Managing alien bird species:

Time to move beyond "100 of the Worst" lists?

Sabrina Kumschick[1]*, Tim M Blackburn[2,3,4] & David M Richardson[1]

[1] *Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa. sabrina.kumschick@alunmi.unibe.ch*

[2] *Department of Genetics, Evolution and Environment, Centre for Biodiversity and Environment Research, University College London, Gower Street, London WC1E 6BT, UK*

[3] *Institute of Zoology, Zoological Society of London, Regent's Park, NW1 4RY London, UK*

[4] *School of Earth & Environmental Sciences and the Environment Institute, University of Adelaide, South Australia 5005, Australia*

** Corresponding author: sabrina.kumschick@alunmi.unibe.ch*

Summary

Alien species can cause severe impacts in their introduced ranges, and management is challenging due to the large number of such species and the diverse nature and context of their impacts. Lists of the most harmful species, like the "100 of the World's Worst" list collated by the Invasive Species Specialist Group of the International Union for Conservation of Nature (IUCN) or the "100 of the Worst" invaders in Europe collated by the Delivering Alien Invasive Species Inventories in Europe (DAISIE) project, raise awareness about these impacts among the public, and can guide management decisions. Such lists are mainly based on expert opinion, but in recent years more objective comparison of impacts has become possible, even between highly diverse taxa. In this study, we use a semi-quantitative generic impact scoring system to assess impacts of the three birds listed among the "100 of the World's Worst" IUCN list (IUCN100) and the four birds on the list of "100 of the Worst" European invaders by DAISIE (DAISIE100) and to compare their impacts with those of other alien birds not present on the respective list. We found that generally, both lists include some of the species with the highest impacts in the respective regions (global or Europe respectively), and these species therefore deserve the dubious honour of being listed among the "worst". However, there are broad overlaps between some species with regards to the impact mechanisms and the related issues of invasions, especially those of the common myna and red-vented bulbul on the IUCN100 are very similar which might not warrant listing both species. To make the selection of species on such lists more transparent we suggest moving beyond lists based on expert opinion to a more transparent and defendable system for listing alien species based on published records of their impacts and related mechanisms.

Keywords

biological invasions, impact, invasive species, hybridisation, *Acridotheres tristis*, *Sturnus vulgaris*, *Pycnonotus cafer, Branta canadensis*

Introduction

Global trade is causing an increasing number of species to be transported outside of their native ranges, and many of these species subsequently establish self-perpetuating populations in new environments (Elton 1958; Richardson 2011). Many of these alien species are relatively benign additions to native biotas, but some have major impacts in their recipient environments. Managing such impacts is an important task for biodiversity conservation, since invasive alien species often have major impacts on biodiversity (e.g., Clavero & Garcia-Berthou 2005), and can cause economic damage. The most cost-effective management option for harmful alien species is to prevent their arrival in the first place (Keller et al. 2007), and border-control risk assessments have been implemented in many parts of the world to this end (Kumschick & Richardson 2013). However, this is not an option for already established alien species, for which other management approaches such as eradication, containment, or mitigation of impacts are required.

It has been estimated that around 400,000 species have been introduced to areas outside of their native geographic ranges (Pimentel et al. 2001), posing a massive management challenge. One response has been to compile lists of alien species to categorise and prioritise species for management (Burgiel & Perrault 2011), and various lists purporting to identify some of the most harmful alien species have been developed (Lowe et al. 2004, Streftaris & Zenetos 2006, Vilà et al. 2009). The most prominent of these are the “100 of the World’s Worst” list compiled by the IUCN Invasive Species Specialist Group (Lowe et al. 2004), hereafter called IUCN100, and the “100 of the Worst” invaders in Europe collated within the DAISIE (Delivering Alien Invasive Species Inventories in Europe) project (Vilà et al. 2009), hereafter called DAISIE100. These lists include a variety of taxa, including animals, plants and microorganisms. Neither was intended to be a definitive catalogue of the worst invaders, but rather they were developed to showcase the diversity of alien species and the diversity of impacts they can have. Thus, the selection of species for inclusion on the lists was based on the severity of impacts on biological diversity and/or human activities, the illustration of important issues of biological invasion and the representation of several taxonomic groups (Lowe et al. 2004; Vilà et al. 2009). The actual choice of species was based largely on expert opinion, and the primary purpose of the lists was to raise awareness about invasive alien species and their impacts in general. The lists nevertheless provide specific targets for action by decision makers and the public, and therefore focus attention on a few key examples rather than "diluting" communication efforts with the full spectrum of alien species and related issues (Luque et al. 2014). While the main intended purpose of these lists was to educate the public, they have also been used by the scientific community, with more than 1,300 citations for the IUCN100 list in the scientific literature (Google Scholar March 2015). Furthermore, they have provided guidance for policy documents (Shine et al. 2000; Genovesi & Scalera 2007).

