Int. Zoo Yb. (2017) **51:** 15–31
DOI:10.1111/izy.12159

Contributions of zoos and aquariums to reintroductions: historical reintroduction efforts in the context of changing conservation perspectives

T. GILBERT[1], R. GARDNER[1,2], A. R. KRAAIJEVELD[2] & P. RIORDAN[1]
[1]*Marwell Wildlife, Colden Common, Winchester SO21 1JH, United Kingdom, and* [2]*Biological Sciences, University of Southampton, University Road, Southampton SO17 1BJ, United Kingdom*
E-mail: taniag@marwell.org.uk

The world faces a biodiversity crisis and efforts are needed to protect species from extinction. Reintroductions using source populations from zoos and aquariums offer a technique to re-establish species in the wild following extinction or population depletion beyond sustainable limits. *Ex situ* populations are a potential source for reintroduction projects but many zoos and aquariums do not necessarily maintain globally rare species. We aimed to quantify the contribution zoos and aquariums make to reintroductions, and evaluate how European Association of Zoos and Aquaria (EAZA) members have contributed to reintroduction projects. Data on the contribution zoos and aquariums make to reintroductions were extracted from the *Global Re-introduction Perspectives* publications, and the EAZA membership was surveyed on historical reintroduction projects. This information was augmented with data from *The IUCN Red List of Threatened Species* and Species360 Zoological Information Management System (ZIMS). The majority of species in EAZA-member institutions were not globally threatened but more than half of the 156 reintroduced species and 260 projects supported by EAZA members concerned species that were threatened (i.e. Critically Endangered, Endangered or Vulnerable), Near Threatened or Extinct in the Wild. Most species that were not of global conservation concern were locally rare. EAZA members provided animals for release, but their greatest contributions to reintroduction projects were funds, staff, expertise and equipment, and project coordination. Zoos and aquariums have an important role to play in reintroductions especially as emphasis shifts away from the *in situ–ex situ* dichotomy and towards integrated conservation management of species.

Key-words: aquariums; conservation translocation; EAZA-member institutions; reintroduction; species conservation; zoos.

INTRODUCTION

At the time of writing, the world is facing an unprecedented loss of biodiversity. Hundreds of species have already been driven to extinction by anthropogenic change and thousands more are imperilled (Pereira *et al.*, 2010; Pimm *et al.*, 2014; WWF, 2016). Decisive conservation action is needed to mitigate threats to species causing local, regional or complete extinctions in the wild.

Conservation translocations, including reintroductions, have a role in re-establishing or reinforcing wild populations where partial or complete extirpation has occurred. This requires sufficient areas of natural habitat and that the threats leading to extirpation have been removed or sufficiently reduced (Stuart, 1991; Gusset, 2012; IUCN/SSC, 2013). Therefore, opportunities to re-establish wild populations through reintroduction are rare. Nonetheless, the number of species that have been reintroduced and the number of reintroduction projects under way have increased substantially in recent years (Stanley Price *et al.*, 2004; Seddon *et al.*, 2007; Conway, 2011).

Conservation translocations may be more successful using wild-caught rather than captive-bred individuals (Griffith *et al.*, 1989). Captivity potentially causes loss of

genetic diversity and may alter life-history traits underpinning species integrity (Lacy, 1994, 2013; Frankham, 1995; Philippart, 1995; Balmford *et al.*, 1996; Snyder *et al.*, 1996; McPhee, 2004). Consequential impacts on post-release survival may also reduce reintroduction success (Kleiman *et al.*, 1994; Snyder *et al.*, 1996; Bowkett, 2009). However, there is an increasing scarcity of suitable wild source populations, along with concerns about their regional appropriateness. While not ideal, an increasing number of reintroduction projects release captive-bred animals (Seddon *et al.*, 2007). Such reintroductions have made a fundamental contribution to the conservation of some iconic species (Stanley Price *et al.*, 2004; Seddon *et al.*, 2007; Conde *et al.*, 2011), notably the Arabian oryx *Oryx leucoryx* (Mésochina *et al.*, 2003), Black-footed ferret *Mustela nigripes* (Dobson & Lyles, 2000), Przewalski's horse *Equus ferus przewalskii* (Van Dierendonck & de Vries, 1996) and Golden lion tamarin *Leontopithecus rosalia* (Kierulff *et al.*, 2012). Hoffmann *et al.* (2010) found that *ex situ* conservation breeding contributed to species recovery for one-quarter of those vertebrate species whose extinction risk was reduced, and captive breeding and reintroduction were the most frequently cited conservation actions leading to improvements in the International Union for Conservation of Nature (IUCN) Red List status (Hoffmann *et al.*, 2010; Conde *et al.*, 2011; Gusset & Dick, 2012). For birds, captive breeding and reintroduction efforts were instrumental in preventing the extinction of six out of 16 species that would probably have gone extinct in the absence of conservation action (Butchart *et al.*, 2006). In some cases, captive breeding and reintroduction can be more effective in conserving mammals than other conservation measures (Hayward, 2011), and have contributed to the genuine improvement in IUCN Red List status of nine mammal species (Hoffmann *et al.*, 2011). One such species is the Greater stick-nest rat *Leporillus conditor* whose reintroduction to Australia resulted in a change in IUCN Red List status from Endangered (EN) to Vulnerable (VU) (Hayward, 2011; Woinarski & Burbidge, 2016).

Species in zoos and aquariums are often viewed as a potential source of animals for reintroduction projects by both the institutions and the public (Stanley Price, 1991; Stanley Price & Fa, 2007; Niekisch, 2010). The idea of returning animals to their 'home' in the wild is compelling and has a strong emotional appeal (Stanley Price & Fa, 2007).

Zoos and aquariums are traditionally associated with the 'Ark' paradigm where individuals of a species are distributed over numerous organizations with the aim of creating a closed genetically and demographically sustainable insurance population. These closed insurance populations are cooperatively managed to retain the maximum amount of genetic diversity, often 90% of wild gene diversity for 100–200 years, to enable future reintroduction should it be feasible and appropriate for the species (Soulé *et al.*, 1986). In essence, the aim of these insurance populations is to 'buy time' for species that are under threat in the wild by providing a source population if and when reintroductions are needed in the future. Additionally, important non-threatened education or exhibit species are managed in the same way to remove the need for importation of animals from the wild and to provide an insurance population should those species become threatened in the future (IUCN/SSC, 2014). The zoo community chooses to apply the 'insurance populations' model to all managed species, and the goal of the average breeding programme under the 'Ark' paradigm is insurance rather than 'breed for release' within a specified time frame. Despite this, reintroduction is often assumed to be the automatic purpose of a breeding programme (Jakob-Hoff *et al.*, 2015). This has led to the expectation that zoos and aquariums hold populations specifically for reintroduction, and are thus involved in many reintroduction projects.

Zoos and aquariums have recognized that the 'insurance population' management

model may not always be the best approach for *ex situ* conservation. Ideally, the conservation needs of a threatened species should be assessed and a programme developed to deliver *ex situ* help if it is required (de Man *et al.*, 2016). This shift away from the traditional 'Ark' paradigm to a more integrated approach to conservation (Keulartz, 2015) is reflected in the changing emphasis of the World Association of Zoos and Aquariums (WAZA) conservation strategies, from the first published in 1993 through to the latest in 2015 (IUDZG/CBSG, 1993; WAZA, 2005; Barongi *et al.*, 2015). The historical emphasis on captive breeding and reintroduction (IUDZG/CBSG, 1993) has evolved into a more holistic approach to biodiversity conservation enshrined in the One Plan approach promoted by the IUCN Species Survival Commission (SSC) Conservation Breeding Specialist Group (CBSG) (CBSG, 2011; Traylor-Holzer *et al.*, in press). The One Plan approach 'supports integrated species conservation planning through the joint development of management strategies and conservation actions by all responsible parties to produce one comprehensive conservation plan for the species' (Byers *et al.*, 2013). Reintroductions should therefore be one component of wider conservation action for a species rather than isolated projects.

Here, we seek to understand the value of zoo and aquarium populations for conservation translocations and evaluate how European Association of Zoos and Aquaria (EAZA)-member institutions have contributed to reintroduction projects. Throughout the rest of the paper, the term 'reintroduction' will include both reintroductions and reinforcements as defined in IUCN/SSC (2013). The reintroduction of animals bred in zoos and aquariums is 'the intentional movement and release of an organism inside its indigenous range from which it has disappeared' with the aim of re-establishing a viable population (IUCN/SSC, 2013). We have also included reinforcements using animals bred in zoos and aquariums, defined as 'the intentional movement and release of an organism into an existing population of conspecifics' (IUCN/SSC, 2013).

