**Application of the Environmental Impact Classification for Alien Taxa (EICAT) to a global assessment of alien bird impacts**

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**Abstract**

***Aim***

To apply the recently published EICAT protocol to an assessment of the magnitude of environmental impacts of alien bird species established worldwide.

***Location***

Global.

***Methods***

A review of published literature and online resources was undertaken to collate information on the reported environmental impacts of 415 bird species with self-sustaining alien populations worldwide. The resulting data were then categorised following the EICAT guidelines, and analysed using R.

***Results***

Environmental impact data were found for approximately 30% of species with alien populations. Most alien birds had low impacts, categorised as either Minimal Concern (**MC**) or Minor (**MN**). However, 44 bird species had moderate (**MO**) impacts or above, with five having massive (**MV**) impacts. Almost half of all impacts identified related to competition between alien birds and native species. Impact magnitudes were non-randomly distributed: Impacts due to predation tended to be more severe than for other impact mechanisms, and impacts on oceanic islands tended to be more severe than for other regions, but impacts associated with Psittaciform species tended to be less severe than for other alien bird orders. Approximately 35% of assessments were allocated a ‘low’ confidence rating.

***Main conclusions***

The EICAT protocol can be effectively applied to categorise and quantify the impacts of all alien species within an entire taxonomic class. The results demonstrate significant variation in both the type and severity of impacts generated by alien birds. However, we found no data regarding the environmental impacts of the great majority of alien bird species, and where impact data were available, our assessments were frequently allocated a ‘low’ confidence rating. Our work therefore identifies major data gaps that will help influence the direction of future invasive alien species impact research.

**Introduction**

It is widely recognised that alien taxa can have significant adverse environmental impacts (Simberloff, 2013a; European Commission, 2015a; Pagad *et al.*, 2015). In recognition of this, the Strategic Plan for Biodiversity 2011-2020 (https://www.cbd.int/sp/), developed under the Convention on Biological Diversity (CBD), includes a specific target to address their impacts. Aichi Target 9 states that by 2020, invasive alien species and their pathways should be identified and prioritised, and priority species should be controlled or eradicated (CBD, 2013). Similarly, in 2015, the European Union (EU) published new legislation in response to the potential threat associated with biological invasions across the region. Target 5 of the EU 2020 Biodiversity Strategy (<http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm>) requires the development of a list of invasive alien species of Union concern, to be drawn up and managed by Member States using risk assessments and scientific evidence (European Commission, 2015b).

However, the type and severity of the impacts associated with alien species varies greatly among taxa, and despite the regulatory requirements imposed by the CBD and the EU, there is much uncertainty regarding the mechanisms and processes that lead to successful invasions; the species which have (or are likely to have) the most damaging impacts; and the most appropriate courses of action to prioritise and manage alien invasions (Ricciardi *et al.*, 2013; Simberloff *et al.*, 2013b; Kumschick *et al.*, 2015a). This may in part be due to the fact that we do not have a standardised method by which to compare and contrast the impacts of alien species. In recognition of this problem, Blackburn *et al.* (2014) proposed a protocol to classify alien species according to the magnitude of their environmental impacts. This protocol was recently formalised as the Environmental Impact Classification for Alien Taxa (EICAT) with the provision of a framework and guidelines for implementation (Hawkins *et al.*, 2015). The principal aim of EICAT is to enable invasion biologists to identify variation in the magnitude and types of impacts associated with alien taxa, allowing clear comparisons to be made regarding their impacts across different regions and taxonomic groups (Hawkins *et al.*, 2015).

The EICAT protocol has been developed in consultation with the IUCN, and it is possible that it will be formally adopted as their mechanism for classifying the environmental impacts of alien species. If this happens, EICAT assessments for all known alien species worldwide should be completed and peer reviewed by 2020, in-line with the requirements stipulated under Aichi Target 9 and Target 5 of the EU 2020 Biodiversity Strategy. It is envisaged that EICAT will be used to develop a biodiversity indicator for invasive alien species impacts, and through on-going periodic assessments of impacts, will provide a mechanism to monitor changes in the impacts of invasive alien species, for example to determine the effectiveness of a management intervention in alleviating adverse impacts. A significant outcome arising from the application of EICAT will be a global stocktake of the broad range of impacts associated with alien taxa. Thus, the EICAT protocol will help to direct attention not only to the most damaging invasive alien species, but also to those species, taxa, locations or impact mechanisms for which we do not have sufficient information from which to make informed management decisions to mitigate the impacts of alien taxa.

A key next step in the development of the EICAT protocol is to apply it to a set of species with alien populations, in order to test how readily it can be applied, and to identify any aspects of the protocol that may need refinement. Thus, here we present one of the first applications of EICAT, with a global assessment of the environmental impacts of alien bird species. More than 400 bird species have established alien populations somewhere in the world (Dyer *et al.* in revision a), and some of these established populations have been shown to cause significant impacts to the environment (Long, 1981; Brochier *et al.*, 2010; Kumschick *et al*., 2015b). For example, on the Seychelles, the common myna (*Acridotheres tristis*) has been found to compete with, and subsequently affect the breeding success of the Seychelles magpie robin (*Copsychus sechellarum*) (Komdeur, 1995); in Sweden, the Canada goose (*Branta canadensis*) damages natural shoreline vegetation communities through intense grazing (Josefsson & Andersson, 2001); in France, the African sacred ibis (*Threskiornis aethiopicus*) predates upon eggs of the sandwich tern (*Thalasseus sandvicensis*) (Yesou & Clergeau, 2005); and in Spain, the ruddy duck (*Oxyura jamaicensis*) hybridises with the globally endangered white-headed duck (*Oxyura leucocephala*) (Muñoz-Fuentes *et al.*, 2007). We use data obtained from a thorough search and review of the available literature to quantify alien bird impacts under the EICAT protocol.