The IUCN100 list includes three bird species: the common myna (*Acridotheres tristis*), European starling (*Sturnus vulgaris*) and red-vented bulbul (*Pycnonotus cafer*). Four different bird species are present on the DAISIE100 list: the Canada goose (*Branta canadensis*), ruddy duck (*Oxyura jamaicensis*), ring-necked parakeet (*Psittacula krameri*) and sacred ibis (*Threskiornis aethiopicus*). The impacts of alien birds can be severe (Kumschick & Nentwig 2010; Evans et al. 2014), resulting in substantial costs (Pimentel 2002). However, there are more than 400 bird species with established alien populations somewhere in the world (Dyer & Blackburn unpub.), and 175 species introduced to Europe (www.europe-aliens.org) and exactly what merits these exemplar species to be chosen as among the 100 worst, rather than any of the others, is not always clear. Here, we attempt to clarify this question using a recently developed impact scoring system, based on semi-quantitative scenarios, to assess the impacts of the seven alien bird species on these lists. We used the scores we derived to compare the impacts of these species with those of a sample of other alien birds, as a means to explore the selection of the species, and to discuss potential caveats with respect to the lists. We aim to test whether the birds on the “100 worst” lists are indeed worthy of this dubious honour. Furthermore, we discuss the utility and benefits of a transparent system for alien species listing. Finally, we suggest a more transparent approach for alien species listing according to their impacts using a semi-quantitative method that includes a systematic review of the literature on a species’ impacts and is therefore more objective than using expert opinion alone, and which can support decisions related to alien species management and help to resolve disputes about their impacts.

Methods

To find the relevant studies where the impacts of the seven listed bird species were mentioned, we conducted a thorough literature search on ISI Web of Knowledge and Google Scholar, using the species’ scientific names as the search terms. We filtered titles and abstracts to find publications on impact and studied the relevant literature in more detail for the scoring. In addition, we included references cited therein, and information in online databases on alien species (www.issg.org/database/welcome, www.europe-aliens.org, www.nobanis.org) as well as primary literature and catalogues on alien birds (Lever 2005; Long 1981). Grey literature was also included where appropriate. Only impacts recorded in the alien ranges of the species were considered. The identified impacts were then categorised using the generic impact scoring system (GISS) originally developed for mammals (Nentwig et al. 2010), and subsequently extended and applied to birds (Kumschick &

Nentwig 2010; Evans et al. 2014) and various other taxa (Kumschick et al. 2012; Vaes-Petignat & Nentwig 2014; van der Veer & Nentwig 2014; Kumschick et al. 2015). The GISS covers environmental and economic impacts, each of which it divides into six distinct impact categories. Environmental impacts consist of competition, predation, herbivory, hybridisation, transmission of diseases and impacts on the ecosystem as a whole, other than the ones covered by the other categories. Economic impacts in the scoring system consist of impact on agriculture, forestry, human health, livestock, infrastructure and human social life.

Each of the categories includes verbal descriptions of scores ranging from 0 (no impact detectable) to 5 (highest impact possible at a site). Impacts recorded in the literature can be matched against these scenarios to derive a numerical estimate of the magnitude of a species' impact in a given category. We then calculated two measures as an indication of a species overall impact on the recipient system. On the one hand, we summed these estimates over the 12 categories as suggested in the original publication by Nentwig et al. (2010) and others who used the scoring system subsequently to give an estimate of a species' environmental impact, economic impact, and total impact (environmental plus economic). As a second measure, we used the maximum score reached in any category as an indicator of a species' most severe impact. A similar approach was suggested by Blackburn et al. (2014) to facilitate the listing of alien species; in Blackburn et al.'s system it is harder to achieve a high score due to slight changes in the description of the categories, and it exclusively includes impacts on the environment, but the general idea remains the same. We compared these scores to those previously calculated for alien bird species in Europe by Kumschick & Nentwig (2010), updated for worldwide impacts by Kumschick et al. (2015), and for alien bird species in Australia (Evans et al. 2014), updated using a literature search as described above to assess the impacts of these species outside of their Australian ranges (this study).

