Invasive vertebrate eradications on islands as a tool for implementing global Sustainable Development Goals

Luz A de Wit1,2, Kelly M Zilliacus3, Paulo Quadri4, David Will5, Nelson Grima6, Dena Spatz7, Nick Holmes8, Bernie Tershy3, Gregg R Howald5 and Donald A Croll3

1Gund Institute for Environment, University of Vermont, Burlington, VT, USA; 2Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT, USA; 3Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA, USA; 4Sky Island Alliance, Tucson, AZ, USA; 5Island Conservation, Santa Cruz, CA, USA; 6Environmental Program, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT, USA; 7Pacific Rim Conservation, Honolulu, HI, USA and 8The Nature Conservancy, Santa Cruz, CA, USA

Summary

The United Nations 2030 Agenda for Sustainable Development sets a framework of universal Sustainable Development Goals (SDGs) to address challenges to society and the planet. Island invasive species eradications have well-documented benefits that clearly align with biodiversity conservation-related SDGs, yet the value of this conservation action for socioeconomic benefits is less clear. We examine the potential for island invasive vertebrate eradications to have ecological and socioeconomic benefits. Specifically, we examine: (1) how SDGs may have been achieved through past eradications; and (2) how planned future eradications align with SDGs and associated targets. We found invasive vertebrate eradication to align with 13 SDGs and 42 associated targets encompassing marine and terrestrial biodiversity conservation, promotion of local and global partnerships, economic development, climate change mitigation, human health and sanitation and sustainable production and consumption. Past eradications on 794 islands aligned with a median of 17 targets (range 13–38) by island. Potential future eradications on 292 highly biodiverse islands could align with a median of 25 SDG targets (range 15–39) by island. This analysis enables the global community to explicitly describe the contributions that invasive vertebrate management on islands can make towards implementing the global sustainable development agenda.

Introduction

Invasive species, particularly invasive vertebrates, have contributed to c. 60% of historical extinctions (Bellard et al. 2016, Doherty et al. 2016) and are the primary driver of extinctions on islands (Tershy et al. 2015, Bellard et al. 2016). They remain one of the main drivers of biodiversity loss, with well-documented negative impacts on terrestrial and marine biodiversity (Littnan et al. 2006, Doherty et al. 2016, Graham et al. 2018) and indirect impacts on ecosystem function (Peltzer et al. 2010, Beltran et al. 2014). The control and eradication of invasive species is a powerful conservation tool for biodiversity, particularly on islands where the eradication of invasive vertebrates has resulted in significant biodiversity benefits (Tershy et al. 2012, Jones et al. 2016, Brooke et al. 2018), yet understanding of how this conservation tool benefits people and the sustainability of economies is limited. It is well established that biodiversity and human well-being are linked (Diaz et al. 2018), including evidence that invasive vertebrates impact local economies and food security through crop damage, erosion and biodiversity losses, and some of these invasive vertebrates are also known to transmit zoonotic pathogens to island human residents (Stenseth et al. 2003, Doherty et al. 2016, de Wit et al. 2019). An analysis of these benefits is especially relevant for small island developing states (SIDS) and other islands with developing economies, many of which host some of the most globally important, threatened biodiversity.
Invasive predators such as rodents (Mus musculus, Rattus spp.), cats (Felis catus) and dogs (Canis familiaris) can directly decimate populations of seabird species (Towns et al. 2011) and indirectly reduce the input of nutrients (e.g., guano) into ecosystems (Graham et al. 2018). These nutrients are often important for terrestrial ecosystems, as well as for adjacent reefs and fish nurseries (Polis & Hurd 1996, Honig and Mahoney 2016, Graham et al. 2018). Through compaction, rooting and grazing, invasive ungulates such as goats (Capra hircus), sheep (Ovis aries), cows (Bos taurus) and pigs (Sus scrofa) alter soil structure and nutrient cycling dynamics, causing sediment and nutrient runoff from land to sea and subsequent terrestrial erosion and eutrophication and sedimentation of coastal marine ecosystems (Peltzer et al. 2010, Dunkell et al. 2011, Beltran et al. 2014). Similarly, invasive herbivores can reduce rates of carbon sequestration through the consumption of woody plants and seeds (Peltzer et al. 2010, Beltran et al. 2014), whereas invasive rodents can indirectly increase rates of aboveground carbon sequestration in islands with seabird populations (e.g., Wardle et al. 2007).

Invasive species can ultimately affect the ecosystem services or benefits that island communities derive from islands and adjacent coastal ecosystems, including fisheries, water purification and ecotourism (Pejchar & Mooney 2009, Mace et al. 2012). The tight links between ecosystem function, ecosystem services (Spangenberg et al. 2014, Hausknotn et al. 2017) and human well-being (MEA 2005) demonstrate how changes in ecosystem composition can quickly lead to effects on human societies. On islands, where the system boundaries are small and firmly defined, ecosystems are often simplified and vulnerable, and alternatives to substitute depleted or damaged resources are extremely limited (Deschenes & Chertow 2004, Chertow et al. 2013).

Invasive rodents, cats, dogs, pigs, raccoons (Procyon lotor) and macaques (Macaca spp.) are reservoirs of several zoonotic pathogens (Supplementary Information S1, available online, adapted from de Wit et al. 2017) (Cotruvo et al. 2000, Engel et al. 2002). Many of these pathogens lead to severe health implications for humans, particularly women and children (e.g., Toxoplasma gondii infection and toxocariasis), and especially people living in marginalized communities with limited access to healthcare and clean water (Torgerson & Mastroiacovo 2013, Torgerson et al. 2014). Such health impacts are particularly worrisome in developing economies such as SIDS and other small islands, where infectious diseases can feed into poverty traps by burdening families with treatment costs and loss of income, slowing down economic development and perpetuating unsustainable uses of ecosystem services (Bonds et al. 2010, Nonghala et al. 2017).