Our study follows two recent global assessments of the impacts of alien birds using different methodologies (Baker *et al.*, 2014; Martin-Albarracin *et al.*, 2015). These assessments identified impact data for a relatively small number of alien bird species (33 and 39, respectively), and concluded that there is a lack of data on the impacts of alien birds, particularly for less developed regions of the world (see also Pyšek *et al.*, 2008). Data availability has also been shown to vary with impact type and alien bird order. For example, Martin-Albarracin *et al.* (2015) found nearly 40% of data were for competition impacts, whilst a recent study comparing the impacts of alien birds in Europe and Australia (Evans *et al.*, 2014) found that orders with a strong association with human activity, particularly Passeriformes (perching birds), Anseriformes (ducks, geese and swans) and Galliformes (gamebirds), were amongst those with the most frequently reported impacts. We therefore expected to find little or no impact data for many alien bird species, and to find significant variation in the availability of data across regions, impact types, and taxa.

Notwithstanding the examples above, we expected to find that impacts associated with alien birds are relatively weak, particularly in comparison to other taxa such as mammals. Baker *et al.* (2014) concluded that there is little evidence for detrimental impacts generated by alien birds, and the low number of alien birds implicated in the extinction of native species (Bellard et *al.*, 2016) also suggests that their impacts are not particularly severe. However, previous studies suggest that impact severity varies with impact mechanism (Kumschick *et al.*, 2013; Evans *et al.*, 2014; Baker *et al.*, 2014; Martin-Albarracin *et al.*, 2015) and across alien bird orders. Kumschick & Nentwig (2010) examined the impacts of alien birds in Europe, and found Anseriformes and Psittaciformes (parrots) to generally be associated with more severe impacts, whilst Martin-Albarracin *et al.* (2015) found Anatidae (Anseriformes) to have the highest impacts globally. Thus, we expected to find variation in impact severity across different types of impact, and across bird orders, with Anseriformes amongst the most damaging. Impacts generated by invasive alien species may be particularly severe on oceanic islands (Pearson, 2009; CBD, 2015). Although to our knowledge no studies have been undertaken to determine whether this generalisation can be extended to alien birds, we expected to find variation in impact severity across geographic regions, with more severe impacts associated with islands.

Based on the evidence provided by past studies, we test whether the magnitude of alien bird impacts varies across impact mechanisms, and whether the magnitude, mechanisms and availability of data on alien bird impacts vary across alien bird orders. We further test whether the magnitude of alien bird impacts varies across biogeographic regions. We also test whether our confidence in the EICAT assessment for each alien bird species (as measured through the allocation of a confidence rating of ‘high’, ‘medium’ or ‘low’ for each assessment) varies with impact mechanism, impact magnitude and across bird orders. By determining the form and extent of such variations, we aim to improve our understanding of the nature of environmental impacts generated by alien birds, and to identify knowledge gaps so as better to prioritise future impact studies on this taxon. We conclude with some observations on the application of the EICAT protocol to real-world data on impacts.

**Methods**

***Data***

A list of 415 alien bird species with self-sustaining populations across the globe was extracted from the Global Avian Invasions Atlas (Dyer *et al.*, in revision a). GAVIA is a global database (incorporating data up to March 2014) that brings together information on global alien bird introductions (from sources including atlases, country species lists, peer-reviewed articles, websites and through correspondence with in-country experts) to provide the most comprehensive resource on the global distributions of alien bird species. Data extracted from the GAVIA database has recently been used to study the drivers of global alien bird species introductions (Dyer *et al.*, in revision a), and also to undertake a global analysis of the determinants of alien bird geographic range size (Dyer *et al.*, in revision b).

A review of published literature was then undertaken to collate information on the reported impacts of each of these species (for details on the method adopted for the literature review, see Supporting Data: Appendix S1). The environmental impacts of each alien bird species identified from the literature search were categorised into one of 12 impact mechanisms defined in the EICAT guidelines (Hawkins *et al.*, 2015) and summarised in Table 1. For each of the 12 mechanisms, a series of semi-quantitative scenarios were used to assign impacts to one of the following five categories, depending on their severity: in order of increasing severity, these are Minimal Concern (**MC**), Minor (**MN**), Moderate (**MO**), Major (**MR**) or Massive (**MV**). The scenarios reflect increases in the order of magnitude of the impacts associated with a species, as reflected in the level of biological organisation affected (a full description of the scenarios associated with each impact mechanism is presented in Hawkins *et al.* 2015). As an example, the most severe impacts associated with alien populations of the rose-ringed parakeet (*Psittacula krameri*) were for competition (impact mechanism 2 in Table 1): parakeets have been found to cause reductions in the size of populations of nuthatches (*Sitta europeae*) in Belgium, but with no evidence to show that these impacts have resulted in local population extinction or changes to the structure of communities (Strubbe & Matthysen 2007; Strubbe & Matthysen 2009). As such, recorded impacts match the semi-quantitative scenario relating to **MO** in the EICAT framework (Hawkins *et al.,* 2015).

Each species was assessed for its impact under all of the 12 mechanisms for which data were available. However, a species was assigned to an impact category in the EICAT scheme based on the evidence of its most severe impacts only. Thus, the rose-ringed parakeet would be assigned to **MO** on the basis of available evidence of its impacts in terms of competition, as this is the mechanism of its highest impact. Some species most severe impacts related to more than one impact mechanism: for example, the most severe impacts associated with the mute swan (*Cygnus olor*) were **MO**, for both competition and grazing/herbivory/browsing. In such cases, species were assigned to impact categories on the basis of all mechanisms ranked equally most severe (in this case of the mute swan, both impacts were assigned to **MO**).