The GISS has been proven useful to compare impact magnitudes between taxa as different as animals and plants, and can therefore provide an objective means to support alien species listing processes. More detailed descriptions of the GISS and its uses can be found in previously published studies (Nentwig et al. 2010, Kumschick & Nentwig 2010, 2011, Kumschick et al. 2011, 2012, 2013, Evans et al. 2014, Vaes-Petignat & Nentwig 2014, Blackburn et al. 2014, Kumschick et al. 2015).

Results

On the global IUCN100 list, the common myna attained the highest summed impact score of the three listed bird species, with a total impact score of 31. It received maximum scores of 5 for impacts through competition (aggression towards the endangered Tahiti flycatcher *Pomarea nigra*; Blanvillain et al. 2003) and predation (Table 1). The European starling scored 23 in total, with highest scores of 4 in two categories. The red-vented bulbul scored 11 points in total and received a maximum score of 5 due to its potentially devastating impact on the endangered Tahiti flycatcher and other *Pomarea* species endemic to the southeastern Pacific (Blanvillain et al. 2003).

Two of the three species listed on the global IUCN100 list - the common myna and European starling - attain high total impact scores relative to other bird species, including impacts on environment and economy (Table 1). They are exceeded in total impact only by four or five species, respectively. There may in fact be other birds with impacts higher than the ones on the IUCN100 list, but only alien birds in Europe and Australia have been systematically assessed to date (Kumschick & Nentwig 2010;

Evans et al. 2014). Despite that, and in contrast, the red-vented bulbul's total GISS score was less than half those of the common myna and European starling, and lower than or similar to that of many other alien birds which are absent from the IUCN100 list (Table 1).

In contrast to the IUCN100, which is a global list, DAISIE100 consists only of alien species introduced to Europe. It includes the species with the highest total score reached by any bird assessed to date (total score of 38), namely the Canada goose (*Branta canadensis*) (Table 2). The four bird species represented amongst DAISIE100 all score higher than other species introduced to Europe and/or have a maximum impact of 5 (ruddy duck *Oxyura jamaicensis* through hybridisation).

The main types of impact for the >50 alien bird species studied in Australia and Europe were competition, disease transmission to wildlife and/or humans, and agriculture, where over 25% of the selected species from each continent had an impact in the respective categories. Looking at Europe only, hybridisation was the most prominent category and almost 58% of alien birds in Europe had reported impact. Considering the representation of these impact mechanisms in the lists, we found that the all had impacts through competition and all but two (ruddy duck and sacred ibis) on agriculture. The common myna and European starling have also been reported to be important hosts of diseases for wildlife, while the Canada goose and ring-necked parakeet are of human health concern (Table 1 and 2). This largely represents the most important mechanisms of impacts for alien birds globally. Hybridisation is represented on the DAISIE100 list by the ruddy duck, while none of the three bird species on the IUCN100 list had reported impacts in this category.

Discussion

We used the semi-quantitative GISS (Kumschick & Nentwig 2010), an impact scoring system developed to compare highly diverse impacts between species and higher taxa, to assess the impacts of the bird species on the IUCN100 and DAISIE100 list. This comparison clarifies how these species compare to other alien birds in terms of the severity of their impacts, and which specific components of impact, or which issues related to alien species' invasions, they represent.

The highest total scores reached by the birds assessed to date except for the Canada goose were mainly caused by bird species native to Europe, namely by the house sparrow (*Passer domesticus*; 33 points), the rock pigeon (*Columba livia*) and the mallard (*Anas platyrhynchos*; both 32 points). This explains why they are missing from DAISIE100, but all these species reach higher scores than the three species listed on IUCN100 as well. Five other alien bird species (spotted dove *Streptopelia chilensis*, European blackbird *Turdus merula*, tree sparrow *Passer montanus*, sacred ibis *Threskiornis aethiopicus* and ring-necked parakeet *Psittacula krameri*; Kumschick & Nentwig 2010, Evans et al. 2014; Kumschick et al. 2015 and this study) have been found to have a total impact higher than or equal to the score of 11 achieved by the red-vented bulbul (listed on IUCN100). The two of these species which have been introduced to Europe (sacred ibis and ring-necked parakeet) are represented on DAISIE100.

For comparing the highest score reached in any one category, impact can be minor (score 1 or 2), moderate (score 3), major (score 4) or massive and in some cases irreversible (score 5) (similar to Blackburn et al. 2014). In this context, the red-vented bulbul and common myna both have massive impacts according to the GISS due to competition with endangered birds on islands in the southeastern Pacific (Blanvillain et al. 2003), whereas the highest impact recorded for the European starling (agricultural damage) is “only” considered to be major (e.g., Brugger et al.

