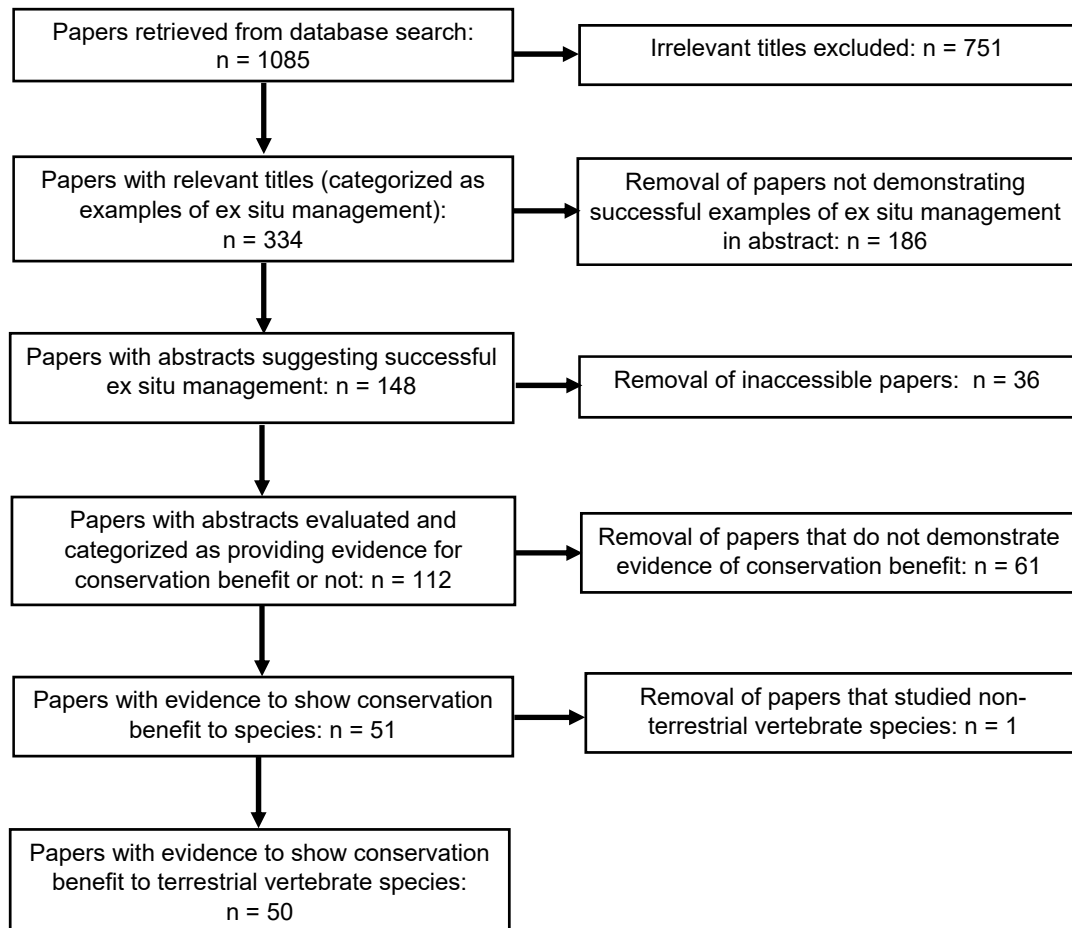


Fragmented evidence for the contribution of ex situ management to species conservation indicates the need for better reporting

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SUPPLEMENTARY TABLE 1 Literature review: topics excluded from the search results in Web of Science (see Methods in main text for details).

Excluded topics	
agriculture	life sciences biomedicine other topics
anatomy morphology	marine freshwater biology
anthropology	mathematics
behavioural sciences	meteorology atmospheric sciences
biochemistry molecular biology	mycology
biotechnology applied microbiology	neurosciences neurology
business economics	nutrition dietetics
chemistry	oceanography
communication	physical geography
developmental biology	physiology
education educational research	plant sciences
endocrinology metabolism	psychology
engineering	public environmental occupational health
entomology	remote sensing
evolutionary biology	reproductive biology
fisheries	science technology other topics
forestry	social sciences other topics
genetics heredity	sociology
geography	toxicology
geology	urban studies
history philosophy of science	veterinary sciences
imaging science photographic technology	water resources
immunology	



SUPPLEMENTARY FIG. 1 Literature review: flowchart of results and selection process for relevant papers retrieved from Web of Science literature search.