To quantify uncertainty about the correct classification of the magnitude of the environmental impacts of any alien species, confidence ratings of ‘high’, ‘medium’ or ‘low’ were appended to each assessment, following the EICAT guidance (Hawkins *et al.*, 2015). For example, the impact data for the rose-ringed parakeet were published, peer reviewed and empirical. There were also several studies suggesting the same level of impact (**MO**). Consequently, a confidence rating of ‘high’ was allocated to the EICAT assessment for this species. Where there was evidence to suggest that a species had an alien population, but insufficient data was available to determine and classify any impacts of that species, it was assigned to the Data Deficient (**DD**) category.

As this represents the first comprehensive assessment of birds using the EICAT protocol, both the Maximum Recorded Impact and the Current Recorded Impact were assessed for each bird species with a known alien population. The Maximum Recorded Impact measures the greatest deleterious impacts associated with a species. The Current Recorded Impact reflects the existing impacts associated with a species. The current and maximum recorded impacts of a species with alien populations may differ, for example if management actions have been applied to mitigate species impacts. For example, rinderpest, a viral disease of ungulates, was introduced from Asia to southern Africa in cattle in the late 19th Century. It caused dramatic declines in the populations of native species including wildebeest (*Connochaetes spp.*) and buffalo (*Syncerus caffer*). Under the EICAT protocol, the Maximum Recorded Impact for rinderpest would therefore be Moderate (MO), as the virus caused declines in populations of native species. However, rinderpest has since been successfully eradicated globally. Under EICAT, the eradication of rinderpest would have initially resulted in its classification being reduced to Minimal Concern (**MC**), and upon official confirmation of its global eradication in 2011, its classification would have been updated to No Alien Population (**NA**) (Simberloff, 2013a).

***Analysis***

The actual and expected distributions of impact magnitudes and impact mechanisms across orders, and impact magnitudes across impact mechanisms, were all analysed using contingency tables tests (Chi-square Test of Independence, or where expected numbers were small (less than 5), Fisher’s Exact Test for Count Data (following McDonald (2014)). Low samples sizes in some of the categories of interest meant that we amalgamated categories for some analyses. Thus, impact categories were combined to produce two groups: ‘lower tier’ impacts, consisting of impacts classified as **MC** and **MN**, and ‘upper tier’ impacts, consisting of impacts classified as **MO**, **MR** and **MV**. We used the Wilcoxon Rank Sum test to compare the number of empirical data sources underlying ‘lower tier’ and ‘upper tier’ impact classifications, and underlying different confidence ratings. For analyses involving bird orders, five orders (Passeriformes, Psittaciformes, Galliformes, Anseriformes and Columbiformes (pigeons and doves)) were tested as separate groups, with the remaining orders combined to produce one group titled ‘other’. For analyses regarding regions, areas were defined by continent (Africa, Asia, Australasia, Europe, North (including Central) America, South America) with the islands of the Atlantic, Indian and Pacific oceans combined to form one category. All analyses were carried out using RStudio version 0.99.893 (R Core Team, 2015).

**Results**

The 415 bird species with alien populations derive from 26 orders. The majority of these species (363, or 87.5%) come from just five orders: Passeriformes (43.9% of the dataset), Psittaciformes (14.9%), Galliformes (13%), Anseriformes (8.9%) and Columbiformes (6.7%). The remaining 52 species are distributed across the other 21 orders. The distribution of assessments across mechanism, category and order is given in Supporting Data: Table S1. The full list of EICAT assessment results for individual species is provided in Supporting Data: Table S2.

Impact data were obtained for 119 species from 14 orders (28.7% of alien bird species) (Figure 1). The same five orders that contain most alien bird species also include most of the species with recorded impacts (88.2%), with the remainder spread across a further nine orders. Data describing the most severe impacts of the 119 alien species (data used to allocate species’ impacts) were obtained from 311 sources, 72.5% of which were anecdotal, with the remainder being empirical. An average of 0.4 empirical data sources per alien bird species was found for those with ‘lower tier’ (**MC** and **MN**) impacts, versus 1.3 per alien bird species with ‘upper tier’ (**MO**, **MR** and **MV**) impacts (Wilcoxon Rank Sum Test; W = 1376.5, N = 102, *P* < 0.001).

No impact data were found for 296 species (71.3%), which were therefore categorised at Data Deficient (**DD**). No impact data were obtained for any of the species in 12 orders with alien populations, such that almost half of the 26 orders with aliens were entirely **DD**. Recorded impacts are non-randomly distributed across orders (2 = 20.6, df = 5, *P* = 0.001). This result arises primarily from fewer Passeriform species, and more Psittaciform species, with recorded impacts than expected (Supporting Data: Table S3).

For all 119 species with recorded impacts, the Maximum Recorded Impact was found to be the same as the Current Recorded Impact. For 23 species, the highest recorded impact was equally high for two or more impact mechanisms, resulting in a total of 146 impact mechanism allocations (Supporting Data: Table S1). The majority of these 146 impacts were categorised as ‘lower tier’ (**MC** or **MN**) (69.9%) (Figure 2). However, 44 species had ‘upper tier’ impacts, with five having massive (**MV**) impacts, resulting in native species’ population extinctions. Impact magnitudes are non-randomly distributed across orders (2 = 16.0, df = 5, *P* = 0.003), primarily because of fewer Psittaciform species with ‘upper tier’ (**MO**, **MR** and **MV**) impacts than expected (Supporting Data: Table S4).

Nearly half of all impact allocations were for competition (43.2%) (Figure 3), whilst no impacts were allocated for physical impacts on ecosystems, poisoning/toxicity or bio-fouling. Impact magnitudes are non-randomly distributed across impact mechanisms (2 = 13.6, df = 5, *P* = 0.018). In particular, more predation impacts are allocated to ‘upper tier’ (**MO**, **MR** and **MV**) categories than expected (Table 2).