Negative impacts of invasive vertebrates can further extend to other areas of local economies, such as food production and storage. Due to their geographical isolation, many SIDS and low-income islands rely on subsistence agriculture or on imported food products that are often housed in inadequate storage facilities, rendering critical foods vulnerable to crop damage, contamination or consumption by invasive vertebrates through crop raids and food storage contamination (Stenseth et al. 2003, Engeman et al. 2010, Singleton et al. 2010). Similarly, many island economies rely on tourism activities, including visitation of natural heritage sites, native animal watching, diving, fishing and snorkelling, all of which can be directly or indirectly negatively affected by the presence or the impacts of invasive vertebrates (Beckman et al. 2014).

The United Nations (UN) 2030 Agenda for Sustainable Development includes 17 Sustainable Development Goals (SDGs) with 169 specific targets. These targets address global challenges such as improving ecosystems and the biodiversity they harbour, human health, education and economic growth (United Nations 2015). Here, we examine whether invasive vertebrate eradication can help build more resilient and sustainable island ecosystems and human communities and examine the potential for eradications to be achieved through international and local collaboration. We developed a framework to assess how the potential biodiversity and socioeconomic benefits of invasive vertebrate eradication align with the UN SDGs, and we use this framework to examine: (1) the SDGs that may have been achieved through past eradications; and (2) how planned future eradications align with SDGs and associated targets. We designed this research to direct future invasive vertebrate eradication efforts towards the sustainability of biodiversity and human communities on islands, some of Earth’s most biologically threatened and socio-ecologically vulnerable systems.

Materials and methods
We grouped the 17 SDGs into the following categories to better describe the socioeconomic, biodiversity and environmental impacts of invasive vertebrates: local economies (Economy: SDGs 1, 4, 8 and 9); peace, justice and equality (Peaceful Living: SDGs 5, 10 and 16); sustainable production and consumption (Sustainable Lifestyles: SDGs 2, 11 and 12); health and sanitation (Health: SDGs 3 and 6); climate change mitigation (Climate Action: SDGs 7 and 13); biodiversity conservation (Conservation: SDGs 14 and 15); and global partnerships (Partnerships for the Goals: SDG 17).

Literature review
We conducted a focused literature review aimed at examining how each of the 169 targets associated with the 17 SDGs could align with invasive vertebrate eradication on islands. We systematically searched Google Scholar for published literature on the socioeconomic and ecological impacts of invasive vertebrates. Our core search consisted of the terms ‘invasive’, OR ‘introduced’ AND ‘vertebrate herbivore’, OR ‘rodent’, OR ‘carnivore’, which are the most common groups of invasive vertebrate species (DIISE 2018), followed by terms associated with each of the SDGs (e.g., ‘agriculture’, ‘economic’, ‘ecotourism’, ‘health’, ‘zoonotic’, ‘neglected tropical disease’, ‘education’, ‘gender equality’, ‘gender inequality’, ‘water sanitation’, ‘water ecosystem’, ‘energy technology’, ‘job creation’, ‘income inequality’, ‘sustainable’, ‘climate change’, ‘carbon sequestration’, ‘marine pollution’, ‘coastal ecosystem’, ‘fisheries’, ‘biodiversity’, ‘conservation ecosystem’, ‘ecosystem service’, ‘peace’, ‘justice’ and ‘international collaboration’). We included articles focused on invasive vertebrates regardless of whether the invasive vertebrate had a positive or negative socioeconomic effect and/or ecological impact. For more extensive reviews on the negative impacts of invasive species on islands, see Medina et al. (2011), Doherty et al. (2016) and Spatz et al. (2017). We included studies regardless of whether the focus was on islands or mainland areas. This non-exhaustive search yielded 140 studies, of which we used 103 reviews and reports, as well as observational and experimental studies that suggested a negative impact of invasive vertebrates on socioeconomic or ecological factors, and which could be linked with the SDG targets (Supplementary Information S2).

Decision tree
To examine how past and future eradications align with SDGs and their associated targets, we used our literature review of invasive vertebrate impacts to inform a decision tree approach to assigning

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potential benefits of invasive eradication for each SDG and their associated targets (Supplementary Information S3). Each decision tree contains a set of inclusion criteria based upon the presence of at least one invasive vertebrate and how eradication benefits related to specific SDGs depended upon invasive vertebrate-specific traits such as trophic level (i.e., herbivore, omnivore, carnivore) or zoonotic disease reservoir (Table 1). In addition, we included island-specific traits where necessary to evaluate a potential link to SDG targets, including presence of humans, presence of agriculture, established tourism and whether an island was classified as a SIDS or if a proportion of the population lived below the international poverty line (Table 1).

**Past and potential future eradication islands**

Using the Database of Island Invasive Species Eradications (DIISE 2018), we applied each decision tree to successful, whole-island invasive vertebrate eradications without reinvasion and with potential benefits from future invasive vertebrate eradications, following recommendations for data use in Holmes et al. (2019a). In order to evaluate the potential benefits from future invasive vertebrate eradications, we applied our decision trees to globally important islands identified by Holmes et al. (2019b), where the eradication of invasive vertebrates could significantly reduce the risk of extinction to the world’s most threatened biodiversity (species classified as Critically Endangered or Endangered on the IUCN Red List), by concentrating eradication efforts on a small number of islands. Specifically, Holmes et al. (2019b) used threatened species extinction risk and irreplaceability, severity of impact from invasive species and technical and socio-political feasibility of eradication to identify 169 islands where invasive mammal eradication planning or operation could be initiated by 2020 (107 islands), or 2030 (62 islands) to increase survival prospects of globally threatened vertebrates. In addition, the study identified 49 islands where eradication was not feasible in the foreseeable future, as well as 74 additional islands where the authors did not receive expert opinion on the socio-political feasibility of eradication (Holmes et al. 2019b). In total, we included all 292 islands identified by Holmes et al. (2019b) in our analysis. We included islands in which eradication is currently not feasible to describe the potential sustainable development benefits on islands where future technology is needed to achieve eradication. We designated the eradication of an invasive vertebrate as being in alignment with meeting an SDG if at least one of the associated targets benefitted from this conservation action.

