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Birds and alien species dispersal: on the need to focus management efforts on primary introduction pathways – comment on Reynolds *et al.* and Green

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ABSTRACT

Two articles published in *Diversity and Distributions* (Green, 2015; Reynolds *et al.*, 2015) demonstrate the role of waterbirds in dispersing alien species and claim that this phenomenon has been largely neglected. Setting out priorities for the future, they focus on the need to improve our understanding of the problem if it is to be successfully managed. We argue that birds are vectors of the secondary spread of alien species already introduced by human agency, rather than the pathway of their primary introduction. The challenge presented by unaided dispersal pathways, such as birds, will not be significantly reduced by future advances in our understanding of their mechanisms. The three-stage hierarchical approach, recommended by the Convention on Biological Diversity, remains the best management option for biological invasions, irrespective of the level of knowledge about their pathways.

Keywords

biological invasions, invasion pathways, invasion vectors, secondary spread, three-stage hierarchical approach, unaided pathways.

Two articles published in *Diversity and Distributions* (Green, 2015; Reynolds *et al.*, 2015) discussed the role of waterbirds in dispersing alien species. The authors provide empirical evidence for such dispersal of 79 alien plant species and eight alien invertebrates, including some of the worst aquatic invaders and the most widely distributed alien terrestrial plant species. In setting out priorities for the future, these authors stress that improving our knowledge of different aspects of this problem is a basic prerequisite of its proactive and effective management. However, they give little practical advice on how this management should be realized. We argue that stopping primary introductions of new alien species and preventing their establishment are the two most important conditions for avoiding their further spread not only by birds but also through other unaided pathways, such as wind or sea currents. Once alien species capable of such hitchhiking have been introduced and established, their containment may be virtually impossible even if we make great progress in understanding the mechanisms of that phenomenon.

Reynolds *et al.* and Green provide a set of priorities for future field and experimental research. They postulate, among other things, that improving predictions of invasive alien species spread by waterbirds requires an understanding of the nature and scale of waterbird movement and foraging ecology, baseline identification of the alien organisms being dispersed by waterbirds in different parts of the globe, the effects of gut passage, the viability and condition of propagules landing at new sites, propagule selectivity and retention, and whether multiple bird species may be spreading a particular alien organism. We claim that our knowledge of some of these aspects is already good enough to lead us to conclude that further progress will add little, regrettably, to our arsenal of practical means to tackle avian dispersal of alien species.

For example, most cases of endozoochory provided by Reynolds *et al.* and Green illustrate only casual links between the bird vectors and the alien species that they disperse. Gulls, for instance, are demonstrated to disperse seeds of terrestrial alien plants by endozoochory. As most of these seeds are tiny, it is not reasonable to assume that gulls actively forage for them, particularly on land. These seeds most likely landed in water and were taken up by gulls as a sort of contaminant, possibly stuck to the food they foraged. Similarly, examples of ectozoochory provided by the authors result from casual links between the alien hitchhikers and their vectors. The actual number of similar connections that remain

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to be detected between bird species and the alien species they can disperse may be enormous, making the practical usefulness of studying them questionable. Considering the mass volume and temporal stability of bird movements, and the high rate of increase of local populations of some alien hitchhikers, in many cases scientific evidence confirming the need for their control is likely to come too late to be of any assistance for effective practical responses. This point is in fact illustrated by the examples of recent evidence, given by Reynolds *et al.* and Green, of waterbird-mediated dispersal of invasive alien species that have been widely spread for decades.

