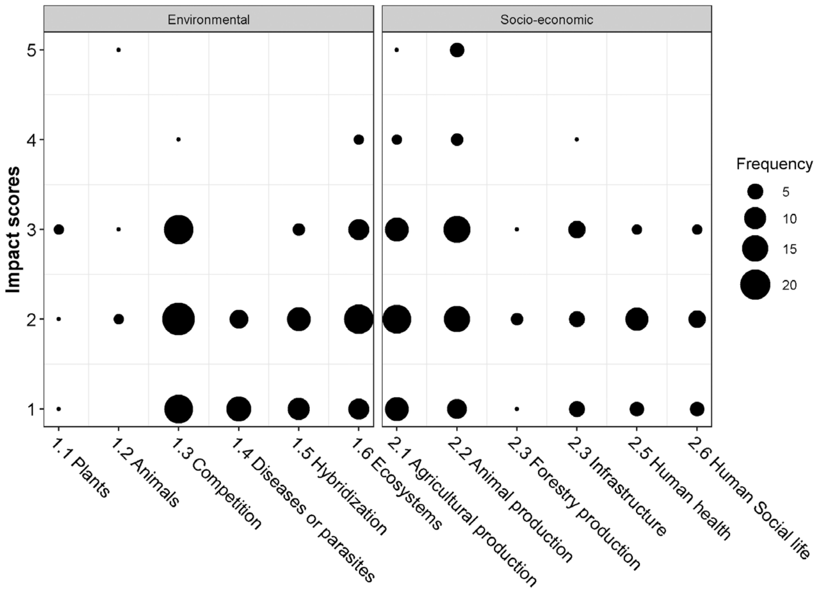

Figure 1. Number of alien grass species per impact mechanism for each impact magnitude. On the x-axis are the GISS environmental and socio-economic impact mechanisms, and on the y-axis are the impact scores according to GISS. The size of the points represents the number of species which had the corresponding maximum recorded impact score for that mechanism (out of the 48 species with impact records). See Suppl. material 1: Table S1 for the full details.

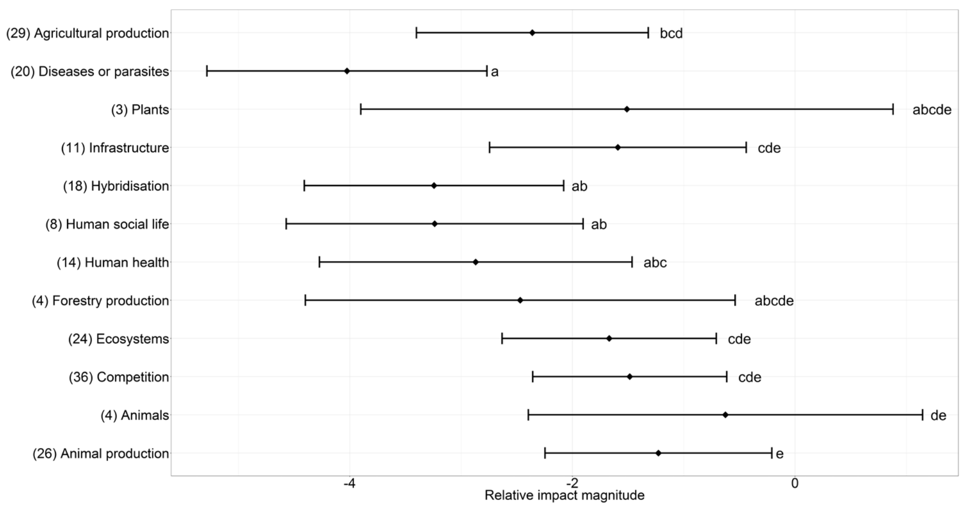

Figure 2. The impact magnitude of the 48 studied alien grasses across different impact mechanisms. On the x-axis are the least-squares means of the impact scores as derived from a cumulative link mixed effects model, and on the y-axis are the GISS impact mechanisms with the number of species in brackets. The points represent the impact magnitudes and the error bars represent 95% confidence intervals. Letters on the right side of the confidence intervals are level groupings indicating significant differences among the mechanisms (level groupings with the same letters are not significantly different, comparisons are Tukey adjusted).

