Chapter 10

Izabela Barata using a standard protocol to visually survey bromeligenous frogs in tropical mountains, Itambé, Brazil, to estimate occupancy for a long-term monitoring programme. © Michel Becheleni

Chapter 10

Surveys and monitoring: challenges in an age of rapid declines and discoveries

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Abstract

Surveys and monitoring are the core means of generating knowledge about the distributions, natural history, and conservation status of amphibians. In an age of rapid declines and discoveries across the globe, it is increasingly urgent that surveys and monitoring efforts are well-designed and linked to clear conservation goals. Here, we surveyed the amphibian conservation community and literature to review the state of the field and update recommendations for surveys and monitoring. Many of the advances of the past 15 years have been technological, including shrinking size and cost of hardware like data loggers and transmitters, which has enabled collection of vast amounts of data and required concomitant advances in analytical tools. Visual encounter surveys are still the most common field method for sampling amphibians, although use of eDNA and automated recorders have increased in recent years. There are new opportunities to couple field techniques with rigorous sampling frameworks and recent advances in analytical methods. Myriad knowledge gaps persist, however, including basic understanding of amphibian biodiversity and natural history in under-sampled regions like the Congo basin and in understudied groups, such as caecilians. Because many knowledge gaps exist and surveys are resource intensive, there is heightened need to apply decision science to prioritise limited resources available for surveying and monitoring. The links between surveys and monitoring and conservation outcomes can ultimately be strengthened by: **1)** defining clear conservation objectives for surveys and monitoring through a participatory process with stakeholders; **2)** using decision support frameworks to prioritise survey efforts; **3)** selecting the most appropriate combination of survey methods, monitoring framework, and analytical approach for the conservation objective; and **4)** effectively communicating survey and monitoring results to decision-makers. Finally, **5)** by leveraging new methods, technologies, and funding mechanisms, scientists and practitioners can enhance the surveys and monitoring efforts that are essential to achieving amphibian conservation goals.

Introduction

Surveys and monitoring are the means by which we not only detect changes in species distributions and populations but also discover and rediscover species. Across the globe, environmental changes are causing rapid amphibian declines, while at the same time more than 100 new species are described every year (Catenazzi, 2015). Rapid declines and discoveries together compound the urgency and challenges of linking surveys and monitoring to effective amphibian conservation. The threats causing amphibian declines – including land use, climate change, and disease – vary geographically in both degree of intensity and overlap with other threats (Hof et al., 2011). Moreover, the diverse ecological traits of amphibians underlie considerable variation in species' sensitivity to threats (Lips, Reeve & Witters, 2003; Nowakowski et al., 2018). Resources for mitigating threats and monitoring populations are also unevenly distributed across the globe, with fewer resources available in hyper-diverse regions with the highest rates of species discovery and endangerment (Balmford & Whitten, 2003). These multidimensional challenges underscore the need to improve coordination of monitoring efforts, capitalise on effective new methods and technologies, prioritise limited resources, and strengthen the links among surveys, monitoring, and conservation action.

Decades of research and practice have led to a set of standards for integrating surveys and monitoring with conservation action through evidence-based adaptive management (Conservation Measures Partnership, 2020; Gillson et al., 2019). Surveys and monitoring critically underpin several of the iterative stages of the adaptive management framework, including initial assessment of threats and population status, monitoring of changes in threats and populations, and evaluation of the effectiveness of interventions. Surveys and monitoring, therefore, provide the crucial evidence base for evaluating management options, decision making, and prioritising conservation actions. These actions can be most effective when designed and monitored with participation of local stakeholders and practitioners. Without adequate survey data and stakeholder participation, the adaptive management cycle breaks down.

The exact methods for surveying and monitoring amphibians are largely determined by the diverse life histories of species (Angulo et al., 2006; Dodd, 2010; Heyer et al., 1994). These characteristics frequently include a bi-phasic lifecycle, species-specific calling of male frogs, temporal variability in activity, and a common association with waterbodies. Anurans alone exhibit at least 39 known reproductive modes (Crump, 2015; Haddad & Prado, 2005), which determine how and where we survey for eggs, larvae, and adults. The habitat associations of species also have an outsized influence on our ability to detect and monitor amphibians. For example, fossorial species like most caecilians and canopy-dwelling species like some tree frogs are difficult to detect with conventional survey methods (Basham & Scheffers, 2020; Basham et al., 2019; Gower & Wilkinson, 2005). Practitioners will need to carefully choose the most appropriate survey methods from a wide range of recent advancements and well-established techniques to effectively monitor focal species.

Confronted with these myriad challenges to amphibian conservation, how can scientists and practitioners more effectively survey and monitor amphibians? Recent advancements in technology in concert with continued population declines create a need to update our knowledge of current monitoring methods and identify existing knowledge gaps to better coordinate and prioritise future surveys. We solicited input from the amphibian conservation community to identify key developments and challenges in amphibian surveys and monitoring. Drawing on these responses, this chapter aims to highlight key knowledge gaps and recommendations for surveys and monitoring programmes (Table 10.1). In the sections *below*, we summarise: **1)** commonly used methods and recent methodological advancements; **2)** key knowledge gaps in amphibian conservation; **3)** approaches to prioritising surveys and monitoring; **4)** improving integration of survey and monitoring data into extinction risk assessments; **5)** avenues for bridging the gap between surveys and conservation action; and **6)** opportunities on the horizon for continued advancement of surveys and monitoring for amphibian conservation.

Advancements in amphibian surveys and monitoring in the last 15 years

Amphibian surveys and monitoring have a long history over which researchers have developed

Table 10.1: Summary of key knowledge gaps and priorities for surveys and monitoring.

Key knowledge gaps
• Knowledge of highly biodiverse and understudied landscapes - for example, the Congo rainforest
• Knowledge of understudied and difficult-to-detect groups, such as fossorial and arboreal species
• Resolution of cryptic species complexes
• Improved natural history and identification information, including calls and larval morphology
• Improved prediction of species responses to threats based on niches and adaptive capacity
• Understanding of interactive effects of multiple threats on populations and assemblages
• Moving beyond presence-absence data to understand long-term population trends for many species
Priorities for better integration of survey data into IUCN Red List assessments
• Increasing capacity for conducting species assessments through Red List training programmes
• Increased efficiency in integrating survey data into Red List assessments
• Encouraging species descriptions to include information useful for Red List assessments (e.g. survey effort, number of individuals, etc.), as they often represent the only information available for species assessments
• The development and maintenance of fewer but more permanent repositories for survey and monitoring data
• A centralised platform for submitting relevant survey and monitoring data for species assessments
Priorities for survey and monitoring programmes
• Designing surveys and monitoring to address clear conservation questions
• Identifying questions and designing monitoring programmes in collaboration with local stakeholders
• Addressing priority knowledge gaps that have clear outcomes for conservation
• Using decision-support frameworks to prioritise limited resources for conservation projects
• Designing surveys and monitoring to evaluate effectiveness of interventions, as part of an adaptive management cycle
• Facilitating use of standard database formats for survey and monitoring data by incorporating archival intent into study designs prior to survey implementation
Potential advancements on the horizon
• Improved machine learning methods to classify both visual (video and photos) and acoustic data for improved monitoring in remote locations
• Continued development of new bioinformatic methods to increase the processing and analysis of increasingly large datasets

- Increased portability of genetic analyses – such as portable sequencers and PCR machines – to allow for molecular work in remote locations
- Through open data repositories and other sharing platforms, improve the interoperability and accessibility of survey and monitoring data
- Governments and institutions will need to better coordinate the collection and distribution of biodiversity monitoring data, adopting shared frameworks for information systems such as those promoted by the GEO Biodiversity Observation Network (GEO BON)
- Conservation financing and other creative funding mechanisms are needed to address the large funding gap for surveys and monitoring

methods that are now commonly used across the globe (Figure 10.1). While many of these methods are established and well-tested, the last 15 years have brought technological advances in hardware, software, and data analyses, as well as increases in knowledge and innovative techniques that have improved amphibian survey and monitoring efforts. For example, researchers have increasingly surveyed subsurface quadrats using "persistent digging" in the top 30cm of soil to uncover fossorial species (Biju et al., 2009, Measey, 2006) and surveyed vertical transects using climbing equipment to study the little-known ecology of canopy-dwelling amphibians (Basham et al., 2019). Hardware improvements have lowered the cost and enhanced performance of tools used for surveys and monitoring (Pimm et al., 2015) including autonomous recording units for passive acoustic monitoring (PAM) (Deichmann et al., 2018; Hill et al., 2018), tracking devices like passive integrated transponder (PIT) tags and miniaturised radio transmitters (Connette & Semlitsch, 2015; Forin-Wiart et al., 2015; Lennox et al., 2017), eDNA samplers (Thomas et al., 2018), camera traps (Hobbs & Brehme, 2017), and drones (Koh & Wich, 2012). Growth in software development, machine learning, and bioinformatic tools has improved our ability to track species, analyse large-scale spatial data (GIS), classify and detect species in images or audio recordings, and analyse big molecular datasets, such as those produced through metabarcoding and next-generation sequencing methods (e.g. whole genome sequencing). Novel molecular methods are allowing for species detection in samples of water, soil and faeces, identification of cryptic species complexes, and detection of pathogens and other microbiota through improved assays. Rapid accumulation of new species descriptions and natural history information has facilitated large-scale phylogenies and resolved taxonomies (Frost, 2021; Jetz & Pyron, 2018; Pyron & Wiens, 2011), improving the way we design surveys. Likewise, enhanced capacity at a local level has increased our ability to survey sites at broader spatial and temporal scales, for example, through national-level programmes for biodiversity monitoring (Schmeller et al., 2017) and coordinated citizen science programmes (Aceves-Bueno et al., 2015; O'Donnell & Durso, 2014). Advancements in statistical and conceptual approaches have resulted in new ways to design surveys (e.g. through participation of local communities as well as citizens across the globe; Table 10.2), integrate disparate datasets, and analyse survey data (e.g. recent advances in hierarchical population models; DiRenzo et al., 2019; Dorazio, 2014; Zipkin et al., 2014).