SUPPLEMENTARY TABLE 2 Literature review: the roles adopted by ex situ management programmes for vertebrate species and the scale of conservation benefit to the species, extracted from the scientific articles retrieved from the Web of Science database literature search.

Species	Citation	Conservation benefit ¹	Ex situ role ²
<i>Antilocapra americana sonoriensis</i>	Horne et al. (2016)	2(a), 3, 4, 5, 6	5(a)
<i>Ara macao</i>	Brightsmith et al. (2005)	5	4
	Estrada (2014)	2(a)	5(a)
<i>Canis rufus</i>	Van Manen et al. (2000)	4	5(a)
<i>Charadrius melodus</i>	Roche et al. (2008)	2(a)	5(b)
<i>Charadrius nivosus</i>	Neuman et al. (2013)	2(a), 5	4, 5, 7
<i>Chlamydotis undulata macqueenii</i>	Combreau and Smith (1998)	2(a)	5(b), 8
<i>Dama mesopotamica</i>	Bar-David et al. (2005)	2(b), 3, 4	5(a)
<i>Dasyprocta leporina</i>	Cid et al. (2014)	2(a), 3, 4	5(a), 6
<i>Dryolimnas cuvieri aldabranus</i>	Wanless et al. (2002)	2(a), 3, 4	5(a)
<i>Emys orbicularis</i>	Canessa et al. (2016)	6 (local scale)	5(b)
<i>Equus ferus</i>	King and Gurnell (2005)	2(a), 3, 4, 6	5(a), 8
	Slotta-Bachmayr et al. (2004)	2(a), 3, 4, 6	5(a)
	Xia et al. (2014)	3, 4, 6	3(a), 5(a)
<i>Falco peregrinus</i>	Tordoff and Redig (2001)	2(a), 3, 4	5(a)
<i>Falco punctatus</i>	Cade and Jones (1993)	2(a), 3, 4, 5, 6	4, 5(a), 5(b)
	Jones et al. (1995)	2(a), 3, 4, 5, 6	4, 5(a), 5(b)
	Nicoll et al. (2004)	2(a), 3, 4, 5, 6	4, 5(a), 5(b)
<i>Gorilla gorilla gorilla</i>	King et al. (2014)	2(a), 3, 4	5(a), 10(a)
<i>Grus americana</i>	Boyce et al. (2005)	4	4
	King et al. (2013)	2(a), 3, 4, 6	4, 7, 8
<i>Gymnogyps californianus</i>	Ralls and Ballou (2004)	2(a), 3, 4, 6	3(a), 5(a)
<i>Gypaetus barbatus</i>	Schaub et al. (2009)	2(a), 3, 4	5(a)
<i>Hylobates lar</i>	Osterberg et al. (2015)	2(a), 3, 4, 7(a), 7(b)	9, 5(a), 10(a)
<i>Lanius ludovicianus migrans</i>	Lagios et al. (2015)	4	1, 5(a)
	Nichols et al. (2010)	2(a), 4	5(a)
<i>Lutra lutra</i>	Hobbs et al. (2011)	2(b)	5(b)
<i>Muscardinus avellanarius</i>	Mitchell-Jones and White (2009)	2(a), 3, 4	5(a)
<i>Mustela nigripes</i>	Cain et al. (2011)	2(a), 3, 4, 6	3(a), 5(a), 5(b)
	Howard et al. (2016)	2(a), e, 6,	5(b), 10(b)
<i>Nipponia nippon</i>	Yu et al. (2015)	2(a), 3, 4	5(a)
<i>Oryx leucoryx</i>	Strauss (2002)	2(a)	5(a),
	Zafar-ul Islam et al. (2011)	2(a), 4	5(a),
<i>Pan troglodytes</i>	Humle et al. (2011)	2(a)	5(b), 10(a)
<i>Panthera leo</i>	Dunston et al. (2017)	2(a)	5(b)
<i>Parantechinus apicalis</i>	Moro (2003)	2(a), 3, 4	1, 7
<i>Perdix perdix</i>	Buckley et al. (2012)	2(a), 3, 4	5(b)
<i>Peromyscus polionotus trissyllepsis</i>	Greene et al. (2017)	2(a), 3, 4, 6	5(a), 8
<i>Porphyrio hochstetteri</i>	Hegg et al. (2012)	2(a)	4
	Hegg et al. (2013)	2(a), 3, 5	4, 5(a), 5(b)
<i>Porphyrio mantelli</i>	Maxwell and Jamieson (1997)	5	4
<i>Psammmodromus algirus</i>	Santos et al. (2009)	2(a)	5(a), 5(b)
<i>Sarcophilus harrisii</i>	Rogers et al. (2016)	2(a), 3, 4	1, 7
<i>Sphenodon guntheri</i>	Nelson et al. (2002)	2(a), 3, 4	4, 5(a)
<i>Trichechus manatus manatus</i>	Normande et al. (2015)	2(a), 7(a), 7(b)	9, 10(a)
<i>Urocyon littoralis</i>	Clifford et al. (2007)	2(a)	1, 5(b)
<i>Varecia variegata variegata</i>	Britt et al. (2004a)	2(a)	5(b)
	Britt et al. (2004b)	2(a)	5(b)
<i>Vulpes velox</i>	Ausband and Foresman (2007)	2(a), 3, 4	5(a)
<i>Zapornia atra</i>	Oppel et al. (2016)	5	2(b), 5(b)