Impact mechanisms are also non-randomly distributed across orders (2 = 116.2, df = 25, *P* < 0.001). There were more Psittaciform species than expected with competition impacts, more Anseriform species with hybridisation impacts, more Columbiform species with disease impacts, and more Galliform species with interaction impacts. There were also more species in ‘other’ orders with predation impacts than expected; these were Accipitriformes (hawks, eagles and allies), Coraciiformes (kingfishers, rollers, hornbills and allies), Cuculiformes (cuckoos), Falconiformes (falcons), Gruiformes (cranes and allies), Pelecaniformes (pelicans and allies) and Strigiformes (owls and allies), which together accounted for 42.3% of all predation impacts (Table 3).

The greatest number of impacts were recorded on oceanic islands (57 impact assignments, or 34%), primarily those of the Pacific (24.4%), particularly Hawaii (13.7% of all impact allocations). Continents with the most recorded impacts were North America (21.4%) and Australasia (17.3%). The fewest impacts were recorded in South America and Africa (3.6% each). Impact magnitudes were non-randomly distributed across regions (2 = 15.5, df = 4, *P* = 0.004). This result arises primarily from more ‘upper tier’ (**MO**, **MR** and **MV**) impacts on oceanic islands than expected, and fewer in North (and Central) America (Supporting Data: Table S5).

Impact assessments were allocated a ‘high’ confidence rating on 53 occasions (36.3%). A similar proportion were allocated a ‘low’ rating (51), whilst 42 were allocated a ‘medium’ rating. Confidence ratings were randomly distributed across impact mechanisms (2 = 19.3, df = 10, *P* = 0.065), although a relatively high proportion of assessments relating to disease transmission were allocated a ‘low’ confidence rating (Table 4a). Confidence ratings were non-randomly distributed across impact magnitudes (2 = 11.9, df = 2, *P* < 0.003), with more ‘upper tier’ (**MO**, **MR** and **MV**) impact assessments allocated a ‘high’ confidence rating than expected (Table 4b). Confidence ratings were also non-randomly distributed across orders (2 = 47.9, df = 10, *P* < 0.001), with more Galliform and Columbiform assessments allocated a ‘low’ confidence rating, than expected. ‘Medium’ confidence ratings tended to be over-represented amongst Psittaciformes (Supporting Data: Table S6).

An average of 2.7 empirical data sources were found for assessments allocated a ‘high’ confidence rating, 0.5 for those allocated a ‘medium’ confidence rating, and 0.4 for those allocated a ‘low’ confidence rating. More empirical data sources were found for ‘high’ confidence assessments than for ‘low’ (Wilcoxon Rank Sum Test; W = 2413.5, N = 102, *P* < 0.001) or ‘medium’ (W = 1986, N = 102, *P* < 0.001), while medium and low categories did not differ in this regard (W = 1050, N = 102, *P* = 0.77).

**Discussion**

Birds are one of the best-known and best-studied groups, yet to date there are no recorded environmental impacts for more than 70% of bird species with alien populations. This includes all the alien species in half of the 26 bird orders with aliens. The obvious exception to this general paucity of data is the Psittaciformes – parrot species tend to be noisy and conspicuous, and are relatively well studied (Supporting Data: Table S3). The absence of knowledge regarding alien bird impacts reflects the findings of other recent studies on the impacts of alien taxa (Roberts *et al.*, unpubl.; Baker *et al.*, 2014; Martin-Alberracin *et al.*, 2015; Kraus, 2015), and alien birds have even received proportionately lower levels of research effort in comparison to other taxonomic groups (Pyšek *et al.* 2008). Despite growth in the study of invasion biology (Richardson & Pyšek, 2008), impact is a topic that remains understudied.

There are at least two broad reasons why no environmental impact data exist for most alien bird species. First, some alien bird populations may be perceived to cause little or no environmental damage, and consequently their potential impacts are not studied. Lack of data here reflects a perceived (but perhaps real) lack of impact. This would fit with a recent synthesis of bias in invasion biology research (Pyšek *et al.*, 2008), which found a tendency for research to focus on species that were considered to have the most severe impacts – as would be expected in a climate of scarce research funding (see Joseph *et al.*, 2009). Whether such species actually have no environmental impacts, or their impacts have just not been noticed, is unknown.

Second, alien bird species may have clear (and perhaps high) impacts, but these impacts are unknown – in this case, a lack of data belies impact. This lack of knowledge may be because alien populations occur in remote locations where they go unnoticed or are not easily recorded or studied (e.g. tropical regions such as parts of Africa and South America). Consistent with this hypothesis, we found more data on alien bird impacts for invasions within more industrially developed regions of the world. At the continental scale, 53.6% of data on recorded impacts came from mainland North (and Central) America, Australia and Europe. For Asia, two-thirds of all impact records were for invasions to Singapore, Japan and Hong Kong, the three most highly ranked Asian economies in the Global Competitiveness Index (World Economic Forum, 2014). The fewest records were for Africa and South America. It is generally the case that comparatively less conservation research is being undertaken in these most biodiverse regions of the world (Wilson *et al.*, 2016).

Pyšek *et al.* (2008) also found a significant geographical bias regarding the locations of invasion biology studies, with oceanic islands (which play host to a large range of invasive alien species) being largely ignored in comparison with North America and continental Europe. Yet, we found that approximately 34% of recorded impacts were for invasions on islands of the Atlantic, Indian and Pacific oceans. This may be because islands are more susceptible to impacts associated with invasive alien species (Pearson, 2009; CBD, 2015; Harper & Bunbury, 2015), and the severity of their impacts has resulted in higher levels of research there. Our results support this suggestion, as we found impacts to be more severe on islands (see Supporting Data: Table S5). It may also be because approximately 65% of the islands identified in this study are territories of developed countries (e.g. Bermuda; Hawaii; Mariana Islands; Marquesas Islands; Tahiti).

