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REVIEW

Wildlife health outcomes and opportunities in conservation translocations

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Abstract

1. It is intuitive that the health status of wildlife might influence conservation translocation outcomes, however, health as a topic has received limited attention in the conservation translocation literature. We determined the forms and frequency of disease and other biological problems reported in translocated animals and plants, and in populations linked to translocation, and associations between their mention and translocation 'success'. From these problems we deduced the forms of ill-health potentially associated with conservation translocation and developed contextual frameworks to inform health management.
2. Using described selection criteria, a subset of case studies of animal and plant conservation translocation from the IUCN's 'Global Reintroduction Perspectives' series (2008–2018) was reviewed. Self-reported information describing or implying mortality, ill-health or reproductive compromise was extracted and categorized as a 'disease' or other biological problem. Problems explicitly described as a 'major difficulty', 'major lesson' or 'reason for failure' were termed 'notable'. We specified the conditions representing ill-health and created diagrams illustrating their relationships to other biological problems and processes, and management measures.
3. Notable 'disease' problems such as infection, (as in stress-related) and husbandry-related disorders were reported in 30% of 295 reviewed case studies and were more likely to be mentioned in less 'successful' projects ($P < 0.05$, χ^2 test). Other biological problems, in particular predation, adverse climate or weather, and anthropogenic trauma, were commonly reported (66% of 295 studies), especially post-release.
4. When present, disease may be an important obstacle to translocation success. The negative health impacts of other, apparently common post-release problems also merit acknowledgement. A broad spectrum of disease and other health-related problems can potentially occur in conservation translocations and impact

conservation and animal welfare outcomes. We suggest health management of translocation has three broad roles: to mitigate disease risks posed to other animals, plants and humans; to mitigate threats to the health of translocated individuals themselves; and to preserve and build their resilience and adaptive capacity, given the apparent high frequency of post-release problems. We advocate a stronger emphasis on fostering health as opposed to solely preventing disease. This is directly and indirectly dependent on a range of related project management actions and on multi-disciplinary expertise.

KEYWORDS
conservation translocation planning, ecosystem restoration, plant reintroduction, wildlife disease management, wildlife disease risk analysis, wildlife disease risk assessment, wildlife health, wildlife reintroduction

1 | INTRODUCTION

Conservation translocations are, 'the deliberate movement[s] of organisms from one site for release in another… intended to yield a measurable conservation benefit at the levels of a population, species or ecosystem', through population reinforcement, reintroduction, assisted colonization or ecological replacement (IUCN/SSC, 2013). They are an increasingly popular conservation tool (Brichieri-Colombi & Moehrenschlager, 2016) and are likely to remain so, given the accelerating pressures on biodiversity (Swan et al., 2018). While conservation translocations have contributed to the recovery of many threatened species (Armstrong et al., 2019), they remain expensive and complex projects to undertake (IUCN/SSC, 2013), so we should endeavour to optimize their outcomes by learning from past experience (Sutherland et al., 2004). It is intuitive that ill-health in translocated animals and plants, or other populations linked to translocation, could hinder conservation outcomes (Parker et al., 2012), yet health has received limited attention in the literature on conservation translocations. The nature and prominence of ill-health conditions in conservation translocations, and their links to translocation success, therefore merit further study (Ewen et al., 2012; Harrington et al., 2013). The lack of focus to date also indicates an opportunity for improved integration of wildlife health concerns in conservation management (e.g. Canessa et al., 2019; Hanisch et al., 2012).

Our review focuses on ill-health in individual animals, plants and humans, and we define 'ill-health' as 'any [physical or mental] impairment that interferes with or modifies the performance of normal functions' (Wobeser, 1981). For the purposes of this study, we use the term 'disease' to imply ill-health conditions apart from traumatic or other injury, noting that in the conservation literature the term tends to be synonymous with infectious disease.

Of the ill-health conditions to potentially impact conservation translocations, infectious disease has received particular attention, given the role translocations can play in driving the spread of harmful infectious agents (e.g. Kock et al., 2010; Martel et al., 2014). Health management therefore plays a well-recognized role in preventing infectious disease transmission to animal, plant or human populations linked to conservation translocation (Sainsbury et al., 2017), and the IUCN recommends a disease risk analysis is undertaken to identify priority infectious agents for management (IUCN/SSC, 2013; OIE & IUCN, 2014). The importance of minimizing stress in conservation translocations has also been highlighted, because translocations force 'the physiological stress response system… beyond [its] normal capacity' to the extent that it can be detrimental to health (Dickens et al., 2010). While disease risk analysis provides a framework for considering stress and non-infectious conditions in conservation translocations, in practice these have tended to receive less attention than infectious disease (e.g. see Jakob-Hoff et al., 2014).

Regarding other biological problems, predation has been a commonly attributed cause of post-release mortality or failure in both animal and plant translocations (e.g. Fischer & Lindenmayer, 2000; Godefroid et al., 2011; Harrington et al., 2013). Other problems commonly emphasized in the literature include anthropogenic trauma in mammal and bird translocations (e.g. Jule et al., 2008; Wolf et al., 1996), and adverse climate or weather in terrestrial insect and herpetofauna translocations (Bellis et al., 2019, 2020). A greater understanding of the forms of ill-health and related problems encountered in conservation translocations, across taxonomic groups (Harrington et al., 2013), will help us better understand health management needs.

The growing body of literature on conservation translocation practice includes the SSC/IUCN's 'Global Re-introduction Perspectives' series of case studies (Soorae, 2008, 2010, 2011, 2013, 2016, 2018, 2021), written primarily by project managers and conservation practitioners. These publications aim to 'provide a broad global perspective on [the] challenges facing reintroduction projects' (Soorae, 2018), and concern a diverse array of animal and plant species from a range of terrestrial, freshwater and marine habitats. The case studies have a standardized format including the sub-headings 'Major difficulties faced', 'Major lessons learned' and 'Success of project: Reason(s) for success/failure', under which authors have the

opportunity to self-report any notable difficulties or obstacles encountered in their projects. Given this focus, and their broad taxonomic and geographical scope, the case studies are a valuable resource from which to glean information about conservation translocation outcomes (Berger-Tal et al., 2020). The case study authors are required to qualitatively rate their project's success as 'Highly successful', 'Successful', 'Partially successful' or 'Failure', and overall they report a strikingly low rate of 'failure' (Beckmann & Soorae, 2022) in comparison to earlier reintroduction literature and recent taxon-specific reviews (Bellis et al., 2019; Cochran-Biederman et al., 2014; Silcock et al., 2019).