1993). Therefore, of the three bird species on the IUCN100 list, only the common myna reaches both a high total score, due to its considerable impacts in many different categories, and the highest maximum score in a single category, through its threats to globally endangered species. Several other bird species not listed as among the IUCN100 reach the same maximum score of 5 in one or several of the impact categories (Table 1 & 2).

The authors of the IUCN100 list stated that the magnitude of impact is not the only criterion upon which species were included - another consideration was the “illustration of important issues of biological invasion” (Lowe et al. 2004). A comparison of the types of impacts displayed by the common myna, European starling and red-vented bulbul to those of other alien bird species reveals that the most common components of alien bird impacts are represented by the chosen species. The three bird species listed are all important agricultural pests (Lowe et al. 2004), while two of the three species potentially threaten globally endangered native birds on islands through aggressive behaviour and competition for nesting sites. In fact, the red-vented bulbul and common myna overlap considerably in these habitats, and their impacts in this respect cannot always be clearly separated (e.g. Thibault et al. 2002; Blanvillain et al. 2003). Consequently, the important issues of biological invasion represented by these three bird species overlap somewhat.

The DAISIE100 list represents the issues alien birds cause in Europe and captures many of the worst avian invaders (Kumschick & Nentwig 2010 and this study). The common myna has a higher global impact than three out of the four birds in DAISIE100, but these impacts have not been expressed in Europe. For most of the other species listed in Table 2 (except the two *Estrilda* species and *Amandava amandava*) the impacts were recorded in Europe.

Hybridisation and introgression are among the known threats that alien animal species pose to recipient communities (Rhymer & Simberloff 1996), and these have been argued to be important mechanisms of impact for alien birds as well (Baker et al. 2014; Kumschick & Nentwig 2010; Kumschick et al. 2011; Kumschick et al. 2015). Several alien bird species, mainly ducks and geese (Anseriformes), readily hybridise with native species (e.g., Table 2). A high profile example is the ruddy duck, which hybridises with the endangered white headed duck (*O. leucocephala*) in Spain (Hughes 1996; Munoz-Fuentes et al. 2007); due to its high impact on an endangered species its inclusion on DAISIE100 is justified, even though its total impact is relatively low. Another example is the mallard, native to Europe, which hybridises with several other duck species worldwide, including the American black duck (*A. rubripes*; Mank et al. 2004), grey duck (*A. superciliosa*; Hitchmough et al. 1990, Tracey et al. 2008), endemic yellow-billed duck (*A. undulata*) in South Africa (Hockey et al. 2005; Lever 2005) and potentially also with endemic species in Australia (Guay & Tracey 2009). Both the ruddy duck and mallard are threatening at least one endangered or endemic native bird species with extinction, or have already led to local extinctions (Baker et al. 2014), yet this significant impact mechanism is not captured on the list of IUCN100 for birds. For a few other animals on the list, hybridisation is mentioned as a (potential) impact on the Global Invasive Species Database (www.issg.org/database/welcome/), namely the crab-eating macaque (*Macaca fascicularis*; potential hybridisation with *Macaca mulatta*), brown trout (*Salmo trutta*; Fumagalli et al. 2002), red-eared slider (*Trachemys scripta elegans*; Powell & Incháustegui 2009), and red fox (*Vulpes vulpes*); the impact of the last is a subspecies and probably of less conservation concern (Sacks et al. 2011). The brown trout however has massive impacts and its hybridisation with endemic marble trout (*Salmo marmoratus*) has led to this species being considered one of the most endangered freshwater fish of the Adriatic basin (Delling et al. 2000). The red-eared slider potentially contributes to the threatened status of two native pond turtles in the Dominican Republic (Powell & Incháustegui 2009).

Lists of harmful species such as the IUCN100 are important tools to educate the public about sensitive issues, but they are also crucial for alien species management and can influence policy (Shine et al. 2000; Genovesi & Scalera 2007). Both, the IUCN100 and DAISIE100 list have probably largely served their intended purposes to raise awareness of problems associated with invasive species. However, a more robust and repeatable framework is needed for scientific purposes, and to prioritise alien species for management. Ranking species with diverse impacts based on expert opinion alone is likely to give subjective outcomes, and could be misleading.

Furthermore, depending on the scale of the assessment and the distribution of the species, a different set of species will be considered as "the worst". For example, there is no overlap between the worst birds listed on IUCN100 and DAISIE100. For policy implications based on such lists it is crucial to consider these factors. Also, there are clearly many species not featured in the IUCN100 or DAISIE100 list that have huge impacts, and an unintended consequence of this may be that their absence from the list creates the impression that they are not worthy of management actions or studies on their impacts.