As we had expected, the environmental impacts of alien bird species were generally low, with approximately 70% found to be either negligible, or without population-level impacts (Figure 2). If invasion research is biased towards species with more severe impacts (Pyšek *et al.*, 2008), this suggests that the majority of alien bird species have low environmental impacts, and lack of data simply reflects lack of impact. The same is true if alien bird species with impact data are a random sample of all alien bird species. Only if studies of alien birds were biased away from species with higher-level impacts would our analyses give a false impression of the levels of alien bird impacts. This is possible if alien birds have lower environmental impacts in areas that are better studied, such as Europe and North America, perhaps because the environments there are generally degraded by other processes (e.g. destruction of primary habitat). Ultimately, there is no way of knowing whether the few higher level impacts for alien bird species is absence of evidence or evidence of absence.

Nevertheless, 44 bird species did have ‘upper tier’ environmental impacts, with 35 negatively affecting populations of native species (**MO**), four affecting the composition of native communities (**MR**), and five resulting in species extinctions (**MV**). For example, on Lord Howe Island (Australia), the mallard (*Anas platyrhynchos*) hybridises with the Pacific black duck (*Anas superciliosa*), resulting in the local extirpation of this native species, and its replacement by mallard x Pacific black duck hybrids (Guay *et al.*, 2014). Despite current concerns regarding the need for eradication campaigns to address the impacts of invasive birds (Strubbe *et al.*, 2011), in the case of the mallard, management is considered warranted.

Four mechanisms accounted for almost 85% of alien bird environmental impacts: competition, predation, interaction with other alien species (which relates primarily to the spread of alien plants) and hybridisation (Supporting Data: Table S1). Almost 45% of all recorded impacts were associated with competition between alien birds and native species. The prevalence of competition may be because this mechanism is associated with frequent, daily interactions between species, when compared to other impact mechanisms (more species compete with others for food or habitat, than predate, hybridise or interact with other aliens to have impacts). However, competition is generally a relatively weak mechanism for population change. Competitive interactions can help drive the displacement of one species by another (e.g. the grey squirrel (*Sciurus carolinensis*) invasion of the UK, resulting in the widespread exclusion of the native red squirrel (*Sciurus vulgaris*); Gurnell *et al.*, 2004), but the process generally tends to be slow and subtle. Thus the competitive impacts of alien bird species tended to be low (Table 2). In contrast, predation tends to be a strong mechanism for population change, and predation by aliens has been associated with numerous native species extinctions (e.g. small Indian mongoose (*Herpestes auropunctatus*) predation of the barred-wing rail (*Nesoclopeus poecilopterus*) in Fiji; Hays & Conant, 2007). Thus, we found that predation by alien birds on native species tended to be associated with more severe impacts when compared to other impact mechanisms (Table 2).

Impact mechanisms were not distributed randomly across bird taxa with alien populations (Table 3). Thus, Psittaciformes were associated with competition impacts, Anseriformes with hybridisation impacts, Columbiformes with disease impacts, Galliformes with impacts generated by interactions with other alien species (primarily the spread of alien plants), and orders grouped together as ‘other’ with predation impacts. These patterns generally reflect the behaviour and life history of species from these orders within their native ranges. For example, Psittaciformes are often cavity-nesting species, and cavities tend to be the subject of competition, particularly by species unable to excavate their own (secondary cavity-nesters) (Newton, 1994; Grarock *et al.*, 2013). Anseriformes have long been associated with hybridisation, with more than 400 interspecies hybrid combinations recorded within the Anatidae – more than for any other bird family (Johnsgard, 1960). Orders associated with predation impacts include well-known avian predators, including Accipitriformes, Falconiformes and Strigiformes.

Impact magnitudes were also not distributed randomly across bird taxa with alien populations (Supporting Data: Table S4). Psittaciformes were associated with less severe impacts when compared to other orders of alien bird, reflecting the fact that parrots generally interact with other native species through competition. Alien parrots have often been introduced to areas with no native parrot species, which may further reduce opportunities for direct competition with species that have similar habitat and food preferences (e.g. rose-ringed parakeet (*Psittacula krameri*) establishment in the UK; Peck *et al.*, 2014). Almost 30% of impact assessments for alien parrots were for North America, which may explain why impacts on this continent were found to be less severe when compared to other continents (Supporting Data: Table S5). Conversely, Passeriformes and orders in the ‘other’ category tended to be associated with more severe environmental impacts (Supporting Data: Table S4). This is because nearly 30% of Passeriform impact assessments (primarily for corvids (crows and allies)), and over 65% of impact assessments for species within the ‘other’ category, related to predation impacts (Table 3), which were found to be more severe when compared to other impact mechanisms (Table 2).

Our results showed that in general, we have higher confidence in assessments associated with more severe impacts (Table 4b). This relationship may arise because severe impacts are more obvious, and therefore the data on impacts used to undertake the EICAT assessment are considered more robust. It may also be attributable to data availability, whereby alien bird species with severe impacts tend to be more frequently studied than those with minor impacts (Pyšek *et al.*, 2008). This was true here, as a significantly greater number of empirical data sources were available for species with ‘upper tier’ (**MO**, **MR** and **MV**) than ‘lower tier’ (**MC** and **MN**) impacts, and also for impacts assigned a ‘high’ confidence rating, compared to those allocated a ‘medium’ or ‘low’ confidence rating. Less confidence was placed in disease impact assessments when compared to assessments for other impact mechanisms (Table 4a). Disease assessments can be complex, with recent studies suggesting it is often difficult to prove whether an alien species is solely responsible for the transmission of a disease to native species (Tompkins & Jakob-Hoff, 2011; Blackburn & Ewen, 2016). Less confidence was also placed in Columbiform assessments when compared to other bird orders (Supporting Data: Table S6), probably because Columbiformes were generally associated with disease impacts (Table 3).

