Tracking invasive species eradications on islands at a global scale

N.D. Holmes[1], B.S. Keitt[1], D.R. Spatz[1,2], D.J. Will[1], S. Hein[1], J.C. Russell[3], P. Genovesi[4], P.E. Cowan[5] and B.R. Tershy[2]

[1]Island Conservation, 2100 Delaware Avenue Suite 1, Santa Cruz California USA 95060. <nick.holmes@islandconservation.org>. [2]Coastal Conservation Action Laboratory, University of California at Santa Cruz, USA. [3]School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand. [4]ISPRA and Chair IUCN Invasive Species Specialist Group, Via V. Brancati 48, 00144, Rome, Italy. [5]Manaaki Whenua Landcare Research, PO Box 69040, Lincoln 7640, New Zealand.

Abstract Indicators for tracking conservation efforts at a global scale are rare but important tools for understanding trends and measuring progress towards global conservation targets. Eradication of invasive species from islands is an increasingly used conservation intervention in countries and territories around the world. With a goal of collating these efforts, the Database of Islands and Invasive Species Eradications (DIISE) holds records of the location, target species, year and outcome of invasive mammal and bird eradications on islands from around the world. The database is publicly available in Spanish and English, at <diise.islandconservation.org>, and represents a partnership between the University of California at Santa Cruz, University of Auckland, IUCN Invasive Species Specialist Group, Landcare Research and Island Conservation. The database holds records for more than 1,200 eradication attempts. This database will continue to be added to and evolve as new opportunities for its application arise; thus, we expect these numbers to change over time as new events are added and knowledge about existing events improves. Updating the DIISE relies on contributions from experts and reporting from island restoration activities. Here we present database history, parameter definitions and database considerations. We also highlight additional studies the underlying data have contributed to, including evaluating the native species benefit from invasive mammal eradications on islands, and global indices to track progress towards the Convention of Biological Diversity Aichi target 9 (Invasive Alien Species), that explicitly requires an increased effort of eradication of priority invasive species.

Keywords: database, eradication, global, invasive, islands, mammal

INTRODUCTION

Eradication of invasive species from islands is an increasingly used conservation intervention in countries and territories around the world. Indicators for tracking conservation efforts at a global scale are rare but important tools for understanding trends, and measuring progress towards global conservation targets (McGeoch, et al., 2010). The number of eradications of invasive species on islands is one response indicator that contributes to measuring such progress. The number of eradications of invasive species on islands is a particularly good metric as these events tend to take place over discrete periods of time, occur in clearly defined spatial areas, and have a clear measure of success or failure (Niemeijer & de Groot, 2008).

With a goal of collating these efforts, the Database of Islands and Invasive Species Eradications (DIISE) holds records of, at a minimum, the location, target species, year and outcome of invasive mammal and bird eradications on islands around the world. Data within the database focus on terrestrial vertebrate species, primarily mammals and birds. Fish eradications are not included, nor are plant or invertebrate eradications (but see Tobin, et al., 2014; Hoffmann, et al., 2016). As of 2016, the database holds records for more than 1,200 eradication attempts. The database is publicly available in Spanish and English, at <diise.islandconservation.org>, and represents an ongoing partnership between the University of California at Santa Cruz, University of Auckland, IUCN Invasive Species Specialist Group, Landcare Research and Island Conservation.

Here we present database history, parameter definitions and database considerations. During 2017, a major update to the data is underway with a goal of using the 2017 Island Invasives Conference as a venue to engage island restoration practitioners to help improve the dataset.

MATERIALS AND METHODS

Database history

The first synthesis of the database (then known as the Global Islands Invasive Vertebrate Eradication Database) was published in the proceedings of the Island Invasives: eradication and management conference in Auckland in 2010 (Keitt, et al., 2011). Data for this synthesis were gathered from published, grey and unpublished literature, with the majority of data from reviews of eradications for rodents (Howald, et al., 2007), goats (Campbell & Donlan, 2005) and cats (Nogales, et al., 2004; Campbell, et al., 2011). Following the conference, the database was shared with all of the attendees of the conference (240 topic experts from 20 countries) with the goals of checking facts and adding missing eradication events. Attendees were encouraged to share the database with their networks to help achieve these goals.

In 2013–2014 an update of the database was undertaken using additional review papers on invasive mice (MacKay, et al., 2007) and small Indian mongoose (Barun, et al., 2011), the two Island Invasives conference proceedings (Veitch & Clout, 2002; Veitch, et al., 2011), summaries of eradication on inhabited islands (Oppel, et al., 2011; Glen, et al., 2013) and regional summaries for New Zealand (Clout & Russell, 2006), Europe and overseas territories (Genovesi, 2005; Genovesi & Carnevali, 2011), USA and territories (Witmer & Fuller, 2011), Galapagos (Carrion, et al., 2011; Harper & Carrion, 2011; Phillips, et al., 2012), California Channel and north-western Baja California Islands (McChesney & Tershy, 1998), Mexico (Aguirre-Muñoz, et al., 2008; Aguirre-Muñoz, et al., 2011), Hawaii and Central Pacific (Hess & Jacobi, 2011), France and overseas territories (Lorvelec & Pascal, 2005) and Seychelles (Beaver & Mougal, 2009).