As Luque et al. (2014) note in their discussion of the IUCN100 list, "… it [is] very hard to rank diverse species with such varied impacts". Nevertheless, the ranking of diverse alien species according to impact severity is possible if a formal quantitative or semi-quantitative framework is adopted, and such a ranking has now been performed several times for different taxa and regions (e.g. Nentwig et al. 2010, Kumschick & Nentwig 2010, Evans et al. 2014, Vaes-Petignat & Nentwig 2014, van der Veer & Nentwig 2014, Kumschick et al. 2015). A unified classification system for alien species based on exactly such a procedure was also proposed recently (Blackburn et al. 2014), and we provide another application of a semi-quantitative ranking framework in this study based on a combination of the total impact and the maximum impact recorded in any one category.

The new impact classification scheme (Blackburn et al. 2014) and the GISS used in this study (see also Kumschick & Nentwig 2010) offer the means for more objective listing of alien species impacts, and for ranking or scoring species in a way that could inform policy and management. Not only do these schemes provide semi-quantitative assessments of impacts (which facilitates comparisons between species and across taxa), but they also give an indication of the mechanisms whereby the impacts are caused (e.g. Kumschick & Nentwig 2010, Kumschick et al. 2011). This provides an important overview of the "issues of biological invasions" and can improve the choice of alien species for the "worst invaders" lists.

It is clearly desirable to work towards regularly updated lists of key target species for management, as the status of species as aliens changes (for better or for worse) over time. One reason why existing lists such as the IUCN100 have limited use for management is that they do not provide the basis for reporting on any progress with management unless a species is eradicated. Only one of the IUCN100 listed taxa has so far been eradicated – rinderpest in 2010 (World Organisation for Animal Health 2011). This species was replaced by giant salvinia (*Salvinia molesta*) on the list in 2013 after a voting process by invasion scientists (Luque et al. 2014). Eradication of widespread alien species which have major impacts is seldom, if ever, possible to achieve (Pluess et al. 2012). However, it is possible with the right management strategies to prevent a species from reaching its maximum impact, and thereby decreasing its impact to a degree that would warrant taking the species off a "worst invaders" list. As a non-avian example, the biological control of prickly-pear cactus (*Opuntia ficus-indica*; Zimmermann & Moran 1991) and other alien plants (e.g., van Wilgen et al. 2004) has led to a drastic reduction of their distribution and impacts.

Management can cause the impacts of alien species to decline over time, but many species in the early stages of an invasion (Blackburn et al. 2011) are likely to increase in their impacts if they get established and start spreading (there is a significant “invasion debt”: Essl et al. 2011). Some alien species have arguably attained impacts more significant than the listed species in the period since the IUCN100 list was developed more than a decade ago. The way this list and many other lists directly relevant to policy were created, however, does not easily allow for adjustments of the status of alien species. In contrast, other schemes, such as that proposed by Blackburn et al. (2014), facilitate the movement of species through different impact classes as their impacts either increase or decrease. Progress in management can therefore be quantified by adjusting the impact status if certain management actions (e.g. containment) have led to decreased impact, even if the actions have not led to eradication. Reporting changes in threat intensity would be very helpful for tracking progress towards the Aichi targets for biodiversity protection of the Convention on Biological Diversity (http://www.cbd.int/sp/targets/).

Selecting the “worst” alien species according to a transparent system or guidelines, and backing up such a selection with quantitative data, would not affect the educational purpose of any list so derived, but could lead to a more balanced representation of the types of impact and related issues that alien species can cause. Furthermore, from a scientific perspective, using a transparent and quantitative system would ensure that the most harmful species can be identified, and would also improve the utility of a list in terms of management and monitoring of progress due to increased flexibility, as elaborated in this study.

Acknowledgements

SK acknowledges financial support from the Swiss National Science Foundation, and the Drakenstein Trust through the DST-NRF Centre of Excellence for Invasion Biology. DMR acknowledges additional support from the National Research Foundation, South Africa (grant 85417).

Conflict of interest

None.

References

Baker, J., Harvey, K.J. and French, K. (2014) Threats from introduced birds to native birds. *Emu* 114: 1-12.

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarošík, V., Wilson, J.R.U. and Richardson, D.M. (2011) A proposed unified framework for biological invasions. *Trends in Ecology and Evolution* 26: 333-339.