METHODS

The contribution of zoos and aquariums to reintroductions

The contribution that zoos and aquariums made to reintroductions was evaluated using two methods. First, a systematic literature review was performed on all editions of *Global Re-introduction Perspectives* (GRP) published by IUCN/SSC Reintroduction Specialist Group and the Environment Agency-Abu Dhabi (Soorae, 2008, 2010, 2011, 2013, 2016) to assess the role of reintroductions, and global zoos and aquariums, in conservation translocations. In total, 243 articles were searched and data extracted on: the total number of conservation-translocation projects per taxa (mammals, birds, reptiles, amphibians, fishes, insects, molluscs, crustaceans, corals, arachnids and 'other invertebrates'); the number of projects that had involvement from any global zoo/aquarium identified by author affiliation or specified in the article; the number of projects that released captive-bred animals; the number of projects where zoos and aquariums provided animals for release.

The second method of evaluation was a direct e-mail survey of EAZA-member zoos and aquariums, targeted at specific individuals, including: the nominated conservation contact at all full, temporary and associate EAZA-member institutions (n = 337); attendees of the September 2013 EAZA Reintroduction and Translocation Group (RTG) meeting (n = 51); core RTG members (n = 11); EAZA Taxon Advisory Group (TAG) chairs (n = 39); institutions that had registered projects in the EAZA Conservation Database (http://www.eazaconservation.org) (n = 56). The survey was sent to a total of 443 contacts, once duplicates were removed. Information was requested for reintroduction projects that involved animals bred at zoos and

aquariums, and excluded plant reintroductions, wild-to-wild translocations (including problem animals), and rehabilitation and release.

Information was requested on the institution's involvement in reintroduction projects using animals bred in zoos and aquariums, specifying (1) the species concerned, (2) the year(s) in which the project took place and (3) the type of involvement by the institution (e.g. animals, staff, expertise, equipment, funding, coordination or 'other' to be specified). The initial request was sent on 17 April 2014, followed by a reminder e-mail 5 weeks later.

Additional data sources

The Species360 (formerly International Species Information System) Zoological Information Management System (ZIMS) database was explored on 28 August 2016 to access the Taxon Advisory Group (TAG) Export Reports for each class of Animalia held by EAZA-member institutions. A species list was compiled, removing subspecies and genus-only data.

Threat-status categories were extracted from the IUCN Red List website on 28 August 2016 (IUCN, 2016). For each reintroduced species reported by EAZA-member institutions, data were compiled on: the Red List status in 2016, population trend (2016) and geographic range (countries of occurrence).

The species reintroduced were also compared with the Annexes of the European Union (EU) Council Directive 92/43/EEC on the conservation of natural habitats of wild fauna and flora (EU Habitats) (Council Directive, 1992), and in Annex I of the Directive 2009/147/EC on the conservation of wild birds (EU Birds) to identify European priority species (Council Directive, 2010).

RESULTS

At the time of reporting, EAZA-member institutions collectively held a total of 5708 species, of which 4852 (85%) were vertebrates, representing *c.* 7% of the estimated 67 050 described vertebrate species globally (IUCN, 2016) (Table 1). The IUCN Red List designated 7967 vertebrate species to the 'threatened' categories of Critically Endangered (CR), Endangered (EN) and Vulnerable (VU), and EAZA members held 683 (9%) threatened species accounting for *c.* 16%, 11%, 13%, 2% and 7% of all threatened mammal, bird, reptile, amphibian and fish species, respectively. Only 1% of all threatened invertebrates were reported to be held in EAZA-member institutions (Table 1). When accounting for all species of conservation concern [i.e. threatened categories plus Extinct in the Wild (EW) and Near Threatened (NT)], the number of species held by EAZA-member institutions increased to 945 (19%) vertebrates and 84 (10%) invertebrates. At the time of writing, only 3947 of the vertebrate species and 184 of the invertebrate species in EAZA-member institutions have been evaluated for the IUCN Red List, including those in the Data Deficient (DD) category (Table 1).

Literature review: GRP

The systematic review of GRP yielded a total of 243 conservation translocation projects, of which 85 (35%) had zoo or aquarium involvement (Fig. 1). Amphibian projects had the greatest involvement, with 16 out of 17 (94%) projects, and seven out of 14 (50%) insect projects had some contribution from a zoo or aquarium. The sole arachnid project (the Fen raft spider *Dolomedes plantarius* in the UK) released individuals bred in zoos. Of four mollusc projects, none reported the involvement of zoos or aquariums, and zoos or aquariums were only involved in two out of 31 (6%) fish-reintroduction projects. Of the projects involving mammals, birds and reptiles, 30 out of 82 (37%), 16 out of 59 (27%) and 13 out of 32 (41%) projects, respectively, reported the involvement of zoos and aquariums (Fig. 1).

Zoos and aquariums provided captive-bred animals for release for 49 (20%)

	IUCN RED LIST STATUS (IUCN, 2016)			IN EAZA-MEMBER INSTITUTIONS (2016)					REINTRODUCED SPECIES FROM EAZA INSTITUTIONS[6]			
	ESTIMATED NUMBER DESCRIBED SPECIES	NUMBER SPECIES EVALUATED	NUMBER THREATENED SPECIES (CR, EN & VU)	NUMBER SPECIES HELD	NUMBER SPECIES EVALUATED (NUMBER DD SPECIES)	NUMBER THREATENED SPECIES (CR, EN & VU)	NUMBER EW SPECIES	NUMBER NT SPECIES	NUMBER REINTRODUCED SPECIES	NUMBER THREATENED SPECIES (CR, EN & VU)	NUMBER EW SPECIES	NUMBER NT SPECIES
VERTEBRATES												
Mammals	5515	5507	1203	678	666 (12)	191	2	51	31	14	2	4
Birds	10 424	10 424	1375	1455	1438 (1)	155	1	107	31	6	1	2
Reptiles	10 391	5150	983	783	481 (10)	132	0	35	6	2	–	1
Amphibians	7520	6525	2063	231	220 (5)	48	0	19	4	0	–	–
Fishes[1]	33 200	15 283	2343	1705	1036 (78)	157	4	43	6	5	–	–
Subtotal	67 050	42 889	7967	4852	3841 (106)	683	7	255	78	27	3	7
INVERTEBRATES												
Insects	1 000 000	6051	1146	255	8 (0)	3	0	1	5	0	–	1
Molluscs[2]	85 000	7251	1967	84	28 (1)	5	10	1	2	2	–	–
Crustaceans[3]	47 004	3173	730	195	48 (7)	8	0	1	1	1	–	–
Corals[4]	2175	682	237	109	78 (0)	20	0	29	–	–	–	–
Arachnids	102 248	212	166	87	5 (0)	3	0	1	1	1	–	–
Others[5]	68 823	491	82	126	9 (0)	0	0	2	–	–	–	–
Subtotal	1 305 250	17 860	4328	856	176 (8)	39	10	35	9	4	0	1
TOTAL	**1 372 300**	**60 749**	**12 295**	**5708**	**4017 (114)**	**722**	**17**	**290**	**87**	**31**	**3**	**8**

Table 1. Data from the International Union for Conservation of Species (IUCN) Red List (IUCN, 2016) and Species360 on the number and distribution of threatened taxa globally, those held in European Association of Zoos and Aquaria (EAZA)-member institutions, and for reintroductions using animals from EAZA-member collections [i.e. animals supplied for reintroductions but not including any other involvement or support (e.g. staff, expertise, funds)]. Date span for EAZA reintroductions is 1981–2014: [1]Fishes comprises the classes Actinopterygii, Cephalaspidomorphi, Chondrichthyes, Myxini and Sarcopterygii; [2]Molluscs comprises the classes of Bivalvia, Cephalopoda and Gastropoda; [3]Crustaceans comprises the classes of Branchiopoda, Malacostraca, Maxillopoda, Merostomata and Ostracoda; [4]Corals are mostly in the classes of Anthozoa (excluding jellyfish and anemones) and Hydrozoa; [5]Others incorporates the following classes: Anthozoa (excluding corals), Asteroidea, Cestoda, Chilopoda, Diplopoda, Echinoidea, Enopla, Entognatha, Holothuroidea, Monogenea, Onychophora, Secernentea, Staurozoa, Tentaculata and Turbellaria; [6]Provision of animals only. Other contributions to reintroductions for additional species are not included. Threatened species relate to the IUCN threat categories: CR, Critically Endangered; EN, Endangered; VU, Vulnerable; other threat categories: DD, Data Deficient; EW, Extinct in the Wild; NT, Near Threatened.