We reviewed the case studies published in 'Global Re-introduction Perspectives' to determine the forms and frequency of 'disease' and other biological problems self-reported in conservation translocations, and their associations with project 'success'. From these analyses, we defined the key conditions representing ill-health in conservation translocations. We then explored diagrammatically the relationships between ill-health and other biological problems and processes, and the role of health management in conservation translocations.

2 | MATERIALS AND METHODS

2.1 | Review of conservation translocation case studies

Using a data set described in Beckmann and Soorae (2022), we reviewed self-reported information presented in a subset of 'Global Reintroduction Perspectives' case studies (Soorae, 2008, 2010, 2011, 2013, 2016, 2018): specifically, those case studies considered to describe, with sufficient detail and clarity, a discrete conservation translocation initiative for which releases were underway or complete at their time of writing. So that we could explore associations between the mention of problems and project 'success', case studies that did not describe a discrete translocation initiative, for example summaries of different translocation projects for a particular species over a prolonged timeframe, or research studies performed in parallel to a translocation for which success criteria were unrelated to translocation outcomes, were not included. Neither were case studies that could be considered as falling outside the definition of a conservation translocation (IUCN/SSC, 2013): those which were very small scale (≤5 individuals released) or for which it was not explicitly clear that wildlife conservation was a primary aim. In order to determine whether the mention of problems was related to case study 'quality', a simple scoring system was used to quantitatively reflect the level of detail presented in each case study (see Table S1).

Since ill-health can cause or contribute to mortality and reproductive compromise, we summarized information relating to any mortality, ill-health or poor fecundity in translocated individuals or in animals, plants or humans linked to translocation, including if this was intimated or implied, for example if a relevant management measure had been instigated or was advocated. These 'problems' were categorized according to their attributed cause (excepting 'poor fecundity'), and our causal categories refined through the course of data collation. Causal categories were grouped into those that could typically be considered 'disease' versus 'other' biological problems. We used the term 'infectious agent' to denote 'parasites (infectious organisms) and other transmissible agents recognized to cause disease, or considered by case study authors to have this potential' (Beckmann & Soorae, 2022). An infectious agent was considered a 'problem' if concern was expressed about it, whether or not there was mention of associated disease. Each 'disease' or other biological problem of a distinct causal category, reported at a particular translocation stage, was considered a discrete problem. For example, if both persecution-related and incidental anthropogenic trauma had occurred post-release, these were considered two separate 'other' biological problems, and if a released population had been affected by two different types of infectious agent during a particular translocation stage, these were considered two distinct 'disease' problems.

A problem was termed 'notable' if mentioned under the subheading 'Major difficulties faced' and/or 'Major lessons learned' and/or 'Success of project: Reason(s) for success/failure'. Standard statistical tests were used to test the null hypothesis that there was no association between the proportion of case studies mentioning at least one notable 'disease' or other biological problem and their success ratings. We explored the translocation stages during which notable problems had occurred (Beckmann & Soorae, 2022), across taxonomic groups. We also determined the proportion of studies explicitly attributing partial or outright project failure to a notable 'disease' or other biological problem, where partial failure was defined as failure or postponement of ≥1 release season or at ≥1 site.

The percentage of case studies mentioning, under any subheading, that a disease risk analysis or 'risk assessment' for disease was performed prior to translocation, or that at least one pre-emptive pre- or post-release health management measure (as outlined in Beckmann & Soorae, 2022) was instigated, was also determined. We also explored the proportion of case studies mentioning, under the subheadings 'Major difficulties faced', 'Major lessons learned', or 'Success of project: Reason(s) for success/failure', the benefits or importance of health management measures and/or expertise, or associated negative experiences, as well as the benefits or importance of husbandry measures/skills and adequate project funding or other resourcing.

2.2 | Ill-health and its management

A register of the forms of ill-health associated with conservation translocations, and their potential causes, was drawn up from the 'disease' problems extracted from the case studies and in addition, the forms of ill-health linked to, or considered a probable consequence of, other biological problems. We explored the relationships between these ill-health conditions and other biological problems and processes in a summary diagram centred on ill-health. We then created influence diagrams (Gregory et al., 2012) exploring the roles of health management, and related project management measures, in the context of the fundamental biological objectives of conservation translocation

TABLE 1 Categorization of self-reported problems describing or implying mortality, ill-health or poor fecundity in reviewed case studies, according to their attributed cause[a]

	Primary category	Subcategory	Further details
1.	**'Disease' problem**		
(a)	**Infectious agent**	Virus	
		Bacterium	
		Fungus	
		Oomycete	
		Protozoan	
		Helminth	
		Arthropod ectoparasite	Including nest parasitism
(b)	**Non-infectious 'disease'**		
(i)	Stress or related disease	Stress-related dispersal	Acute post-release dispersal
		Capture myopathy	
		Other stress-related disease or mortality	Associated with capture/collection; handling, examination or transit; or holding/captivity
(ii)	Poisoning, pollution or eutrophication	Poisoning (targeted or non-target):	
		Lead	
		Poison bait	
		Other	Including pesticide or herbicide
		Pollution or eutrophication	
(iii)	Nutritional disease or deficiency		
(iv)	Other husbandry-related disorder	Developmental disease	
		Obesity or inadequate exercise	
		Insufficient supplementation of food/water	In the captive environment or post-release
		Temperature-related disorder	
		Housing-related disorder	
		Other	Including due to equipment failure or lack of infrastructure
(v)	Side-effect of veterinary or phytosanitary intervention	Side-effect of anaesthesia or chemical capture	Not including trauma (see below)
(c)	**'Disease' or 'health' problem of undetermined or unspecified cause**		
2.	**Other biological problem**		
(a)	**Ecological or environmental**		
(i)	Predation		Including grazing of plants
(ii)	Adverse climate or weather	Extreme climatic event:	
		Drought	
		Extreme heat	
		Fire	Including human-induced fire
		Storm or flooding	
		Extreme winter weather	
		Unseasonable/variable weather	

(Continues)

TABLE 1 (Continued)

	Primary category	Subcategory	Further details
(iii)	Other 'natural' trauma	Interspecies aggression	
		Intraspecies aggression	
		Animal disturbance	
		Other	Including cliff fall
(iv)	Other environmental injury	Drowning	
		Electrocution	
(v)	Other ecological or environmental problem	Fouling	Marine species
		Interspecies competition	
		Poor adaptation to release site	
		Suboptimal release habitat	
		Other	Including post-release 'starvation' of unspecified cause
(b)	**Anthropogenic trauma**	Incidental trauma	Including road traffic collision, other collision, entanglement, electrocution
		Intentional trauma	Collection/harvest, offtake or persecution
		Translocation-related trauma	Trauma associated with capture/collection, transit, handling or monitoring, including from a monitoring device
		Human disturbance	
(c)	**Other behavioural abnormality**[b]	Abnormal ecological, social or reproductive behaviour	Including poor predator avoidance
		Abnormal behaviour towards humans	Imprinting, tameness or aggression towards humans
(d)	**Detrimental genetic process**	Low genetic diversity or inbreeding depression	
		Hybridization	
(e)	**Poor fecundity**		

[a]With the exception of 'poor fecundity', which is categorized separately.
[b]Noting that Berger-Tal et al. (2020) defined behavioural problems more broadly to include, for example dispersal, poor adaptation to a release site and interspecific aggression.