Blackburn, T.M., Essl, F., Evans, T., Hulme, P.E., Jeschke, J.M., Kühn, I., Kumschick, S., Marková, Z., Mrugała, A., Nentwig, W., Pergl, J., Pyšek, P., Rabitsch, W., Ricciardi, A., Richardson, D.M., Sendek, A., Vilà, M., Wilson, J.R.U., Winter, M., Genovesi, P. and Bacher, S. (2014) A unified classification of alien species based on the magnitude of their environmental impacts. *PLoS Biology* 12: e1001850.

Blanvillain, C., Salducci, J.M., Tutururai, G. and Maeura, M. (2003) Impact of introduced birds on the recovery of the Tahiti Flycatcher (*Pomarea nigra*), a critically endangered forest bird of Tahiti. *Biological Conservation* 109: 197-205.

Brugger, K.E., Nol, P. and Phillips, C.I., 1993. Sucrose repellency to European starlings: Will high-sucrose cultivars deter bird damage to Fruit? *Ecological Applications* 3: 256-261.

Burgiel, S.W. and Perrault, A.M. (2011) Black, white and gray lists. Pp. 75-77 in Simberloff D. and Rejmánek M., eds. *Encyclopedia of biological invasions*. University of California Press, Berkeley.

Clavero, M. and Garcia-Berthou, E. (2005) Invasive species are a leading cause of animal extinctions. *Trends in Ecology and Evolution* 20: 110.

Delling, B., Crivelli, A.J., Rubin, J.-F. and Berrebi, P. (2000) Morphological variation in hybrids between *Salmo marmoratus* and alien *Salmo* species in the Volarja stream, Soča River basin, Slovenia. *Journal of Fish Biology* 57: 1199-1212.

Elton, C. (1958) *The ecology of invasions by animals and plants*. Methuen, London.

Essl, F., Dullinger, S., Rabitsch, W., Hulme, P.E., Hülber, K., Jarošík, V., Kleinbauer, I., Krausmann, F., Kühn, I., Nentwig, W., Vila, M., Genovesi, P., Gherardi, F., Desprez-Loustau, M.-L., Roques, A., and Pyšek, P. (2011) Socioeconomic legacy yields an invasion debt. *Proceedings of the National Academy of Sciences USA* 108: 203-207.

Evans, T., Kumschick, S., Dyer, E. and Blackburn, T.M. (2014) Comparing determinants of alien bird impacts across two continents: implications for risk assessment and management. *Ecology and Evolution* 4: 2957-2967.

Fumagalli, L., Snoj, A., Jesenek, D., Balloux, F., Jug, T., Duron, O., Brossier, F., Crivelli, A.J. and Berrebi, P. (2002) Extreme genetic differentiation among the remnant populations of marble trout (*Salmo marmoratus*) in Slovenia. *Molecular Ecology* 11: 2711-2716

Genovesi, P. and Scalera, R. (2007) Towards a black list of invasive alien entering Europe through trade, and proposed responses. Convention on the conservation of European wildlife and natural habitats. Standing Committee 27th Meeting, Strasbourg, 26-29 November 2007. T-PVS/Inf 9

Guay, P.-J. and Tracey, J.P. (2009) Feral mallards: A risk for hybridisation with wild Pacific ducks in Australia? *The Victorian Naturalist* 126: 87-91.

Hitchmough, R.A., Williams, M. and Daugherty, C.H. (1990) A genetic analysis of mallards, grey ducks, and their hybrids in New Zealand. *New Zealand Journal of Zoology* 17: 467-472.

Hockey, P.A.R., Dean, W.R.J. and Ryan, P.G. (2005) *Roberts birds of southern Africa.* Trustees of the John Voelcker Bird Book Fund, Cape Town, South Africa.

Hughes, B. (1996) The ruddy duck *Oxyura jamaicensis* in the Western Palearctic and the threat to the white-headed duck *Oxyura leucocephala*. Pp. 79-86 in J.S. Holmes and J.R. Simons, eds. *The introduction and naturalization of birds*. The Stationary Office, London.

Hughes, B., Henderson, I. and Robertson, P. (2006) Conservation of the globally threatened white-headed duck, *Oxyura leucocephala*, in the face of hybridisation with the North American ruddy duck, *Oxyura jamaicensis*: results of a control trial. *Acta Zoological Sinica* 52: 576-578.

Keller, R.P., Lodge, D.M. and Finnoff, D.C. (2007) Risk assessment for invasive species produces net bioeconomic benefits. *Proceedings of the National Academy of Sciences USA* 104: 203–207.