¹Scale of conservation benefit:

- 1 Down-listed category of threat on the IUCN Red List (e.g. from Critically Endangered (CR) to Endangered (EN))
- 2 Expanded population census numbers: (a) with evidence of reproduction; (b) without evidence of reproduction
- 3 Establishment of additional (reproducing) populations
- 4 Expanded geographic range into suitable habitat
- 5 Reversal or substantial reduction of population decline
- 6 Reduction of extinction risk (probability of extinction)
- 7 Other: (a) raised awareness among the general public; (b) supported education

²Ex situ roles:

- 1 Insurance population
- 2 Temporary rescue: (a) from catastrophe; (b) from predicted imminent threat
- 3 Maintenance of long term ex situ population after extinction of all known wild populations: (a) for reintroduction; (b) for assisted colonization
- 4 Demographic manipulation (e.g. head-start programme)
- 5 Source for population restoration: (a) to re-establish the species into part of its former range from which it has disappeared; (b) to reinforce an existing population
- 6 Source for ecological replacement to re-establish a lost ecological function and/or modify habitats
- 7 Source for assisted colonization to introduce the species outside of its indigenous range to avoid extinction
- 8 Research and/or training that will directly benefit conservation of the species, or a similar species, in the wild
- 9 Basis for an education and awareness programme that addresses specific threats or constraints to the conservation of the species or its habitat
- 10 Other: (a) rehabilitation and release of orphaned/confiscated individuals; (b) cryopreservation of gametes.

SUPPLEMENTARY TABLE 3 IUCN Red List analysis: vertebrate species that were downlisted on the IUCN Red List during 2007–2017 because of a genuine change in conservation status, and for which ex situ management had been implemented as a conservation action.