Given the limited socioeconomic information available for most of the identified islands, we made some assumptions for all islands for several inclusion criteria (Supplementary Information S3). We used the DIISE (DIISE 2018) and the Threatened Island Biodiversity Database (TIB; Threatened Island Biodiversity Database Partners 2019) to obtain information on the presence of humans as described in Spatz et al. (2017), and we considered an island inhabited if at least one person was present. The TIB and DIISE also described the type of human habitation present on the island as either permanent community, seasonal community, military, research station, multiple, none or unknown based on available information. Using the Poverty and Equity Data Portal of the World Bank and the international poverty threshold of US$1.90 day⁻¹ (2011 purchasing power parity) established by this organization (World Bank Group 2019), we classified islands as having some proportion of the population living below the international poverty line if any percentage of the population of a country an island was part of lived at or at less than this threshold. However, this list does not include poverty data for developed countries; thus, we assumed developed countries have 0% living below the absolute poverty threshold. We also excluded islands from developing countries for which country-level poverty data were unavailable. In addition, we excluded islands that

### Table 1. Summary of invasive vertebrate and island-specific traits used to define the inclusion criteria for aligning eradication benefits with the United Nations Sustainable Development Goals (SDGs).

| SDG narrative          | Invasive vertebrate traits                                      | Island traits                |
|------------------------|-----------------------------------------------------------------|------------------------------|
| **Biodiversity** (SDG 14, 15) | Impacts native species | Elevation                      |
|                        | Impacts fisheries species |                              |
|                        | Impacts marine nutrient input | Small island developing state |
| **Global Partnerships** (SDG 17) | Impacts native species | Small island developing state |
|                        | Impacts fisheries species |                              |
|                        | Impacts marine nutrient input |                              |
|                        | Zoonotic reservoir |                              |
|                        | Impacts watersheds |                              |
|                        | Impacts agriculture |                              |
|                        | Impacts food sources |                              |
|                        | Impacts food storage |                              |
|                        | Impacts vegetation |                              |
|                        | Impacts ecosystem resilience |                              |
| **Local Economies** (SDG 1, 4, 8, 9) | Impacts quality of tourism experience | Human habitation |
|                        | Impacts natural heritage | Agriculture                  |
|                        | Zoonotic reservoir | Tourism                       |
|                        | Impacts fisheries species | Small island developing state |
|                        | Impacts agriculture | Population living under the international poverty line |
|                        | Impacts vegetation |                              |
|                        | Impacts quality of tourism experience |                              |
| **Climate Change** (SDG 13) | Impacts vegetation |                              |
|                        | Impacts ecosystem resilience |                              |
| **Health and Sanitation** (SDG 3, 6) | Zoonotic reservoir | Human habitation |
|                        | Impacts watersheds | Agriculture                  |
| **Sustainable Production** (SDG 2, 11, 12) | Impacts natural heritage |                              |
|                        | Impacts food sources |                              |
|                        | Impacts food storage |                              |

### Table 2. Socioeconomic characteristics of past and future human-inhabited eradication islands.

|                     | Number of small island developing states | Number of islands with people living below the international poverty line | Number of islands with agriculture present |
|---------------------|------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------|
| **Past eradications** – 121 total islands | 22                                       | 83                                                                       | 13                                         |
| **Future eradications** – 146 islands     | 25                                       | 59                                                                       | 62                                         |

*Based on any percentage of the population living at equal to or less than US$1.90 per day as established by the World Bank; islands with no data were excluded from analyses, as well as islands with research or military stations (14 past eradication islands and 25 future eradication islands).
exclusively held research or military stations if the island belonged to a country that crossed the poverty threshold. We classified islands as SIDS based on the UN classification of the island’s home country (United Nations 2019), regardless of whether the island was a UN Member or Associate Member. To establish whether agriculture was present on human-inhabited islands, we used Google Earth imagery to survey entire islands for visible agricultural plots at an eye altitude of c. 8 km. We defined agricultural plots as human-made and geometrically distinguishable areas with barren soil or vegetation growing in defined rows (e.g., uniform lines of vegetation or sharp boundaries between native vegetation and crops), and we confirmed them at an eye elevation of c. 1.5 km. We assumed an invasive vertebrate impacted human health if the invasive vertebrate species is an identified zoonotic disease reservoir (i.e., rodents, cats, dogs, pigs, raccoons and macaques) (Supplementary Information S1). To establish whether an island has tourism, we performed a Google search (in English) using each island’s name or archipelago followed by the terms ‘tourism’, ‘tours’, ‘visits’, ‘dive’, ‘diving’, ‘snorkelling’, ‘fishing’ and ‘bird watching’. We determined tourism to be present if at least one search indicated that any of the above forms of tourism were present. The tourism activities identified in our search may exist on some islands, but not all, and may underestimate the outcome of whether tourism does occur on the island. We also assumed that all invasive vertebrate eradications are associated with an improvement in the quality of education through the involvement of island-scale. See Supplementary Information S3 for a detailed list of assumptions made for each inclusion criterion.