Kumschick, S. and Richardson, D.M. (2013) Species-based risk assessments for biological invasions: advances and challenges. *Diversity and Distributions* 19: 1095-1105.

Kumschick, S. and Nentwig, W. (2010) Some alien birds have as severe an impact as the most effectual alien mammals in Europe. *Biological Conservation* 143: 2757-2762.

Kumschick, S., Alba, C., Hufbauer, R.A. and Nentwig, W. (2011) Weak or strong invaders? A comparison of impact between the native and invaded ranges of mammals and birds alien to Europe. *Diversity and Distributions* 17: 663-672.

Kumschick, S., Bacher, S. and Blackburn, T.M. (2013) What determines the impact of alien birds and mammals in Europe? *Biological Invasions* 15: 785-797.

Kumschick, S., Bacher, S., Dawson, W., Heikkilä, J., Sendek, A., Pluess, T., Robinson, T.B. and Kühn, I. (2012) A conceptual framework for prioritization of invasive alien species for management according to their impact. *NeoBiota* 15: 69-100.

Kumschick, S., Bacher, S., Marková, Z., Pergl, J., Pyšek, P., Vaes-Petignat, S., van der Veer, G., Vilà, M. and Nentwig, W. (2015) Comparing impacts of alien plants and animals using a standard scoring system. *Journal of Applied* Ecology (in press). DOI: 10.1111/1365-2664.12427.

Lever, C. (2005) *Naturalised Birds of the World*. T and A D Poyser, London.

Long, J.L. (1981) *Introduced Birds of the World*. David and Charles, Newton Abbot, UK.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M. (2004) *100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database*. Published by The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12pp.

Luque, G.M., Bellard, C., Bertelsmeier, C., Bonnaud, E., Genovesi, P., Simberloff, D. and Courchamp, F. (2014) The 100th of the world's worst invasive alien species. *Biological Invasions* 16: 961-985.

Mank, J.E., Carlson, J.E. and Brittingham, M.C. (2004) A century of hybridization: Decreasing genetic distance between American black ducks and mallards. *Conservation Genetics* 5: 395-403.

Munoz-Fuentes, V., Vila, C., Green, A.J., Negro, J.J. and Sorenson, M.D. (2007) Hybridization between white-headed ducks and introduced ruddy ducks in Spain. *Molecular Ecology* 16: 629-638.

Nentwig, W., Kühnel, E. and Bacher, S. (2010) A generic impact-scoring system applied to alien mammals in Europe. *Conservation Biology* 24: 302-311.

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T. and Tsomondo, T. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment* 84: 1-20.

Pimentel, D. (2002) *Biological invasions: economic and environmental costs of alien plant, animal, and microbe species*. CRC Press, Boca Raton.

Pluess, T., Jarošík, V., Pyšek, P., Cannon, R., Pergl, J., Breukers, A. and Bacher, S. (2012) Which factors affect the success or failure of eradication campaigns against alien species? *PLoS ONE* 7: e48157.

Powell, R. and Incháustegui, S.J. (2009) Conservation of the herpetofauna of the Dominican Republic. *Applied Herpetology* 6: 103–122.

Rhymer, J.M. and Simberloff, D. (1996) Extinction by hybridisation and introgression. *Annual Reviews of Ecology and Systematics* 27: 83-109.

Richardson, D.M. (ed.)(2011). *Fifty years of invasion ecology. The legacy of Charles Elton.* Wiley-Blackwell, Oxford.

Shine, C., Williams, N. and Gündling, L. (2000) A guide to designing legal and institutional frameworks on alien invasive species. IUCN, Gland

Streftaris, N. and Zenetos, A. (2006) Alien marine species in the mediterranean-the 100 'worst invasives' and their impact. *Mediterr Marine Sci* 7: 87–118.

Thibault, J.-C., Martin, J.-L., Penloup, A. and Meyer, J.-Y. (2002) Understanding the decline and extinction of monarchs (Aves) in Polynesian Islands. *Biological Conservation* 108: 161-174.

Tracey, J.P., Lukins, B.S. and Haselden, C. (2008) Hybridisation between mallard (*Anas platyrhynchos*) and grey duck (*A. superciliosa*) on Lord Howe Island and management options. *Notornis* 55: 1-7.