***Conclusions***

Our study represents one of the first large-scale applications of the EICAT protocol, demonstrating that it is a practical means to categorise and quantify the impacts of alien species for a complete taxonomic class. Overall, the impact assessment phase of the work took about 3 months, suggesting an average of < 1 day per species assessed. The actual time taken to assess a species obviously varied substantially, but was manageable even for data-rich species. On the whole, it was straightforward to assign impacts to mechanism, if harder to assign impacts to categories. The process did, however, highlight some gaps in the existing EICAT guidelines (Hawkins *et al.*, 2015), most notably in terms of limited guidance on the approach to adopt when searching for, and recording, impact data. Based on this assessment, we are developing search guidelines and a recording sheet for use during EICAT assessments, which will be made available under the formal EICAT protocol in future. In the mean time, it is recommended that literature reviews are carried out following the approach outlined in Supporting Data: Appendix S1.

The biggest hindrance to the successful application of EICAT is the lack of impact data for most species. This problem is of course common to all evidence-based protocols. Unlike other recent studies (Baker *et al.* 2014; Martin-Albarracin *et al.* 2015), we used all available data to conduct assessments, from peer-reviewed papers in international scientific journals to unreviewed information lodged on websites. The quality of these data is likely to vary substantially, and we used EICAT confidence ratings to reflect any uncertainty regarding their robustness. We also used confidence ratings to reflect uncertainty related to the presence of additional factors that could adversely impact upon native species (primarily habitat loss and other alien species). For example, local population extinctions of the Cocos buff-banded rail (*Gallirallus philippensis andrewsi*) on the Cocos (Keeling) Islands (Australia) have been attributed to competition between this species and introduced junglefowl (*Gallus gallus* and *G. varius*). However, habitat modification and predation by introduced mammals are also believed to have contributed to the decline of the native rail (Reid & Hill, 2005). In such cases, it was often difficult to determine the level of impact attributable solely to the subject of the EICAT assessment.

Our use of the EICAT protocol to identify variation associated with the type and severity of impacts generated by alien birds sets the scene for further studies to test for causes of this variation, to improve our understanding of the factors that influence the mechanism and magnitude of impacts when species are introduced to novel locations. Obvious avenues for future investigation include whether or not certain life-history characteristics of alien birds (e.g. diet generalism, body mass, fecundity) are associated with more severe impacts, and more detailed exploration of spatial variation in impacts, and characteristics of the receiving environment that moderate them. Such studies have the potential to assist in predicting the potential impacts of species that do not yet have alien populations, and to inform recommendations for alien species management.

Nevertheless, our work demonstrates that there is still a long way to go to understand the impacts of even a well-studied group such as birds. We have no information on the environmental impacts of the great majority of bird species with alien populations. Further, even where impact data were available, assessments were frequently allocated a ‘low’ confidence rating. One of the potential benefits of the EICAT protocol is that it can be used to identify knowledge gaps and hopefully influence the direction of future invasive alien species research.

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**Supporting Information**

Additional Supporting Information may be found in the online version of this article:

**Appendix S1** {Insert short legend to online Appendix S1}

**Table S1** {Insert short legend to online Table S1}

**DATA ACCESSIBILITY**

{All topographic and environmental GIS layers, the habitat suitability model and BTM results generated for this study are available as raster grids from the Pangaea database: [http://doi.pangaea.de/10.1594/PANGAEA.808540.](http://doi.pangaea.de/10.1594/PANGAEA.808540)}

**Biosketch**

Thomas Evans is currently undertaking a PhD at University College London (UCL) having been awarded a studentship from the Natural Environment Research Council (NERC). His research focuses on the identification and management of impacts associated with invasive alien species.

Tim Blackburn is a Professor of Invasion Biology at University College London (UCL). His research is predominantly focused on understanding the processes driving human-mediated biological invasions, using birds as a model taxon.

Sabrina Kumschick’s research focuses on the impacts of alien species and the prioritisation of measures for their management. She aims to improve our ability to predict the level of risk posed by alien species, and to provide the evidence that enables more robust listings of harmful alien species.

**Tables**

Table 1: The 12 EICAT impact mechanisms used to categorise the impacts of alien species (Hawkins *et al.*, 2015), and alien bird impact examples.