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Other resources reviewed include, but were not limited to, IUCN SSC Invasive Species Specialist Group Invasives listserv, Pacific Seabird Group listserv, Pacific Invasives Initiative listserv; new sites including Agreement for the Conservation of Albatrosses and Petrels <http://acap.aq/news>, Seychelles Island Foundation newsletter <http://www.sif.sc/index.php?langue=eng&rub=19>; industry sources including the Australian Invasive Animals Cooperative Research Centre <https://www.pestsmart.org.au/tag/invasive-animals-cooperative-research-centre/> and <https://invasives.com.au/about/our-legacy/>, Mediterranean Small Islands Initiative <http://initiative-pim.org/> and the Web of Science for the key words "island" and "eradication". Further, we were fortunate to benefit from communications with practitioners who maintain regularly updated databases for territories including the Falklands / Islas Malvinas (Falkland Islands Rat Eradication Register, S. Poncet pers. comm.), France and overseas territories (O. Lorvelec pers. comm.), Seychelles (G. Rocamura pers. comm.), and worldwide (J. Parkes pers. comm.). This effort also included an evaluation period where entries were cross-checked with experts, and review of emails sent to directly to database managers.

During 2017, a third update began, including review of regional assessments including Italy (Capizzi, et al., 2016), Australia (Gregory, et al., 2014), California (California Department of Fish and Wildlife (CDFW, 2015) and the Indian Ocean (Russell, et al., 2016). Additional listservs and new sites reviewed include the NZ Department of Conservation media <http://www.doc.govt.nz/news/media-releases/>, South Pacific Regional Environment Program media <http://www.sprep.org/news>, Pacific Invasives Learning Network soundbites <http://www.sprep.org/piln/soundbites-documents>, Battler resource base <https://piln.sprep.org/>, and BirdLife news <http://www.birdlife.org/news>. The keyword 'eradication' was used to search these sites, plus the word 'deratisation' for French language sites. This review is expected to continue through 2017 including an expert review to validate new or changed entries.

Parameter definitions

Keitt et al (2011) describe the general methods used to populate the DIISE for the first synthesis. Each eradication event is an attempt to eradicate an invasive vertebrate population from an island. Where multiple invasive species are eradicated from an island these are considered separate eradication events, even if using the same technique. Each eradication event has a unique identification number and can generally be identified by the combination of the key parameters of species removed + island + eradication end date + eradication status. Citations for each eradication event are recorded.

For the 2013–2014 update, the parameter definitions were expanded to also include data quality, primarily to classify how eradication events were verified for inclusion the database. We assessed the quality of data available for all eradication attempts within the database using criteria in Table 1. We encourage other users of DIISE data to use data classified as good or satisfactory data quality event only. We retain events classified as poor data quality in the online database in the hope others can help us further qualify or remove these events.

Each eradication event was linked to an island. Each island was given a unique ID based on the World Conservation Monitoring Centre (WCMC) Global Islands Database (GID) (Depraetere, 2007), a spatial dataset with 180,000 unique island locations of the world. Eradications on different islands were recorded as separate events, regardless of whether it was in the same archipelago or treated concurrently (e.g. Montebello islands in Western Australia). For coral atolls, if the project targeted individual motu these were treated as separate events and linked to individual motu accordingly. However, projects that occurred at the atoll scale were treated as one event. For islands that were not in the GID we allocated our own ID number and metadata. Locations were verified in Google Earth and corrected if necessary. Island names are standardised to the common proper noun within the larger country/territory, excluding frequently used words for 'island' (e.g. islets, rocks, etc.). Country or territory was based on International Standards Organization (ISO) 3166-1 alpha-2 codes. In 2016, the DIISE island locations were migrated to the GID2, a higher resolution product by WCMC that holds approximately 460,000 islands. Each polygon used for the DIISE was validated for island location and size against Google Earth and other satellite imagery.

Each invasive species has a unique ID code, and the common name, scientific name, family, trophic level (omnivore, herbivore, carnivore), and nominate type [amphibian, flying bird; non-flying bird; rodents (*Mus*); rodents (*Rattus*); cat; dogs or foxes, mongooses or weasels, rabbits or hares, reptiles (excluding snakes), snakes, ungulates, or other mammals] were recorded. Invasive species populations were either classified as feral, semi-feral, domestic, or a combination, with semi-feral defined as having some human care but not restricted in movement (e.g. fences).