Although many survey and monitoring methods are currently widely used (Fig 10.1), each nevertheless has disadvantages to weigh alongside their benefits before implementation. For example, pitfall and funnel trapping can result in high mortality rates (Enge, 2001) and marking methods such as toe clipping and PIT tagging can also reduce survival in some species (Guimarães et al., 2014). Time- and area-constrained survey methods are often implemented in a way that precludes analysing the data with more rigorous statistical methods, such as those that account for imperfect detection. Methods that result in the accumulation of big data, like PAM, DNA sampled

Figure 10.1: Trends in prevalence of active **(a)** and passive **(b)** sampling methods and marking techniques **(c)** in published literature. Active survey methods include those that require observers to actively search or listen for individual animals, including visual encounter searches (VES; inclusive of area and/or time constrained sampling such as transects and plots), dip netting, electrofishing, and active call surveys. Passive sampling methods include those where observed animals are detected in artificial structures (traps or coverboards), with sensors (passive acoustic monitoring and camera traps), or in environmental samples (eDNA). Common marking techniques include use of natural marking (e.g. dorsal patterns), toe clipping, passive integrated transponders (PIT tags), and visual implant elastomer (VIE). Source: Data based on a Web of Science search of published literature from 2006-2021.

from an organism's environment (eDNA), camera trapping, or photographic mark-recapture, have the added challenge of immense data storage and management needs, as well as complex analytical methods that are still under development. Finally, it is important to consider sampling biases associated with different methods that can affect estimates of population abundances and demographic structure (Nowakowski & Maerz, 2009; Ribeiro-Júnior, Gardner & Ávila-Pires, 2008). These challenges underlie the importance of carefully designing surveys around a question and selecting the most suitable method or combination of methods for answering that question. Fortunately, there is no end to the ingenuity of amphibian biologists and many of these methods, if combined with an effective monitoring framework (Table 10.2) and/or additional methodologies, can result in efficient data collection and high-quality data. For example, pairing on-the-ground methods (e.g. visual encounter surveys, quadrats, pitfalls) with remote sensing or molecular methods (PAM, eDNA) can provide complimentary data streams that, through modelling, can provide insights over much broader temporal and spatial scales than one method alone. These recent advances in surveys and monitoring can be used to address key knowledge gaps that currently hinder a concerted global conservation response to amphibian declines.

Table 10.2: A non-exhaustive list of frameworks for surveying and monitoring amphibians. Within each temporal category (static and dynamic) general sampling frameworks are listed in order of increasing rigour, complexity, and cost for a given number of locations. Opportunistic observations are playing an increasingly important role due to rapid increases in citizen science programmes and data platforms. However, these approaches come with limitations on analytical methods and inferences, stemming from lack of standardisation. Well-designed, planned surveys offer greater opportunity for standardisation and generate data that can be analysed with a wider array of modelling approaches, including those that account for imperfect detection. A 'robust design' generally refers to a class of standardised surveys wherein there are replicated temporal or spatial sub-samples within a defined spatial unit of aggregation (e.g. 1-ha plot) and that occur over a short enough timeframe to assume the populations are closed to demographic changes.

	Example activities	Example inferences	Example analyses
Static (single year)	Opportunistic observations		
	Citizen science (FrogWatch, eBird, iNaturalist, etc), rapid inventories, expert elicitation	Habitat suitability, projected range shifts, species lists, presence only, known range expansions	SDMs, jSDMs, integrated population models
	Single visit, standardised surveys		
	Surveys of occupancy and counts, distance sampling, molecular sampling	Drivers of spatial variation in occurrence, abundance, and genetic diversity; habitat associations; weaker inferences about interventions	GLM/GLMM, distance sampling, ordination, single-season occupancy models
	Repeated surveys		
	Camera trapping, acoustic surveys, multiple VES	Drivers of spatial variation in occurrence or abundance while accounting for imperfect detection	Single-season occupancy, N-mixture models, MR abundance estimation
Dynamic (multiyear)	Multiyear opportunistic observations		
	Citizen science (FrogWatch, eBird, iNaturalist, etc), rapid inventories, expert elicitation	Phenology changes (e.g. timing of breeding), projected range shifts, and species lists	SDMs, jSDMs, integrated population models
	Multiyear single visit (per year), standardised surveys		
	Mark-recapture, surveys of occupancy and counts, distance sampling, genetic monitoring	Population or community dynamics (survival, immigration), drivers of trends; demographic rates, stronger inferences about interventions	GLM/GLMM, state-space models, integrated population model
	Robust design		
	Mark-recapture, Camera trapping, acoustic surveys, multiple VES, tracking studies	Population or community dynamics, drivers of trends, stronger inferences about interventions, accounting for imperfect detection	Dynamic occupancy and N-mixture models; multiyear MR abundance estimates

Abbreviations: SDM: species distribution model; jSDM: joint species distribution model; GLM: generalised linear model; GLMM: generalised linear mixed model; VES: visual encounter surveys; MR: mark-recapture. Source: MacKenzie & Royle, 2005; Pollock, 1982

Key knowledge gaps that could be addressed with additional surveys

Considerable gaps remain in our knowledge of amphibians. At the most basic level, it is estimated that ~27% of amphibian species (~3,000 species) remain undescribed (Giam et al., 2012), and 25% of those that are described have too few range data to accurately predict threat status (González-del-Pliego et al., 2019). The primary causes of these data deficiencies are: 1) insufficient surveys in highly biodiverse and understudied landscapes, for example, the Congo rainforest, Papua New Guinea, and other habitats that are difficult to access in regions that are amphibian species-rich but resource-limited (Guerra et al., 2020; Vieites, Wollenberg & Andreone, 2009); and 2) difficulty in detecting some amphibian groups, including caecilians and canopy dwelling species. Thus, monitoring programmes that target understudied biodiversity hotspots combined with canopy and sub-surface survey methods, for example, would significantly improve our global understanding of amphibian distributions and status. Increased surveys and monitoring in these contexts would also lead to increased understanding of natural history, which would not only improve our overall ability to detect species, but also help us better understand how amphibians may be impacted by environmental change.

Undescribed species hidden within cryptic species complexes represent another important knowledge gap (McLeod, 2010). Such species make up a significant proportion of undescribed amphibian diversity (Funk, Caminer & Ron, 2012) and resolution of these taxa could be addressed with increases in both the number of genetic studies and more widespread geographic sampling. These efforts can be accelerated by integrating genetic sampling (eDNA or tissue samples) and laboratory methods like gene sequencing into standard monitoring protocols. As they become increasingly affordable, genetic methods will uncover considerable hidden diversity and help overcome inaccuracies in field identifications, which can be an issue even for local experts (Deichmann et al., 2017). In addition to collecting tissues for molecular studies, it is also essential to collect additional data that can improve the efficacy of surveys and monitoring. Examples include tadpole morphology data that will allow for improved identification of larvae when adults are not present (Schulze, Jansen & Köhler, 2015), and calls and photographs of voucher specimens that can be used as training data in machine learning methods for species classification (i.e. call and image recognition models; Xie et al., 2016).

With climate extremes increasing and habitat loss decimating tropical biodiversity hotspots, concerted survey efforts coupled with information on both species' exposure and sensitivity to threats – including traits, niche dimensions, and adaptive capacities – are needed to adequately forecast current and future threat impacts (Murray, Nowakowski & Frishkoff, 2021; Urban et al., 2016). In particular, efforts to manage or conserve species may fall short of their goals if they fail to anticipate interactive effects of co-occurring threats, such as land use, climate change, and disease (Hof et al., 2011). As more than 70% of the Earth's land surface is modified by human activities (Hobbs, Higgs & Harris, 2009), more work is needed to identify key habitats for amphibian persistence in working landscapes, such as riparian corridors and remnant trees (Mendenhall et al., 2014), while also identifying at-risk, intact habitats with high numbers of threatened species to prioritise for site protection (Nowakowski & Angulo, 2015; Venter et al., 2014). An important outcome of survey and monitoring can be the prioritisation of areas of intact habitat that can serve as climate refugia and connected nodes in climate resilient protected areas networks (Marquet, Lessmann & Shaw, 2019).

Although many datasets exist describing the presence of species in localities, there is very little information on population trends over time. Long-term data are needed to rigorously assess population and range dynamics, sensitivity to threats like land use and climate change, and the impacts of management interventions. Recent developments in statistical methods – such as dynamic occupancy, N-mixture, and integrated population models – along with advances in computing can be employed in conjunction with long-term monitoring of populations and communities, thereby enabling the detection of slow declines and species range shifts (Plard et al., 2019; Zipkin et al., 2014). For example, passive sampling methods such as acoustic monitoring can be combined with machine learning for call identification and spatially explicit capture–recapture (aSCR) for quantitative density estimates of vocalizing animals (Measey et al., 2017). Long-term genetic monitoring can reveal changes in genetic structure that may indicate past declines and ongoing genetic erosion that can precipitate future population declines and extirpations (Stephens, Tolley & da Silva, 2022). Increases in open data repositories are facilitating comparative analyses and synthesis of amphibian population trends (Collen et al., 2009; Dornelas et al., 2018). Existing knowledge gaps are manifold and resolving each will likely have unequal returns on investment for conservation. In the face of such uncertainty, addressing the knowledge gaps identified here may serve as only one important criterion for prioritising limited resources for surveys and monitoring.

Prioritising limited resources for surveys and monitoring

Reliable, timely, and accessible information on the status of species and their threats is critical to achieving successful conservation interventions. However, despite considerable progress over recent decades in the standardisation of research methods and early detection of species declines, we have largely failed to halt ongoing declines in both common and rare amphibian species (Bishop et al., 2012; Campbell Grant et al., 2019). Given the limited resources available for surveys and monitoring, a key goal should be to prioritise the collection of actionable information that provides the greatest chance to change conservation outcomes (Buxton et al., 2020; Lindenmayer, Piggott & Wintle, 2013).

Even with this ‘value of information’ perspective, the challenge of how and where to prioritise research efforts remains daunting. Many rare and at-risk species are disproportionately under-studied by researchers (da Silva et al., 2020; Walls, 2014), while at the same time the proactive monitoring of widespread, common species can both decrease the cost of management interventions and increase the likelihood of success (Sterrett et al., 2019). In light of such trade-offs, decision science has produced an array of decision support frameworks that help practitioners and scientists structure potentially overwhelming complexity, including stakeholder interests and system uncertainty, to prioritise limited resources for conservation projects (see recent reviews of decision support frameworks; Schwartz et al., 2018; Wright et al., 2020). Decision frameworks can help researchers identify cases where surveys and monitoring are needed and avoid cases where additional monitoring efforts would be unlikely to change management actions (McDonald-Madden et al., 2010). However, the evidence base for informing management decisions remains extremely limited for certain taxa and geographies, due to a lack of data on population status and effectiveness of management interventions (Canessa et al., 2019; Christie et al., 2020). Although widely adopted, successful application of decision frameworks throughout a project, from initial planning to intervention and evaluation stages, remains relatively rare, including among amphibian projects (Redford et al., 2018; Wright et al., 2020). This clearly highlights the need for an objective-oriented approach to setting research priorities to provide baseline information on species with limited data, identify threats, monitor population status, and inform the implementation of specific management interventions (Table 10.3).