| Impact mechanism | Description | Alien bird example | Impacted species / location | Reference |
| --- | --- | --- | --- | --- |
| (1) Competition | The alien taxon competes with native taxa for resources (e.g. food, water, space), leading to deleterious impact on native taxa. | Green junglefowl (*Gallus varius*) | Buff banded rail (*Gallirallus philippensis andrewsi*) – Cocos (Keeling) Islands (Australia) | Reid & Hill, 2005 |
| (2) Predation | The alien taxon predates on native taxa, either directly or indirectly (e.g. via mesopredator release), leading to deleterious impact on native taxa. | American crow (*Corvus brachyrhynchos*) | White-eyed tropicbird (*Phaethon lepturus catsbyii*) – Bermuda (British Overseas Territory) | Madeiros, 2011 |
| (3) Hybridisation | The alien taxon hybridises with native taxa, leading to deleterious impact on native taxa. | Chukar (*Alectoris chukar*) | Rock partridge (*Alectoris graeca*); red-legged partridge (*Alectoris rufa*) – France, Italy, Spain, Portugal | Barilani *et al.*, 2007 |
| (4) Transmission of disease to native species | The alien taxon transmits diseases to native taxa, leading to deleterious impact on native taxa. | House finch (*Carpodacus mexicanus*) | Various (song birds) – USA | Fischer *et al.*, 1997 |
| (5) Parasitism | The alien taxon parasitises native taxa, leading directly or indirectly (e.g. through apparent competition) to deleterious impact on native taxa. | Shiny cowbird (*Molothrus bonariensis*) | Yellow-shouldered blackbird (*Agelaius xanthomus*) – Puerto Rico | Cruz *et al.*, 2005 |
| (6) Poisoning/toxicity | The alien taxon is toxic, or allergenic by ingestion, inhalation or contact to wildlife, or allelopathic to plants, leading to deleterious impact on native taxa. | No impacts identified |  |  |
| (7) Bio-fouling | Bio-fouling by the alien taxon leads to deleterious impact on native taxa. | No impacts identified |  |  |
| (8) Grazing/herbivory/browsing | Grazing, herbivory or browsing by the alien taxon leads to deleterious impact on native plant species. | Mute swan (*Cygnus olor*) | Various (submerged aquatic vegetation) – USA | Allin & Husband, 2003 |
| (9) Chemical impact on ecosystem | The alien taxon causes changes to the chemical biotope characteristics of the native environment; nutrient and/or water cycling; disturbance regimes; or natural succession, leading to deleterious impact on native taxa. | Egyptian goose (*Alopochen aegyptiaca*) | Various (eutrophication of waterbodies) – UK | Rehfisch *et al.*, 2010 |
| (10) Physical impact on ecosystem | The alien taxon causes changes to the physical biotope characteristics of the native environment; nutrient and/or water cycling; disturbance regimes; or natural succession, leading to deleterious impact on native taxa. | No impacts identified |  |  |
| (11) Structural impact on ecosystem | The alien taxon causes changes to the structural biotope characteristics of the native environment; nutrient and/or water cycling; disturbance regimes; or natural succession, leading to deleterious impact on native taxa. | Superb lyrebird (*Menura novaehollandiae*) | Various (forest floor communities including invertebrate assemblages) – Tasmania (Australia) | Tassell, 2014 |
| (12) Interaction with other alien species | The alien taxon interacts with other alien taxa, (e.g. through pollination, seed dispersal, habitat modification), facilitating deleterious impact on native species. These interactions may be included in other impact classes (e.g. predation, apparent competition) but would not have resulted in the particular level of impact without an interaction with other alien species. | Japanese white-eye (*Zosterops japonicus*) | Various (native plant communities) – Hawaii (USA) | Chimera & Drake, 2010 |

Table 2: Contingency table (Fisher’s Exact Test for Count Data) showing actual and expected numbers of impact allocations to ‘lower tier’ (**MC** and **MN**) and ‘upper tier’ (**MO**, **MR** and **MV**) impact categories for each impact mechanism. Expected values are displayed in italics. Individual X-squared values are displayed in (parentheses). Data for impact mechanisms (5) Parasitism, (9) Chemical impact on ecosystem and (11) Structural impact on ecosystem were removed from the dataset for the test, due to low sample size.

|  |  |  |  |
| --- | --- | --- | --- |
|  | No. of allocations to **MC** and **MN** impact category (‘lower tier’) | No. of allocations to **MO**, **MR** and **MV** impact category (‘upper tier’) | Total impact allocations |
| Competition | 49*43.65*(0.66) | 14*19.35*(1.48) | 63 |
| Predation | 11*18.01*(2.73) | 15*7.99*(6.16) | 26 |
| Interaction with other alien species | 16*13.16*(0.61) | 3*5.84*(1.38) | 19 |
| Hybridisation | 9*10.39*(0.19) | 6*4.61*(0.42) | 15 |
| Grazing/herbivory/browsing | 7*6.93*(0.00) | 3*3.07*(0.00) | 10 |
| Transmission of disease to native species | 5*4.85*(0.00) | 2*2.15*(0.01) | 7 |
| Total | 97 | 43 | 140 |

Table 3: Contingency table (Fisher’s Exact Test for Count Data) showing actual and expected numbers of impact allocations to each impact mechanism for each order. Expected values are displayed in italics. Individual X-squared values are displayed in (parentheses). Data for impact mechanisms (5) Parasitism, (9) Chemical impact on ecosystem and (11) Structural impact on ecosystem were removed from the dataset for the test, due to low sample size.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Competition | Predation | Interaction with other alien species | Hybridisation | Grazing/herbivory/browsing | Transmission of disease to native species |
|  Passeriformes | 20*20.70*(0.02) | 13*8.54*(2.33) | 8*6.24*(0.49) | 1*4.93*(3.13) | 1*3.29*(1.59) | 3*2.30*(0.21) |
|  Psittaciformes | 27*14.40*(11.02) | 1*5.94*(4.11) | 0*4.34*(4.34) | 1*3.43*(1.72) | 2*2.29*(0.04) | 1*1.60*(0.23) |
|  Galliformes | 5*7.65*(0.92) | 1*3.16*(1.47) | 7*2.31*(9.55) | 3*1.82*(0.76) | 1*1.21*(0.04) | 0*0.85*(0.85) |
|  Anseriformes | 5*7.65*(0.92) | 0*3.16*(3.16) | 0*2.31*(2.31) | 7*1.82*(14.72) | 5*1.21*(11.80) | 0*0.85*(0.85) |
|  Columbiformes | 4*4.95*(0.18) | 0*2.04*(2.04) | 2*1.49*(0.17) | 2*1.18*(0.57) | 0*0.79*(0.79) | 3*0.55*(10.91) |
|  Other | 2*7.65*(4.17) | 11*3.16*(19.48) | 2*2.31*(0.04) | 1*1.82*(0.37) | 1*1.21*(0.04) | 0*0.85*(0.85) |
|   | 63 | 26 | 19 | 15 | 10 | 7 |