(IUCN/SSC, 2013). This register and the diagrams were primarily compiled from information presented in the case series, supplemented as appropriate with ill-health conditions and management actions mentioned in the wider literature.

3 | RESULTS

3.1 | Review of conservation translocation case studies

Eighty-four per cent ($n = 295$) of 351 case studies fulfilled our criteria for inclusion in the review (Table S2). Of these, 60% were reintroductions, 18% were population reinforcements, 5% were assisted colonizations and 1% were ecological replacements (8% of case studies performed multiple types of translocation, and in another 8% the type was not specified; Beckmann & Soorae, 2022). The case studies spanned mammals (29% of 295 studies, $n = 86$), birds and plants (19%, $n = 55$, for each taxon), reptiles (10%, $n = 30$), fish (10%, $n = 29$), invertebrates (8%, $n = 23$) and amphibians (6%, $n = 17$), with some animal orders and plant families particularly strongly represented. The scale of projects varied markedly within and between these taxonomic groups, both in terms of their time-scale and the number of individuals released (Beckmann & Soorae, 2022). The 'detail scores' for case studies ranged from 0.25 to 1 (where 1 was the highest level of detail possible under our scoring system, as per Table S1) and averaged 0.93 across reviewed studies; plant case studies had a comparatively small pool of first authors relative to other studies.

The attributed causes of problems and our categorization of them are described in Table 1. Thirty per cent ($n = 89$) of reviewed case studies mentioned a notable 'disease' problem, and 66% ($n = 194$) mentioned another notable biological problem (Figure 1). Overall, 75%

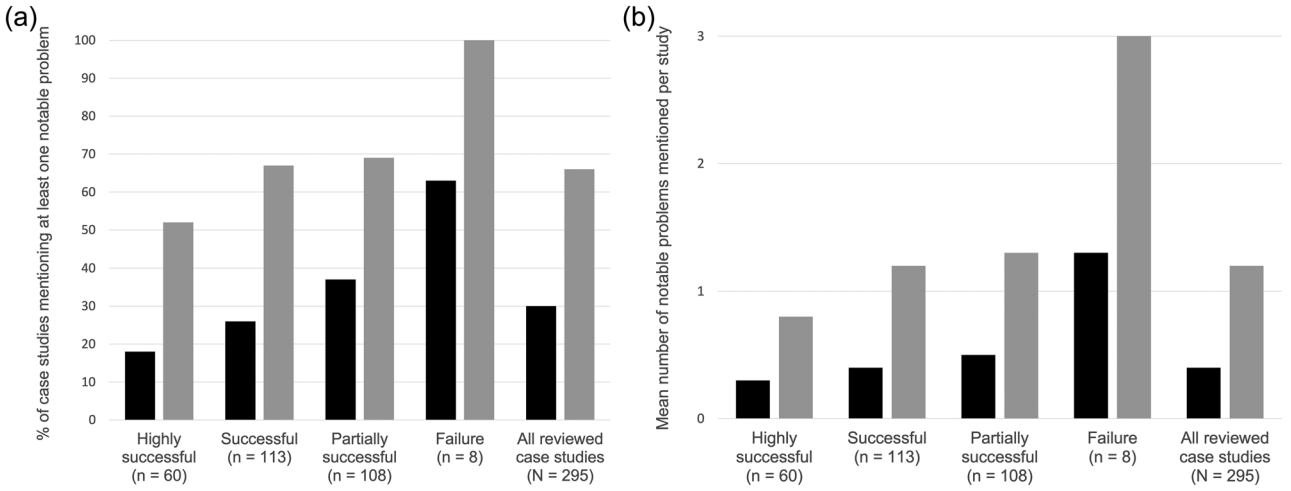

FIGURE 1 Proportion of reviewed case studies (a) self-reporting a notable 'disease' (black bars) or other biological problem (dark grey bars; see Table 1 for definitions), and (b) the mean number of notable 'disease' (black bars) or other biological problems (dark grey bars) mentioned per case study, according to project success rating. There was a significant relationship between the mention of notable 'disease' problems and success rating on a χ^2 test ($P < 0.05$). There was no significant relationship between the mention of other notable biological problems and 'Highly successful', 'Successful' or 'Partially successful' ratings on a χ^2 test at the 5% significance level ($P = 0.066$), but there was a significant association between their mention and 'Highly successful' versus 'Failure' ratings on a Fisher's exact test ($P < 0.05$) (see Table S3). Associations between the number of notable problems per case study and success ratings were not explored statistically. Six case studies did not give one success rating (five gave multiple ratings, e.g. for releases at different locations, and one did not give a rating)

($n = 222$) of case studies mentioned any type of notable problem (Table S3); a further 13% of studies ($n = 39$) mentioned a problem that was not 'notable', that is it was not described under a relevant section of the case study. An average of 0.4 'disease' and 1.2 other biological problems were mentioned per case study (ranges 0–4 and 0–6, respectively; Figure 1).

Notable 'disease' problems were mentioned in only 18% (11) of 60 'Highly successful' case studies and were significantly more likely to be mentioned in case studies with poorer success ratings ($P < 0.05$ on a χ^2 test): for example, in 63% (five) of eight failed projects (Figure 1 and Table S3). Similarly, on average, 0.3 notable 'disease' problems (range 0–3) were mentioned per 'Highly successful' case study, versus 1.3 (range 0–3) per failed case study (Figure 1 and Table S3). Other notable biological problems were commonly mentioned, including in 52% of 60 'Highly successful' case studies (Figure 1) and in a higher proportion of less successful case studies ($P = 0.066$, χ^2 test; Figure 1). Case studies of less 'successful' projects also described a higher number of other biological problems per case study, on average, than more 'successful' projects (Figure 1). The mention of notable problems was unrelated to case study quality: the mean quality scores (Table S1) of case studies that referred to them, versus those that did not, were 0.92 and 0.94, respectively.

While notable problems occurred at all stages of translocation, notable 'other' biological problems were mentioned particularly frequently in the post-release phase: in 60% of 225 *ex situ*-to-wild and 57% of 60 wild-to-wild case studies (Figure 2). The proportion of case studies mentioning a notable problem of each attributed cause, at each translocation stage, is summarized in Table 2, and a more detailed taxonomic breakdown is provided in Supporting Information (Figure S1; Tables S4 and S5).