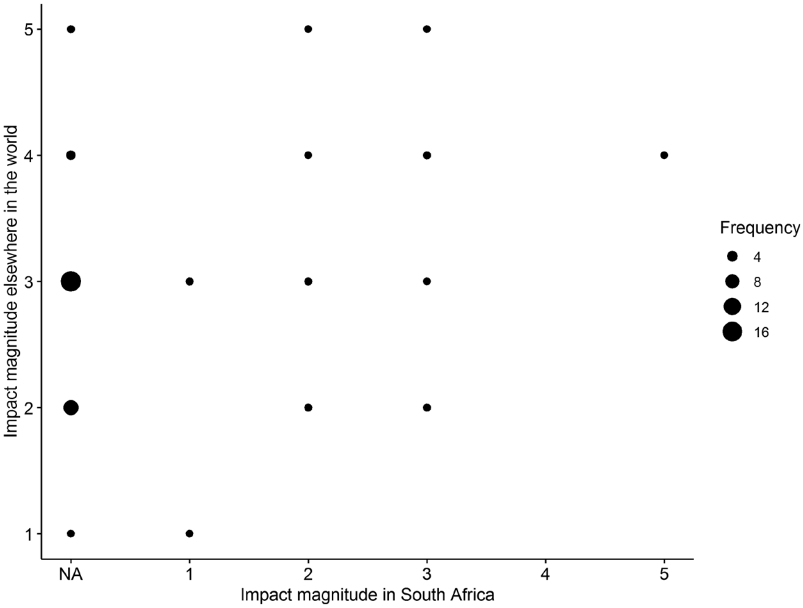

Figure 3. Comparison between impact magnitude of alien grasses in South Africa and elsewhere in the world. The values 1 to 5 on the x- and y-axis represent the GISS impact magnitudes and NA indicates no impact record found. The size of the points represents the frequency of species with impacts records.

however,as with "region" as a predictor of impact magnitude, habitat type was also not a significant predictor (P = 0.49, Table 2), and differences among habitats were not statistically significant (Suppl. material 2: Figure S2). Including mechanism nested within impact type (environmental or socio-economic) as a random effect provided no improvement in model fit (Suppl. material 1: Table S2). However, we kept this nested random effect in the analysis because it accounts and corrects for non-independence of the observations and reflects the actual design of this study.

Impact of alien grasses in South Africa versus elsewhere

We found that only 16 of the 58 alien grasses had recorded impacts in South Africa, 13 for inland and three for the offshore islands (Table 1). These impacts were mostly lower than elsewhere, with the exception of *Nassella trichotoma* and *Hordeum murinum* (Figure 3). However, there is no correlation ($\tau = 0.14$, P = 0.28) between impacts of alien grasses in South Africa and those recorded elsewhere in the world.

Discussion

This study is the first environmental and socio-economic impact assessment to focus specifically on alien grasses. Using the GISS we were able to quantify the impacts of alien grasses using information from across the globe. This study, therefore, provides a useful overview of the literature on evidence-based impacts of alien grasses and highlights potential risks to South Africa. Furthermore, it shows gaps in the available literature as some species could not be assessed due to a lack of impact studies.

We found that alien grasses generally scored higher for socio-economic than environmental impacts. Grass impact scores were particularly high for agricultural and animal production. This might reflect the large number of agricultural weeds that are grasses (Daehler 1998) or their initial introduction for agricultural purposes (Hancock 2012). Alien grasses scored the lowest for impacts caused via transmission of diseases or parasites to native species, with a maximum score of 2, which represents a minor impact (Nentwig et al. 2016), while the frequency under this mechanism was larger. On the contrary, mechanisms with scarce literature, such as impacts on native animals, obtained higher impact scores. This could be because impacts through the transmission of disease or parasites between plant species are not readily observed in the wild, most of the literature under this mechanism is form small-scale laboratory studies which do not report impacts on the overall population.