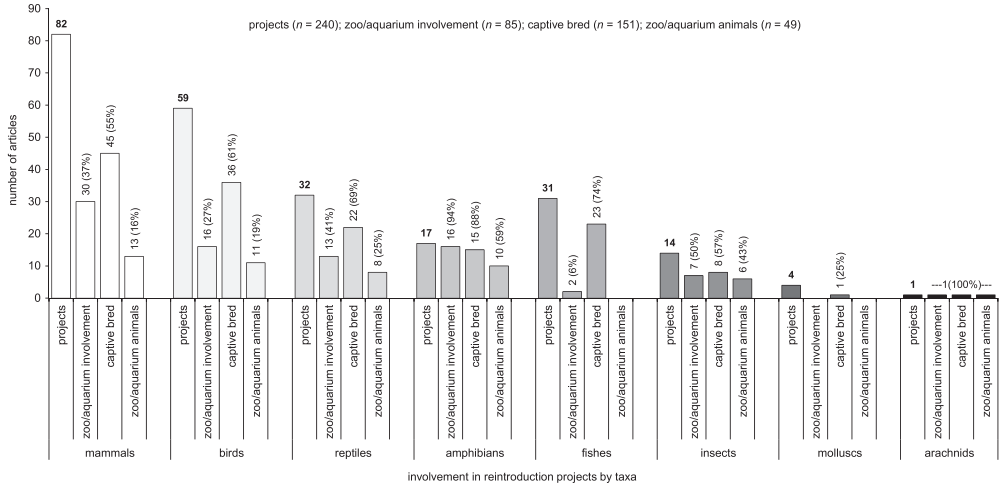

Fig. 1. Involvement of global zoos and aquariums in reintroductions based on published articles in five editions of *Global Re-introduction Perspectives* (Soorae, 2008, 2010, 2011, 2013, 2016). Of the 243 projects described, two coral projects and one 'other invertebrate' did not have any zoo or aquarium involvement and the projects did not utilize captive-bred stocks. Consequently, these projects are not included in this figure. There were no projects involving crustaceans. 'Captive bred', refers to animals bred in any type of *ex situ* institution; 'zoo animals', refers to the release of animals from global zoos or aquariums; 'zoo involvement', refers to any involvement from global zoos or aquariums.

projects. Of 243 projects, 102 (68% of projects utilizing captive-bred stock) released captive-bred animals from non-zoo/aquarium sources, including 23 of 31 (74%) fish-reintroduction projects (Fig. 1). Projects for other taxa released animals bred at zoos and aquariums for 13 of 82 (16%) mammal reintroductions, 11 of 59 (19%) bird reintroductions, eight of 32 (25%) reptile reintroductions, ten of 17 (59%) amphibian reintroductions and six of 14 (43%) insect reintroductions (Fig. 1).

Survey: EAZA-member institutions

Replies were received from 105 EAZA-member institutions, representing 31% of the 337 institutions sent the survey. Of these, 15 (14% of respondents) EAZA institutions reported no involvement in reintroduction projects, and 90 (86% of respondents) institutions reported involvement in 284 reintroduction projects carried out between 1956 and 2014 (Fig. 2). Twenty-four of these projects were disregarded because they either provided no further details ($n = 5$), were plant reintroduction projects ($n = 7$) or did not meet the IUCN definition of a reintroduction project using captive-bred individuals ($n = 12$). This left 84 institutions involved in 260 reintroduction projects following the criteria provided.

Most of the species reintroduced were birds [$n = 62$ (39·7%)] or mammals [$n = 58$ (37·2%)], accounting for 77% ($n = 120$) of the 156 species reintroduced (Fig. 3a) and 80% ($n = 207$) of the 260 reported reintroduction projects (Fig. 3c; Table 2). When total contributions were considered (i.e. one institution reporting a contribution to one project for one species), 83% [$n = 278$ (of 337)] of contributions were for bird [$n = 122$ (of 337)] or mammal [$n = 156$ (of 337)] species. This represents projects for 4% [$n = 62$ (of 1455)] of bird species and 9% [$n = 58$ (of 678)] of mammal species at EAZA-member institutions (Tables 1 and 2). [Note. Data in Table 1 refers to actual animals provided

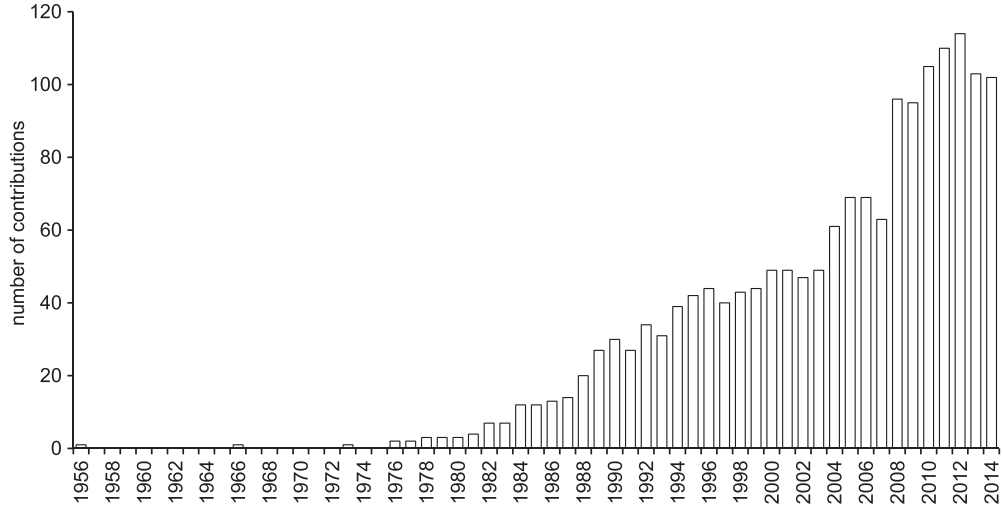

Fig. 2. Contribution of European Association of Zoos and Aquaria (EAZA)-member institutions per year to reintroduction projects (n = 1687). A contribution is recorded as the year that an EAZA-member institution reported involvement in a reintroduction project. A count was included in each specified year when an institution reported involvement over a date range.

by EAZA-member institutions, whereas Table 2 and Fig. 3 include all reintroduction projects where an EAZA-member institution made a contribution.] Other vertebrates (i.e. reptiles, amphibians and fishes) accounted for 16% of species reintroduced (n = 25 of 156 spp reintroduced; Fig. 3a; Table 2) and 15% of projects (n = 40 of 260 projects; Fig. 3c; Table 2). Invertebrate reintroductions (i.e. arachnids, crustaceans, insects and molluscs) were reported for 7% (n = 11) of 156 species in EAZA collections and 5% (n = 13) of 260 projects (Fig. 3a,c; Table 2).

EAZA-member institutions contributed to reintroductions for seven species of fish, representing 0·41% of the 1705 fish species held by EAZA-member institutions (Table 2). Of 231 amphibian species at EAZA-member institutions, 3·5% (n = 8) were reintroduced (Table 2). Similarly, there were comparatively few reptile (1·3% of n = 783) and invertebrate (1·1% of n = 856) reintroductions in relation to the number of species held for each taxa (Table 2).

When considering the supply of animals to reintroduction projects, 4·6% of mammals, 2·1% of birds, 0·8% of reptiles, 1·7% of amphibians, 0·4% of fishes and 1·1% of invertebrate species at EAZA-member institutions have been released as part of a reintroduction project (Table 1). However, 32% (n = 28 of 87) of reintroduced species released by EAZA-member institutions had an associated coordinated captive-breeding programme.

EAZA institutions have been involved in reintroductions of 32 species not held by EAZA-member institutions at the time of writing. Of those, 18 (56%) species have no historical EAZA populations recorded in ZIMS, such as the Reddish buff moth *Acosmetia caliginosa* reintroduced to the Isle of Wight, UK, between 1996 and 1998. Survey respondents reported that nine of the 18 species included the provision of animals to reintroduction projects.