Green (2015) argues that our insufficient understanding is reflected in inadequate representation of birds as introduction pathways and means of dispersal in many databases on alien species or in analyses of invasion pathways. However, such databases and analyses, including the one mentioned by Green (Convention on Biological Diversity, 2014), may explicitly concentrate on the primary pathways of alien species introductions and not on the mechanisms of secondary spread of already present alien species by natural means. The only situation in which a bird movement would be such a primary pathway of an alien species introduction is when the dispersing bird itself was an alien species at its take-off point, for example as a result of an earlier escape from a collection or a deliberate release for fauna improvement, and it brought a new alien species into a destination region. Contrary to Green, we think that the absence of avian vectors in databases on alien species and in analyses of their primary introduction pathways is not only due to negligence but also to scarcity of examples supporting this scenario. Although the number of alien bird species naturalized world-wide exceeds 200 (Lever, 2005; Martin-Albarracin *et al.*, 2015), the mechanism by which their subsequent movements beyond the introduction site result in transport of new alien species to new areas (particularly for long distances) has not been documented in the literature. Cases accessible in the Global Invasive Species Database (http://www.issg.org/database/welcome/) confirm that alien bird movements are not the primary drivers of long-distance introduction of new alien species, but that they rather constitute an additional local factor of secondary dispersal for aliens introduced earlier by human agency. In fact, all the examples given by Reynolds *et al.* and Green follow the same mechanism, the only difference being the native provenance of the avian vectors. Moreover, most of these examples (in particular those based on field studies) refer to birds that are not typical long-distance migrants, and although the ultimate result of their movements may indeed be long-distance secondary dispersal of alien species, it usually is realized in many short steps.

Green points out that reaching Aichi Target 9 of the Convention on Biological Diversity (CBD), related to the identification, prioritization and management of invasion pathways to prevent the introduction of invasive alien species (Convention on Biological Diversity, 2014), may be hindered by neglect of the role of waterbirds in their dispersal. However, we argue that managing this pathway, as with any other natural pathway capable of spread of alien species, is extremely problematic. Limiting the intensity of the operation of native avian vectors would require a significant reduction of bird numbers, which in most cases is neither ethically and legally acceptable nor technically realistic. Control of avian vectors would only be justified in the case of alien bird species. One of the best known examples of alien waterbird management programs is the nearly complete eradication of the Ruddy duck *Oxyura jamaicensis* from Western Europe (Robertson *et al.*, 2015). However, gaining public support and mobilizing financial resources and international coordination for this campaign have presented a challenge even though the species poses a very serious threat to the globally threatened native white-headed duck *O. leucocephala* with which it hybridizes. It would be even more difficult to undertake control of an alien bird whose only impact is dispersal of other alien species.

Practical efforts to reach Aichi Target 9 should therefore concentrate on the human-operated pathways of primary introductions rather than on unaided pathways of the secondary spread of already introduced alien species. The CBD's Guiding Principles, including the three-stage hierarchical approach (Convention on Biological Diversity, 2002), highlight the obvious point that preventing the introduction of new alien species at take-off and stopover points for migrating birds is crucial to successful management of biological invasions caused by avian vectors (Table 1). Keeping alien bird species, particularly long-distance migrants, from being introduced at those sites would prevent new dispersal vectors from becoming operational, but it is more important – and more problematic – to prevent the introduction of potential alien hitchhikers that could be further dispersed from those sites by *any* migrating birds, whether alien or native. Such hitchhikers can be introduced by a variety of primary pathways, including deliberate release, escape from captivity, transport of a contaminated commodity or stowaways, or construction of transport infrastructure (e.g. canals) serving as invasion corridors. Management of each of these pathways is very costly and complicated, involving the development and implementation of international and national legal regulations and procedures, voluntary codes of conduct and awareness-raising campaigns (Hulme *et al.*, 2008; Hulme, 2015).

If prevention focused on primary introduction pathways fails, the CBD recommends early detection and rapid response as the second line of defence against the establishment of alien species (Convention on Biological Diversity, 2014). Implementing surveillance systems and contingency planning increases the likelihood that unprevented alien species will not establish, build up population numbers and expand their range. Complete eradication of early detected potential alien hitchhikers is the preferred outcome; it is the only way to ensure that they will not be further dispersed by secondary introduction pathways, whether human-operated or unaided (Table 1). The feasibility of early detection and eradication differs between the taxonomic groups of target

Table 1 Options to manage dispersal of alien species by birds, based on the Guiding Principles of the Convention on Biological Diversity (Convention on Biological Diversity 2002).