### Results

Of the 17 UN SDGs and 169 associated targets, we found the benefits of invasive vertebrate eradication to align with 13 SDGs and 42 associated targets (Supplementary Information S2). Aligned SDGs include: Goal 1, No Poverty; Goal 2, Zero Hunger; Goal 3, Good Health and Well-Being; Goal 4, Quality Education; Goal 6, Clean Water and Sanitation; Goal 8, Decent Work and Economic Growth; Goal 9, Technology and Innovation; Goal 11, Sustainable Cities and Communities; Goal 12, Responsible Consumption and Production; Goal 13, Climate Action; Goal 14, Life below Water; Goal 15, Life on Land; and Goal 17, Partnerships for the Goals.

We found no clear connection between invasive vertebrate eradication and Goals 5 (Gender Equality), 7 (Affordable and Clean Energy), 10 (Reduced Inequalities) and 16 (Peace, Justice and Strong Institutions). Eradications aligned with the following categories: biodiversity conservation (Conservation: SDGs 14 and 15), global partnerships (Partnerships for the Goals: SDG 17), climate change mitigation (Climate Action: SDG 13), local economies (Economy: SDGs 1, 4, 8 and 9), health and sanitation (Health: SDGs 3 and 6) and sustainable production and consumption (Sustainable Lifestyles: SDGs 2, 11 and 12).

We analysed 794 islands (Supplementary Information S4) where invasive vertebrates have been eradicated and 292 islands (Supplementary Information S5) where future invasive vertebrate eradication is a priority for biodiversity conservation based on Holmes et al. (2019b). We identified 58 unique invasive vertebrate species targeted for eradication (Supplementary Information S6). Forty-four of these species are mammals, including 14 ungulate species, 11 carnivores, 9 rodents, 4 marsupials, 3 lagomorphs, 2 procyonids and 1 primate; the remaining 12 species are non-carnivorous birds, reptiles and amphibians (Supplementary Information S6). Of the 794 islands with past eradications, 121 had confirmed human habitation. From these 121 islands, 18% are classified as SIDS, 21% are classified as having populations living at or below the international poverty line and agriculture was identified on 11% of islands (Table 2). In addition, tourism is present on 76% (602) of the 794 islands. For future eradications on islands identified by Holmes et al. (2019b), 146 have confirmed human habitation, of which 57% are SIDS, 40% are classified as having populations living at or below the international poverty line and agriculture is present on 50% of islands (Table 2). In addition, tourism is present on 89% (259) of the 292 islands identified by Holmes et al. (2019b).

| Island, territory | Invasive species | Total goals | Total targets | Eradication timeframe |
|-------------------|------------------|-------------|---------------|-----------------------|
| Nioufou, Tonga    | Dog, cat, Polynesian rat, pig | 13          | 38            | Future                |
| Denis, Seychelles | Black rat, common myna, cat, house mouse | 13          | 38            | Past                  |
| Floreana, Ecuador | Future: cow, dog, horse, cat, house mouse, black rat | 13          | 36            | Future                |
| Robinson Crusoe, Chile | Past: donkey, goat, pig | 13          | 36            | Past                  |
| Nanuya Levu, Fiji | Cat, black rat | 13          | 34            | Future                |
| San Esteban, Mexico | Black rat | 12          | 39            | Future                |
| Canton, Kiribati  | Cat, Polynesian and black rats | 12          | 37            | Future                |
| Alejandro Selkirk, Chile | Cow, goat, cat, house mouse, brown and black rats | 12          | 36            | Future                |
| Guadalupe, Mexico | Cat, house mouse | 12          | 34            | Future                |
| Chincha Norte, Peru | Cat, rat | 12          | 34            | Future                |
| Denis, Seychelles | Black rat, common myna, cat, house mouse | 12          | 38            | Past                  |
| Fregate, Seychelles | Brown rat, common myna, cat, house mouse | 12          | 34            | Past                  |
| Grande Soeur, Seychelles | Barn owl, black rat, cat | 12          | 34            | Past                  |
| Natividad, Mexico | Cat, dog, sheep, goat | 12          | 34            | Past                  |
| Chumbe, Tanzania  | Black rat | 12          | 32            | Past                  |
| Sangalaki, Indonesia | Black rat | 12          | 32            | Past                  |
| Lana’S, United States | Sheep, goat, pig | 12          | 32            | Past                  |

### Table 3. Islands where past and future invasive vertebrate eradication align with the most Sustainable Development Goals and targets.
Information S5). Of the 19 islands where past and future eradica-
tions aligned with most SDG targets, rodents were the invasive ver-
terbrate most commonly targeted for eradication (84%), followed
by domestic cats (79%) (Table 3). Based on the categories described
above, local economies were associated with invasive vertebrate
eradications through country and island residents being trained