Native conservation

Many zoos and aquariums have exotic species as part of their living collections but

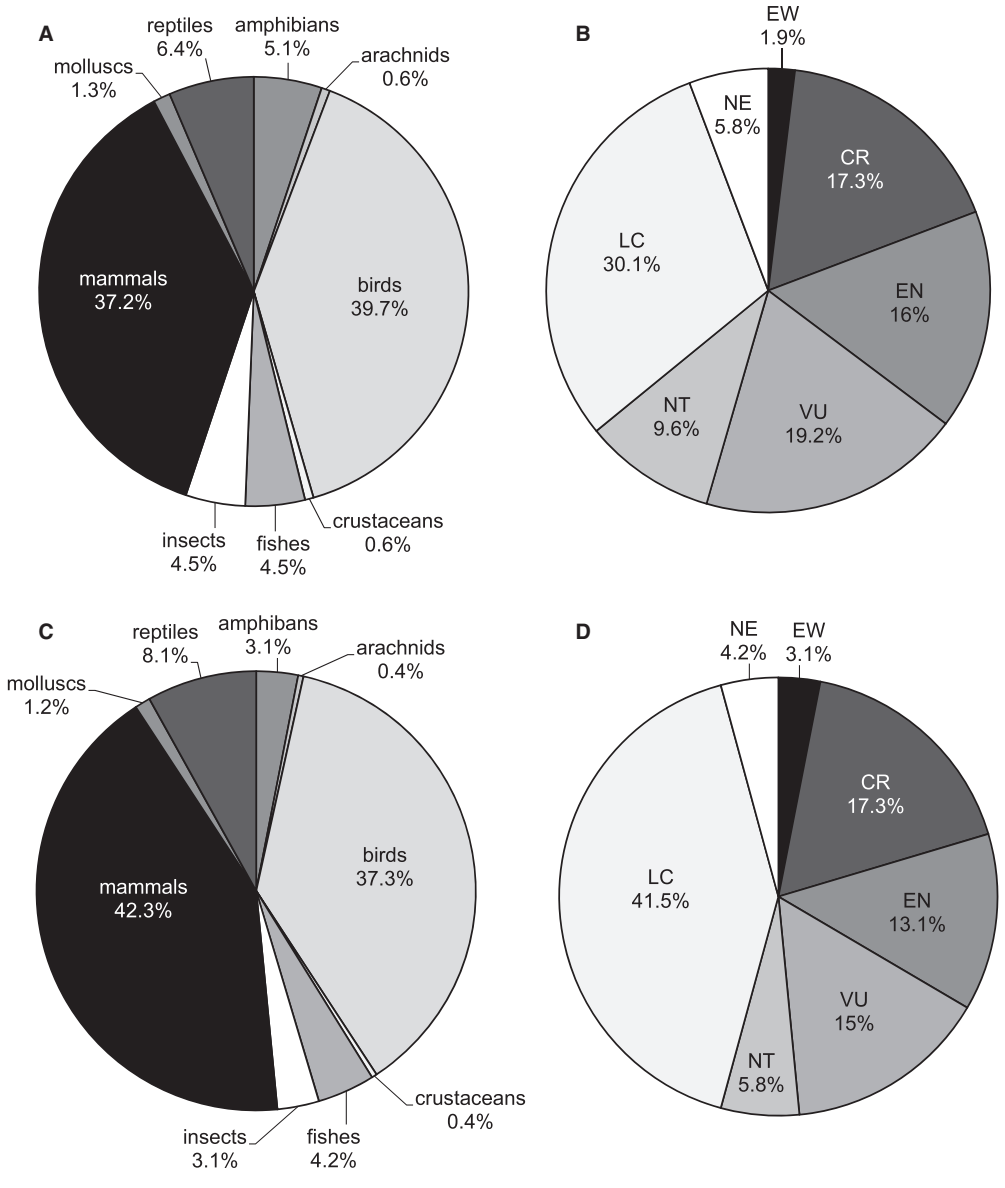

Fig. 3. Involvement of European Association of Zoos and Aquaria (EAZA) members in reintroductions: a, taxonomic representation by species (n = 156); b, International Union for Conservation of Nature (IUCN) Red List status by species (n = 156); c, taxonomic representation by project (n = 260); d, IUCN Red List status by project (n = 260). IUCN Red List status: CR, Critically Endangered; EN, Endangered; EW, Extinct in the Wild; LC, Least Concern; NE, Not Evaluated; NT, Near Threatened; VU, Vulnerable.

survey respondents reported that 90 (58%) species (n = 156) and 179 (69%) projects (n = 260) concerned native European species. The EAZA region extends beyond Europe and into Asia, and EAZA-member institutions reported 190 (56%) (n = 337) contributions for species native to the same country as the institution.

TAXONOMY	NO. SPECIES	%	NO. PROJECTS	%
VERTEBRATES				
Mammals	58	37·2	110	42·3
Birds	62	39·7	97	37·3
Reptiles	10	6·4	21	8·1
Amphibians	8	5·1	8	3·1
Fishes	7	4·5	11	4·2
INVERTEBRATES				
Insects	7	4·5	8	3·1
Molluscs	2	1·3	3	1·2
Crustaceans	1	0·6	1	0·4
Arachnids	1	0·6	1	0·4
TOTAL	**156**		**260**	

Table 2. Data collected from an e-mail survey sent to European Association of Zoos and Aquaria (EAZA)-member institutions (n = 84 institutions). The number of species in each class and the number of projects for each class are also given as percentages of the total number of species reintroduced (n = 156) and the total number of reintroduction projects (n = 260) in which EAZA-member institutions were involved.

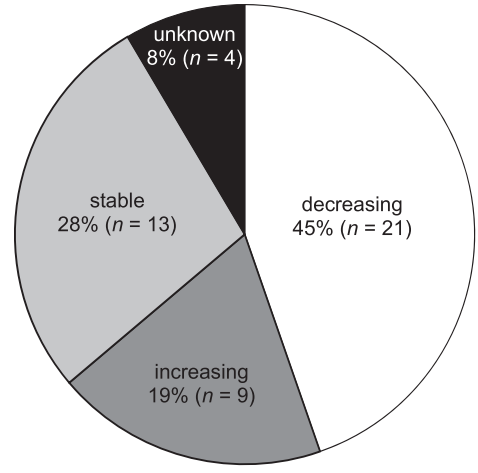

Fig. 4. The International Union for Conservation of Nature (IUCN) wild-population trends for the 47 species assessed as Least Concern that were reintroduced with the involvement of European Association of Zoos and Aquaria (EAZA)-member institutions.

Conservation status

Of the species reintroduced with the involvement of EAZA-member institutions, 82 out of 156 species (53%) were assessed as threatened (i.e. CR, EN and VU), 100 (64%) were of conservation concern (i.e. CR, EN and VU, plus EW and NT) and 47 (30%) were assessed as LC (Fig. 3b). Of the 47 LC species reintroduced by EAZA-member institutions, 45% (n = 21) had declining wild-population trends, while 19% (n = 9) had increasing trends, 28% (n = 13) had stable populations and the status was unknown for 8% (n = 4) (Fig. 4).

From the survey, 55 of the species reintroduced with the collaboration of EAZA-member institutions were listed in the appendixes of the two Council Directives (1992, 2010). Of the 47 reintroduced species that were considered LC (IUCN, 2016), 35 appeared in the two Council Directives, of which 14 [30% (total n = 47)] were listed in Annex II, IV or V of the EU Habitats Directive, while 21 (45%) were listed in Annex 1 of the EU Bird Directive. There were also eight (17%) unlisted EU species and four (9%) non-EU species reported (Fig. 5).