Addressing the magnitude of global amphibian declines requires considerable effort to expand the coverage of existing monitoring, particularly in under-studied geographies and for species lacking data. Filling these information gaps requires an increased commitment by funders and researchers to ensure that local researchers have the skills and resources to do effective monitoring, data reporting, and conservation planning. Establishing new monitoring networks in under-studied areas of high amphibian species richness would offer the potential for rapid, widespread deployment of standardised survey methods. Such monitoring networks would also ensure that data are accessible and comparable

Table 10.3: Priorities for survey and monitoring in relation to perceived risk of species decline

Perceived Risk of Decline	Survey & Monitoring Approaches
Unknown	• Species discovery (prioritise poorly studied and species rich areas) • Basic assessment of genetic diversity (prioritise detection of cryptic species and evolutionarily distinct lineages) • Collect distribution data to delineate species range, identify habitat associations, and identify potential threats
Low	• Targeted surveillance with standardised methods to detect change • Targeted disease surveillance
Medium	• Targeted monitoring of occurrence/abundance (ideally using methods capable of detecting gradual population trends) • Perform studies to evaluate management effectiveness (prioritise setting management triggers) • Test and adapt potential management strategies • Predict impacts of potential threats (e.g. habitat loss, climate change, etc.)
High	• Intensive demographic monitoring of populations • Evaluate relative importance of threats • Intensive adaptive management and threat monitoring • Species rediscovery efforts

Source: Adapted from Lindenmayer et al. (2013) and Sterrett et al. (2019)

across time and space, while potentially affording opportunities for further expansion of surveillance capacity through the integration of volunteers and citizen scientists (Aceves-Bueno et al., 2015). As much of the tropics remain understudied, additional layers of prioritisation of new monitoring networks could include 1) areas with many threatened or data deficient species, 2) highly threatened ecosystems, 3) areas with high endemism, 4) rediscovery of "lost species" that have not been observed for years or decades (González-Maya et al., 2013) and 5) using phylogenetic information to prioritise sensitive clades and evolutionarily distinct species (González-del-Pliego et al., 2019; Jetz & Pyron, 2018). Although this broadening of surveillance efforts would undoubtedly improve our ability to detect and respond to species declines, it is also imperative that researchers are equally committed to proactively proposing and evaluating potential conservation interventions to avoid simply monitoring species as they go extinct (Canessa et al., 2019; Lindenmayer et al., 2013).

Improving integration of survey and monitoring data into Red List assessments

The IUCN Red List of Threatened Species™ (Red List) assessments are widely accepted standards for measuring species' risk of extinction on global and national scales and a powerful tool for conservation policy and planning (Brito, 2010; Hoffmann et al., 2010; Rodrigues et al., 2006). Assessments are designed to be consistent, transparent, and structured by objective criteria and guidelines (Mace et al., 2008) to ensure repeatability over time. The effectiveness of the Red List depends on each assessment containing up-to-date information; however, data and the capacity needed to complete these assessments are unevenly distributed among geographic regions and across different taxonomic groups (Collen et al., 2009).

The high proportion of amphibian species that have not been assessed (13% of described species) or that are Data Deficient (16-17% of assessed species at the time of writing) illustrate the challenges posed by rapid species discovery and lack of meaningful data for many species, especially in the tropics (Collen et al., 2008; IUCN, 2021; Stuart et al., 2004). During the previous Global Amphibian Assessment for the Red List (GAA), 5,743 amphibian species had been described, of which 22.5% were assessed as Data Deficient (Stuart et al., 2004). Since then, the number of known species has increased remarkably (8,309 species at the time of writing; Frost, 2021). With so many new and little-known species, there is interest within the amphibian conservation community to increase the rate of species assessments. Addressing these challenges requires increased assessment capacity, new survey data, and more efficient integration of survey data into the assessment process.

Expanding the network of experts contributing to assessments and increasing Red List training and mentoring opportunities for the broader conservation

Box 10.1: Ancillary data

While in the field conducting surveys and/or monitoring, information that is important for conservation planning and research objectives can be collected with little additional effort. These data include: **1)** habitat and microhabitat attributes (e.g. habitat types and sizes, vegetation, canopy cover, water depth and flow, stream gradient, substrates, water quality, calling site, hiding refugia); **2)** species life history or behavioural observations (e.g. life stage occurrence, breeding/foraging/dispersal behaviours); **3)** community composition (e.g. prey, predators, invasive species); **4)** human activities (e.g. timber harvest, livestock grazing, agriculture, wildlife harvesting, nearby human community activities); **5)** threats (e.g. algal bloom, fire, trees killed by pests/disease, chemical contamination, erosion, pathogens or poor animal health observations). For long-term monitoring, it could be useful to establish a monumented photo point (e.g. phenocams; Brown et al., 2016) to compare the habitat condition throughout the years, to show natural succession or effects of disturbances. As weather and microclimate conditions drive amphibian activity and distributions, it is important to obtain data from the nearest weather station or, preferably, to deploy weather data loggers at sampled sites. Additional sampling could include collection of a species voucher (adult, tadpole/larval and egg stages), genetic sample, carcass, vocalisations, eDNA samples for full analyses of the community and /or a photographic voucher - taken with species-specific characteristics shown, which may be of great value for later species confirmation or disease detection. Metadata from surveys should include disposition of samples and survey data in archived databases. Including these ancillary data and materials in standard survey and/or monitoring protocols will ensure they are collected. Although it may seem ambitious to record as many ancillary data as feasible and some data may require additional permitting (e.g. species vouchers and DNA samples), these ancillary data provide critical context to the species occurrence or abundance data and potentially the entire programme. Information ancillary to amphibian species occurrence or abundance is particularly useful for discerning environmental changes in long-term monitoring programmes and can shed light on the cause(s) of later-documented trends, information essential for conservation planning.

community could help improve the speed, standardisation, and interpretation of Red List assessments. Training can enhance knowledge of the guidelines for applying the Red List Categories and Criteria as well as the data required to estimate trends in species abundance and distributions (Collen et al., 2016), assisting the design of future surveys and improving data integration into species assessments. For instance, assessment rates could be increased if authors of species descriptions, which often represent the only information available for species assessments, routinely included information such as descriptions of survey effort, abundance, habitats, and threats (Tapley et al., 2018). To this end, IUCN, in collaboration with The Nature Conservancy (TNC), developed a free online Red List training course available in IUCN's three official languages (see https://www.iucnredlist.org/resources/online). Expanded networks and increased capacity may also facilitate knowledge transfer and data sharing within and across regions, thereby synergising efforts across assessments and working groups and increasing rates of assessment.

As capacity to support Red List assessments improves and monitoring programmes continue to increase data availability, there is a need for more efficient dataflow to ensure that different types of survey and monitoring data effectively contribute to assessments. New approaches to data-sharing (e.g. online databases, repositories, data papers, data archiving) are required to improve dataflow and increase the availability of data across multiple regions. Current biodiversity data are spatially biased and are either scattered in many databases or reside on paper or behind pay walls, impeding access and collation for assessments (Beck et al., 2014; Chavan & Penev, 2011). A sustainable data management system requires the development and maintenance of fewer but more permanent data repositories (Bach et al., 2012) that are subject to data quality control (Costello et al., 2013; Huang, Hawkins & Qiao, 2013). Current standards and best practices for the management and publication of biodiversity data are already available (Costello & Wieczorek, 2014). Furthermore, the implementation of a process that awards professional recognition for contributors (e.g. citation and co-authorship) would likely increase contributions of scientists to open data repositories. However, to improve integration of available survey and monitoring data into Red List assessments, specific guidelines and a platform for submitting relevant data for species assessment could be implemented, strengthening links among experts and allowing a broader participation of trained professionals and citizen scientists alike. New survey and monitoring projects could facilitate data sharing and integration into Red List assessments by including data standards and plans for archival in the design phase of the project.

Bridging the gap between survey and monitoring data and conservation action

Frameworks for linking surveys and monitoring data to conservation actions

Adaptive management is a framework – widely used by non-governmental organisations (NGOs), government agencies and funders – that links survey and monitoring to conservation actions (Conservation Measures Partnership, 2020; Gillson et al., 2019; Schwartz et al., 2018). Following this framework, survey and monitoring data inform assessment of threats and population status, tracking of progress toward conservation goals, and evaluation of management interventions (Conservation Measures Partnership, 2020). Adaptive management is data and resource intensive, however, as it is tailored to system complexities and idiosyncrasies on the ground. In many understudied biodiversity hotspots, detailed population data are lacking and can take years or decades to accumulate; by then, actions may be too late (Martin et al., 2012). Other decision support frameworks exist – such as structured decision-making and evidence-based practice – and tools from each can be blended to achieve conservation objectives (Schwartz et al., 2018). For example, evidence-based conservation is a complementary framework that instead draws on the broader body of survey data and impact evaluations to identify best practices, when at least some information exists on the state of the system; this approach mirrors the learning process widely used by medical practitioners (Gillson et al., 2019; Sutherland et al., 2004). Adaptive management and evidence-based frameworks can be