Scientific name	Class	Category change ¹	Number of categories downlisted	Strength of evidence	IUCN Red List account citation
<i>Ailuropoda melanoleuca</i>	Mammalia	EN–VU	1	Weak	(Swaigood et al., 2016)
<i>Anas chlorotis</i>	Aves	EN–NT	2	Moderate	(BirdLife International, 2016a)
<i>Anas nesiotis</i>	Aves	CR–EN	1	Strong	(BirdLife International, 2016b)
<i>Bettongia lesueur</i>	Mammalia	VU–NT	1	Weak	(Richards et al., 2008)
<i>Bison bonasus</i>	Mammalia	EN–VU	1	Strong	(Olech & IUCN SSC Bison Specialist Group, 2008)
<i>Castor fiber</i>	Mammalia	NT–LC	1	Weak	(Batbold et al., 2016)
<i>Columba junoniae</i>	Aves	EN–NT	2	Moderate	(BirdLife International, 2017)
<i>Cyclura lewisi</i>	Reptilia	CR–EN	1	Strong	(Burton, 2012)
<i>Dasyurus geoffroii</i>	Mammalia	VU–NT	1	Moderate	(Morris et al., 2008)
<i>Equus ferus</i>	Mammalia	EW–CR	1	Strong	(King et al., 2015)
<i>Foudia rubra</i>	Aves	CR–EN	1	Strong	(BirdLife International, 2016d)
<i>Leontopithecus chrysopygus</i>	Mammalia	CR–EN	1	Moderate	(Kierulff et al., 2008)
<i>Leporillus conditor</i>	Mammalia	EN–VU	1	Strong	(Woinarski and Burbidge, 2016)
<i>Lynx pardinus</i>	Mammalia	CR–EN	1	Moderate	(Rodríguez and Calzada, 2015)
<i>Mustela nigripes</i>	Mammalia	EW–EN	2	Strong	(Belant et al., 2015)
<i>Onychogalea fraenata</i>	Mammalia	EN–VU	1	Weak	(Burbidge et al., 2016)
<i>Oryx leucoryx</i>	Mammalia	EN–VU	1	Weak	(IUCN SSC Antelope Specialist Group, 2011)
<i>Urocyon littoralis</i>	Mammalia	CR–NT	3	Strong	(Coonan et al., 2013)

¹Red List categories: LC, Least Concern; NT, Near Threatened; VU, Vulnerable; EN, Endangered; CR, Critically Endangered; EW, Extinct in the Wild.

SUPPLEMENTARY MATERIAL 1 Practitioner survey questions.

Q1. Which species (and from which taxonomic group) was managed in the ex situ programme?

Taxonomic group (scientific and common name)

- Agnatha (jawless fishes)
- Chondrichthyes (cartilaginous fishes)
- Osteichthyes (bony fishes)
- Amphibia (amphibians)
- Reptilia (reptiles)
- Aves (birds)
- Mammalia (mammals)
- Invertebrate (invertebrates)
- Plantae (plants)

Species (scientific and common name of the taxon)

Q2. What IUCN Red List Category is the species listed under?

- Extinct In The Wild (EW)
- Critically Endangered (CR)
- Endangered (EN)
- Vulnerable (VU)
- Near Threatened (NT)
- Least Concern (LC)
- Not yet assessed

Q3. What was the intended role of the ex situ management programme? (Please see following link to the IUCN Species Survival Commission Guidelines on the Use of Ex situ Management for Species Conservation for definitions of terms for roles:

cpsg.org/sites/cbsg.org/files/IUCN_SSC_ex_situ_guidelines_FINAL.pdf)

- Insurance population
- Temporary rescue (from catastrophe)
- Temporary rescue (from predicted imminent threat)
- Maintenance of long-term ex situ population after extinction of all known wild populations (for reintroduction)
- Maintenance of long-term ex situ population after extinction of all known wild populations (for assisted colonization)
- Demographic manipulation (e.g. head-start programme)
- Source for population restoration (to re-establish the species into part of its former range from which it has disappeared)
- Source for population restoration (to reinforce an existing population)
- Source for ecological replacement to re-establish a lost ecological function and/or modify habitats

- Source for assisted colonization to introduce the species outside of its indigenous range to avoid extinction
- Research and/or training that will directly benefit conservation of the species, or a similar species, in the wild
- Basis for an education and awareness programme that addresses specific threats or constraints to the conservation of the species or its habitat

Other (please specify)

Q4. Was the intended role of the ex situ management programme achieved?

- Yes
- No

Q5. Did monitoring occur to measure the success of the ex situ programme (in terms of conservation benefit to the species) and how was it measured?