Contributions to reintroduction

In total, EAZA-member institutions made 637 contributions to reintroduction projects. While supplying animals for release was the single biggest contribution made to reintroduction projects [n = 225 contributions (35%)], involvement also included funding [n = 96 contributions (15%)], staff [n = 89 contributions (14%)], expertise [n = 85 contributions (13%)], equipment [n = 51 contributions (8%)] and project coordination [n = 37 contributions (6%)] (Fig. 6). Respondents also itemized 'other' contributions [n = 54 contributions (9%)] in an unspecified field on the survey questionnaire (Fig. 6). EAZA-member institutions advised that their 'other' contributions to reintroductions included providing resources for education (n = 3), research (n = 3), food (n = 2), training (n = 3), habitat management and restoration (n = 2), animal husbandry (n = 10), infrastructure (n = 13), press and public relations (n = 2), transportation

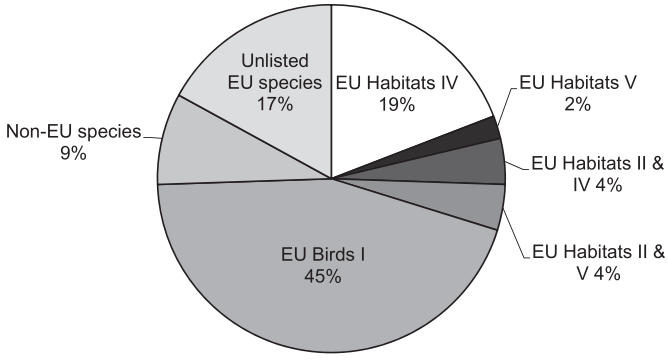

Fig. 5. Least Concern species reintroduced with the involvement of European Association of Zoos and Aquaria (EAZA)-member institutions (n = 47). In total, 14 of these species are listed in Annex II, IV or V of Council Directive 92/43/EEC on the Conservation of Natural Habitats of Wild Fauna and Flora (EU Habitats) (Council Directive, 1992), and 21 species appear in Annex I of Directive 2009/147/EC on the Conservation of Wild Birds (EU Birds) (Council Directive, 2010). Species with an EU distribution not listed in the annexes of either Council Directive [i.e. unlisted EU species (n = 8)], and species with distributions outside the EU [i.e. non-EU species (n = 4)], were also included.

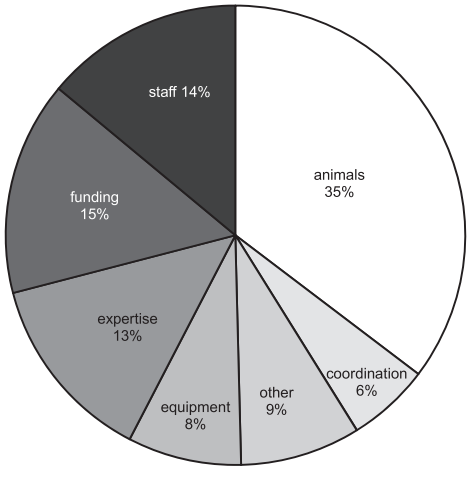

Fig. 6. Total contribution of European Association of Zoos and Aquaria (EAZA)-member institutions to reintroductions (n = 637).

(n = 3) and veterinary support (n = 13). The phrasing of the question means this is likely to be an incomplete list of activities in support of reintroduction projects.

DISCUSSION

The case studies in all five GRP publications reveal a continued taxonomic bias (Seddon *et al.*, 2005) towards vertebrates in general, but specifically towards birds and mammals, both in terms of the number of projects carried out, and the number of projects to which zoos and aquariums contributed (Fig. 1). The survey responses from EAZA-member institutions also indicated a taxonomic bias towards bird and mammal reintroductions (Fig. 3). Vertebrate reintroductions, in particular birds and mammals, are over-represented with respect to their prevalence in nature, and this bias is not related to vulnerability to threat (Seddon *et al.*, 2005; Conway, 2011) (Table 1). The bias towards birds and mammals is equally apparent in other conservation projects supported by zoos and aquariums (Gusset & Dick, 2010). The bias can be partially explained because flagship or umbrella species are often used for reintroduction projects on the assumption that they confer protection on other fauna and flora in the habitat, as well as stimulate conservation awareness (Sarrazin & Barbault, 1996; Seddon *et al.*, 2005). The predominance of vertebrate reintroductions may also reflect the bias towards large, charismatic and iconic species in the living collections of zoos and aquariums, which favour vertebrate species over

invertebrates because of their perceived public appeal.

However, some zoos and aquariums have put resources into priority areas that run counter to previous ideas of public appeal. For example, 94% (n = 17) of amphibian projects had zoo and aquarium involvement, with projects sourcing amphibians from zoos/aquariums 59% (n = 10) of the time (Fig. 1). This may be explained in light of the recent response to the amphibian crisis and the production of an *Amphibian Conservation Action Plan* (ACAP) (Gascon *et al.*, 2007), with the formation of an 'Amphibian Ark' designed to unite the *ex situ* conservation community and deliver the captive components of the ACAP (McGregor Reid & Zippel, 2008; Zippel *et al.*, 2011).

Furthermore, the relative involvement of zoos and aquariums with insect, reptile, amphibian and arachnid conservation translocation projects was proportionally greater than those for birds and mammals, although still small. This suggests that zoos and aquariums are realigning reintroduction efforts onto the less charismatic species that are under-represented in their collections, in response to conservation priorities. Furthermore, over two-thirds of EAZA projects concerned European species, indicating a shift towards regional priorities (Fig. 5).

The provision of animals is often considered an important role for zoos and aquariums in reintroductions. EAZA members hold only a small proportion of globally threatened species, which because of their rarity are the most likely candidates for reintroduction (Stanley Price *et al.*, 2004; Stanley Price & Fa, 2007). However, some globally non-threatened species may be locally rare, or of regional or national conservation concern, making them suitable for reintroduction. Available space within institutions, as well as the public appeal of larger, more-charismatic species, is a restricting factor (Stanley Price *et al.*, 2004), although Conde *et al.* (2011) noted that the number of threatened species in Species360-registered institutions had increased over the past 20 years to the point where 691 (17·5%) of the 3955 terrestrial vertebrate species in Species360-registered institutions are threatened (Conde *et al.*, 2013). What is more, it is not always possible to predict which species might need to be given reintroduction support in the future (Lees & Wilcken, 2009).

EAZA members have been involved in the reintroduction of 32 species that, at the time of writing, were not being held in EAZA institutions. Some species were managed as part of temporary 'breed-for-release' populations and the institutions stopped holding the species after the reintroductions had taken place. Zoos and aquariums are well-placed to respond to emergency conservation needs, such as temporary rescue of a species in response to an environmental disaster or conservation breeding to provide individuals to a reintroduction programme (IUCN/SSC, 2014).

Zoos and aquariums provided animals to one-fifth of the conservation-translocation projects reported in five *Global Re-introduction Perspectives* publications [i.e. zoo/aquarium animals supplied in 49 of 243 projects (20%)], and were directly involved with implementation of one-third of projects therein [i.e. zoo/aquarium involvement in 85 of the 243 projects (35%)] (Fig. 1). These figures accord with the survey results from EAZA-member institutions, demonstrating that the contributions of global zoos and aquariums extend beyond the provision of animals to conservation translocations. Nonetheless, releasing animals still constitutes the largest contribution (35%) to reintroduction projects by EAZA-member institutions, but zoos and aquariums also provide other resources to reintroductions (Fig. 6). The experience of managing species within the environment of a zoo or aquarium facilitates the development of skills and expertise in animal handling, husbandry and veterinary care, as well as collection and conservation planning, education, public engagement and logistics, all of which are valuable to reintroduction

projects (Stanley Price *et al.*, 2004; Stanley Price & Fa, 2007; Conde *et al.*, 2011). These skills are applicable to field situations, regardless of whether the institutions provide animals for release or whether the species has been held in an EAZA zoo or aquarium at all. In some cases (6% of all contributions), EAZA-member institutions took a leading role and coordinated initiatives.

Ecosystems are becoming increasingly fragmented with humans intervening in the management of wild populations in numerous ways. Some populations are now found only within fenced or protected areas, while others are isolated by increasingly human-dominated landscapes (Mallon & Stanley Price, 2013). The traditional distinctions between *in situ* and *ex situ* are being replaced with a spectrum of interventions required to support species conservation, ranging from self-sustaining populations that require little support to populations that are entirely reliant on human care (Redford *et al.*, 2012). The decrease in both the size and genetic diversity of wild populations makes them increasingly comparable to managed populations in zoos or aquariums. Consequently, the tools and techniques in conservation genetics and population management that have been developed for managed populations can be successfully applied to the conservation of wild metapopulations (Stanley Price *et al.*, 2004; Stanley Price & Fa, 2007; Gusset & Dick, 2013; Keulartz, 2015), and re-establishment in their indigenous ranges.

Not all of the species reintroduced from EAZA-member institutions were assessed to be globally rare. Just over half of the species (53%) were threatened (i.e. IUCN Red List CR, EN and VU), increasing to 64% when all species of conservation concern (i.e. IUCN Red List CR, EN and VU, plus NT and EW) were considered (Fig. 3b). Nearly one-third (30·1%) of the species reintroduced from EAZA institutions were LC (Fig. 3b), indicating that threat status was not a prerequisite for reintroduction. This is reflected in the published reintroduction literature where 49·3% of reintroduction projects were for LC species (Seddon *et al.*, 2005). Seddon *et al.* (2005) concluded that it was likely that the selection of reintroduction candidates was determined more by national priorities, funding and the support of non-governmental organizations (NGOs) and local communities, than purely by their global conservation status (Seddon *et al.*, 2005).