Table 4: Contingency table showing actual and expected numbers of ‘low’, ‘medium’ and ‘high’ confidence assessments allocated to (a): each impact mechanism (Fisher’s Exact Test for Count Data); and (b): ‘lower tier’ (**MC** and **MN**) and ‘upper tier’ (**MO**, **MR** and **MV**) impact categories (Chi-square Test of Independence). Expected values are displayed in italics. Individual X-squared values are displayed in (parentheses). Data for impact mechanisms (5) Parasitism, (9) Chemical impact on ecosystem and (11) Structural impact on ecosystem were removed from the dataset for the test, due to low sample size (Table 4a only).

Table 4(a)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | No. of ‘low’ confidence assessments | No. of ‘medium’ confidence assessments | No. of ‘high’ confidence assessments | Total confidence assessment allocations |
| Competition | 21*22.50*(0.10) | 23*17.55*(1.69) | 19*22.95*(0.68) | 63 |
| Predation | 8*9.29*(0.18) | 8*7.24*(0.08) | 10*9.47*(0.03) | 26 |
| Interaction with other alien species | 10*6.79*(1.52) | 3*5.29*(0.99) | 6*6.92*(0.12) | 19 |
| Hybridisation | 3*5.36*(1.04) | 3*4.18*(0.33) | 9*5.46*(2.29) | 15 |
| Grazing/herbivory/browsing | 2*3.57*(0.69) | 2*2.79*(0.22) | 6*3.64*(1.53) | 10 |
| Transmission of disease to native species | 6*2.50*(4.90) | 0*1.95*(1.95) | 1*2.55*(0.94) | 7 |
|  Total | 50 | 39 | 51 | 140 |
| Table 4(b) |  |  |  |  |
| **MC** and **MN** impact categories (‘lower tier’) | 42*35.63*(1.14) | 32*29.34*(0.24) | 28*37.03*(2.20) | 102 |
| **MO**, **MR** and **MV** impact categories (‘upper tier’) | 9*15.37*(2.64) | 10*12.66*(0.56) | 25*15.97*(5.10) | 44 |
| Total | 51 | 42 | 53 | 146 |

**Figures**

Figure 1: The distribution across orders of alien bird species with impact data. Pas = Passeriformes; Psi = Psittaciformes; Ans = Anseriformes; Gal = Galliformes; Col = Columbiformes; Oth = Other orders.



Figure 2: The number of impacts assigned to each impact category. A further 296 species were Data Deficient (**DD**). **MC** = Minimal Concern; **MN** = Minor; **MO** = Moderate; **MR** = Major; **MV** = Massive.



Figure 3: The number of impacts assigned to each impact mechanism. Com = Competition; Pre = Predation; Int = Interaction with other alien species; Hyb = Hybridisation; Gra = Grazing/herbivory/browsing; Dis = Transmission of disease to native species; Che = Chemical impact on ecosystem; Par = Parasitism; Str = Structural impact on ecosystem.



**Supporting Data: Appendix S1**

**EICAT Assessment – Alien Birds: Literature Search**

**Search protocol**

An exhaustive literature review was undertaken to identify sources of data describing the impacts of each alien bird species. Following an initial search using online databases (see below), a search for references listed in the articles/data sources found through the initial search was undertaken. This process was repeated to a point where no new sources of data were identified.

**Search terms**

Online searches were undertaken using the following search terms within a search string, in conjunction with the species scientific and common name: “introduced species”, “invasive species”, “invasive alien species”, “IAS”, “alien”, “non-native”, “non-indigenous”, “invasive bird”, “pest”, “feral” and “exotic”. Thus, the search string for the species Eurasian blackbird was (“introduced species” OR “invasive species” OR “invasive alien species” OR “IAS” OR “alien” OR “non-native” OR “non-indigenous” OR “invasive bird” OR “pest” OR “feral” OR “exotic”) AND (“Eurasian blackbird” OR “blackbird” OR “Turdus merula”).

**Data sources**

Databases searched included:

* Web of Science (<http://apps.webofknowledge.com/>).
* Google (<https://www.google.co.uk>).
* Google Scholar (<https://scholar.google.co.uk>).
* UCL Explore (<https://www.ucl.ac.uk/library/electronic-resources/about-explore>), which provides access to a range of online publication databases including JSTOR (<http://www.jstor.org>), Springer Link (<http://link.springer.com>), Wiley Online Library (<http://onlinelibrary.wiley.com>), Cambridge University Press (<http://www.cambridge.org>), Oxford University Press (<http://www.oxfordjournals.org/en/>), The Royal Society (<https://royalsociety.org/library/collections/journals/>) and ProQuest (<http://www.proquest.com/libraries/academic/databases/>).

Other online resources searched included the IUCN Red List of Threatened Species (<http://www.iucnredlist.org>), Delivering Alien Invasive Species Inventories for Europe (DASIE) (<http://www.europe-aliens.org>), CABI’s Invasive Species Compendium (<http://www.cabi.org/isc/>) and the Global Invasive Species Database (GISD) of the Invasive Species Specialist Group (ISSG) (<http://www.issg.org/database/welcome/>).

Key texts on avian invasions were used to guide the assessment process, including Long (1981), Lever (2005) and Blackburn *et al.* (2009).

**Reference documents**

Relevant data sources and articles were selected according to the information provided in the titles and abstracts, based on the search terms above, and the EICAT impact mechanisms and criteria. The following reference documents were used to collate data on alien bird impacts during the EICAT assessment:

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