'Stress or related disease' was the most commonly mentioned notable problem during capture/collection, transit and handling (in 6% of all 295 case studies) and in temporary holding in wild-to-wild translocations (7% of 60 studies). Other husbandry-related disorders were the most frequently mentioned notable 'disease' problem in the *ex situ* stage (in 6% of 225 *ex situ*-to-wild translocations). Chytrid fungus (*Batrachochytrium dendrobatidis*) infection was a notable post-release problem in 29% ($n = 5$) of 17 amphibian case studies (Table S4), frequently with associated disease (chytridiomycosis; in at least four of these five case studies, since one did not mention whether disease was present). Overall, notable infection was described in released individuals in 6% ($n = 19$) of case studies, and at any translocation stage in 11% ($n = 31$) of case studies. Where specified or deducible, notable infection was most often due to a 'destination' infectious hazard, that is an infectious agent encountered by translocated individuals in the release area (at least 43% of 37 infection concerns; Table S6).

Predation was the most commonly mentioned post-release problem, in both *ex situ*-to-wild and wild-to-wild translocations (27% of 225 and 25% of 60 case studies, respectively). Adverse climate or weather, most commonly drought (Table S5), and anthropogenic trauma were also frequently mentioned post-release (in 22%, 14% and 18% of all studies, respectively). In plant case studies, notable interspecies competition was also commonly reported (in 25% of 55 case studies; Table S4). Poor fecundity was the most frequently described notable problem associated with the captive environment (in 8% of 225 *ex situ*-to-wild case studies).

Notable problems posed *by* translocated individuals to the survival, health or fecundity of other animals, plants or humans were mentioned in only 5% ($n = 10$) of the 222 case studies describing a notable problem, that is much less frequently than problems in translocated

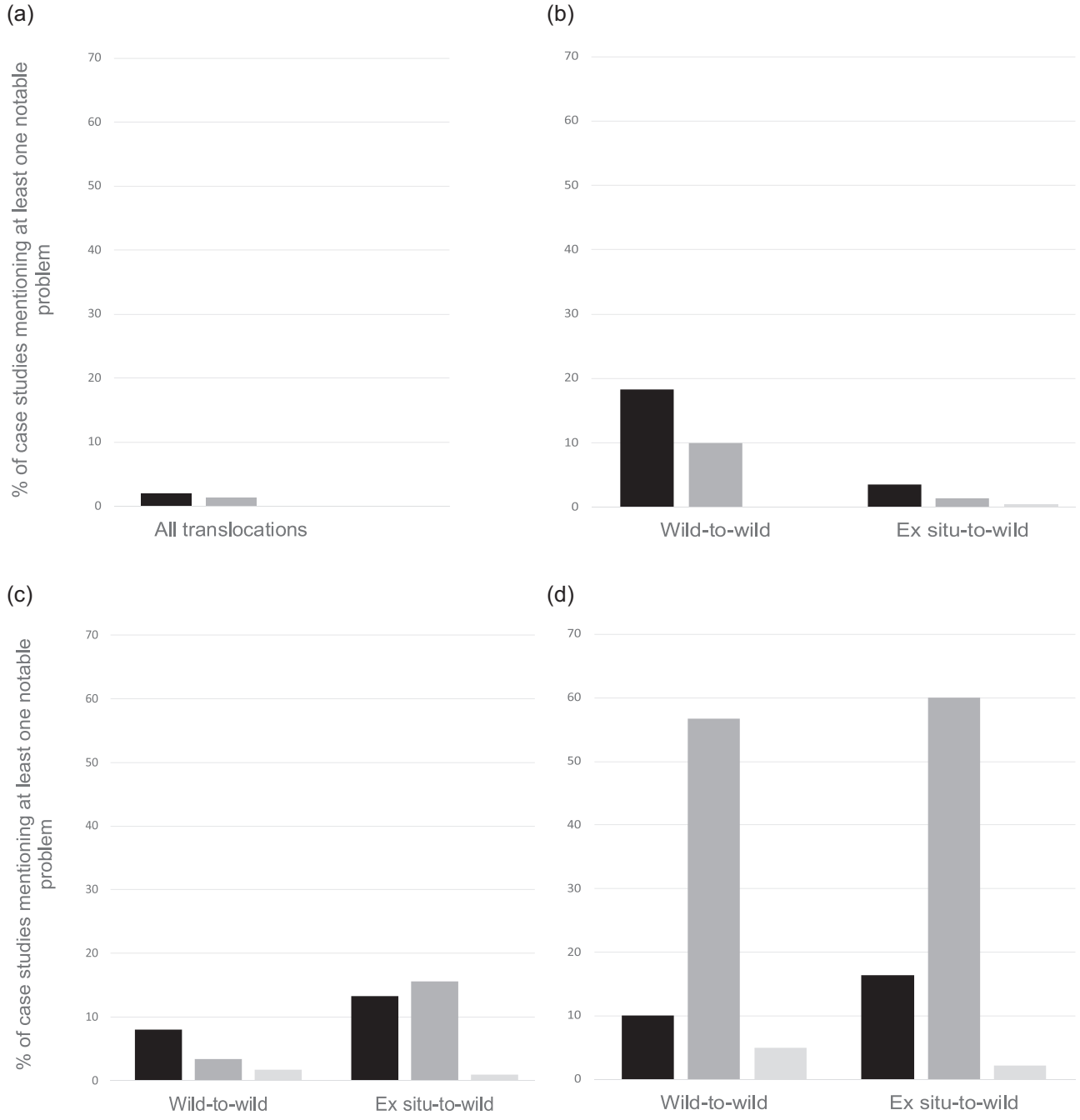

FIGURE 2 Proportion of reviewed case studies self-reporting a notable 'disease' (black bars), other biological (dark grey bars) or unspecified/undetermined (light grey bars) problem, (a) in the source population, (b) during capture/collection, transit or handling, (c) in the captive environment, including temporary holding, or (d) post-release, for wild-to-wild ($n = 60$) and *ex situ*-to-wild ($n = 225$) case studies of conservation translocation. 'Problems' described or implied mortality, ill-health or poor fecundity (see Table 1 for definitions of 'disease' and other biological problems)

individuals themselves. Specifically, 3% (seven) of these 222 studies described a notable problem due to an infectious agent that had been detected in the source or translocated population and was considered a *potential* novel disease threat to the release area. Either the agent had caused disease in the source population or translocated individuals ($n = 3$), or was known to have disease-causing potential ($n = 2$), or this was unknown ($n = 1$) or not specified ($n = 1$). In one chimpanzee *Pan troglodytes* and one African elephant *Loxodonta africana* translocation, released animals had attacked, and (in the case of elephants) killed, people; and in one Asian elephant *Elephas maximus* translocation, released individuals had been aggressive towards wild conspecifics, with aggression also resulting in some individuals not being released.