Regional or local rarity appeared to influence the species selected for reintroduction by EAZA zoos and aquariums. Most of the LC European species reintroduced by EAZA-member institutions were listed in the annexes of the EU Birds and Habitats Directives identifying them as priorities for conservation (Council Directive, 1992, 2010). For example, the Sand lizard *Lacerta agilis* is classed LC and is widely distributed throughout Europe. However, global populations are declining with increasing fragmentation in the UK (Woodfine *et al.*, 2017). The species is protected at a national level throughout the EU and is listed in Appendix II of the Bern Convention and Annex IV of EU Habitats Directive (Agasyan *et al.*, 2010). Similarly, LC species not covered by EU legislation (e.g. non-European species) may be locally rare or the reintroduced individuals may be from a subspecies that has not been assessed at the subspecies level. The Ostrich *Struthio camelus* is a widespread and locally abundant species across eastern and southern Africa, and is listed as LC on the IUCN Red List (BirdLife International, 2014). However, the distinctive North African or Red-necked ostrich *Struthio camelus camelus* subspecies has not been assessed by the Red List despite disappearing from most of its former range and is now thought to be restricted to a few fragmented populations in Cameroon, Chad, Central African Republic and Senegal (Sahara Conservation Fund, 2014a). Reintroduction initiatives have thus been put in place for the subspecies in Tunisia, Morocco and Niger (Sahara Conservation Fund, 2014b; Woodfine *et al.*, 2015).

The number of species that have been reintroduced is a small proportion of the total number held by EAZA-member institutions, and the reintroduction of 156 species over 58 years from 337 surveyed institutions might be considered a comparatively minor contribution to species conservation. However, this is an overly simplistic view, and a number of questions must be answered before we can determine whether zoos and aquariums are fulfilling their roles in support of species reintroductions. First, is reintroduction an appropriate component of the conservation strategy for a species and, if so, for how many of those species that are maintained in EAZA institutions? Second, if reintroduction is appropriate, is it a realistic possibility at the moment and, if so, is there a role for zoos and aquariums to play in the reintroduction of the species? At the time of writing there is insufficient information to answer these questions for many species. To counter this, a species-conservation plan (One Plan approach) should be developed by *in situ* and *ex situ* experts with the use of the *ex situ* guidelines (IUCN/SSC, 2014) for each species. This would determine if *ex situ* management is appropriate for the species and, if so, what the role of zoos and aquariums might be. Once this has been accomplished, it will be possible to determine whether zoos and aquariums are fulfilling their potential with regard to conservation and, in particular, reintroduction of species back to their indigenous range.

Responses to our survey were received from 31% of surveyed institutions, but it is unknown whether this is representative of the whole membership or if the responses were biased towards those that had been involved in reintroduction projects. The earliest project began in 1956 but the contributions to reintroductions increased substantially from the mid-1980s onwards, reflecting the increase in published accounts of reintroductions in the wider scientific literature (Seddon *et al.*, 2007). Furthermore, the exclusion of plant reintroductions, wild-to-wild translocations, and rehabilitation and release projects from our analyses, underestimates the total involvement of EAZA-member institutions in conservation translocations.

While the management of insurance populations and reintroductions have historically been the focus of many conservation efforts by zoos and aquariums (IUDZG/CBSG, 1993), it is clear that zoo and aquarium conservation is shifting away from the 'Ark' paradigm towards integrated conservation management. While reintroductions may form a component of this, the emphasis is on meeting the global conservation needs of species (Barongi *et al.*, 2015). Reintroductions form only a small proportion of the conservation activities of zoos and aquariums, many of which now operate as conservation NGOs with a total combined annual spend of more than US $350 million on wildlife conservation efforts (Gusset & Dick, 2011). When we searched the EAZA Conservation Database with the keyword 'reintroduction' entered into the project-description field on 18 September 2016, we found that 106 out of 1372 (8%) historical projects were species reintroductions. The percentage increased to 11% (59 out of 537 projects) when we searched for ongoing reintroduction projects. This is an underestimate of the conservation activities of EAZA-member institutions because some have yet to enter their data (M. Zimmermann, pers. comm., 2016); however, it provides an indication that most of the conservation activities carried out by EAZA-member institutions do not relate to species reintroductions.

Reintroductions can be a useful tool as part of the suite of conservation interventions that contribute to integrated conservation management (i.e. the One Plan approach: Byers *et al.*, 2013) but should be considered within the context of the conservation needs of the species. Zoos and aquariums are well-positioned to use their skills and expertise for the process of re-establishing species in the wild, and in some cases provide short-term space and resources to manage species for specific

reintroduction projects, or to provide animals from insurance populations for release.

The initial survey issued to EAZA-member institutions was deliberately short to increase the likelihood that there would be as many respondents as possible. However, the limited information available on which to assess the contribution of EAZA-member institutions to reintroductions identified a need for improved communication and evaluation of conservation interventions. The EAZA Conservation Database should help to fulfil this function but it has not yet reached its full potential.

There is a clear taxonomic bias in historical reintroduction efforts but this is shifting in response to changing conservation needs. As species conservation moves towards a more integrated approach, zoos and aquariums have an opportunity to apply their wealth of experience, expertise and resources to species-conservation initiatives across the management spectrum from *ex situ* management with a variety of forms and roles to the re-establishment or reinforcement of populations in the wild, and on to the conservation of species in their indigenous range. Zoos and aquariums have a greater role to play in wider habitat and ecosystem management, and species conservation will be enhanced by greater engagement by the zoo and aquarium community.

ACKNOWLEDGEMENTS

We would like to thank all the EAZA zoos and aquariums that provided data for this analysis. We would also like to thank two anonymous referees whose comments improved the quality of this manuscript.

REFERENCES

Agasyan, A., Avci, A., Tuniyev, B., Lymberakis, P., Andrén, C., Cogalniceanu, D., Wilkinson, J., Ananjeva, N., Üzüm, N., Orlov, N., Podloucky, R., Tuniyev, S., Kaya, U., Crnobrnja Isailovic, J., Vogrin, M., Corti, C., Pérez Mellado, V., Sá-Sousa, P., Cheylan, M., Pleguezuelos, J., Kyek, M., Westerström, A., Nettmann, H. K., Borczyk, B., Sterijovski, B. & Schmidt, B. (2010): *Lacerta agilis*. In *The IUCN Red List of Threatened Species*. Gland, Switzerland, and Cambridge, UK: International Union for Conservation of Nature. Available at http://www.iucnredlist.org/details/157288/0 (Accessed 21 October 2016).

Balmford, A., Mace, G. M. & Leader-Williams, N. (1996): Designing the ark: setting priorities for captive breeding. *Conservation Biology* **10**: 719–727.

Barongi, R., Fisken, F. A., Parker, M. & Gusset, M. (Eds) (2015): *Committing to conservation: the world zoo and aquarium conservation strategy*. Gland, Switzerland: WAZA Executive Office.

BirdLife International (2014): *Struthio camelus*. In *The IUCN Red List of Threatened Species*. Gland, Switzerland, and Cambridge, UK: International Union for Conservation of Nature. Available at http://www.iucnredlist.org/details/45020636/0 (Accessed 13 September 2016).

Bowkett, A. E. (2009): Recent captive-breeding proposals and the return of the ark concept to global species conservation. *Conservation Biology* **23**: 773–776.

Butchart, S. H. M., Stattersfield, A. J. & Collar, N. J. (2006): How many bird extinctions have we prevented? *Oryx* **40**: 266–278.

Byers, O., Lees, C., Wilcken, J. & Schwitzer, C. (2013): The One Plan approach: the philosophy and implementation of CBSG's approach to integrated species conservation planning. *WAZA Magazine* **14**: 2–5.

CBSG (2011): *Intensively managed populations for conservation workshop report*. Apple Valley, MN: IUCN SSC Conservation Breeding Specialist Group.

Conde, D. A., Flesness, N., Colchero, F., Jones, O. R. & Scheuerlein, A. (2011): Zoos and captive breeding: response. *Science* **332**: 1150–1151.

Conde, D. A., Colchero, F., Gusset, M., Pearce-Kelly, P., Byers, O., Flesness, N., Browne, R. K. & Jones, O. R. (2013): Zoos through the lens of the IUCN Red List: a global metapopulation approach to support conservation breeding programs. *PLoS ONE* **8**: e80311.