Despite most grasses not having very high overall impact scores compared to other species (e.g., Kumschick et al. 2015), many alien grasses scored high across the full range of impact mechanisms (i.e. alien grasses can cause a wide range of environmental and socio-economic impacts) and so had high total impact scores. For example, *Cortaderia selloana* did not have any individual mechanism score over 3 but has the highest overall score (Table 1) due to the many different mechanisms through which it causes impacts. In contrast, *Polypogon monspeliensis* and *Phalaris aquatica* scored the highest impact (5) in certain impact mechanisms, but their overall score is lower. This trend is not observed in other studies, such as the one conducted on alien aquatics by Laverty et al. (2015), where the species with the highest overall score also obtained an impact score of 5 for two different mechanisms. Grasses thus provide an interesting case to explore whether we should be more concerned with invasive species that cause a range of different types of impacts or invasive species that only cause a few types of impacts but with greater magnitude.

Grasses are one of the most cosmopolitan plant families in the world and are present in almost all terrestrial habitats. They also impact a wide range of habitats, as demonstrated in this study. Knowledge about which habitats are most severely impacted by alien grasses is essential for their management. Grasses can cause rapid and dramatic transformation of non-grassy habitats into grass-dominated communities. For example, *Bromus rubens* and *B. madritensis* have caused widespread transformation of shrubby systems in the Mojave Desert (DeFalco et al. 2007, Jurand et al. 2013). With regards to regions, we found that Antarctica (sub-Antarctic islands mostly) on average has the highest alien grass impact scores. Grasses such as *Agrostis stolonifera* reduce moss diversity, liverwort populations, and replace the rosaceous dwarf shrub (*Acaena magellanica*) with dense grassland patches on Marion Island (Gremmen et al. 1998). It is not clear, however, whether this trend is due to differences in sampling effort or a greater susceptibility of sub-Antarctic islands to impacts than the mainland (Hagen and Kumschick 2018).

However, neither habitat nor region were found to be significant predictors of impact magnitude. This could suggest that the impacts are the same across habitats and regions, but the lack of signal likely also reflects the low sample sizes for most habitat types and some regions. Furthermore, it will be interesting to repeat this study based on a more representative global sample of species (the bias in this current analysis towards grasses alien to South Africa was simply for applied reasons).

When we compare impacts scores of alien grasses with impact scores of studies that assessed other plant taxa (Kumschick et al. 2015, Rumlerová et al. 2016), our results also show that the competition with native plant species is the most frequent mechanism through which alien grasses cause impacts. Four species from our list were previously assessed in those studies (Kumschick et al. 2015, Rumlerová et al. 2016), and our results were similar to them for two of the species (*Arundo donax* and *Paspalum dilatatum*), each with a difference of less than 5 between the overall impact scores. However, we obtained higher overall impacts than Kumschick et al. (2015) and Rumlerová et al. (2016) for the other two species (*Cortaderia selloana* and *Hordeum jubatum*), each with a difference of 9 and 8 respectively. These differences can be explained by the broader search criteria applied; for example, authors of the above-mentioned studies used keywords such as "invas* or exot* or weed*" in addition to the species name, while we only used the species name as a search term.