Box 10.2: The Mountain Chicken Recovery Programme

Thought to have once existed on at least seven islands in the Caribbean, the mountain chicken (*Leptodactylus fallax*) is a Critically Endangered frog restricted to the islands of Montserrat and Dominica, most likely due to the impacts of hunting and introduced species such as the mongoose (Adams et al., 2014). Chytridiomycosis, caused by the fungal pathogen *Batrachochytrium dendrobatidis* (Bd), has resulted in the near extinction of the species. In the early 2000s, a population monitoring and disease surveillance programme was established to determine the extent and impact of chytridiomycosis in Dominica (Cunningham et al., 2008), and these data showed a loss of over 85% of the population in fewer than 18 months (Hudson et al., 2016). This prompted Monserrat to develop the Mountain Chicken Species Action Plan, prioritising biosecurity measures (Martin et al., 2007). Despite this, Bd was detected in Montserrat in 2009 and near-extinction occurred on Montserrat within 6 months, in one of the fastest observed vertebrate declines of all time (Hudson et al., 2016). In 2010, the Mountain Chicken Recovery Programme was formed (Adams et al., 2014) with a collection of European Zoos and the governments of Dominica and Montserrat coordinating conservation for this species based on robust long-term monitoring data. Between 2011-2014, in the absence of detection of wild animals, the programme implemented experimental reintroductions of captive-bred animals onto Montserrat (Hudson et al., 2016). In 2019, 27 frogs were introduced to a semi-wild enclosure in Montserrat in an attempt to use environmental manipulation to enable frogs to survive in the face of endemic Bd in reservoir species. The first breeding pairs were recorded in 2020, culminating in what likely represents the first observed fertilised nest in Montserrat in 11 years, although this nest later failed. In Dominica, the remnant wild population appears to number < 100, and continues to be threatened by chytridiomycosis and habitat loss. As part of the Long-Term Recovery Plan for the Mountain Chicken (Adams et al., 2014), monitoring of frog populations and Bd continues on both islands, alongside research into mechanisms to ensure the survival of remnant populations and the reintroduction of others.

integrated to implement best practices as a starting point and then adapt interventions as monitoring data and impact evaluations accumulate for a system. A complete cycle of adaptive management would **1)** define clear conservation objectives that are part of a ‘theory of change’ results chain (Salafsky et al., 2008), with input from stakeholders; **2)** plan and implement interventions alongside standardised, recurring surveys to monitor threats and focal taxa; and **3)** use survey data to evaluate and adapt management interventions over time.

Linking surveys and monitoring to clear conservation objectives with stakeholder input

Critical to bridging the gap between data and effective conservation actions, is designing survey and monitoring efforts around clear conservation objectives, which are ideally defined with input from multi-stakeholder groups. These objectives may include: **1)** protection of iconic places for a species or a location’s natural heritage such as a national park; **2)** assessing the status of rare or little-known species; **3)** reversing suspected population declines; and **4)** monitoring responses to specific threat factors. While long-term monitoring programmes are ideal for obtaining actionable data, such programmes often require significant human and financial resources and are less common outside of developed countries (Proença et al., 2017). With limited resources, it may only be possible to survey a site a single time. These one-off inventories are nevertheless essential for evidence-based conservation, as well-designed surveys may still allow researchers to discover new species, update species ranges, understand habitat associations, or identify potential threats (Tables 10.1 & 10.2).

Identifying the conservation objectives that guide a monitoring programme should ideally be a participatory process, involving input from multiple stakeholders and drawing on local knowledge. The importance of integrating stakeholder input into species monitoring and conservation programmes is increasingly recognised, especially for amphibians (Olson & Pilliod, 2021). This may include integration of local or regional communities in programme planning and implementation through conservation cooperatives, participatory panels, and citizen science involvement. Outreach and education can inspire appreciation for the awe, wonder, and importance of amphibians, which is needed to ensure their persistence for generations to come (*see* Chapter 8). Importantly, educating natural resource managers and policymakers about amphibians and their importance to ecosystems may be needed, especially if resources have been historically diverted to other priorities.

Development of monitoring programmes

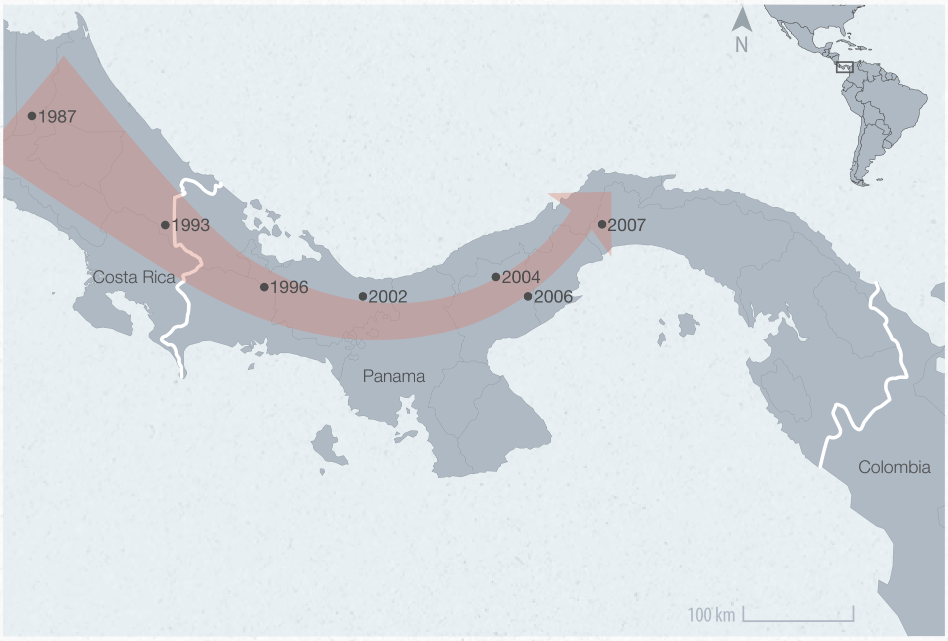
The combination of standardised methodologies with recurrent surveys forms the foundation of a monitoring programme (example amphibian monitoring programmes: Boxes 10.1, 10.2, 10.3,10.4; Table S1). These programmes generate information on population status and dynamics that can be fed into decision support frameworks, such as adaptive management, and contribute to the planning and learning phases of a conservation project (Schwartz et al., 2018). A key aim of new monitoring programmes is often to conduct initial surveys that establish baseline information (Proença et al., 2017). This baseline can be used to assess current threats and the status of focal populations and may then contribute to conservation planning by prompting decisions about the need for additional monitoring and interventions. Other common aims of survey programmes are to understand species occurrence patterns and habitat associations, to quantify population trends and identify drivers of occurrence and trends, and to support planning and evaluation of management interventions. Some programmes may span multiple monitoring objectives. For example, the US northwest federal "Survey and Manage Program" is focused on five plethodontid salamanders (Text Box 10.4) and expanded over time to include surveys at additional sites, and of additional species, and using new survey methods to improve inferences about populations and their habitat associations across the landscape (Olson, Van Norman & Huff, 2007).

Additionally, survey and monitoring programmes may have qualitative or quantitative goals, or a mix of each. For example, annual visits to breeding sites may generate qualitative information such as the date of breeding, lists of calling species, and anomalies noted – data-poor metrics that are potentially informative for detecting changing conditions that may warrant more rigorous follow-up surveys. At the other end of the spectrum, a mark-recapture programme could generate information about individuals across their life spans for more quantitative assessments of demographic status and trends. Data from long-term monitoring programmes can be used to develop reliable models that can inform conservation actions (e.g. determining extinction risk of development activities for focal species or identifying habitat critical for preservation to ensure survival of target metapopulations; Howell et al., 2020). Ancillary data collected during surveys for amphibian occurrence or population status may also have benefits to advance basic species knowledge, conservation, or research (Boxes 10.1, 10.2, 10.3,10.4). Lastly, tracking of multiple monitoring, conservation, or restoration programmes can facilitate synthesis of actions and outcomes across broad geographic areas. For example, the Canadian province of British Columbia has developed an amphibian conservation and restoration database to help track these efforts across their province (Table S1).

Considerations of paramount importance for the long-term success of surveys and monitoring efforts include: **1)** institutional support (e.g. can the programme become institutionalised, or are there multi-partner trust agreements to ensure longevity, such as researchers, local people, governments, decision makers, and others); **2)** clear priorities and design; **3)** capability (personnel infrastructure e.g. biological, technical, administrative, policy); **4)** funding; **5)** communication (stakeholder updates, reports, outreach and education, media and social media information releases); and **6)** adaptive

Box 10.3: Atelopus conservation

Survey efforts in Central America uncovered the first evidence of massive amphibian declines in the 1980s (Box Figure 10.1). Although the cause was unknown, continued monitoring in Costa Rica and Panama documented a south-east progression of population declines moving towards Colombia (Lips, 1999). By 1999, the emerging infectious disease chytridiomycosis, caused by the fungal skin pathogen *Batrachochytrium dendrobatidis* (Bd) had been identified as a major threat to the *Atelopus* genus of bufonid toads in Central America (a threat later recognised for *Atelopus* throughout the Neotropics; La Marca et al., 2005). Survey data showed that Bd was an imminent threat to the continued existence of multiple threatened species, including the Panamanian golden frog (*Atelopus zeteki*), one of the world's most culturally significant, recognisable, and Critically Endangered amphibians (Gagliardo et al., 2008). Based on these alarming survey results, representatives from an international collaboration of universities, zoos, and conservation organisations established colonies of wild populations of multiple *Atelopus* species in ex situ management centres (Zippel, 2002). In 2004, wild populations from Panamanian sites were decimated by Bd as predicted, rendering many *Atelopus* species Critically Endangered or Possibly Extinct in the Wild (Zippel, 2002). Remnant captive populations have since been successfully bred in captivity as source populations for reintroductions, where surplus individuals are also providing a key role in understanding infection pathways and fungal resistance (Becker et al., 2011).



Box Figure 10.1: Amphibian surveys and monitoring in Central America documented a 20-year southeast progression of population declines that was eventually attributed to the skin disease chytridiomycosis caused by the amphibian chytrid fungus *Batrachochytrium dendrobatidis*. Source: Adapted from figure in http://amphibianrescue.org/2011/06/15/chytrid-spreading-fast-and-furiously/

management (cyclic learning to improve execution of the programme). The last two considerations, communication and adaptive management, are opportunities to build stakeholder trust and leverage the results of surveys and monitoring into reactive conservation actions.