Conway, W. G. (2011): Buying time for wild animals with zoos. *Zoo Biology* **30**: 1–8.

Council Directive (1992): Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Communities* **22 July 1992**: L206/7–L206/50. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043&from=EN

Council Directive (2010): Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version). *Official Journal of the European Union* **26 January 2010**: L20/7–L20/25. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:020:0007:0025:EN:PDF

Dobson, A. & Lyles, A. (2000): Black-footed ferret recovery. *Science* **288**: 985–988.

Frankham, R. (1995): Conservation genetics. *Annual Review of Genetics* **29**: 305–327.

Gascon, C., Collins, J. P., Moore, R. D., Church, D. R., McKay, J. & Mendelson III, J. (2007): *Amphibian conservation action plan*. Gland, Switzerland, and

Cambridge, UK: IUCN/SSC Amphibian Specialist Group.

Griffith, B., Scott, J. M., Carpenter, J. W. & Reed, C. (1989): Translocation as a species conservation tool: status and strategy. *Science* **245**: 477–480.

Gusset, M. (2012): Species reintroduction. In *Berkshire encyclopedia of sustainability*. **5.** *Ecosystem management and sustainability*: 371–376. Pardy, B., Nagle, J. C., Schmitz, O. J., Craig, R. K. & Smith, W. K. (Eds). Great Barrington, MA: Berkshire Publishing Group.

Gusset, M. & Dick, G. (2010): 'Building a future for wildlife'? Evaluating the contribution of the world zoo and aquarium community to *in situ* conservation. *International Zoo Yearbook* **44**: 183–191.

Gusset, M. & Dick, G. (2011): The global reach of zoos and aquariums in visitor numbers and conservation expenditures. *Zoo Biology* **30**: 566–569.

Gusset, M. & Dick, G. (2012): Editorial. *WAZA Magazine* **13**: 1–2.

Gusset, M. & Dick, G. (Eds) (2013): Towards integrated species conservation. *WAZA Magazine* **14**: 1–44.

Hayward, M. W. (2011): Using the IUCN Red List to determine effective conservation strategies. *Biodiversity and Conservation* **20**: 2563–2573.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H. M., Carpenter, K. E., Chanson, J., Collen, B., Cox, N. A., Darwall, W. R. T., Dulvy, N. K., Harrison, L. R., Katariya, V., Pollock, C. M., Quader, S., Richman, N. I., Rodrigues, A. S. L., Tognelli, M. F., Vié, J.-C., Aguiar, J. M., Allen, D. J., Allen, G. R., Amori, G., Ananjeva, N. B., Andreone, F., Andrew, P., Ortiz, A. L. A., Baillie, J. E. M., Baldi, R., Bell, B. D., Biju, S. D., Bird, J. P., Black-Decima, P., Blanc, J. J., Bolaños, F., Bolivar, G. W., Burfield, I. J., Burton, J. A., Capper, D. R., Castro, F., Catullo, G., Cavanagh, R. D., Channing, A., Chao, N. L., Chenery, A. M., Chiozza, F., Clausnitzer, V., Collar, N. J., Collett, L. C., Collette, B. B., Cortez Fernandez, C. F., Craig, M. T., Crosby, M. J., Cumberlidge, N., Cuttelod, A., Derocher, A. E., Diesmos, A. C., Donaldson, J. S., Duckworth, J. W., Dutson, G., Dutta, S. K., Emslie, R. H., Farjon, A., Fowler, S., Freyhof, J., Garshelis, D. L., Gerlach, J., Gower, D. J., Grant, T. D., Hammerson, G. A., Harris, R. B., Heaney, L. R., Hedges, S. B., Hero, J.-M., Hughes, B., Hussain, S. A., Icochea, M. J., Inger, R. F., Ishii, N., Iskandar, D. T., Jenkins, R. K. B., Kaneko, Y., Kottelat, M., Kovacs, K. M., Kuzmin, S. L., La Marca, E., Lamoreux, J. F., Lau, M. W. N., Lavilla, E. O., Leus, K., Lewison, R. L., Lichtenstein, G., Livingstone, S. R., Lukoschek, V., Mallon, D. P., McGowan, P. J. K., McIvor, A., Moehlman, P. D., Molur, S., Alonso, A. M., Musick, J. A., Nowell, K., Nussbaum, R. A., Olech, W., Orlov, N. L., Papenfuss, T. J., Parra-Olea, G., Perrin, W. F., Polidoro, B. A., Pourkazemi, M., Racey, P. A., Ragle, J. S., Ram, M., Rathbun, G., Reynolds, R. P., Rhodin, A. G. J., Richards, S. J., Rodríguez, L. O., Ron, S. R., Rondinini, C., Rylands, A. B., De Mitcheson, Y. S., Sanciangco, J. C., Sanders, K. L., Santos-Barrera, G., Schipper, J., Self-Sullivan, C., Shi, Y., Shoemaker, A., Short, F. T., Sillero-Zubiri, C., Silvano, D. L., Smith, K. G., Smith, A. T., Snoeks, J., Stattersfield, A. J., Symes, A. J., Taber, A. B., Talukdar, B. K., Temple, H. J., Timmins, R., Tobias, J. A., Tsytsulina, K., Tweddle, D., Ubeda, C., Valenti, S. V., Van Dijk, P. P., Veiga, L. M., Veloso, A., Wege, D. C., Wilkinson, M., Williamson, E. A., Xie, F., Young, B. E., Akcakaya, H. R., Bennun, L., Blackburn, T. M., Boitani, L., Dublin, H. T., Da Fonseca, G. A. B., Gascon, C., Lacher Jr, T. E., Mace, G. M., Mainka, S. A., McNeely, J. A., Mittermeier, R. A., Reid, G. M., Rodriguez, J. P., Rosenberg, A. A., Samways, M. J., Smart, J., Stein, B. A. & Stuart, S. N. (2010): The impact of conservation on the status of the world's vertebrates. *Science* **330**: 1503–1509.

Hoffmann, M., Belant, J. L., Chanson, J. S., Cox, N. A., Lamoreux, J., Rodrigues, A. S. L., Schipper, J. & Stuart, S. N. (2011): The changing fates of the world's mammals. *Philosophical Transactions of the Royal Society B* **366**: 2598–2610.

IUCN (2016): *The IUCN Red List of Threatened Species*. Gland, Switzerland, and Cambridge, UK: International Union for Conservation of Nature. Available at http://www.iucnredlist.org

IUCN/SSC (2013): *Guidelines for reintroductions and other conservation translocations* version 1.0. Gland, Switzerland: International Union for Conservation of Nature Species Survival Commission.

IUCN/SSC (2014): *Guidelines on the use of* ex situ *management for species conservation* version 2.0. Gland, Switzerland: International Union for Conservation of Nature Species Survival Commission.

IUDZG/CBSG (1993): *The world zoo conservation strategy: the role of the zoos and aquaria of the world in global conservation*. Chicago, IL: Chicago Zoological Society.

Jakob-Hoff, R., Harley, D., Magrath, M., Lancaster, M. & Kuchling, G. (2015): Advances in the contribution of zoos to reintroduction programs. In *Advances in reintroduction biology of Australian and New Zealand fauna*: 201–215. Armstrong, D. P., Hayward, M. W., Moro, D. & Seddon, P. J. (Eds). Clayton South, Vic: CSIRO Publishing.

Keulartz, J. (2015): Captivity for conservation? Zoos at a crossroads. *Journal of Agricultural & Environmental Ethics* **28**: 335–351.

Kierulff, M. C. M., Ruiz-Miranda, C. R., Procópio de Oliveira, P., Beck, B. B., Martins, A., Dietz, J. M., Rambaldi, D. M. & Baker, A. J. (2012): The golden lion tamarin *Leontopithecus rosalia*: a conservation success story. *International Zoo Yearbook* **46**: 36–45.

Kleiman, D. G., Stanley Price, M. R. & Beck, B. B. (1994): Criteria for reintroductions. In *Creative conservation: interactive management of wild and captive animals*: 287–303. Olney, P. J. S., Mace, G. M. & Feistner, A. T. C. (Eds). London: Chapman and Hall.