- No monitoring occurred
- Yes, population viability analysis
- Yes, population census surveys
- Yes, survival and reproductive rate

Other (please specify)

Q6. What evidence was there to demonstrate success in terms of conservation benefit to the species (e.g. supporting references or data)?

Q7. If the ex situ programme was not successful (in terms of conservation benefit to the species), why was it not successful?

Q8. Did the ex situ management programme result in conservation benefit to the species, and if so, to what scale?

- No conservation benefit to the species
- Downlisted threat category on the IUCN Red List (e.g. from Critically Endangered to Endangered)
- Expanded population census numbers (with evidence of reproduction)
- Establishment of additional (reproducing) populations
- Expanded geographic range into suitable habitat
- Reversal or substantial reduction of population decline
- Reduction of extinction risk (probability of extinction)

Other (please specify)

Q9. Has this information been published? If so, where? (e.g. journal)

Q10. How long has the ex situ programme been running?

- 0–5 years
- 6–10 years
- 11–15 years
- 16–20 years
- 21+ years

If longer than 21 years, please state how long

Q11. Please name any partner organizations and whether they are government, NGO or academic

- Government
- NGO
- Academic

Please name any partner organizations

SUPPLEMENTARY TABLE 4 The roles adopted by ex situ management programmes for vertebrate species and the scale of conservation benefit to species as reported by respondents to the survey of practitioners.

Response	Species	Years running	Conservation benefit ¹	Ex situ role ²
1	<i>Actinemys marmorata</i>	21+	2, 3, 4	2(a), 4, 5(a), 5(b)
2	<i>Anthochaera phrygia</i>	21+	6	1, 5(a), 5(b)
3	<i>Apteryx mantelli</i>	21+	1	4, 5(a), 5(b), 9
4	<i>Bettongia penicillata</i>	11–15	5, 6	1, 2(a), 5(a), 5(b)
5	<i>Burramys parvus</i>	6–10	2	5(b), 8, 9
6	<i>Calidris pygmaea</i>	6–10	2, 3, 5	1, 4, 5(a), 5(b), 9
7	<i>Cyclura collei</i>	21+	2, 5, 6	1, 5(a), 5(b)
8	<i>Elephas maximus</i>	21+	2, 5, 6	3(b), 8
9	<i>Halcyon cinnamominus</i>	21+	3	2(a),
10	<i>Hippocamelus bisulcus</i>	11–15		5(a), 8, 9
11	<i>Leporillus conditor</i>	16–20	2, 3, 6	1, 5(a)
12	<i>Macropus eugenii eugenii</i>	11–15	3, 6	2(a), 3(a), 5(a)
13	<i>Macrotis lagotis</i>	21+	3, 6	5(a), 5(b)
14	<i>Marmota vancouverensis</i>	16–20	2, 3, 4, 5, 6	5(a), 5(b), 8
15	<i>Neophema chrysogaster</i>	11–15	6	1, 5(a), 5(b)
16	<i>Neophema chrysogaster</i>	11–15	3, 6	1, 2(a), 5(a), 5(b)
17	<i>Oligosoma spp. (c.f. infrapunctatum)</i>	0–5	6	1, 2(a), 2(b), 5(a)
18	<i>Perameles gunnii</i>	21+	2, 3, 4, 5, 6	1, 3(a), 3(b), 9
19	<i>Petrogale lateralis</i>	6–10	2, 3, 5, 6	1, 5(a), 5(b)
20	<i>Petrogale xanthopus</i>	21+	1, 2, 3, 5, 6	1, 5(a), 5(b), 8, 10(b)
21	<i>Porcula salvania</i>	21+	6	5(a)
22	<i>Pseudemadura umbrina</i>	16–20	2, 6	1, 5(a), 5(b)
23	<i>Sarcophilus harrisii</i>	11–15	3, 6	1, 2(a), 5(a), 5(b)
24	<i>Sphenodon punctatus</i>	16–20	5	5(b)
25	<i>Strigops habroptila</i>	11–15	6	10(a)
26	<i>Tiliqua adelaidensis</i>	0–5	3, 6	1, 5(a), 5(b)