Priority	Objective	Methods	Best-practice examples
Prevention	Limiting primary introductions of potential alien hitchhikers and alien birds that may disperse them	Development and implementation of international and national legal regulations and procedures, voluntary codes of conduct and awareness-raising campaigns; development of tools for assessment of invasiveness of alien hitchhikers	Regulation No. 1143/2014 of the European Parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species (European Commission, 2014) Code of conduct on horticulture and invasive alien species (Heywood & Brunel, 2011) New Zealand Biosecurity Strategy (Simberloff, 2014)
Early Detection and Rapid Response (EDRR)	Reducing establishment of unprevented potential alien hitchhikers and alien birds that may disperse them	Development of contingency plans; implementation of surveillance systems focused on high-risk entry points; undertaking prompt actions after detection of an incursion, with complete eradication as the preferred outcome; post-eradication monitoring	Regulation No. 1143/2014 of the European Parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species (European Commission, 2014) New Zealand National Interest Pest Responses (NIPR; Champion *et al.*, 2014) Australian National Weed Incursion Plan (Simberloff, 2014)
Containment and long-term control	Limiting further spread of established potential alien hitchhikers; reducing their numbers in areas of incursion	Management of human-operated pathways of secondary dispersal; monitoring linked with quick action to eradicate any new outbreaks	Physical control of water primrose (*Ludwigia grandiflora*) in Germany (Hussner *et al.*, 2016) Physical control of European beachgrass (*Ammophila arenaria*) at minimal levels in the Humboldt Bay National Wildlife Refuge (Pickart, 2013) Chemical control of hydrila *Hydrilla verticillata* in Florida (Puri *et al.*, 2007)
Research	Prioritization of areas that are the most risky sources of dispersal of most invasive alien hitchhikers (rather than detailed study of bird–hitchhiker interactions on a species-by-species basis)	Use of the extant data on the local numbers and diversity of alien species and their avian vectors (e.g. List of Wetlands of International Importance, EC Water Framework Directive); possible proxies for the susceptibility of these areas to invasions: local intensity of primary invasion pathways (e.g. shipping, boating, fish restocking, fishing or angling); country statistics (e.g. human population density, GDP); remote sensing (e.g. calculating distances from major shipping ports)	The Ramsar Strategic Plan 2009-2015 (Ramsar Convention, 2008) Monitoring ecological status under the EC Water Framework Directive (Vandekerkhove *et al.*, 2013)

species and between the environments in which they occur (Pluess *et al.*, 2012). One of the biggest challenges is control of aquatic alien invaders, for which there usually are no effective eradication methods. Once introduced into waters they are often beyond any control, even if detected early and immediately subjected to extensive, publicly supported actions. Although the number of examples of successful eradication programs in water ecosystems is increasing, the targeted alien species usually are not the type of hitchhiker that can be easily transported by birds (Genovesi, 2011).

The third stage of the CBDs hierarchical approach, in the event that eradication is not feasible because of ethical, technical or financial limitations, is to contain further spread or to implement long-term control measures to reduce population numbers or ameliorate the damage caused. Regular monitoring is essential and needs to be linked with quick action to eradicate any new outbreaks (Convention on Biological Diversity, 2014; Table 1). Human-operated pathways responsible for primary introductions of alien species may play an equally important role in their secondary spread

(Banha *et al.*, 2016). Therefore, management efforts to limit the role of these pathways in new introductions are equally important for containment of unprevented alien species (Hulme *et al.*, 2008; Hulme, 2015). However, the complexity of pathways of primary and secondary introductions, combined with the lack of effective control methods, makes containment and long-term control of aquatic invaders very problematic. Moreover, if they are also able to use unaided pathways for their secondary spread, the final result of costly efforts to contain them by controlling human-driven dispersal may be nil. Given the massive scale and temporal stability of unaided pathways, including bird movement, secondary spread of alien hitchhikers seems almost inevitable if their numbers in the source area are not reduced to zero as a result of prevention or eradication efforts (Wilk-Woźniak & Najberek, 2013). The remarkable rate of such spread is in fact illustrated by some of the examples of secondary spread by birds provided by Reynolds *et al.* and Green.