As per above and Figure 1, eight case studies were rated as 'Failure', five of which mentioned notable 'disease' and all mentioned other

TABLE 2 Proportion of reviewed case studies self-reporting a notable 'disease' or other biological problem according to attributed cause and project stage (see Table 1 for definitions)[a]

	% of case studies mentioning at least one notable problem																			
	'Disease' problem								Other biological problem											
		Non-infectious disease							Ecological or environmental											
Translocation stage	Infectious agent[d]	Stress or related disease	Poisoning, pollution or eutrophication	Other husbandry-related disorder	Nutritional disease/ deficiency	Side-effect of anaesthesia or chemical capture	Disease or ill-health of unknown or unspecified cause	**Any 'disease' problem**	Predation	Adverse climate or weather	Other natural trauma[e]	Other environmental injury	Other ecological or environmental problem	Anthropogenic trauma	Behavioural abnormality[f]	Detrimental genetic process	Poor fecundity	**Any 'other' biological problem**	**Cause of problem unknown[g]**	**Any type of problem[g]**
Source population (n = 295)	2	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	3
Capture/collection, transit or handling (n = 295)	0	6	0	0	0	1	0	7	0	1	0	0	0	3	0	0	0	3	0	9
Captive environment: Wild-to-wild (n = 60)[b]	2	7	0	2	0	0	0	8	2	0	0	0	0	2	0	0	0	3	2	10
Captive environment: *Ex situ*-to-wild (n = 225)[c]	4	4	0	6	0	0	2	13	3	1	2	0	0	1	2	2	8	16	1	25
Post release (n = 295)	6	3	5	1	1	0	1	15	26	22	7	2	14	18	6	1	1	60	3	64

Key (% case studies): 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 | 31-35 | ≥ 36

[a]Problems affected translocated individuals unless otherwise indicated (see d–f below).
[b]Wild-to-wild translocations: temporary holding only.
[c]Translocations including an *ex situ* stage (either exclusively or in a proportion of releases), including temporary holding.
[d]Include seven case studies (23% of all 31 case studies mentioning a notable infection problem) where an infectious agent was a notable problem because it was detected in the source or translocated population and may have been exotic to—and therefore a novel disease threat in—the release area: either it had caused disease in translocated individuals or the source population ($n = 3$), was known to have disease-causing potential ($n = 2$), or this was unknown ($n = 1$) or not specified ($n = 1$).
[e]Include one Asian elephant (*Elephas maximus*) case study in which released individuals were implicated in aggression towards wild conspecifics post-release (4% of all 28 case studies mentioning notable natural trauma).
[f]Include one chimpanzee (*Pan troglodytes*) and one African elephant (*Loxodonta africana*) case study where released individuals were aggressive towards people (there were human fatalities in the latter case study), and one Asian elephant (*Elephas maximus*) case study where aggressive behaviour prevented individual bulls from being released (in total, 14% of all 22 case studies mentioning notable behavioural problems).
[g]A 'problem' involved mortality, ill-health or poor fecundity, or this was implied.

notable biological problems, though their outright failure was not explicitly attributed to these problems. Of all case studies mentioning a notable 'disease' or other biological problem, 1% explicitly described a problem ultimately causing translocation failure (one of 89 and two of 194 case studies mentioning each type of problem—these case studies were still rated 'Partially successful'), and 19% described either type of problem as causing partial project failure (17 of 89 and 37 of 194 studies). The problems to which partial or ultimate failure were attributed mainly occurred post-release (80% of 74 problems), but also in the captive environment or source population (18% and 1% of problems, respectively; the stage at which one problem occurred was not specified). The attributed causes of these problems spanned five 'disease' and seven 'other' biological problem categories. The case study that described notable 'disease' as the cause of translocation failure was a short-tailed bat *Mystacina tuberculata* translocation, in which released bats suffered from a disease of undetermined cause; post-release predation was considered the ultimate cause of failure in two other case studies.

Four per cent ($n = 12$) of reviewed case studies self-reported a disease risk analysis or 'risk assessment' for a disease threat being undertaken, the majority of which (eight case studies) had commenced releases since 2005; a further 11% ($n = 31$) of case studies mentioned following conservation translocation guidelines published by the IUCN or another body, which might have included disease risk analysis. In 61% ($n = 180$) of case studies, there was mention of at least one pre-emptive pre- and/or post-release health management measure being implemented. Under the subheadings 'Major difficulties faced', 'Major lessons learned' or 'Success of project: Reason(s) for success/failure', health management or specialist health expertise was advocated or cited as a benefit in 27% ($n = 81$) of projects. Conversely, negative experiences associated with health management measures were mentioned in 12% ($n = 36$) of case studies, for example: 3% ($n = 9$) described challenges associated with a lack of knowledge of the natural parasite complement of their target species or the pathogenicity of a newly identified infectious agent, which had led to the postponement of releases in 2% ($n = 5$) of all projects; 3% ($n = 9$) cited challenges posed by national or international disease-related restrictions on animal movement; and in 2% ($n = 5$), disease screening or veterinary examination ($n = 2$), or extended holding in captivity to facilitate this ($n = 3$), was considered to have negatively impacted the health of

TABLE 3 Register of the forms of ill-health that have been, or could be, associated with conservation translocations

Form of ill-health	Potential causes
Forms of disease directly extracted from the case studies	
1. Infectious disease	Infectious agent: virus, bacterium, fungus, protozoan, helminth, arthropod, oomycete or other
	Other transmissible agent, e.g. prion and transmissible tumour[a(1)]
2. Stress-related disorder, e.g. capture myopathy[b]	Associated with:
	Capture/collection, handling or transport
	Holding or captivity
	Release process
	Post-release monitoring
	Human or animal disturbance
3. Toxicity or contaminant-related disorder	Poison exposure, including to lead, poison bait, pesticide, herbicide or other poison. Targeted or non-target
	Pollution or eutrophication
4. Nutritional disease or deficiency	From captive, supplemental or natural diet
5. Other husbandry-related disorder, e.g. obesity or developmental disease	Inadequate exercise or overfeeding
	Inappropriate or suboptimal housing, climate or lighting[a(2)] conditions
	Poor infrastructure, equipment or training or another cause
6. Side effect of veterinary or phytosanitary intervention (other than traumatic injury)[c]	Side-effect of anaesthesia or chemical immobilization
	Adverse consequence of other veterinary or phytosanitary intervention
7. Other disease/disorder	a. Associated with:
	A detrimental genetic process, e.g. low genetic diversity, inbreeding or hybridization
	Behavioural abnormality
	Poor fecundity
	b. Other, primary disease, e.g. degenerative, cancerous, allergic[a(3)]
Forms of ill-health resulting from, or considered a likely implicit consequence of, other biological problems	
8. Traumatic injury	a. Anthropogenic:
	Translocation-related: associated with capture/collection, transit, handling or monitoring method/device
	Incidental (accidental): including road traffic collision, other collision or entanglement
	Intentional[d]: collection/harvest, offtake or persecution
	Human disturbance
	b. Ecological or environmental:
	Predation[d]
	Other natural trauma: inter- or intraspecies aggression, animal disturbance, fouling (marine organisms) or other, e.g. cliff fall