Impact evaluations for adapting interventions

Evaluating the effectiveness of conservation interventions depends on the availability and design of survey and monitoring datasets. Often, interventions and monitoring programmes are designed independently,

Box 10.4: The Survey and Manage Program: Siskiyou Mountains and Scott Bar salamanders

The US Pacific Northwest federal 'Survey and Manage Program' was developed to address persistence of species associated with late-successional and old-growth forest conditions that were not protected by federal reserved lands (Molina, Marcot & Lesher, 2006). One of the five amphibian species included in the programme was the Siskiyou Mountains salamander, (*Plethodon stormi*), a terrestrial woodland salamander with rocky substrate and shade habitat associations (Suzuki, Olson & Reilly, 2008). Its range was not well delineated upon programme initiation in 1993, when 47 site localities were known for the species across a ~61-ha area. Hence, salamander occurrence surveys were mandated within 40 km (25 miles) of the outer-most known localities before any forest management proposals could be developed on federal lands within the species range. In addition, strategic surveys and independent research projects were conducted to collect additional data on occurrence, habitat associations, and genetic diversity. By 1999, there were 163 sites known for the species and the known range had doubled in size (~137 ha), extending 18 km to the south, 11 km to the east, and 16 km to the west (Nauman & Olson, 1999). To the south, a new morphologically and genetically distinct species was encountered, the Scott Bar salamander (*Plethodon asupak;* Mead et al., 2005). The combined survey and research efforts for the Siskiyou Mountains salamander resulted in a tri-agency Conservation Agreement in Oregon where high-priority sites for conservation were identified as a pre-emptive effort to avoid its listing as federally Threatened or Endangered, while allowing for continued forest management within the species' range (Olson et al., 2009). Additionally, species-management recommendations were developed to reduce fuel loading to reduce risk of wildfire at salamander sites (Clayton et al., 2009). At this time, a multi-agency Conservation Agreement is in development for the Siskiyou Mountains and Scott Bar salamanders in California. The outcome of the Survey-and Manage Program for this originally little-known species has been significant knowledge discovery (reviewed in Olson et al., 2007) and a series of successful conservation measures with reconciliation of forest management disturbances and proactive measures to address the threat of wildfire.

requiring retrospective impact evaluations that use existing monitoring data. In these cases, monitoring data from treated and untreated sites can be statistically matched after data collection, while accounting for confounding variables (Schleicher et al., 2020). In other cases, surveys and monitoring programmes are co-designed alongside interventions and ideally built on theories of change (Rice, Sowman & Bavinck, 2020). Surveyed sites for planned impact evaluations are either haphazardly assigned to treatments (sites receiving the intervention) and controls – as is most common – or are randomly assigned to each. Randomised controlled trials are the research gold standard but are rare in conservation impact evaluations (Burivalova et al., 2019), perhaps owing to logistics or ethical concerns under certain contexts. Co-designing interventions and monitoring for impact evaluation requires a greater level of planning and coordination but, when well-implemented, can lead to stronger inferences about intervention effectiveness (Baylis et al., 2016; Burivalova et al., 2019), which in turn can reduce uncertainty and wasted resources in conservation (Buxton et al., 2021). Lessons learned from impact evaluations then inform future implementation and adaptation of management interventions. For example, Canessa et al. (2019) monitored stage-specific survival rates of the threatened toad, *Bombina variegata*, to evaluate effectiveness of three methods of reintroduction: captive rearing, head-starting, and direct translocations. They then adapted to focus survey and implementation efforts solely on headstarting, based on the data generated during the first years of monitoring. The specific interventions implemented for an amphibian conservation initiative will invariably depend on species life history and system context; the evidence base for a number of interventions is reviewed in Smith, Meredith & Sutherland (2018).

On the horizon: potential for advancing surveys and monitoring

As threats to amphibian populations increase, the future of surveying and monitoring will require increased capacity, efficiency, and funding if conservation is to succeed. Advances in technologies are enhancing efficiency of monitoring through remote detection and tracking of species with higher spatial and temporal resolution. A broad trend in greater accessibility of micro technologies for tracking small-bodied amphibians with corresponding analytical tools is likely to further increase the resolution of monitoring and the breadth of species that are appropriate to different methods. More passive monitoring through drones and remote technologies can help expand the geographic coverage of monitoring efforts by reducing time and resource requirements (Marvin et al., 2016; Wilson et al., 2016).

For amphibians in particular, technology has been an effective aid to surveys and monitoring. Many populations are now monitored through acoustic sensors at very high temporal resolution, thereby generating massive amounts of data. However, lags in development of analytical tools still constrain our ability to comprehensively process acoustic data (Brodie et al., 2020; Deichmann et al., 2018). In the future, we are likely to resolve these issues with improved machine learning methods that will classify both visual (video and photos) and acoustic data to enable the identification of cryptic species and allow improved monitoring in remote locations. This may lead to real-time monitoring at a large scale, for example, by employing automated detection of calls. Additionally, cutting-edge artificial intelligence, such as algorithms used in the gaming industry, may provide a means to test and predict scenarios as they unfold through monitoring and to guide management (Barbe, Mony & Abbott, 2020). At the same time, continued development of new bioinformatic methods will enable the processing and analysis of increasingly large datasets (La Salle, Williams & Moritz, 2016; Snaddon et al., 2013).

Accompanying advances in technology, the accessibility of genetic methods to inform monitoring has increased greatly. Genetic methods are an important piece of the conservation puzzle, informing our understanding of the underlying resilience of populations, resolving cryptic species, and guiding conservation strategy. The ongoing reduction in cost and increase in portability of genetic analyses – such as portable sequencers and PCR machines for molecular work in remote locations (Menegon et al., 2017) – coupled with the increased utility and complexity of laboratory and statistical analysis, will likely continue apace. For threatened amphibians, the continued rise in throughput and resolution of genetic methods will aid managers in prediction and decision-making around interventions for threatened species. Already we have seen the unit of focus change from species to sub-species management units in many cases, and with the advent of genomics we may soon be monitoring many populations at the individual or gene level.

Through open data repositories and other sharing platforms, there is a need to further improve the interoperability and accessibility of survey and monitoring data, including those generated by new technologies and molecular methods. However, these efforts will require a transformation in organisation and political will to ensure usefulness and equity of open data resources for conservation action (Stephenson et al., 2017). Governments and institutions will need to better coordinate the collection and distribution of biodiversity monitoring data, adopting shared frameworks for information systems such as those promoted by the GEO Biodiversity Observation Network (Navarro et al., 2017). The need for science to become more openly accessible, more robust, and replicable is becoming increasingly crucial as resources are further restricted (Hampton et al., 2013). Digital platforms that manage data and enable sharing globally will need to become more coordinated and regulated over time, including adherence to meta-data standards. As developing countries gain better access to technology and communication, open data repositories and resources should be intentionally designed and maintained to improve equity of access and use of open data. Open data platforms can facilitate collaborations and knowledge exchanges between specialties and disciplines, from those collecting data on the ground to those analysing data in the cloud. Technology has the potential to reduce the resource disparity between different socioeconomic backgrounds and to provide access to open-source software and related training modules needed for planning and analysis of survey and monitoring data. This should increase the capacity of local stake-holders, which is an important goal in conservation (Brooks et al., 2012).

While there will always be a need for well-designed, on-the-ground monitoring programmes, surveys and monitoring efforts may increasingly take advantage of non-traditional sources of data to minimise the resources needed to gather data necessary for decision-making. With the proliferation of environmental impact assessments associated with infrastructure development projects, grey literature reports of species occurrences are becoming more accessible. Similarly, as the push to improve data formatting and data sharing bears fruit, mining biodiversity data portals may provide some of the information traditionally gathered in on-the-ground surveys. Consulting these portals will be an important initial step in designing strategic amphibian surveys and monitoring programmes (Garcia Fontes et al., 2015). In addition, social media harbours a wealth of georeferenced biodiversity information that could be scraped and accessed through content analysis or other methods to inform amphibian surveys and monitoring (Toivonen et al., 2019).

Arguably, the greatest impediment to amphibian surveys and monitoring and to achieving amphibian conservation goals is lack of funding (*see* Chapter 2). This necessitates creativity to look beyond traditional sources of conservation research financing. Fortunately, there are opportunities on the horizon: it is increasingly feasible to engage the private sector to generate funding for biodiversity conservation. In some locations, the private sector's stake in biodiversity is tied to its obligation to meet national and global development goals (Nationally Determined Contributions, post-2020 Biodiversity Targets, UN Sustainable Development Goals, etc.), to the will of activist shareholders and board members, and to the value of ecosystem services upon which corporations rely (Barbier, Burgess & Dean, 2018). Multilateral development banks often fund projects initiated by corporations and they also play a role in financing conservation as part of the environmental responsibility standards tied to those projects. Development projects funded by the banks signed on to the Equator-Principles are required to implement the mitigation hierarchy to manage their impacts to biodiversity and to implement biodiversity offset mechanisms. Amphibian conservation activities can be strategically woven into these projects (Deichmann et al., 2013). Among private investors, there is growing interest in 'impact projects', those that generate a measurable social or environmental benefit alongside a financial return (Rodewald et al., 2020). In amphibian-rich but resource-limited countries, these projects are often driven by an initial philanthropic contribution (blended financing), that catalyses investment from other entities. Ensuring survey objectives are clear and intentionally tied to national and global conservation goals will be essential in securing outside support for projects and conservation initiatives in resource-limited nations.

Amphibian surveys and monitoring vitally underpin much of our knowledge about the natural history, status, and population trends of amphibian species. As many populations have declined across the globe, ensuring that surveys and monitoring efforts are linked to conservation outcomes is increasingly urgent. These links can be strengthened by:

- Defining clear, applied objectives for amphibian surveys and monitoring through a participatory process.
- Using decision support frameworks (such as adaptive management) to prioritise surveys.
- Selecting the most appropriate survey methods among traditional and recently advanced techniques.
- Communicating survey and monitoring data in formats appropriate for informing decision-making.
- By leveraging new methods, technologies, and funding mechanisms, we can ensure surveys and monitoring contribute to achieving amphibian conservation goals in an age of rapid amphibian declines and discoveries.

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References

Aceves-Bueno, E., Adeleye, A. S., Bradley, D., Brandt, W. T., Callery, P., Feraud, M., … Tague, C. (2015). Citizen science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: Criteria and evidence. *Ecosystems*, *18*(3), 493–506. https://doi.org/https://doi.org/10.1007/s10021-015-9842-4

Adams, S. L., Morton, M. N., Terry, A., Young, R. P., Dawson, J., Martin, L., … Gray, G. (2014). *Long-Term recovery strategy for the Critically Endangered mountain chicken 2014-2034*. https://doi.org/10.13140/RG.2.1.3836.8487

Angulo, A., Rueda Almonacid, J. V, Rodríguez-Mahecha, J. V, & La Marca, E. (2006). *Tecnicas de inventario y monitoreo para los anfibios de la region tropical andina*. Bogotá, Colombia: Conservation International – Andes CBC.