Although impacts of alien grasses are poorly studied when compared to other species, such as birds and mammals, we were able to find impact records for more than 80% of the grass species selected for the assessment, which is higher than for other species, such as amphibians (41.3%) (Measey et al. 2016). The average number of papers (5.7) used to score impacts of alien grasses across the globe was also higher than the amphibians and other species (Kumschick et al. 2015, Measey et al. 2016). Similar to the mammals and other plants (Kumschick and Nentwig 2010, Kumschick et al. 2015), alien grasses were also reported to cause impact across all impact mechanisms. This might be because grasses occur across a wide range of sectors and habitats, which allows them to exert impact across all mechanisms. When prioritising management of all alien species, our list can be compared to other assessments conducted for other species, such as birds, amphibians, mammals, and aquatic species (Kumschick and Nentwig 2010, Laverty et al. 2015, Measey et al. 2016, Nentwig et al. 2010). However, it is important to note that impact assessments of some of those species are based on impacts recorded only in Europe and not globally, which may cause a bias to the overall impact scores. More impact studies are still needed for alien grass species, especially when it comes to species with no impact records across all introduced ranges, but with taxonomic characteristics of invaders (such as *Bambusa balcooa*, Canavan et al. 2016). It will be interesting to see if the findings of Canavan et al. (2018a), that bamboos have similar impacts in their native and alien ranges are the same for other grasses or perhaps only other tall-statured grasses (Canavan et al. 2018b). However, we suspect there are qualitative differences between the impacts in the native and alien ranges, for the grasses studied here, as the impacts observed are not primarily a response to human disturbance.

Two species were scored as causing very high impacts (4 or 5) outside of South Africa, but only low levels of impact (1 or 2) in South Africa. For instance, *Glyceria maxima* obtained a score of 5 because it is associated with the death of livestock through poisoning in Australia (Barton et al. 1983), but such impacts have not (yet) been recorded in South Africa. This can flag species that could potentially cause high impacts in South Africa and which should therefore be monitored, or preventative measures put in place to limit such impacts occurring in future. In most other cases the impact elsewhere was either the same or slightly higher than that recorded in South Afica, except for *Agrostis stolonifera*, *Hordeum murinum*, and *Nassella trichotoma*. This included two species (*Nassella trichotoma* and *Hordeum murinum*) whose impacts in South Africa were one level higher than elsewhere. For example, *Nassella trichotoma* obtained a score of 5 in South Africa and 4 elsewhere (in Australia) for impacts on animal production by reducing livestock carrying capacity and pasture production (Klepeis et al. 2009). The lack of correlation between impacts found in South Africa and elsewhere should, however, be assessed with caution – it is indicative of a research gap. Records of impacts are generally fewer in South Africa (with a maximum of five sources per species and an average of 1.9) and even lacking for most species. Alternatively, it could indicate that there is an impact debt (Rouget et al. 2016), i.e. species have not reached their full impact potential in South Africa (yet), as species with more information in South Africa did not show higher similarities in impact magnitudes to elsewhere. Finally, South Africa might be more resilient to grass invasions, and impacts are actually lower here (Visser et al. 2017). These hypotheses warrant more research and can only be disentangled once more data become available.

In summary, the lack of statistically significant differences in impact magnitudes across habitats and regions for alien grasses suggests that impact in this group is not habitat or region specific as in other groups (cf. Hulme et al. 2013, Pyšek et al. 2011). As such, we recommend that different habitats should be equally considered for alien grass impact management. While we recommend that impact scoring schemes, such as the one used in this study, should be incorporated in the decision-making processes for alien species management, we caution that extrapolations from other invaded regions indicate potential and not actual impacts.

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Appendix 1

Literature, websites, and databases used to score environmental and socio-economic impacts of 58 alien grass species according to the GISS.

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Supplementary material 1

Table S1, Table S2, Figure S1

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Data type: species data

Link: https://doi.org/10.3897/neobiota.41.26599.suppl1

Supplementary material 2

Figure S2

Authors: Khensani V. Nkuna, Vernon Visser, John R.U. Wilson, Sabrina Kumschick

Data type: statistical data

Explanation note: The impact magnitude of the 48 studied alien grasses across different habitats. The impact magnitudes on the x-axis are the least-square means of the impact scores as derived from a cumulative link mixed effects model. On the y-axis are the habitat types impacted by alien grasses and in brackets is the number of species with records in that habitat. The points represent the impact magnitudes and the error bars represent 95 % confidence intervals. Letters on the right side of the confidence intervals are level groupings indicating no significant differences among the habits. Comparisons are Tukey adjusted.

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