¹Scale of conservation benefit:

- 1 Down-listed category of threat on the IUCN Red List (e.g. from Critically Endangered (CR) to Endangered (EN))
- 2 Expanded population census numbers with evidence of reproduction
- 3 Establishment of additional (reproducing) populations
- 4 Expanded geographic range into suitable habitat
- 5 Reversal or substantial reduction of population decline
- 6 Reduction of extinction risk (probability of extinction)

²Ex situ roles:

- 1 Insurance population
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- 4 Demographic manipulation (e.g. head-start programme)
- 5 Source for population restoration: (a) to re-establish the species into part of its former range from which it has disappeared; (b) to reinforce an existing population
- 6 Source for ecological replacement to re-establish a lost ecological function and/or modify habitats
- 7 Source for assisted colonization to introduce the species outside of its indigenous range to avoid extinction
- 8 Research and/or training that will directly benefit conservation of the species, or a similar species, in the wild
- 9 Basis for an education and awareness programme that addresses specific threats or constraints to the conservation of the species or its habitat
- 10 Other: (a) veterinary support; (b) surrogate for other species.

SUPPLEMENTARY TABLE 5 Cross-referencing among data sources: the 76 species in total that were reported as receiving conservation benefit from ex situ management, as reported from across all three sources of information (search of the scientific literature, IUCN Red List and survey of practitioners). The source of information for each species is indicated, and the six species that were reported from more than one source are highlighted in grey.

Species	Source of reported conservation benefit from ex situ management		
	Scientific Literature	IUCN Red List	Survey of practitioners
<i>Actinemys marmorata</i>	-	-	Yes
<i>Ailuropoda melanoleuca</i>	-	Yes	-
<i>Anas chlorotis</i>	-	Yes	-
<i>Anas nesiotis</i>	-	Yes	-
<i>Anthochaera phrygia</i>	-	-	Yes
<i>Antilocapra americana sonoriensis</i>	Yes	-	-
<i>Apteryx mantelli</i>	-	-	Yes
<i>Ara macao</i>	Yes	-	-
<i>Bettongia lesueur</i>	-	Yes	-
<i>Bettongia penicillata</i>	-	-	Yes
<i>Bison bonasus</i>	-	Yes	-
<i>Burramys parvus</i>	-	-	Yes
<i>Calidris pygmaea</i>	-	-	Yes
<i>Canis rufus</i>	Yes	-	-
<i>Castor fiber</i>	-	Yes	-
<i>Charadrius melodus</i>	Yes	-	-
<i>Charadrius nivosus</i>	Yes	-	-
<i>Chlamydotis undulata macqueenii</i>	Yes	-	-
<i>Columba junoniae</i>	-	Yes	-
<i>Cyclura collei</i>	-	-	Yes
<i>Cyclura lewisi</i>	-	Yes	-
<i>Dama mesopotamica</i>	Yes	-	-
<i>Dasyprocta leporina</i>	Yes	-	-
<i>Dasyurus geoffroii</i>	-	Yes	-
<i>Dryolimnas cuvieri aldabranus</i>	Yes	-	-
<i>Elephas maximus</i>	-	-	Yes
<i>Emys orbicularis</i>	Yes	-	-
<i>Equus ferus</i>	Yes	Yes	-
<i>Falco peregrinus</i>	Yes	-	-
<i>Falco punctatus</i>	Yes	-	-
<i>Foudia rubra</i>	-	Yes	-
<i>Gorilla gorilla gorilla</i>	Yes	-	-
<i>Grus americana</i>	Yes	-	-
<i>Gymnogyps californianus</i>	Yes	-	-
<i>Gypaetus barbatus</i>	Yes	-	-
<i>Halcyon cinnamominus</i>	-	-	Yes
<i>Hippocamelus bisulcus</i>	-	-	Yes
<i>Hylobates lar</i>	Yes	-	-
<i>Lanius ludovicianus migrans</i>	Yes	-	-
<i>Leontopithecus chrysopygus</i>	-	Yes	-
<i>Leporillus conditor</i>	-	Yes	Yes
<i>Lutra lutra</i>	Yes	-	-
<i>Lynx pardinus</i>	-	Yes	-
<i>Macropus eugenii</i>	-	-	Yes
<i>Macrotis lagotis</i>	-	-	Yes
<i>Marmota vancouverensis</i>	-	-	Yes
<i>Muscardinus avellanarius</i>	Yes	-	-
<i>Mustela nigripes</i>	Yes	Yes	-