| UN Sustainable Development Goals | Past eradications, n = 794 (%) | Future eradications, n = 292 (%) |
|---------------------------------|---------------------------------|---------------------------------|
| 1. Poverty                      | 17 (2.1)                        | 57 (21.3)                       |
| 2. Hunger                       | 7 (0.88)                        | 43 (14.73)                      |
| 3. Health                       | 79 (9.9)                        | 142 (48.6)                      |
| 4. Education                    | 32 (4)                          | 100 (34.2)                      |
| 5. Technical and vocational em-
ployments                          | 794 (100)                       | 292 (100)                       |
| 6. Drinking water (6.1, 6.3)    | 107 (13.5)                      | 146 (50)                        |
| 7. Water-related ecosystems (6.6) | 95 (11.9)                      | 134 (45.9)                      |
| 8. Sustainable tourism (8.9)    | 597 (75.2)                      | 256 (87.7)                      |
| 9. Sustainable industry, tech-
nological innovation (9.4)       | 96 (12.1)                      | 53 (18.2)                       |
| 10. Scientific research for 
technology innovation (9.5)     | 794 (100)                      | 292 (100)                       |
| 11. Natural heritage sites (11.4) | 116 (14.6)                  | 144 (49.3)                      |
| 12. Food waste (12.3)           | 58 (7.3)                        | 93 (31.8)                       |
| 13. Harmony with nature (12.8)  | 121 (15.2)                      | 146 (50)                        |
| 14. Adaptive capacity to climate change (13.a) | 188 (23.7) | 96 (32.9) |
| 15. Climate change policy (13.1) | 474 (59.7)                  | 167 (57.2)                      |
| 16. Climate change mitigation (13.2) | 662 (83.4)             | 263 (90.1)                      |
| 17. Marine pollution (14.1)     | 786 (98.9)                      | 292 (100)                       |
| 18. Coastal ecosystems (14.2, 14.5) | 794 (100)                  | 292 (100)                       |
| 19. Bycatch regulation (14.4)   | 101 (12.7)                      | 56 (19.2)                       |
| 20. Sustainable fisheries man-
agement (14.7)                    | 171 (21.5)                      | 170 (58.2)                      |
| 21. Conservation of terrestrial ecosystems (15.1, 15.2, 15.3, 15.5, 15.8, 15.9, 15.a, 15.b) | 794 (100)                  | 292 (100)                       |
| 22. Conservation of mountain ecosystems (15.4) | 91 (11.5)                  | 47 (16.1)                       |
| 23. International cooperation (17.6) | 158 (19.9)              | 211 (72.2)                      |
| 24. Capacity building and tech-
nology transfer (17.7)            | 158 (19.9)                      | 211 (72.2)                      |
| 25. Multi-stakeholder partnerships (17.16) | 794 (100)                  | 292 (100)                       |

* Islands with no data were excluded from analyses, as well as islands with research or military stations (14 past eradication islands and 25 future eradication islands).

![Eradication Graph](https://www.cambridge.org/core).
invasive vertebrate management and monitoring techniques on all islands with past and future eradications, and these were associated with 75% and 88% of islands, respectively, through improvements in tourism opportunities (Fig. 1 & Table 4). Invasive vertebrate eradications aligned with SDGs and associated targets that promote sustainable lifestyles on 15% of past eradication islands and 50% of future eradication islands through the elimination of impacts to local food sources and food storage and through harmony with nature (Table 4). Human health and clean water sanitation were associated with invasive vertebrate eradication on 13.5% and 50.0% of islands with past and future eradications, respectively, through elimination of zoonotic disease reservoirs and through reduced impacts of herbivores on watersheds (Table 4). A total of 83% of past and 90% of future invasive vertebrate eradications were associated with climate change through the elimination of the impacts of invasive herbivores on vegetation and potential net-positive effects on rates of carbon sequestration (Table 4). All invasive vertebrate eradications (past and future) were associated with biodiversity conservation through elimination of invasive vertebrate impacts on terrestrial ecosystems and native species and through elimination of invasive vertebrate impacts on coastal ecosystems (Table 4). All past and future eradications enhance international partnerships, mostly through capacity building and the transfer of invasive vertebrate eradication and monitoring technologies between developed and developing countries (Table 4).

Discussion
We used the UN SDGs to analyse potential biodiversity, socioeconomic and ecological benefits of past and potential future invasive vertebrate eradications on 1086 islands worldwide. Despite being conducted for biodiversity conservation outcomes, we found that eradication of invasive vertebrates from islands contributed directly to the SDGs, aligning with multiple goals and associated targets and encompassing categories that include biodiversity conservation, global partnerships, climate change mitigation, local economies, health and sanitation and sustainable production and consumption. Inclusion of these broader categories can improve individual project evaluation and expand funding opportunities, presenting new opportunities for cross-sector collaboration.

Overall, past eradications aligned with proportionally fewer SDGs and associated targets than potential future eradications. This is mostly because more than half of the SDG decision trees...
included human habitation as a requisite element of our selection criteria (Supplementary Information S3), and 85% of past eradication primarily occurred on uninhabited islands. On islands with human habitation, eradication of invasive herbivores, rodents or cats aligned with the highest number of SDGs and associated targets through the elimination of impacts on local food sources, food storage and zoonotic disease reservoirs and reduced impacts to watersheds. In most cases, these inhabited islands harboured multiple invasive species, the potential impacts of which on island communities could overlap. However, we did not seek to differentiate the benefits of removing a single versus multiple invasive species.

**Box 2. Human health benefits of cat eradication.**

The majority of islands do not harbour native cats, and invasive cats (*Felis catus*) are the sole reservoirs of the zoonotic parasite *Toxoplasma gondii* (Dubey 1998). Infection can cause miscarriage and severe ocular and neurological lesions in new-borns (Torgerson & Mastroiacovo 2013, Maenz et al. 2014, Ngô et al. 2017). Invasive cats were eradicated from Isla Natividad, Mexico, resulting in complete elimination of the sole reservoir of *T. gondii* on the island. Human health benefits of cat eradication on Natividad were assessed by measuring serological exposure (seroprevalence) to *T. gondii*, and the results show that seroprevalence was significantly lower on Natividad compared to five other inhabited islands in the region where invasive cats were present (de Wit et al. 2019) (Box Fig. 2). Similarly, seroprevalence of children born after cats were eradicated was 0% and significantly lower than in children of the same age group from the three islands with cats that had comparable sample sizes. Invasive cats have been eradicated from 30 human-inhabited islands globally, and their eradication is feasible on another 40 islands (Holmes et al. 2019b) (Supplementary Information S4 & S5). Invasive vertebrate eradication can have tangible human health benefits, particularly if the invasive vertebrate target is a zoonotic pathogen reservoir. Island inhabitants can further benefit from these eradications if health services and infrastructure on the island are limited and if the consequences of the disease result in unsustainable costs associated with diagnosis, treatment and labour disability.