Vaes-Petignat, S. and Nentwig, W. (2014) Environmental and economic impact of alien terrestrial arthropods in Europe. *NeoBiota* doi: 10.3897/neobiota.@@.6620 van der Veer, G. and Nentwig, W. (2014) Environmental and economic impact assessment of alien and invasive fish species in Europe using the generic impact scoring system. *Ecology of Freshwater Fish* doi: 10.1111/eff.12181

Van Wilgen, B.W., de Wit, M.P., Anderson, H.J., Le Maitre, D.C., Kotze, I.M., Ndala, S., Brown, B. and Rapholo, M.B. (2004) Costs and benefits of biological control of invasive alien plants: case studies from South Africa. *South African Journal of Science* 100: 113-122.

Vilà, M., Basnou, C., Gollasch, S., Josefsson, M., Pergl, J. and Scalera, R. (2009) One hundred of the most invasive alien species in Europe. Pp. 265–268 in *Handbook of alien species in Europe*. Springer, Netherlands.

World Organisation for Animal Health (2011) *Resolution no. 18. Declaration of global eradication of rinderpest and implementation of follow-up measures to maintain world freedom from rinderpest*. The Organisation, Paris

Zimmermann, H.G. and Moran, V.C. (1991) Biological control of prickly pear, *Opuntia ficus-indica* (Cactaceae), in South Africa. *Agriculture, Ecosystem and Environment* 37: 29-35.

Table 1: Impact scores of the 15 alien birds introduced to Australia and Europe reaching the highest impact scores. Species listed in IUCN100 are highlighted. Data from Kumschick & Nentwig (2010), Evans et al. (2014), Kumschick et al. (2015) and this study.

	Environmental impacts						Economic impacts							
	Herbivory	Competition	Predation	Disease to wildlife	Hybridisation	Ecosystem	Agriculture	Animal production	Forestry	Infrastructure	Human health	Human social life	Sum	Max
Branta canadensis	2	4		2	4	5	4	3		5	4	5	**38**	**5**
Passer domesticus		5	2	5		2	5	3		4	5	2	**33**	**5**
Columba livia		3	1	5	1		4	4		5	5	4	**32**	**5**
Anas platyrhynchos		3	1	4	5	4	3	4		2	3	3	**32**	**5**
Acridotheres tristis		5	5	4		2	4	3		2	2	4	**31**	**5**
Turdus merula	1	5	5	1	2	2	4				4		**24**	**5**
Sturnus vulgaris		3		2		2	4	3		4	2	3	**23**	4
Passer montanus	1	2	1	1	2		3	2		3	1	2	**18**	3
Psittacula krameri		3		1		2	4				5	2	**17**	**5**
Streptopelia chilensis	1	3		1	1	2	3	3			1	2	**17**	3
Threskiornis aethiopicus		3	5			1	2	2		2	1		**16**	**5**
Pycnonotus cafer		5	1			2	3						**11**	**5**
Cairina moschata		1		2	1	2				1	3		**10**	3
Myiopsitta monachus		2		1			2			4		1	**10**	4
Cygnus atratus		2		1	1	2					3		**9**	3

Table 2: Impact scores of the 20 alien birds introduced to Europe which scored impacts <1, with species listed in the DAISIE100 list highlighted. Data from Kumschick & Nentwig (2010) and Kumschick et al. (2015).

	Environmental impacts						Economic impacts						
	Herbivory	Competition	Predation	Disease to wildlife	Hybridisation	Ecosystem	Agriculture	Animal production	Forestry	Infrastructure	Human health	Human social life	Sum	Max
Branta canadensis	2	4		2	4	5	4	3		5	4	5	**38**	**5**
Acridotheres tristis		5	5	4		2	4	3		2	2	4	**31**	**5**
Psittacula krameri		3		1		2	4				5	2	**17**	**5**
Threskiornis aethiopicus		3	5			1	2	2		2	1		**16**	**5**
Myiopsitta monachus		2		1			2			4		1	**10**	4
Cairina moschata		1		2	1	2				1	3		**10**	3
Cygnus atratus		2		1	1	2					3		**9**	3
Oxyura jamaicensis		3			5								**8**	**5**
Anser cygnoides		2		1	4								**7**	4
Estrilda astrild		3					3				1		**7**	3
Anser caerulescens		2			3		1						**6**	3
Anser indicus		1			4								**5**	4
Syrmaticus reevesii		1			4								**5**	4
Chrysolophus pictus					4								**4**	4
Coturnix japonica					4								**4**	4
Phoenicopterus chilensis					4								**4**	4
Aix galericulata		2			1								**4**	2
Estrilda troglodytes		3											**3**	3
Aix sponsa				1	1								**2**	1
Amandava amandava		1					1						**2**	1