(Continues)

TABLE 3 (Continued)

Form of ill-health	Potential causes
9. Undernourishment	a. Direct anthropogenic:
	Inadequate provisioning of food or water, in the captive environment or post-release
	b. Ecological/environmental:
	Adverse climate: drought, extreme heat/fire, storm, flooding, extreme cold, or unseasonable/variable weather
	Inter- or intraspecies competition
	Fouling (marine organisms)
	Suboptimal release habitat or poor adaptation to release site
10. Disorder relating to extreme climate[b], e.g. exposure and hyperthermia	Adverse climate, i.e. extreme heat or cold, or unseasonable/variable weather
11. Other environmental injury, including drowning[d], burn or radiation[a(3)]	Water body
	Fire or electricity cables
	Radiation source[a(3)]

Note: This summary combines inferences from 'Global Reintroduction Perspectives' case studies and additional primary literature. It includes explicit forms of 'disease' and conditions implicit in 'other' biological problems, to provide a holistic view of the forms of ill-health that are associated with, or could arise in, conservation translocations.

[a]Factors not mentioned in the case study series, but recognized from the wider literature, e.g. (1) Tompkins et al. (2015); (2) Tapley et al. (2015); (3) Jakob-Hoff et al. (2014).

[b]High ambient temperatures may also predispose to capture myopathy.

[c]Also termed 'iatrogenic' disorders.

[d]Recognizing that these problems would most often cause outright mortality.

translocated mammals. Under the same subheadings, 48% (n = 142) of case studies advocated, or cited as a benefit to their project, appropriate or specialist husbandry methods/skills. In 51% (n = 149) of case studies, the importance of securing sufficient funding, project personnel or material resources was highlighted.

3.2 | Ill-health and its management

In Table 3, we specify the forms of ill-health associated with conservation translocations, deduced from the above review. These include forms of 'disease' directly extracted from case studies: infectious disease; stress-related disorders; toxicity or contaminant-related disorders; nutritional disease or deficiency; other husbandry-related disorders; side effects of veterinary/phytosanitary intervention (other than traumatic injury); and other diseases/disorders. And, additionally, forms of ill-health that we considered implicit in other biological problems described in case studies, namely: traumatic injury; undernourishment; disorders relating to extreme climate; and other forms of environmental injury. We also list the range of potential causes of each form of ill-health, as primarily inferred from the case studies, illustrating how conditions such as traumatic injury have a diversity of possible anthropogenic, ecological or environmental causes.

Through Figure 3, we illustrate this broader context relating to ill-health. We show how the above forms of ill-health are closely related to proximate anthropogenic, ecological and environmental problems; underlying anthropogenic driving processes; genetic processes; behaviours; and conservation strategy and methods. Finally, in Figure 4, we illustrate how health management and related project management measures influence health outcomes in this broader biological context. The figure illustrates how a broad range of potential management actions can directly or indirectly influence the health of translocated individuals, and populations of animals, plants and humans linked to translocation. These interrelationships are explored further in Figure S2.

4 | DISCUSSION

Our results suggest that disease problems such as infection, stress- and husbandry-related disorders may be less frequently observed or detected in conservation translocations than some other biological problems; however, the negative relationship between their mention and project success implies that, when manifest, disease may be an important obstacle to success (Muths & McCallum, 2016). Ecological or environmental problems, particularly predation and adverse climate or weather, and anthropogenic trauma, appeared to occur frequently post-release consistent with previous studies (e.g. Harrington et al., 2013; Silcock et al., 2019; Wolf et al., 1996): these problems were mentioned commonly even in the most successful projects. Ill-health can be a component of these problems, and all forms of ill-health potentially associated with conservation translocations (presented in Table 3) merit recognition in conservation translocation planning, given their relevance to animal welfare as well as conservation outcomes. Figure 4