**Box 3. Agricultural and economic impacts of invasive macaques.**

The socioeconomic impacts of non-native non-hominid primates such as macaques (*Macaca fascicularis*) have been documented on several islands (Engeman et al. 2010, Jones et al. 2018). Aside from the potential for macaques to transmit zoonotic pathogens (e.g., Cercopithecine herpesvirus 1-B virus) (Engel et al. 2002, Huff & Barry 2003) and engage in violent behaviour against people (mostly children), macaques are known to take advantage of food sources from agriculture (Jones et al. 2018). In Puerto Rico, the economic losses on commercial farms caused by crop raiding from non-native non-hominid primates have reached up to US$1.46 million per year (Engeman et al. 2010). On Angaur Island, Palau, macaques raid fruit crops, causing significant economic and social impacts, as well as exacerbation of gender inequalities, as management of these crops is one of the main economic activities for women on the island (McGregor & Bishop 2011). As a consequence, macaques on Angaur Island are currently a target for eradication for multiple purposes, including biodiversity conservation, food security and gender and income equality (McGregor & Bishop 2011).
and indirect impacts of invasive herbivores, rodents and cats on island communities could catalyse partnership opportunities for entities interested in socioeconomic and ecological sustainability development.

Although past eradications were implemented with the aim of protecting island native species (i.e., biodiversity conservation), most eradications also aligned with benefits beyond biodiversity conservation. These non-biodiversity benefits were principally concentrated in SDGs focused on local economies, global partnerships and climate change through the training and capacity building of eradication techniques and monitoring, improvements in tourism opportunities and elimination of impacts on vegetation (Box 1). However, a small number of past eradications (15%) were also associated with SDGs aligned with sustainable production and consumption and health and sanitation, suggesting that invasive vertebrate eradications probably benefited the livelihoods of island communities (Box 2). Importantly, while past eradications were focused on protecting the world’s most threatened biodiversity, future eradications aligned more consistently with SDGs related to sustainable production and consumption and health and sanitation than past eradications, despite being focused on protecting the world’s most threatened biodiversity. This implies that even with a significant biodiversity focus, invasive species eradications provide genuine opportunities to provide ecological and socioeconomic benefits (Box 3). Thus, the eradication of invasive species from islands provides opportunities for scalable cross-sector sustainability development.

The socioeconomic consequences of invasive vertebrate eradication should be considered on an island-by-island basis, since there may be benefits derived from the presence of invasive species to island inhabitants. For example, local inhabitants on some islands hunt invasive herbivores such as goats, sheep, cows and pigs for food, or as part of their culture (Pejchar & Mooney 2009). Therefore, eradication of these species could substantially limit access to important food sources. The eradication of invasive predators (e.g., cats) can result in changes in rodent population dynamics (Rayner et al. 2007), potentially impacting food production and storage and the transmission dynamics of rodent-borne diseases. Eradication of certain invasive vertebrates such as non-hominid primates can affect the tourism industry on islands, as these species can be tourist attractions (Serio-Silva 2006). Evaluating all of the potential positive and negative consequences of invasive vertebrate eradication and incorporating them into feasibility assessments of invasive vertebrate management will dictate the applicability of this conservation tool to additional areas of sustainable development.

Our study demonstrates that past and future invasive vertebrate eradications create multiple socioeconomic and ecological benefits and highlights the potential for invasive vertebrate eradication to be used as an effective sustainable development tool for island communities and ecosystems. Although our results are based on multiple assumptions due to the limited availability of specific and accurate socioeconomic data for most islands (e.g., poverty, agriculture, tourism, ownership, resource use), there is growing interest, beyond biodiversity conservation, in the impacts of invasive vertebrates on local communities (Pejchar & Mooney 2009, Shackleton et al. 2019). Additional research, focused upon specific islands, is needed in order to more explicitly assign potential economic, human health and social outcomes from conservation actions such as invasive vertebrate eradication. Unlike many conservation and social interventions, invasive vertebrate eradication is usually a one-time intervention conducted over short timeframes that can simultaneously result in the implementation of sustainable food production and consumption systems, improvements in human health and water quality, generation of employment and opportunities for climate change mitigation. Thus, ongoing or long-term investment in intervention is not necessary, and benefits can be realized over relatively short timeframes (Jones et al. 2016). These potential outcomes of invasive vertebrate eradication are particularly important for SIDS and other developing islands that are vulnerable to economic and environmental instability. Our study enables the incorporation of economic development and human health and well-being into the narrative and rationale for invasive vertebrate management, while offering an effective tool for working towards the achievement of the UN 2030 Sustainable Development Agenda.

Invasive vertebrate eradications can have far-reaching and mutual benefits for biodiversity and the human communities that rely on islands. Eradication of invasive vertebrates can serve as a nature-based solution for countries to help meet their contributions to the UN SDGs. In addition, because islands are particularly vulnerable to the impacts of climate change, vertebrate eradications can enhance much-needed island resilience (Spatz et al. 2017). By evaluating the ability of eradication projects to promote human well-being and biodiversity conservation, we hope to promote focused investment and innovation in insular vertebrate eradications, so that future eradication efforts can be adjusted in scope and scale to best support the SDGs of improved health and well-being, economic development, environmental restoration and the future of life on Earth.

**Supplementary material.** To view supplementary material for this article, please visit [https://doi.org/10.1017/S0376892920000211](https://doi.org/10.1017/S0376892920000211)

**Acknowledgements.** The authors would like to thank Jamie Bechtel, Hazel Thornton, Lauren Weatherdon and Holly Brooks for their insightful comments.