Given the limited resources that can be spent on management of biological invasions, it is very important to prioritize areas where management efforts should be concentrated. Perhaps the most straightforward procedure for waterbirds as a secondary dispersal pathway would be to base the prioritization process on extant data on the local numbers and diversity of avian vectors, such as the List of Wetlands of International Importance (Ramsar Convention, 2012). Distribution data on potential alien hitchhikers occurring there could be a useful source of primary information to use for selecting sites that may be important hubs for biological invasions. As these data may not be available, however, the local intensity of primary introduction pathways, such as shipping, boating, fish restocking, fishing or angling, could be used as a proxy in such an assessment. This could be done using available country statistics (human population density, GDP) and by remote sensing (e.g. calculating distances from major shipping ports; Pyšek *et al.*, 2010; Gallardo, 2014; Table 1).

The practical advantage of focusing management efforts on Wetlands of International Importance is that, given their conservation status, it should be easier to mobilize financial resources there than in areas not under protection. Also, usually the importance of these wetlands is not limited to the migration period, or to waterbirds. While Reynolds *et al.* and Green restrict their analyses to waterbirds, the majority of their examples of dispersed species are terrestrial plants, and thus, there is no reason to exclude terrestrial bird migrants from the pool of potential secondary dispersers of alien species. However, the main drawback of restricting management to known centres of avian biodiversity is that it excludes potential invasion hubs that fall well below the thresholds that signal them as important for birds. A single transport event by an avian vector can be enough to effectively disperse an alien species to a new area from such a neglected invasion hotspot, particularly as species capable of such hitchhiking may be preadapted for establishment despite low propagule pressure (e.g. via asexual reproduction or production of resting stages; MacIsaac, 2011).

In conclusion, the challenge presented by unaided dispersal pathways, such as birds, will not be significantly reduced by future advances in our understanding of their detailed mechanisms. The three-stage hierarchical approach recommended by the Convention on Biological Diversity remains the best management option for biological invasions, irrespective of the level of knowledge about their pathways.

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REFERENCES

Banha, F., Gimeno, I., Lanao, M., Touya, V., Durán, C., Peribáñez, M.A. & Anastácio, P.M. (2016) The role of waterfowl and fishing gear on zebra mussel larvae dispersal. *Biological Invasions*, **18**, 115–125.

Champion, P.D., de Winton, M.D. & Clayton, J.S. (2014) A risk assessment based proactive management strategy for aquatic weeds in New Zealand. *Management of Biological Invasions*, **5**, 233–240.

Convention on Biological Diversity (2002) COP 6 Decision VI/23. Alien Species That Threaten Ecosystems, Habitats or Species. Available at: http://www.cbd.int/decision/cop/?id=7197 (accessed 17 December 2015).

Convention on Biological Diversity (2014) Analysis on Pathways for the Introduction of Invasive Alien Species: Updates Information Document 12th Meeting of the Conference of the Parties to the Convention on Biological Diversity. Available at: http://www.cbd.int/doc/meetings/cop/cop-12/information/cop-12-inf-10-en.pdf (accessed 17 December 2015).

European Commission (2014) Regulation No. 1143/2014 of the European Parliament and of the Council on the Prevention and Management of the Introduction and Spread of Invasive Alien Species. *Official Journal of the European Union*, **317**, 35–55.

Gallardo, B. (2014) Europe's top 10 invasive species: relative importance of climatic, habitat and socio-economic factors. *Ethology Ecology & Evolution*, **26**, 130–151.

Genovesi, P. (2011) Eradication. *Encyclopedia of biological invasions* (ed. by M. Rejmánek and D. Simberloff), pp. 198–203. University of California Press, Berkeley.

Green, A.J. (2015) The importance of waterbirds as an overlooked pathway of invasion for alien species. *Diversity and Distributions*, **22**, 239–247.

Heywood, V.H. & Brunel, S. (2011) Code of conduct on horticulture and invasive alien species. Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), Nature and Environment, no. 162.