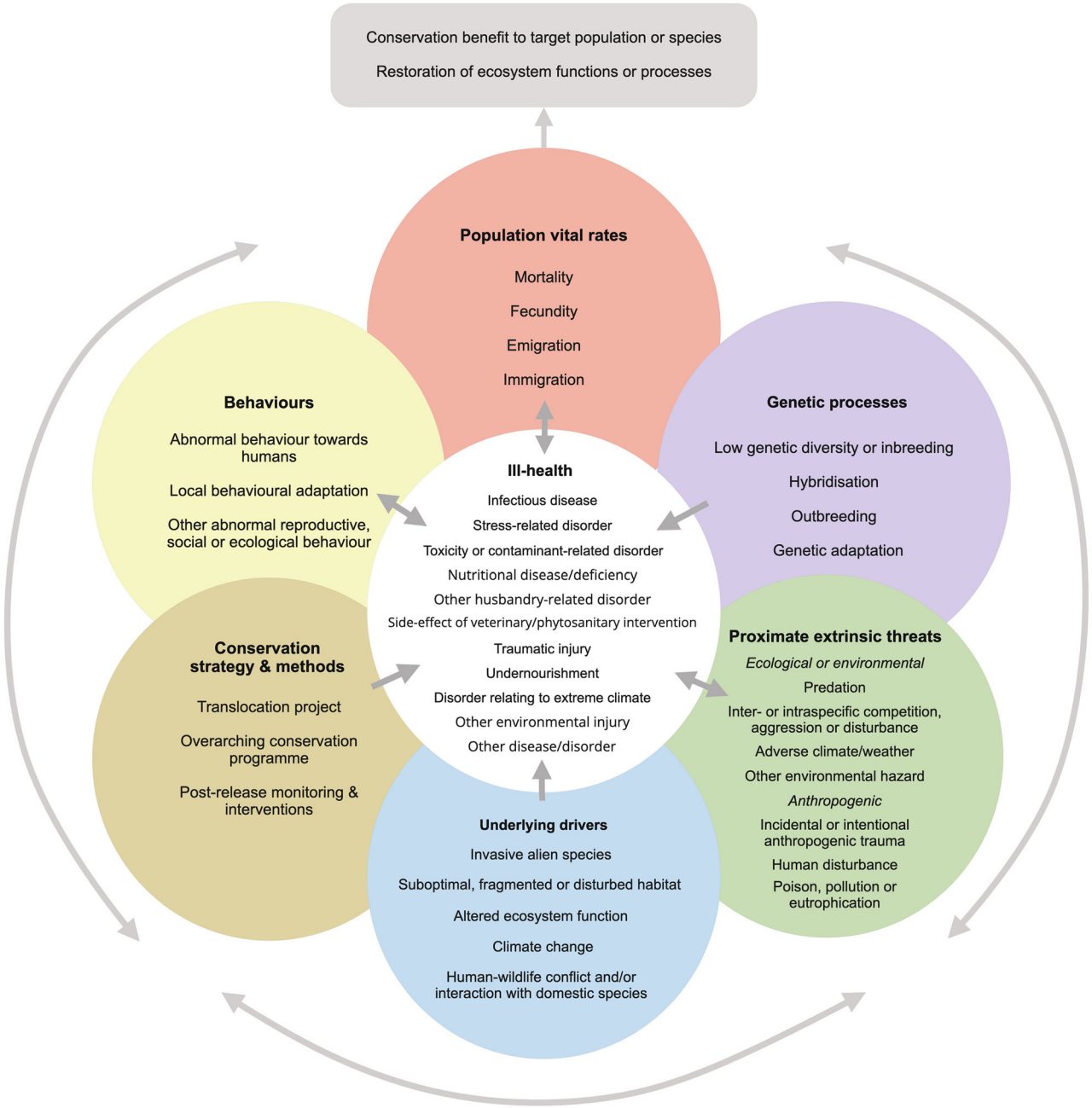

FIGURE 3 The relationships between ill-health, other biological problems and processes and conservation strategy and methods, relative to the fundamental objectives of conservation translocation (IUCN/SSC, 2013)

illustrates how health management measures influence the health of translocated individuals, and of wild-living, *ex situ* and domestic populations of animals and plants, and humans, linked to translocation. We illustrate the close relationships between health and other biological problems and processes (Figure 3), and how a wide range of other project management strategies and methods therefore play a key accompanying role in health management (Figure 4).

The case studies demonstrate how threats to the health of translocated individuals are numerous and varied, and that any one problem, at any translocation stage, has the potential to impede translocation progress. Therefore, disease risk analysis and health management planning need to be comprehensive in scope, and give due consideration to non-infectious conditions—including stress- and husbandry-related conditions—in addition to infectious disease. The case studies also demonstrate how disease problems are context specific. For example, while infectious disease may have been reported relatively infrequently across the case series as a whole, chytridiomycosis appeared to be a frequent post-release problem in amphibian translocations, consistent with a recent review by Scheele et al. (2021). This disease has had devastating impacts on biodiversity (Scheele et al., 2019) and when it is present at a destination site, novel or complex management actions may be required to secure the persistence of released

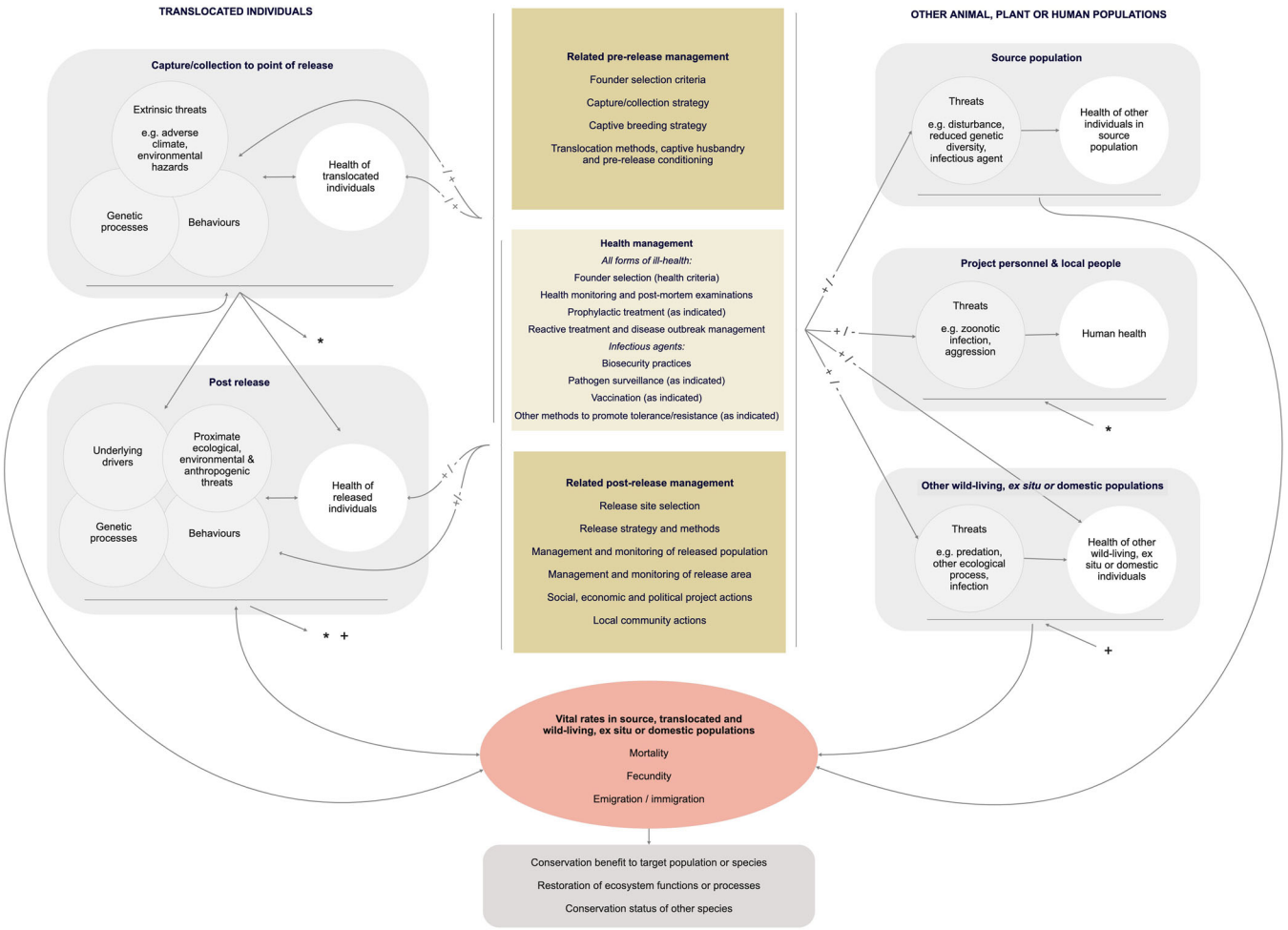

FIGURE 4 Influence diagram summarizing the role of health management in conservation translocations, in the context of related management actions, problems and processes, relative to the fundamental objectives of conservation translocation (IUCN/SSC, 2013). Threats to other populations of animals, plants or humans can be mediated by translocated individuals; project personnel, infrastructure or activities, including post-release provisioning; associated translocated species (other than infectious agents); and, for source populations, loss of translocated individuals. Management actions were drawn from 'Global Reintroduction Perspectives' case studies and the wider literature (notably Moehrenschlager & Lloyd, 2016; Muths & McCallum, 2016; Parker et al., 2012).

populations (e.g. Hunter et al., 2010, in this case series; Muths & McCallum, 2016; Scheele et al., 2021).