**Financial support.** This work was supported by a grant from the Willow Grove Foundation and Charities Aid Foundation Canada. LA&IW would like to thank the Gund Institute for Environment for institutional support.

**Conflict of interest.** None.

**Ethical standards.** None.

**References**

Beckman M, Hill KE, Farnworth MJ, Bolwell CG, Bridges J, Acke E (2014) Tourists’ perceptions of the free-roaming dog population in Samoa. *Animals* 4: 599–611.

Bellard C, Cassey P, Blackburn TM (2016) Alien species as a driver of recent extinctions. *Biological Letters* 12: 20150623.

Beltran RS, Kreidler N, Van Vuren DH, Morrison SA, Zavaleta ES, Newton K et al. (2014) Passive recovery of vegetation after herbivore eradication on Santa Cruz Island, California. *Restoration Ecology* 22: 790–797.

Bonds MH, Keenan DC, Rohani P, Sachs JD (2010) Poverty trap formed by the ecology of infectious diseases. *Proceedings of the Royal Society B: Biological Sciences* 277: 1185–1192.

Bowen I, Van Vuren D (1997) Insular endemic plants lack defenses against herbivores. *Conservation Biology* 11: 1249–1254.

Brooke MdeL, Bonnau E, Dilley BJ, Flint EN, Holmes ND, Jones HP et al. (2018) Seabird population changes following mammal eradications on islands. *Animal Conservation* 21: 3–12.

Chertow M, Fugate E, Ashton W (2013) The intimacy of human–nature interactions on islands. In: *Long Term Socio-Ecological Research*, eds SJ Singh, H Haberl, M Chertow, M Mirtl, M Schmid, pp. 315–337. Dordrecht, The Netherlands: Springer.
Cotruvo JA, Dufour A, Rees G, Barton J, Carr R, Cliver DO et al. (2000) Waterborne Zoonoses: Identification, Causes and Control. Geneva, Switzerland: WHO Press.

Cromarty PL, Broome KG, Cox A, Empson RA, Hutchinson WM, McFadden I (2002) Eradication planning for invasive alien animal species on islands – the approach developed by the New Zealand Department of Conservation. In: *Turning the Tide: The Eradication of Invasive Species*, eds CR Veitch, MN Clout, pp. 85–91. Gland, Switzerland and Cambridge, UK: IUCN SSC Invasive Species Specialist Group.

de Wit LA, Croll D, Tershy B, Correa D, Luna-Pasten H, Quadri P, Kilpatrick AM (2019) Potential public health benefits of cat eradications on islands. *PLoS Neglected Tropical Diseases* 13: e0007040.

de Wit LA, Croll DA, Tershy B, Newton KM, Spatz DR, Holmes ND, Kilpatrick AM (2017) Estimating burdens of neglected tropical zoonotic diseases on islands with introduced mammals. *American Journal of Tropical Medicine and Hygiene* 96: 749–757.

Deschenes PJ, Chertow M (2004) An island approach to industrial ecology: towards sustainability in the island context. *Journal of Environmental Planning and Management* 47: 201–217.

Díaz S, Pascual U, Stenseke M, Martín-López B, Watson RT, Molnár Z et al. (2018) Assessing nature’s contributions to people. *Science* 359: 270–272.

DISE (2018) The Database of Island Invasive Species Eradication, developed by Island Conservation, Coastal Conservation Action Laboratory UCSC, IUCN SSC Invasive Species Specialist Group, University of Auckland and Landcare Research New Zealand [www document]. URL http://dise.islandconservation.org

Doherty TS, Glen AS, Nimmo DG, Ritchie EG, Dickman CR (2016) Invasive predators and global biodiversity loss. *Proceedings of the National Academy of Sciences of the United States of America* 113: 11261–11265.

Dubey JP (1998) Advances in the life cycle of *Toxoplasma gondii*. *Journal of Parasitology* 84: 1019–1024.

Dunkell DO, Bruland GL, Evensen CI, Litton CM (2011) Runoff, sediment transport, and effects of feral pig (*Sus scrofa*) exclusion in a forested Hawaiian watershed. *Pacific Science* 65: 173–194.

Engel GA, Jones-Egel L, Schillaci MA, Suaryana KG, Putra A, Fuentes A, Henkel R (2002) Human exposure to herpesvirus B-seropositive macaques, Bali, Indonesia. *Emerging Infectious Diseases* 8: 788–795.

Engeman RM, Laborde JE, Constantin BU, Stiwill SA, Hall P, Duffiney A, Glen AS, Atkinson R, Campbell KJ, Hagen E, Holmes ND, Keitt BS et al. (2013) The political dimensions of Payments Engeman RM, Laborde JE, Constantin BU, Shwiff SA, Hall P, Duffiney A, Glen AS, Atkinson R, Campbell KJ, Hagen E, Holmes ND, Keitt BS et al. (2009) A global assessment of endemic and species richness across island and mainland regions. *Proceedings of the National Academy of Sciences of the United States of America* 106: 9322–9327.

Littnan CL, Stewart BS, Yochem PK, Braun R (2006) Survey for selected pathogens and evaluation of disease risk factors for endangered Hawaiian monk seals in the main Hawaiian islands. *EcoHealth* 3: 232–244.

Mace GM, Norris K, Fitter AH (2012) Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology and Evolution* 27: 19–26.

Maenaz M, Schlüter D, Liesenfeld O, Schares G, Gross U, Pleyer U (2014) Ocular toxoplasmosis past, present and new aspects of an old disease. *Progress in Retinal and Eye Research* 39: 77–106.