<i>Neophema chrysogaster</i>	-	-	Yes
<i>Nipponia nippon</i>	Yes	-	-
<i>Oligosoma spp.</i>	-	-	Yes
<i>Onychogalea fraenata</i>	-	Yes	-
<i>Oryx leucoryx</i>	Yes	Yes	-
<i>Pan troglodytes</i>	Yes	-	-
<i>Panthera leo</i>	Yes	-	-
<i>Parantechinus apicalis</i>	Yes	-	-
<i>Perameles gunnii</i>	-	-	Yes
<i>Perdix perdix</i>	Yes	-	-
<i>Peromyscus polionotus trissyllepsis</i>	Yes	-	-
<i>Petrogale lateralis</i>	-	-	Yes
<i>Petrogale xanthopus</i>	-	-	Yes
<i>Porcula salvania</i>	-	-	Yes
<i>Porphyrio hochstetteri</i>	Yes	-	-
<i>Porphyrio mantelli</i>	Yes	-	-
<i>Psammodromus algirus</i>	Yes	-	-
<i>Pseudemys umbrina</i>	-	-	Yes
<i>Sarcophilus harrisi</i>	Yes	-	Yes
<i>Sphenodon punctatus</i>	-	-	Yes
<i>Sphenodon guntheri</i>	Yes	-	-
<i>Strigops habroptila</i>	-	-	Yes
<i>Tiliqua adelaidensis</i>	-	-	Yes
<i>Trichechus manatus manatus</i>	Yes	-	-
<i>Urocyon littoralis</i>	Yes	Yes	-
<i>Varecia variegata variegata</i>	Yes	-	-
<i>Vulpes velox</i>	Yes	-	-
<i>Zapornia atra</i>	Yes	-	-

SUPPLEMENTARY TABLE 6 Results of cross-referencing the species identified from the search of the scientific literature with the IUCN Red List, without imposing restrictions on the timing of Red List assessments. Vertebrate species that were identified from the literature search as having derived a conservation benefit from ex situ management, and for which ex situ management was described on the IUCN Red List as having contributed to the species being down-listed, are given. Species' previous Red List category, the most recent year that it was assessed in that category, the downlisted category and the year that it was downlisted are given.

Scientific name	Common name	Previous category ¹ (year)	Downlisted category ¹ (year)	Red List citation	Publication(s) from the search of the scientific literature
<i>Charadrius melodus</i>	Piping plover	VU (2004)	NT (2005)	BirdLife International (2016c)	Roche et al. (2008)
<i>Equus ferus</i>	Przewalski's horse	CR (2008)	EN (2011)	King et al. (2015)	King and Gurnell (2005); Slotta-Bachmayr et al. (2004); Xia et al. (2014)
<i>Lutra lutra</i>	Eurasian otter	VU (2000)	NT (2004)	Roos et al. (2015)	Hobbs et al. (2011)
<i>Mustela nigripes</i>	Black-footed ferret	EW (1996)	EN (2008)	Belant et al. (2015)	Cain et al. (2011); Howard et al. (2016)
<i>Nipponia nippon</i>	Asian crested ibis	CR (1996)	EN (2000)	BirdLife International (2016g)	Yu et al. (2015)
<i>Oryx leucoryx</i>	Arabian oryx	EN (2008)	VU (2011)	King et al. (2015)	Strauss (2002); Zafar-ul Islam et al. (2011)
<i>Urocyon littoralis</i>	Island fox	CR (2008)	NT (2013)	Coonan et al. (2013)	Clifford et al. (2007)

¹Red List categories: NT, Near Threatened; VU, Vulnerable; EN, Endangered; CR, Critically Endangered; EW, Extinct in the Wild.