We also sought to classify the eradication type, based upon the extent of the established invasive species population on the island and thus the scale of the operation necessary to achieve eradication. The aim of the database is to only include events where the goal was complete removal of an invasive species population from the island, and not removal from only part of an island such as fenced

Table 1 Data quality definitions

Data quality	Data quality definition
Good	We can verify the attempt; we have a copy of the primary reference (e.g. from a report, or peer reviewed publication) that details the effort, typically allowing us to populate almost all fields
Satisfactory	An expert practitioner has verified the event and/or we have limited information about an eradication but what we do have has come from a verifiable source (e.g. email from a reputable practitioner or cited in a review paper), and we can typically identify all of the following attributes: the island, end year (if applicable), invasive species type, eradication status, and primary eradication method
Poor	We cannot verify the attempt (conflicting information nor unverifiable resource) and/or we lack evidence for at least one of the following parameters: island, end year (if applicable), invasive animal type, eradication status, or primary eradication method
Unknown	The data quality has not yet been assessed for this event

areas (however, note we retain events where fences are used as a tool to achieve eradication at an island scale). We delineate whether the operation required treatment of the entire island, or only part of the island (restricted range), to achieve eradication of the invasive species population at the island scale. We also delineate between incursion responses and restricted range, whereby incursions represent operations to remove a recently arrived population prior to their spread across the island. If an incursion response fails, it is assumed a new eradication operation would be necessary. Although some incursion responses are recorded in the database, there is not a deliberate attempt to record every incursion response for each island because these may reflect a minor or ongoing management activity that may go unrecorded in the sources accessed. A classification of unknown is also used if it is unclear what the eradication type was, and this is also typically used where the cause of the extirpation of the invasive species population is unknown.

The timing of the eradication operation is typically based on the end date for the operation and is reported in years only. We considered eradication end date to be the year that major eradication operations ceased. This typically coincided with the end of hunting / trapping for ungulates and predators or the end of toxicant application (or other methods) for rodent projects. We note that monitoring required to determine if an operation was successful often occurs in years after the operation ending. The primary and secondary method of the eradication is collected, including disease, hunting, trapping, toxicant, other, or unknown. Where toxicant was used we sought to identify the baiting method, including aerial broadcast, bait station or bait piles, hand broadcast, unknown, or other, plus the toxicant compound used.

Eradication status is based on definitions in Table 2. When an eradication event is declared successful, the target invasive was removed from the entire island. We considered failures to be operational failures, i.e. the project did not successfully remove the entire invasive population. We considered reinvasion as separate to operational failure and recorded this separately. Reinvasion was defined as a previously successfully removed population becoming re-established back on the island. In the case of rodent eradications, reinvasion may also represent misdiagnosed failure (Russell, et al., 2010) but can be assessed through techniques such as genetic analyses, distance to potential source populations and the time elapsed between the eradication operation and subsequent rodent detections. When experts or source material indicated uncertainty about whether an invasive rodent population remains due to an operational failure or a reinvasion back onto the island, we assumed operational failure and classified data quality for the event as ‘poor’.

DISCUSSION

Collating the location, method, outcome and target animal for invasive vertebrate eradications on islands offers a unique opportunity to contribute to global indicators for conservation. Collating these data over time offers insight into the response of a state-pressure-response model (Niemeijer & de Groot, 2008). The DIISE dataset holds many characteristics identified as necessary for effective threat (i.e. pressure in the state-pressure-response model) databases at a global scale, including: being freely available, spatially explicit, inclusion of a measure of expert validation, and is updated in a reasonable timeframe (Joppa, et al., 2016). The DIISE can contribute towards measuring progress of Aichi Target 9 of the global Convention on Biological Diversity, whereby signatory parties (nations) are committed to controlling or eradicating priority invasive alien species by 2020 (Convention on Biological Diversity, 2011), and is being used for the Biodiversity Indicator Partnership accordingly <https://www.bipindicators.net/indicators/trends-in-invasive-alien-species-vertebrate-eradications>.

The collation of more than 1,000 different eradication events inevitably encounters challenges. Reconciling the area (ha) and location (latitude and longitude) of small islands targeted for invasive species eradications against global data layers, has presented challenges to maintaining accuracy. In general, relying on one dataset (the GID) provides consistency, and seeking to validate those locations with satellite or other imagery should improve rigour. For rodent eradications, there is the risk that some projects classified as successful but reinvaded were in fact misdiagnosed operational failures. The time

Table 2 Eradication status definitions.