Hulme, P.E. (2015) Invasion pathways at a crossroad: policy & research challenges for managing alien species introductions. *Journal of Applied Ecology*, **52**, 1418–1424.

Hulme, P.E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., Nentwig, W., Olenin, S., Panov, V., Pergl, J., Pyšek, P., Roques, A., Sol, D., Solarz, W. & Vilà, M. (2008) Grasping at the routes of biological invasions: a framework for integrating pathways into policy. *Journal of Applied Ecology*, **45**, 403–414.

Hussner, A., Windhaus, M. & Starfinger, U. (2016) From weed biology to successful control: an example of successful management of Ludwigia grandiflora in Germany. *Weed Research*, doi:10.1111/wre.12224.

Lever, C. (2005) *Naturalized birds of the world*. Poyser, London.

MacIsaac, H.J. (2011) Lakes. *Encyclopedia of biological invasions* (ed. by M. Rejmánek and D. Simberloff), pp. 410–422. University of California Press, Berkeley.

Martin-Albarracin, V.L., Amico, G.C., Simberloff, D. & Nuñez, M.A. (2015) Impact of non-native birds on native ecosystems: a global analysis. *PLoS ONE*, **10**, e0143070.

Pickart, A. (2013) Dune restoration over two decades at the Lanphere and Ma-le'l Dunes in Northern California. *Restoration of coastal dunes* (ed. by M.L. Martinez, J.B. Gallego-Fernandez and P.A. Hesp), pp. 159–171. Springer, New York, NY.

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

Puri, A., MacDonald, G.E. & Haller, W.T. (2007) Stability of fluridone-resistant hydrilla (*Hydrilla verticillata*) biotypes over time. *Weed Science*, **55**, 12–15.

Pyšek, P., Jarošík, V., Hulme, P.E., Kühn, I., Wild, J., Arianoutsou, M., Bacher, S., Chiron, F., Didžiulis, V., Essl, F., Genovesi, P., Gherardi, F., Hejda, M., Kark, S., Lambdon, P.W., Desprez-Loustau, M.L., Nentwig, W., Pergl, J., Poboljšaj, K., Rabitsch, W., Roques, A., Roy, D.B., Shirley, S., Solarz, W., Vilà, M. & Winter, M. (2010) Disentangling the role of environmental and human pressures on biological invasions across Europe. *Proceedings of the National Academy of Sciences USA*, **107**, 12157–12162.

Ramsar Convention (2008) COP X Resolution X.1. The Ramsar Strategic Plan 2009-2015. Available at: http://www.ramsar.org/sites/default/files/documents/library/key_res_x_01_e.pdf (accessed 24 August 2016).

Ramsar Convention (2012) Strategic framework and guidelines for the future development of the List of Wetlands of International Importance of the Convention on Wetlands (Ramsar, Iran, 1971) – 2012 revision. Resolution XI.8 Annex 2. Available at: http://www.ramsar.org/sites/default/files/documents/pdf/cop11/res/cop11-res08-e-anx2.pdf (accessed 24 May 2016).

Reynolds, C., Miranda, N.A. & Cumming, G.S. (2015) The role of waterbirds in the dispersal of aquatic alien and invasive species. *Diversity and Distributions*, **21**, 744–754.

Robertson, P.A., Adriaens, T., Caizergues, A., Cranswick, P.A., Devos, K., Gutiérrez-Expósito, C., Henderson, I., Hughes, B., Mill, A.C. & Smith, G.C. (2015) Towards the European eradication of the North American ruddy duck. *Biological Invasions*, **17**, 9–12.

Simberloff, D. (2014) Biological invasions: what's worth fighting and what can be won? *Ecological Engineering*, **65**, 112–121.

Vandekerkhove, J., Cardoso, A.C. & Boon, P.J. (2013) Is there a need for a more explicit accounting of invasive alien species under the water framework directive. *Management of Biological Invasions*, **4**, 25–36.

Wilk-Woźniak, E. & Najberek, K. (2013) Towards clarifying the presence of alien algae in inland waters—can we predict places of their occurrence? *Biologia*, **68**, 838–844.

BIOSKETCH

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