Bach, K., Schäfer, D., Enke, N., Seeger, B., Gemeinholzer, B., & Bendix, J. (2012). A comparative evaluation of technical solutions for long-term data repositories in integrative biodiversity research. *Ecological Informatics*, *11*, 16–24. https://doi.org/10.1016/j.ecoinf.2011.11.008

Balmford, A. & Whitten, T. (2003). Who should pay for tropical conservation, and how could the costs be met? *Oryx*, *37*(2), 238–250. https://doi.org/10.1017/S0030605303000413

Barbe, L., Mony, C. & Abbott, B. W. (2020). Artificial intelligence accidentally learned ecology through video games. *Trends in Ecology & Evolution*, *35*(7), 557–560. https://doi.org/10.1016/j.tree.2020.04.006

Barbier, B. E. B., Burgess, J. C. & Dean, T. J. (2018). How to pay for saving biodiversity. *Science*, *360*(6388), 486–488. https://doi.org/10.1126/science.aar3454

Basham, E. W. & Scheffers, B. R. (2020). Vertical stratification collapses under seasonal shifts in climate. *Journal of Biogeography*, *47*(9), 1888–1898. https://doi.org/10.1111/jbi.13857

Basham, E. W., Seidl, C. M., Andriamahohatra, L. R., Oliveira, B. F., & Scheffers, B. R. (2019). Distance-decay differs among vertical strata in a tropical rainforest. *Journal of Animal Ecology*, *88*(1), 114–124. https://doi.org/10.1111/1365-2656.12902

Baylis, K., Honey-Rosés, J., Börner, J., Corbera, E., Ezzine-de-Blas, D., Ferraro, P. J., … Wunder, S. (2016). Mainstreaming impact evaluation in nature conservation. *Conservation Letters*, *9*(1), 58–64. https://doi.org/10.1111/conl.12180

Beck, J., Böller, M., Erhardt, A., & Schwanghart, W. (2014). Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecological Informatics*, *19*, 10–15. https://doi.org/10.1016/j.ecoinf.2013.11.002

Becker, M. H., Harris, R. N., Minbiole, K. P. C., Schwantes, C. R., Rollins-Smith, L. A., … Gratwicke, B. (2011). Towards a better understanding of the use of probiotics for preventing chytridiomycosis in Panamanian golden frogs. *EcoHealth*, *8*, 501–506. https://doi.org/10.1007/s10393-012-0743-0

Biju, S. D., Kamei, R., Gower, D. J., & Wilkinson, M. (2009). *Conservation of Caecilians in the Eastern Himalayas Region*. CEPF and Conservation International, USA. https://www.cepf.net/sites/default/files/final_uofdelhi_caecilians_eastern_himalayas.pdf

Bishop, P. J., Angulo, A., Lewis, J. P., Moore, R. D., Rabb, G. B., & Garcia Moreno, J. (2012). The amphibian extinction crisis - what will it take to put the action into the Amphibian Conservation Action Plan? *S.A.P.I.EN.S*, *5*(2), 97–111.

Brito, D. (2010). Overcoming the Linnean shortfall: Data deficiency and biological survey priorities. *Basic and Applied Ecology*, *11*(8), 709–713. https://doi.org/10.1016/j.baae.2010.09.007

Brodie, S., Allen-Ankins, S., Towsey, M., Roe, P., & Schwarzkopf, L. (2020). Automated species identification of frog choruses in environmental recordings using acoustic indices. *Ecological Indicators*, *119*, 106852. https://doi.org/10.1016/j.ecolind.2020.106852

Brooks, J. S., Waylen, K. A. & Borgerhoff Mulder, M. (2012). How national context, project design, and local community characteristics influence success in community-based conservation projects. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(52), 21265–21270. https://doi.org/10.1073/pnas.1207141110

Brown, T. B., Hultine, K. R., Steltzer, H., Denny, E. G., Denslow, M. W., Granados, J., … Richardson, A. D. (2016). Using phenocams to monitor our changing Earth: toward a global phenocam network. *Frontiers in Ecology and the Environment*, *14*(2), 84–93. https://doi.org/10.1002/fee.1222

Burivalova, Z., Miteva, D., Salafsky, N., Butler, R. A., & Wilcove, D. S. (2019). Evidence types and trends in tropical forest conservation literature. *Trends in Ecology & Evolution*, *34*(7), 669–679. https://doi.org/10.1016/j.tree.2019.03.002

Buxton, R. T., Avery-Gomm, S., Hsein-Yung, L., Smith, P. A., Cooke, S. J., & Bennett, J. R. (2020). Half of resources in threatened species conservation plans are allocated to research and monitoring. *Nature Communications*, *11*(1), 4668. https://doi.org/10.1038/s41467-020-18486-6

Buxton, R. T., Nyboer, E. A., Pigeon, K. E., Raby, G. D., Rytwinski, T., Gallagher, A. J., … Roche, D. G. (2021). Avoiding wasted research resources in conservation science. *Conservation Science and Practice*, *3*(2), e329. https://doi.org/10.1111/csp2.329

Campbell Grant, E. H., Muths, E., Schmidt, B. R., & Petrovan, S. O. (2019). Amphibian conservation in the Anthropocene. *Biological Conservation*, *236*, 543–547. https://doi.org/10.1016/j.biocon.2019.03.003

Canessa, S., Ottonello, D., Rosa, G., Salvidio, S., Grasselli, E., & Oneto, F. (2019). Adaptive management of species recovery programs: A real-world application for an endangered amphibian. *Biological Conservation*, *236*, 202–210. https://doi.org/10.1016/j.biocon.2019.05.031

Canessa, S., Spitzen-van der Sluijs, A., Martel, A., & Pasmans, F. (2019). Mitigation of amphibian disease requires a stronger connection between research and management. *Biological Conservation*, *236*, 236–242. https://doi.org/10.1016/j.biocon.2019.05.030

Catenazzi, A. (2015). State of the world's amphibians. *Annual Review of Environment and Resources*, *40*, 91–119. https://doi.org/10.1146/