The common mention of post-release ecological and environmental problems reflects the acknowledged 'release costs' of conservation translocation (e.g. Bertolero et al., 2018; Tavecchia et al., 2009). As above, practitioners should strive to minimize these losses, not just from a biological standpoint, but also from the perspectives of animal welfare and ethics (Harrington et al., 2013). Figure 4 illustrates how the health status of individuals at the point of release will influence their susceptibility to post-release threats. So, given the apparently high likelihood of these threats, we propose that an important and somewhat overlooked aim of health management should be to foster and safeguard the health of translocated animals or plants during the translocation process (from capture/collection up to the point of release), in order to maximize their post-'release' resilience and adaptive capacity (Dickens et al., 2010; Parker et al., 2012). There may be more opportunities for rounded health assessment of individuals or populations prior to their selection for translocation or release, and further exploration of health 'markers' as predictors of post-release survival may be worthwhile in some species (Campera et al., 2020; Mathews et al., 2006).

Compared to ill-health in translocated individuals themselves, threats posed by translocated individuals or the translocation process to the health of other wild-living, *ex situ* or domestic animals or plants, or humans, appeared to be an infrequent problem. However, a handful of case studies demonstrated the potentially severe consequences of these forms of problem, emphasizing the need for them to be addressed in project planning (Banasiak et al., 2021). Although some infectious agents were considered a potential threat to populations in the release area, no case study reported a confirmed disease outbreak in recipient populations as a consequence of infectious agent translocation. While other types of translocation are a well-recognized driver of infectious agent spread and disease emergence (e.g. Kock et al., 2010; Martel et al., 2014; Simler et al., 2019), to date, few studies have

provided compelling evidence of *conservation* translocations leading to novel infectious disease introduction in wild-living populations (excepting, e.g., Walker et al., 2008). However, this may simply reflect the challenges associated with undertaking post-release monitoring and disease surveillance (Berger-Tal et al., 2020; Griffith et al., 1993).

Given the inextricable links between ill-health and other biological problems and processes (Figure 3), holistic health management of conservation translocations clearly necessitates a broad range of related management actions and skillsets, such as ecological, biological, husbandry, genetic and behavioural expertise (Figure 4; Parker et al., 2012). Underlying anthropogenic problems must also be addressed if the health of released individuals is to be safeguarded—a point that has been highlighted by many authors from the related perspective of population persistence (e.g. Fischer & Lindenmayer, 2000; Griffith et al., 1989). For example, in these case studies, suboptimal habitat quality and invasive alien species were described as 'Major difficulties' in 26% and 9% of projects, respectively (Berger-Tal et al., 2020).

Although the broad array of potential problems highlights the need for a comprehensive approach to disease risk analysis and health management, the highly contextual nature of *infectious* threats and the apparent frequent predominance of other types of problem mean that infectious disease risk analysis and management can also be proportionate to the translocation scenario (IUCN/SSC, 2013). Given the potential for some health management actions to have unintended negative consequences, their costs and benefits require careful case-by-case consideration (e.g. Fogell et al., 2019). There is scope for more-objective health management decision-making in conservation translocations (Ballou, 1993; Sainsbury et al., 2012; Scheele et al., 2021), and Figures 4 and S2 can potentially inform models linking health and related management actions to broader conservation objectives.

We have highlighted the health consequences of other biological problems, however, the extent to which ill-health might have *predisposed* to these problems was not possible to determine from the case studies (e.g. Dickens et al., 2010). Also, whether the reported causes of problems had been proven, and the extent to which problems had been objectively demonstrated to impede translocation progress or success, was often unclear (as per Hayward, 2009). Disease problems might have been overlooked, for example due to authors' different perspectives, or because disease can be inconspicuous in the absence of diagnostic post-mortem or clinical examinations (e.g. Gabriel et al., 2015; Griffith et al., 1993), or due to suboptimal post-release monitoring (Berger-Tal et al., 2020). It can take years for disease problems to be detected in released populations (e.g. Sainsbury et al., 2008), and many case studies were published at a relatively early stage in their progress (Beckmann & Soorae, 2022). Failed translocations were probably under-represented in this case series (Godefroid et al., 2011; Miller et al., 2014), but are evidently the projects we would be likely to learn most lessons from. Further limitations in this data set included marked variation in the scale of projects, and taxonomic and geographical biases in the case series (Beckmann & Soorae, 2022) consistent with wider conservation translocation literature (Bajomi et al., 2010; Fischer & Lindenmayer, 2000). Taxon-specific patterns are explored further in the Supporting Information (Figure S1, Tables S4 and S5 and accompanying text).

5 | CONCLUSION

While disease problems may be less frequently reported relative to some other biological problems in conservation translocations, they cannot be overlooked and we provide supportive evidence for their association with project 'success'. Other ecological, environmental and anthropogenic problems appear to occur commonly post-release, with implicit negative impacts on health and welfare. In addition to mitigating disease risks to translocated animals or plants, and to other populations of animals, plants or humans linked to translocation, health management should aim to foster health in translocated individuals, given the apparent frequency of post-release problems. The work of the whole project team influences health outcomes, and holistic health management requires multi-disciplinary planning and management of translocation as a whole.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Katie Beckmann and Richard Kock conceived the study idea and methods. Geoff Hilton and John Ewen helped to refine the study aims and framing. Katie Beckmann collated and analysed the data, and led preparation of the manuscript, tables and figures. Pritpal Soorae edited the 'Global Reintroduction Perspectives' series from which data were extracted. All co-authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

The data set of information extracted from the 'Global Reintroduction Perspectives' case series has been published (Beckmann & Soorae, 2021, https://doi.org/10.7488/ds/3135) and is described in an accompanying data article (Beckmann & Soorae, 2022).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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