Lacy, R. C. (1994): Managing genetic diversity in captive populations of animals. In *Restoration of*

endangered species: 63–89. Bowles, M. L. & Whelan, C. J. (Eds). Cambridge: Cambridge University Press.
Lacy, R. C. (2013): Achieving true sustainability of zoo populations. *Zoo Biology* **32**: 19–26.
Lees, C. M. & Wilcken, J. (2009): Sustaining the ark: challenges faced by zoos in maintaining viable populations. *International Zoo Yearbook* **43**: 6–18.
Mallon, D. P. & Stanley Price, M. R. (2013): The fall of the wild. *Oryx* **47**: 467–468.
de Man, D., Leus, K. & Holst, B. (2016): Creating a flexible future. *Zooquaria* **Spring** (93): 26–27.
McGregor Reid, G. & Zippel, K. C. (2008): Can zoos and aquariums ensure the survival of amphibians in the 21st century? *International Zoo Yearbook* **42**: 1–6.
McPhee, M. E. (2004): Generations in captivity increases behavioral variance: considerations for captive breeding and reintroduction programs. *Biological Conservation* **115**: 71–77.
Mésochina, P., Bedin, E. & Ostrowski, S. (2003): Reintroducing antelopes into arid areas: lessons learnt from the oryx in Saudi Arabia. *Comptes Rendus Biologies* **326**: S158–S165.
Niekisch, M. (2010): International conservation policy and the contribution of the zoo and aquarium community. In *Building a future for wildlife: zoos and aquariums committed to biodiversity conservation*: 45–48. Dick, G. & Gusset, M. (Eds). Gland, Switzerland: WAZA Executive Office.
Pereira, H. M., Leadley, P. W., Proenca, V., Alkemade, R., Scharlemann, J. P. W., Fernandez-Manjarrés, J. F., Araújo, M. B., Balvanera, P., Biggs, R., Cheung, W. W. L., Chini, L., Cooper, H. D., Gilman, E. L., Guénette, S., Hurtt, G. C., Huntington, H. P., Mace, G. M., Oberdorff, T., Revenga, C., Rodrigues, P., Scholes, R. J., Sumaila, U. R. & Walpole, M. (2010): Scenarios for global biodiversity in the 21st century. *Science* **330**: 1496–1501.
Philippart, J. C. (1995): Is captive breeding an effective solution for the preservation of endemic species. *Biological Conservation* **72**: 281–295.
Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., Raven, P. H., Roberts, C. M. and Sexton, J. O. (2014): The biodiversity of species and their rates of extinction, distribution, and protection. *Science* **344**(6187): Art. 1246752. DOI: 10.1126/science.1246752.
Redford, K. H., Jensen, D. B. & Breheny, J. J. (2012): Integrating the captive and the wild. *Science* **338**: 1157–1158.
Sahara Conservation Fund (SCF) (2014a): *Ostrich*. L'Isle, Switzerland: Sahara Conservation Fund. Available at http://www.saharaconservation.org/?Ostrich (Accessed 12 June 2014).
Sahara Conservation Fund (SCF) (2014b): *Ostrich conservation, Niger*. L'Isle, Switzerland: Sahara Conservation Fund. Available at http://www.saharaconservation.org/?Ostrich-Conservation-Niger (Accessed 12 June 2014).
Sarrazin, F. & Barbault, R. (1996): Reintroduction: challenges and lessons for basic ecology. *Trends in Ecology & Evolution* **11**: 474–478.
Seddon, P. J., Soorae, P. S. & Launay, F. (2005): Taxonomic bias in reintroduction projects. *Animal Conservation* **8**: 51–58.
Seddon, P. J., Armstrong, D. P. & Maloney, R. F. (2007): Developing the science of reintroduction biology. *Conservation Biology* **21**: 303–312.
Snyder, N. F. R., Derrickson, S. R., Beissinger, S. R., Wiley, J. W., Smith, T. B., Toone, W. D. & Miller, B. (1996): Limitations of captive breeding in endangered species recovery. *Conservation Biology* **10**: 338–348.
Soorae, P. S. (Ed.) (2008): *Global re-introduction perspectives: re-introduction case-studies from around the globe*. Abu Dhabi: IUCN/SSC Re-introduction Specialist Group.
Soorae, P. S. (Ed.) (2010): *Global re-introduction perspectives: additional case-studies from around the globe*. Abu Dhabi: IUCN/SSC Re-introduction Specialist Group.
Soorae, P. S. (Ed.) (2011): *Global re-introduction perspectives: 2011. More case studies from around the globe*. Gland, Switzerland: IUCN/SSC Re-introduction Specialist Group, and Abu Dhabi: Environment Agency-Abu Dhabi.
Soorae, P. S. (Ed.) (2013): *Global re-introduction perspectives: 2013. Further case studies from around the globe*. Gland, Switzerland: IUCN/SSC Re-introduction Specialist Group, and Abu Dhabi: Environment Agency-Abu Dhabi.
Soorae, P. S. (Ed.) (2016): *Global re-introduction perspectives: 2016. Case-studies from around the globe*. Gland, Switzerland: IUCN/SSC Reintroduction Specialist Group, and Abu Dhabi: Environment Agency-Abu Dhabi.
Soulé, M., Gilpin, M., Conway, W. & Foose, T. (1986): The millennium ark: how long a voyage, how many staterooms, how many passengers? *Zoo Biology* **5**: 101–113.
Stanley Price, M. R. (1991): A review of mammal reintroductions, and the role of the Re-introduction Specialist Group of IUCN/SSC. In *Beyond captive breeding: re-introducing endangered mammals to the wild*: 9–25. Gipps, J. H. W. (Ed.). Oxford: Clarendon Press.
Stanley Price, M. R. & Fa, J. E. (2007): Reintroduction from zoos: guiding light or shooting star? In *Zoos in the 21st century: catalysts for conservation?*: 155–177. Zimmerman, A., Hatchwell, M., Dickie, L. & West, C. (Eds). Cambridge: Cambridge University Press.
Stanley Price, M. R., Maunder, M. & Soorae, P. S. (2004): *Ex situ* support to the conservation of wild populations from zoos and opportunities for botanic gardens. In Ex situ *plant conservation: supporting species survival in the wild*: 84–110. Guerrant Jr, E. O., Havens, K. & Maunder, M. (Eds). Washington, DC: Island Press.
Stuart, S. N. (1991): Re-introductions: to what extent are they needed? In *Beyond captive breeding: re-introducing endangered mammals to the wild*: 27–37. Gipps, J. H. W. (Ed.). Oxford: Clarendon Press.

TRAYLOR-HOLZER, K., LEUS, K. & BYERS, O. (In press): Integrating *ex situ* management options as part of a One Plan approach to species conservation. In *The ark and beyond*. Minteer, B. A., Maienschein, J. & Collins, J. P. (Eds). Chicago, IL: University of Chicago Press.

VAN DIERENDONCK, M. C. & DE VRIES, M. F. W. (1996): Ungulate reintroductions: experiences with the Takhi or Przewalski horse (*Equus ferus przewalskii*) in Mongolia. *Conservation Biology* **10**: 728–740.

WAZA (2005): *Building a future for wildlife: the world zoo and aquarium conservation strategy*. Bern, Switzerland: World Association of Zoos and Aquariums Executive Office.

WOINARSKI, J. & BURBIDGE, A. A. (2016): *Leporillus conditor*. In *The IUCN Red List of Threatened Species*. Gland, Switzerland, and Cambridge, UK: International Union for Conservation of Nature. Available at http://www.iucnredlist.org/details/11634/0 (Accessed 16 October 2016).

WOODFINE, T., PETRETTO, M. & LANGENHORST, T. (2015): *Reintroduction and conservation of North African/red-necked ostrich,* Struthio camelus camelus*, to protected areas in southern Tunisia. Report and funding proposal*. Winchester: Marwell Wildlife.

WOODFINE, T., WILKIE, M., GARDNER, R., EDGAR, P., MOULTON, N. & RIORDAN, P. (2017): Outcomes and lessons from a quarter of a century of sand lizard *Lacerta agilis* reintroductions in southern England. *International Zoo Yearbook* **51**: 87–96.

WWF (2016): *Living Planet Report 2016. Risk and resilience in a new era*. Gland, Switzerland: WWF International.

ZIPPEL, K., JOHNSON, K., GAGLIARDO, R., GIBSON, R., MCFADDEN, M., BROWNE, R., MARTINEZ, C. & TOWNSEND, E. (2011): The amphibian ark: a global community for *ex situ* conservation of amphibians. *Herpetological Conservation and Biology* **6**: 340–352.

Manuscript submitted 1 November 2016; revised 9 March 2017; accepted 22 March 2017