annurev-environ-102014-021358
Chavan, V. & Penev, L. (2011). The data paper: a mechanism to incentivize data publishing in biodiversity science. *BMC Bioinformatics*, *12*(Suppl 15), S2. https://doi.org/10.1186/1471-2105-12-S15-S2
Christie, A. P., Amano, T., Martin, P. A., Petrovan, S. O., Shackelford, G. E., Simmons, B. I., … Sutherland, W. J. (2020). Poor availability of context-specific evidence hampers decision-making in conservation. *Biological Conservation*, *248*, 108666. https://doi.org/10.1016/j.biocon.2020.108666
Clayton, D., Olson, D. H., Nauman, R. S., & Reilly, E. C. (2009). Managing for the Siskiyou Mountains salamander (*Plethodon stormi*) in fuel treatment areas around at-risk communities. In Deanna H. Olson, D. Clayton, R. S. Nauman, & H. H. Welsh Jr. (Eds.) *Conservation of the Siskiyou Mountains salamander (Plethodon stormi). Northwest Fauna 6* (pp. 39–42). Society for Northwestern Vertebrate Biology.
Collen, B., Dulvy, N. K., Gaston, K. J., Gärdenfors, U., Keith, D. A., Punt, A. E., … Akçakaya, H. R. (2016). Clarifying misconceptions of extinction risk assessment with the IUCN Red List. *Biology Letters*, *12*, 20150843. https://doi.org/10.1098/rsbl.2015.0843
Collen, B., Loh, J., Whitmee, S., McRae, L., Amin, R., & Baillie, J. E. M. (2009). Monitoring change in vertebrate abundance: the Living Planet Index. *Conservation Biology*, *23*(2), 317–327. https://doi.org/10.1111/j.1523-1739.2008.01117.x
Collen, B., Ram, M., Zamin, T., & Mcrae, L. (2008). The tropical biodiversity data gap: addressing disparity in global monitoring. *Tropical Conservation Science*, *1*(2), 75–88. https://doi.org/10.1177/194008290800100202
Connette, G. M. & Semlitsch, R. D. (2015). A multistate mark-recapture approach to estimating survival of PIT-tagged salamanders following timber harvest. *Journal of Applied Ecology*, *52*(5), 1316–1324. https://doi.org/10.1111/1365-2664.12472
Conservation Measures Partnership. (2020). *Open standards for the practice of conservation. Version 4.0*. https://conservationstandards.org/download-cs/
Costello, M. J., Michener, W. K., Gahegan, M., Zhang, Z., & Bourne, P. E. (2013). Biodiversity data should be published, cited, and peer reviewed. *Trends in Ecology & Evolution*, *28*(8), 454–461. https://doi.org/10.1016/j.tree.2013.05.002
Costello, M. J. & Wieczorek, J. (2014). Best practice for biodiversity data management and publication. *Biological Conservation*, *173*, 68–73. https://doi.org/10.1016/j.biocon.2013.10.018
Crump, M. L. (2015). Anuran reproductive modes: Evolving perspectives. *Journal of Herpetology*, *49*(1), 1–16. https://doi.org/10.1670/14-097
Cunningham, A. A., Lawson, B., Burton, M., & Thomas, R. (2008). *Addressing a threat to Caribbean amphibians: capacity building in Dominica. Darwin Initiative Final Report.* https://www.darwininitiative.org.uk/project/DAR13032/
da Silva, A. F., Malhado, A. C. M., Correia, R. A., Ladle, R. J., Vital, M. V. C., & Mott, T. (2020). Taxonomic bias in amphibian research: Are researchers responding to conservation need? *Journal for Nature Conservation*, *56*, 125829. https://doi.org/10.1016/j.jnc.2020.125829
Deichmann, J. L., Acevedo-Charry, O., Barclay, L., Burivalova, Z., Campos-Cerqueira, M., D'Horta, F., … Aide, T. (2018). It's time to listen: there is much to be learned from the sounds of tropical ecosystems. *Biotropica*, *50*(5), 713–718. https://doi.org/10.1111/btp.12593
Deichmann, J. L., Mulcahy, D. G., Vanthomme, H., Tobi, E., Wynn, A. H., Zimkus, B. M., & McDiarmid, R. W. (2017). How many species and under what names? Using DNA barcoding and GenBank data for west Central African amphibian conservation. *PLoS ONE*, *12*(11), e0187283. https://doi.org/10.1371/journal.pone.0187283
Deichmann, J. L., Sahley, C., Vargas, V., Chipana, O., Velasquez, W., Smith, E., … Catenazzi, A. (2013). Monitoring an endemic amphibian along a natural gas pipeline in the Peruvian Andes. *FrogLog*, *21*, 65–68.
DiRenzo, G. V, Che-Castaldo, C., Saunders, S. P., Campbell Grant, E. H., & Zipkin, E. F. (2019). Disease-structured N-mixture models: A practical guide to model disease dynamics using count data. *Ecology and Evolution*, *9*, 899–909. https://doi.org/10.1002/ece3.4849
Dodd, C. K. (2010). Amphibian ecology and conservation. *Oxford University Press Inc., New York*, 556. https://doi.org/10.1073/pnas.0703993104
Dorazio, R. M. (2014). Accounting for imperfect detection and survey bias in statistical analysis of presence-only data. *Global Ecology and Biogeography*, *23*(12), 1472–1484. https://doi.org/10.1111/geb.12216
Dornelas, M., Antão, L. H., Moyes, F., Bates, A. E., Magurran, A. E., Adam, D., Akhmetzhanova, A. A., Appeltans, W., Arcos, J. M., Arnold, H., Ayyappan, N., Badihi, G., Baird, A. H., Barbosa, M., Barreto, T. E., Bässler, C., Bellgrove, A., Belmaker, J., Benedetti-Cecchi, L., … Zettler, M. L. (2018). BioTIME: A database of biodiversity time series for the Anthropocene. *Global Ecology and Biogeography*, *27*(7), 760–786. https://doi.org/10.1111/geb.12729
Enge, K. M. (2001). The pitfalls of pitfall traps. *Journal of Herpetology*, *35*(3), 467–478. https://doi.org/10.2307/1565965
Forin-Wiart, M. A., Hubert, P., Sirguey, P., & Poulle, M.-L. (2015). Performance and accuracy of lightweight and low-cost GPS data loggers according to antenna positions, fix intervals, habitats and animal movements. *PLoS ONE*, *10*(6), e0129271. https://doi.org/10.1371/journal.pone.0129271
Frost, D. R. (2021). Amphibian species of the world: an online reference. Version 6.1. https://doi.org/doi.org/10.5531/db.vz.0001
Funk, W. C., Caminer, M. & Ron, S. R. (2012). High levels of cryptic species diversity uncovered in Amazonian frogs. *Proceedings of the Royal Society B*, *279*, 1806–1814. https://doi.org/10.1098/rspb.2011.1653
Gagliardo, R., Crump, P., Griffith, E., Mendelson, J., Ross, H., & Zippel, K. (2008). The principles of rapid response for amphibian conservation, using the programmes in Panama as an example. *International Zoo Yearbook*, *42*, 125–135. https://doi.org/10.1111/j.1748-1090.2008.00043.x
Garcia Fontes, S., Stanzani, S. L. & Pizzigatti Correa, P. L. (2015). A data mining framework for primary biodiversity data analysis. In A. Rocha, A. M. Correia, S. Costanzo, & L. P. Reis (Eds.) *New contributions in information systems and technologies* (pp. 813–821). Springer International Publishers. https://doi.org/10.1007/978-3-319-16486-1
Giam, X., Scheffers, B. R., Sodhi, N. S., Wilcove, D. S., Ceballos, G., & Ehrlich, P. R. (2012). Reservoirs of richness: least disturbed tropical forests are centres of undescribed species diversity. *Proceedings of the Royal Society B*, *279*, 67–76. https://doi.org/10.1098/rspb.2011.0433
Gillson, L., Biggs, H., Smit, I. P. J., Virah-Sawmy, M., & Rogers, K. (2019). Finding common ground between adaptive management and evidence-based approaches to biodiversity conservation. *Trends in Ecology & Evolution*, *34*(1), 31–44. https://doi.org/10.1016/j.tree.2018.10.003
González-del-Pliego, P., Freckleton, R. P., Edwards, D. P., Koo, M. S., Scheffers, B. R., Pyron, R. A., & Jetz, W. (2019). Phylogenetic and trait-based prediction of extinction risk for data-deficient amphibians. *Current Biology*, *29*(9), 1557-1563.e3. https://doi.org/10.1016/j.cub.2019.04.005
González-Maya, J. F., Belant, J. L., Wyatt, S. A., Schipper, J., Cardenal, J., Corrales, D., … Fischer, A. (2013). Renewing hope: The rediscovery of *Atelopus varius* in Costa Rica. *Amphibia Reptilia*, *34*(4), 573–578. https://doi.org/10.1163/15685381-00002910
Gower, D. J. & Wilkinson, M. (2005). Conservation biology of caecilian amphibians. *Conservation Biology*, *19*(1), 45–55. https://doi.org/10.1111/j.1523-1739.2005.00589.x
Guerra, V., Jardim, L., Llusia, D., Márquez, R., & Bastos, R. P. (2020). Knowledge status and trends in description of amphibian species in Brazil. *Ecological Indicators*, *118*, 106754. https://doi.org/10.1016/j.ecolind.2020.106754
Guimarães, M., Corrêa, D. T., Filho, S. S., Oliveira, T. A. L., Doherty Jr, P. F., & Sawaya, R. J. (2014). One step forward: contrasting the effects of Toe clipping and PIT tagging on frog survival and recapture probability. *Ecology and Evolution*, *4*(8), 1480–1490. https://doi.org/10.1002/ece3.1047
Haddad, C. F. B. & Prado, C. P. A. (2005). Reproductive modes in frogs and their unexpected diversity in the Atlantic Forest of Brazil. *BioScience*, *55*(3), 207–217. https://doi.org/10.1641/0006-3568(2005)055[0207:RMIFAT]2.0.CO;2
Hampton, S. E., Strasser, C. A., Tewksbury, J. J., Gram, W. K., Budden, A. E., Batcheller, A. L., … Porter, J. H. (2013). Big data and the future of ecology. *Frontiers in Ecology and the Environment*, *11*(3), 156–162. https://doi.org/10.1890/120103
Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L. C., & Foster, M. S. (1994). *Measuring and monitoring biological diversity: Standard methods for amphibians*. Smithsonian Institution Press: London; Washington.
Hill, A. P., Prince, P., Piña Covarrubias, E., Doncaster, C. P., Snaddon, J. L., & Rogers, A. (2018). AudioMoth: Evaluation of a smart open acoustic device for monitoring biodiversity and the environment.

Methods in Ecology and Evolution, *9*(5), 1199–1211. https://doi.org/10.1111/2041-210X.12955

Hobbs, M. T. & Brehme, C. S. (2017). An improved camera trap for amphibians, reptiles, small mammals, and large invertebrates. *PLoS ONE*, *12*(10), e0185026. https://doi.org/10.1371/journal.pone.0185026

Hobbs, R. J., Higgs, E. & Harris, J. A. (2009). Novel ecosystems: implications for conservation and restoration. *Trends in Ecology and Evolution*, *24*(11), 599–605. https://doi.org/10.1016/j.tree.2009.05.012

Hof, C., Araújo, M. B., Jetz, W., & Rahbek, C. (2011). Additive threats from pathogens, climate and land-use change for global amphibian diversity. *Nature*, *480*(7378), 516–521. https://doi.org/10.1038/nature10650

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T.M., Butchart, S.H.M., Carpenter, K.E., Chanson, J., Collen, B., Cox, N.A., Darwall, W.R.T., Dulvy, N.K., Harrison, L.R., Katariya, V., Pollock, C.M., Quader, S., Richman, N.I., Rodrigues, A.S.L., Tognelli, M.F., … Stuart, S.N. (2010). The impact of conservation on the status of the world's vertebrates. *Science*, *330*(6010), 1503–1509. https://doi.org/10.1126/science.1194442

Howell, P. E., R, H. B., Muths, E., Sigafus, B. H., & Chandler, R. B. (2020). Informing amphibian conservation efforts with abundance-based metapopulation models. *Herpetologica*, *76*(2), 240–250. https://doi.org/10.1655/0018-0831-76.2.240

Huang, X., Hawkins, B. A. & Qiao, G. (2013). Biodiversity data sharing: Will peer-reviewed data papers work? *BioScience*, *63*(1), 5–6. https://doi.org/10.1525/bio.2013.63.1.2

Hudson, M. A., Young, R. P., D'Urban Jackson, J., Orozco-Terwengel, P., Martin, L., James, A., … Cunningham, A. A. (2016). Dynamics and genetics of a disease-driven species decline to near extinction: Lessons for conservation. *Scientific Reports*, *6*, 1–13. https://doi.org/10.1038/srep30772

Hudson, M. A., Young, R. P., Lopez, J., Martin, L., Fenton, C., McCrea, R., … Cunningham, A. A. (2016). In -situ itraconazole treatment improves survival rate during an amphibian chytridiomycosis epidemic. *Biological Conservation*, *195*, 37–45. https://doi.org/10.1016/j.biocon.2015.12.041

IUCN. (2021). The IUCN Red List of Threatened Species. Version 2021-2. Retrieved March 30, 2021, from https://www.iucnredlist.org

Jetz, W. & Pyron, R. A. (2018). The interplay of past diversification and evolutionary isolation with present imperilment across the amphibian tree of life. *Nature Ecology & Evolution*, *2*, 850–858. https://doi.org/10.1038/s41559-018-0515-5

Koh, L. P. & Wich, S. A. (2012). Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. *Tropical Conservation Science*, *5*(2), 121–132.