McGregor AM, Bishop RV (2011) A technical assessment of the current agricultural conditions of Angaur Island Palau: with recommendations for the sustainable use of the island’s natural resources [www document]. URL https://www.sprep.org/attachments/UtilLib/Palau/technical-assessment-current-agricultural-conditions-angaur-island-Palau.pdf

MEA (2005) *Ecosystems and Human Well-Being: Synthesis*. Washington, DC, USA: Millennium Ecosystem Assessment.

Medina FM, Bonnaud E, Vidal E, Tershy BR, Zavaleta ES, Josi Donlan C et al. (2011) A global review of the impacts of invasive cats on island endangered vertebrates. *Global Change Biology* 17: 3503–3510.

Ngø HM, Zhou Y, Lorenzi H, Wang K, Kim TK, Zhou Y et al. (2017) Toxoplasma modulates signature pathways of human epilepsy, neurodegeneration and cancer. *Scientific Reports* 7: 1–32.

Nongchala CN, De Leo GA, Pascual MM, Keenan DC, Dobson AP, Bonds MH (2017) General ecological models for human subsistence, health and poverty. *Nature Ecology and Evolution* 1: 1153–1159.

Pejchar L, Mooney HA (2009) The impact of invasive alien species on ecosystem services and human well-being. *Trends in Ecology and Evolution* 24: 497–504.

Pelling M, Utito JI (2001) Small island developing states: natural disaster vulnerability and global change. *Global Environmental Change Part B: Environmental Hazards* 3: 49–62.

Peltzer DA, Allen RB, Lovett GM, Whitehead D, Wardle DA (2010) Effects of biological invasions on forest carbon sequestration. *Global Change Biology* 16: 732–746.

Polu GA, Harnd SD (1996) Linking marine and terrestrial food webs: allochthonous input from the ocean supports high secondary productivity on small islands and coastal land communities. *American Society of Naturalists* 147: 396–423.

Rayner MJ, Hauber ME, Imber MJ, Stamp RK, Clout MN (2007) Spatial heterogeneity of mesopredator release within an oceanic island system. *Proceedings of the National Academy of Sciences of the United States of America* 104: 20862–20865.

Reaser JK, Meyerson LA, Cronk Q, De Poorter M, Eldridge LG, Green E et al. (2007) Ecological and socioeconomic impacts of invasive alien species in island ecosystems. *Environmental Conservation* 34: 98–111.

Santo AR, Sorice MG, Donlan CJ, Franck CT, Anderson CB (2015) A human-centered approach to designing invasive species eradication programs on human-inhabited islands. *Global Environmental Change* 35: 289–298.

Seychvens R, Moomsen JH (2008) Tourism and poverty reduction: issues for small island states. *Tourism Geographies* 10: 22–41.

Sierra Silva JC (2006) Las Islas de los Chongos (the Monkey Islands): the economic impact of ecotourism in the Region of Los Tuxtlas, Veracruz, Mexico. *American Journal of Primatology* 68: 499–506.

Shackleton RT, Larson BMH, Novoa A, Richardson DM, Kull CA (2019) The human and social dimensions of invasion science and management. *Journal of Environmental Management* 229: 1–9.

Singleton GR, Belmain S, Brown PR, Aplin K, Htwe NM (2010) Impacts of rodent outbreak on food security in Asia. *Wildlife Research* 37: 355–359.

Spenenberg JH, Görg C, Truong DT, Tekken V, Bustamante JV, Settele J (2014) Provision of ecosystem services is determined by human agency, not ecosystem functions. Four case studies. *International Journal of Biodiversity Science, Ecosystem Services and Management* 10: 40–53.
Spatz DR, Zilliacus KM, Holmes ND, Butchart SHM, Genovesi P, Ceballos G et al. (2017) Globally threatened vertebrates on islands with invasive species. Science Advances 3: e1603080.

Stenseth NC, Leirs H, Skonhoft A, Davis SA, Pech RP, Andreassen HP et al. (2003) Mice and rats: the dynamics and bio-economics of agricultural rodent pests. Frontiers in Ecology and the Environment 1: 367–375.

Tershy BR, Croll DA, Newton KM (2012) Accomplishments and impact of the NGO, Island Conservation, over 15 years (1994–2009). Biodiversity and Conservation 21: 957–965.

Tershy BR, Shen KW, Newton KM, Holmes ND, Croll DA (2015) The importance of islands for the protection of biological and linguistic diversity. BioScience 65: 592–597.

United Nations (2015) Transforming our world: the 2030 Agenda for Sustainable Development. United Nations Sustainable development platform. Sustainable Development Goals: 1–40a [www document]. URL https://sustainabledevelopment.un.org/post2015/transformingourworld

Varnham K, Glass T, Stringer C (2011) Involving the community in rodent eradication on Tristan da Cunha. In: Island Invasives: Eradication and Management, eds CR Veitch, MN Clout, DR Towns, pp. 504–507. Gland, Switzerland: IUCN.

Torgerson PR, de Silva NR, Fèvre EM, Kasuga F, Rokni MB, Zhou XN et al. (2014) The global burden of foodborne parasitic diseases: an update. Trends in Parasitology 30: 20–26.

Tompsett JD, Zilliacus KM, Holmes ND, Butchart SHM, Genovesi P, Ceballos G et al. (2017) Globally threatened vertebrates on islands with invasive species. Science Advances 3: e1603080.

Wardle DA, Bellingham PJ, Fukami T, Mulder CPH (2007) Promotion of ecosystem carbon sequestration by invasive predators. Biology Letters 3: 479–482.

World Bank Group (2019) Poverty and Equity Data Portal [www document]. URL http://povertydata.worldbank.org/Poverty/Home