Eradication status	Definition
Successful	The operation to eradicate the invasive was successful and confirmed
Failed	The eradication operation was completed (there is an end date) yet it failed to remove the entire invasive population. Operational failure (as opposed to reinvasion). For rodent eradications, if there was uncertainty about why the invasive population remained (failure versus reinvasion), we assumed operational failure and classified data quality as ‘poor’
To be confirmed	The eradication effort is complete, but the operation has yet to be "confirmed" as successful or failed. This stage is typical for rodent eradication operations, with confirmation monitoring occurring 1–2 years after the eradication operation has ended
In progress	Eradication operation is currently in progress at time of reporting
Planned	Eradication is being planned for the island at time of reporting. End year will be unknown accordingly
Incomplete	An eradication was started, but not followed through to completion
Trial or research only	The eradication was undertaken for trial or research purposes and the goal was to gain new knowledge, not eradicate invasive species
Unknown	Information does not allow allocation into one of the other mutually exclusive categories and an expert cannot do the same (e.g. unclear if an eradication took place or if the species "died out" naturally). Selection of this category will often be aligned with poor data quality
Unknown pre-status	Eradication was undertaken but the status of the invasive species was unclear beforehand. Typically undertaken for precautionary measures for rodent eradications

elapsed between the operation and invasion, and robust genetic analyses can confirm this classification (Russell, et al., 2010), but these may not be available on all projects, particularly islands that are not visited regularly, or for older projects where genetic tools were not available (Holmes, et al., 2015). In general, data in the DIISE rely on the eradication status provided by the practitioner. Including successful but reinvaded in data summaries may overestimate the success rate, but this can be mitigated by excluding those events. Similarly, outcomes of multiple adjacent islands that may function as a single eradication unit may skew success rates if they are treated as separate events. This can be accommodated for by selecting one representative island in that unit (e.g. see Holmes, et al., 2015).

Opportunities exist to improve and expand the schema and content of the DIISE. The DIISE is currently organised by island unit but currently does not link events based on operation (islands treated concurrently) or eradication unit (Abdelkrim, et al., 2005), whereby an invasive animal population may move freely between adjacent islands based on swimming or flying ability ('natural' reinvasion risk – Harris, et al., 2012). Most (98%) of the target animals in the DIISE are invasive mammals. A handful of bird eradications are recorded although they may require a different spatial organisational unit and consideration, particularly where entire archipelagos are invaded, and birds can move freely between islands. Some areas of the world may be under-represented in the database, including Small Island Developing States (Russell, et al., 2017) where resources to report outcomes may be scarcer, and the known lack of expert contacts in SE Asia, possibly reflecting a language barrier. More deliberate attempts to track these data may expand the dataset.

The DIISE dataset is freely available online, and requests for datasets to answer specific questions are responded to as best possible. There is a genuine resource cost to maintaining this data accessibility and a more significant investment required to undertake a major update. Thus, ensuring financial investment is key to maintaining this service. Despite the best of intentions, errors and omissions may occur in the dataset and, depending on the significance of the end goal users require the data for, additional validation of events in the DIISE may be warranted (e.g. Holmes, et al., 2015). A commonly sought-after use is summary statistics, for which we encourage those to check existing literature as they may already exist from sufficiently recent summaries (e.g. Russell & Holmes, 2015). For those seeking novel statistics not reported elsewhere, using only good or satisfactory data quality events is encouraged, as is being conscious of eradication type (whole island or restricted range). Events generating failure rates for rodents may need to consider that some reinvasion events may be misdiagnosed failures, and for events targeting species that have agricultural or domestic analogues (ungulates, dogs, cats), consideration may need to be given to whether domestic or feral populations are included. Using the data requires agreeing with a terms-of-use and checking with database managers is strongly encouraged to guide appropriate use of data.

Conservation databases provide a key role for informing decision making and assessing trends (e.g. the IUCN Red List) (Joppa, et al., 2016). At a project scale, data from the DIISE regularly features within feasibility assessments, by providing a comparison of proposed activities against past efforts. Data from the DIISE dataset has been used as a baseline to inform other conservation-based studies. Holmes, et al. (2015) and Russell & Holmes (2015) used the data to evaluate trends evident in why rodent eradication failed at higher rates in the tropics although note that predicting failure from operational covariates is not a panacea. Russell, et al. (2017) evaluated trends in where eradications occur, or may be under-reported, amongst different countries of the world. Importantly, recent efforts include Jones, et al. (2016) and Brooke, et al. (2017), who used validated DIISE data to explore biodiversity conservation outcomes, and seabird demographic response to invasive mammal eradications, respectively. Jones, et al. (2016) reported 596 populations of 236 native species on 181 islands benefiting after eradications. These types of studies are immensely valuable for measuring the true 'effect' (Kapos, et al., 2010) of eradication of invasive species on islands as a management action.

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