La Marca, E., Lips, K. R., Lötters, S., Puschendorf, R., Ibáñez, R., Rueda-Almonacid, J. V., ... & Young, B. E. (2005). Catastrophic population declines and extinctions in Neotropical harlequin frogs (Bufonidae: Atelopus) 1. *Biotropica*, *37*(2), 190-201. https://doi.org/10.1111/j.1744-7429.2005.00026.x

La Salle, J., Williams, K. J. & Moritz, C. (2016). Biodiversity analysis in the digital era. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*, 20150337. https://doi.org/10.1098/rstb.2015.0337

Lennox, R. J., Aarestrup, K., Cooke, S. J., Cowley, P. D., Deng, Z. D., Fisk, A. T., Harcourt, R. G., Heupel, M., Hinch, S. G., Holland, K. N., Hussey, N. E., Iverson, S. J., Kessel, S. T., Kocik, J. F., Lucas, M. C., Flemming, J. M., Nguyen, V. M., Stokesbury, M. J. W., Vagle, S., … Young, N. (2017). Envisioning the future of aquatic animal tracking: technology, science, and application. *BioScience*, *67*(10), 884–896. https://doi.org/10.1093/biosci/bix098

Lindenmayer, D. B., Piggott, M. P. & Wintle, B. A. (2013). Counting the books while the library burns: why conservation monitoring programs need a plan for action. *Frontiers in Ecology and the Environment*, *11*(10), 549–555. https://doi.org/10.1890/120220

Lips, K. R. (1999). Mass mortality and population declines of anurans at an upland site in Western Panama. *Conservation Biology*, *13*(1), 117–125. https://doi.org/10.1046/j.1523-1739.1999.97185.x

Lips, K. R., Reeve, J. D. & Witters, L. R. (2003). Ecological traits predicting amphibian population declines in Central America. *Conservation Biology*, *17*(4), 1078–1088. https://doi.org/10.1046/j.1523-1739.2003.01623.x

Mace, G. M., Collar, N. J., Gaston, K. J., Hilton-Taylor, C., Akçakaya, H. R., Leader-Williams, N., … Stuart, S. N. (2008). Quantification of extinction risk: IUCN's system for classifying Threatened species. *Conservation Biology*, *22*(6), 1424–1442. https://doi.org/10.1111/j.1523-1739.2008.01044.x

MacKenzie, D. I. & Royle, J. A. (2005). Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology*, *42*, 1105–1114. https://doi.org/10.1111/j.1365-2664.2005.01098.x

Marquet, P. A., Lessmann, J. & Shaw, M. R. (2019). Protected-area management and climate change. In T. E. Lovejoy & L. Hannah (Eds.) *Biodiversity and climate change: Transforming the biosphere* (p. 283). Yale University Press. https://doi.org/10.12987/9780300241198-033

Martin, L., Morton, M. N., Hilton, G. M., Young, R. P., Garcia, G., Cunningham, A. A., … Mendes, S. (2007). *A Species Action Plan for the Montserrat mountain chicken Leptodactylus fallax*. Department of Environment, Montserrat. https://www.researchgate.net/publication/305281172_Species_Action_Plan_for_the_Mountain_Chicken_in_Montserrat

Martin, T. G., Nally, S., Burbidge, A. A., Arnall, S., Garnett, S. T., Hayward, M. W., … Possingham, H. P. (2012). Acting fast helps avoid extinction. *Conservation Letters*, *5*, 274–280. https://doi.org/10.1111/j.1755-263X.2012.00239.x

Marvin, D. C., Pin, L., Lynam, A. J., Wich, S., Davies, A. B., Krishnamurthy, R., … Asner, G. P. (2016). Integrating technologies for scalable ecology and conservation. *Global Ecology and Conservation*, *7*, 262–275. https://doi.org/10.1016/j.gecco.2016.07.002

McDonald-Madden, E., Baxter, P. W. J., Fuller, R. A., Martin, T. G., Game, E. T., Montambault, J., & Possingham, H. P. (2010). Monitoring does not always count. *Trends in Ecology and Evolution*, *25*(10), 547–550. https://doi.org/10.1016/j.tree.2010.07.002

McLeod, D. S. (2010). Of Least Concern? Systematics of a cryptic species complex: *Limnonectes kuhlii* (Amphibia: Anura: Dicroglossidae). *Molecular Phylogenetics and Evolution*, *56*(3), 991–1000. https://doi.org/10.1016/j.ympev.2010.04.004

Mead, L. S., Clayton, D. R., Nauman, R. S., Olson, D. H., & Pfrender, M. E. (2005). Newly discovered populations of salamanders from Siskiyou County California represent a species distinct from *Plethodon stormi*. *Herpetologica*, *61*(2), 158–177. https://doi.org/10.1655/03-86

Measey, G. J. (2006). Surveying biodiversity of soil herpetofauna: towards a standard quantitative methodology. *European Journal of Soil Biology*, *42*, S103-S110. https://doi.org/10.1016/j.ejsobi.2006.07.034

Measey, G. J., Stevenson, B. C., Scott, T., Altwegg, R., & Borchers, D. L. (2017). Counting chirps: acoustic monitoring of cryptic frogs. *Journal of Applied Ecology*, *54*(3), 894-902. https://doi.org/10.1111/1365-2664.12810

Mendenhall, C. D., Frishkoff, L. O., Santos-Barrera, G., Pacheco, J., Mesfun, E., Mendoza Quijano, F., … Pringle, R. M. (2014). Countryside biogeography of Neotropical reptiles and amphibians. *Ecology*, *95*(4), 856–870. https://doi.org/10.1890/12-2017.1

Menegon, M., Cantaloni, C., Rodriguez-Prieto, A., Centomo, C., Abdelfattah, A., Rossato, M., … Delledonne, M. (2017). On site DNA barcoding by nanopore sequencing. *PLoS ONE, 12*(10), e0184741. https://doi.org/10.1371/journal.pone.0184741

Molina, R., Marcot, B. G. & Lesher, R. (2006). Protecting rare, old-growth, forest-associated species under the survey and manage program guidelines of the Northwest Forest Plan. *Conservation Biology*, *20*(2), 306–318. https://doi.org/10.1111/j.1523-1739.2006.00386.x

Murray, A. H., Nowakowski, A. J. & Frichkoff, L. O. (2021). Climate and land-use change severity alter trait-based responses to habitat conversion. *Global Ecology and Biogeography*, *30*, 598–610. https://doi.org/10.1111/geb.13237

Nauman, R. S. & Olson, D. H. (1999). Survey and Manage salamander known sites. In D. H. Olson (Ed.) *Survey protocols for amphibians under the Survey and Manage provision of the Northwest Forest Plan. Version 3.0.* (pp. 43–78). Interagency publication of the Regional Ecosystem Office, Portland, OR. Bureau of Land Management Publication BLM/OR/WA/PT-00/033+1792; U.S. G.

Navarro, L. M., Fernández, N., Guerra, C., Guralnick, R., Kissling, W. D., Londoño, M. C., Muller-Karger, F., Turak, E., Balvanera, P., Costello, M. J., Delavaud, A., El Serafy, G. Y., Ferrier, S., Geijzendorffer, I, Geller, G. N., Jetz, W., Kim, E-S., Kim, H., Matin, C. S., … Pereira, H. M. (2017). Monitoring biodiversity change through effective global coordination. *Current Opinion in Environmental Sustainability*, *29*, 158–169. https://doi.org/10.1016/j.cosust.2018.02.005

Nowakowski, A. J. & Angulo, A. (2015). Targeted habitat protection and its effects on the extinction risk of threatened amphibians. *FrogLog*, *23 (4)* (116), 8–10.

Nowakowski, A. J. & Maerz, J. C. (2009). Estimation of larval stream salamander densities in three proximate streams in the Georgia Piedmont. *Journal of Herpetology*, *43*(3), 503–509. https://doi.org/10.1670/07-128R2.1

Nowakowski, A. J., Watling, J. I., Thompson, M. E., Brusch IV, G. A., Catenazzi, A., Whitfield, S. M., … Todd, B. D. (2018). Thermal biology mediates responses of amphibians and reptiles to habitat modification. *Ecology Letters*, *21*(3), 345–355. https://doi.org/10.1111/ele.12901

O'Donnell, R. P. & Durso, A. M. (2014). Harnessing the power of a global network of citizen herpetologists by improving citizen science databases. *Herpetological Review*, *45*(1), 151–157.

Olson, D. H., Clayton, D., Nauman, R. S., & Welsh Jr, H. (2009). *Conservation of the Siskiyou Mountains Salamander (Plethodon stormi). Northwest Fauna 6*. The Society for Northwestern Vertebrate Biology.

Olson, D. H. & Pilliod, D. S. (2021). Philosophy, authority, and strategic pragmatism of amphibian and reptile conservation. In S. C. Walls & K. M. O'Donnell (Eds.) *Strategies for conservation success in herpetology*. Society for the Study of Amphibians and Reptiles.

Olson, D. H., Van Norman, K. J. & Huff, R. D. (2007). *The utility of strategic surveys for rare and little-known species under the Northwest forest plan. General technical report PNW-GTR-708*. Portland.

Pimm, S. L., Alibhai, S., Bergl, R., Dehgan, A., Giri, C., Jewell, Z., … Loarie, S. (2015). Emerging technologies to conserve biodiversity. *Trends in Ecology & Evolution*, *30*(11), 685–696. https://doi.org/10.1016/j.tree.2015.08.008

Plard, F., Fay, R., Kéry, M., Cohas, A., & Schaub, M. (2019). Integrated population models: powerful methods to embed individual processes in population dynamics models. *Ecology*, *100*(6), e02715. https://doi.org/10.1002/ecy.2715

Pollock, K. H. (1982). A capture-recapture design robust to unequal probability of capture. *The Journal of Wildlife Management*, *46*(3), 752–757. https://doi.org/10.2307/3808568

Proença, V., Martin, L. J., Pereira, H. M., Fernandez, M., McRae, L., Belnap, J., … van Swaay, C. A. M. (2017). Global biodiversity monitoring: From data sources to Essential Biodiversity Variables. *Biological Conservation*, *213*, 256–263. https://doi.org/10.1016/j.biocon.2016.07.014

Pyron, R. A. & Wiens, J. J. (2011). A large-scale phylogeny of Amphibia including over 2800 species, and a revised classification of extant frogs, salamanders, and caecilians. *Molecular Phylogenetics and Evolution*, *61*, 543–583. https://doi.org/10.1016/j.ympev.2011.06.012

Redford, K. H., Hulvey, K. B., Williamson, M. A., & Schwartz, M. W. (2018). Assessment of the Conservation Measures Partnership's effort to improve conservation outcomes through adaptive management. *Conservation Biology*, *32*(4), 926–937. https://doi.org/10.1111/cobi.13077

Ribeiro-Júnior, M. A., Gardner, T. A. & Ávila-Pires, T. C. S. (2008). Evaluating the efectiveness of herpetofaunal sampling techniques across a gradient of habitat change in a tropical forest landscape. *Journal of Herpetology*, *42*(4), 733–749. https://doi.org/10.1670/07-097R3.1

Rice, W. S., Sowman, M. R. & Bavinck, M. (2020). Using Theory of Change to improve post-2020 conservation: A proposed framework and recommendations for use. *Conservation Science and Practice*, e301. https://doi.org/10.1111/csp2.301

Rodewald, A. D., Arcese, P., Sarra, J., Tobin-de la Puente, J., Sayer, J., Hawkins, F., … Wachowicz, K. (2020). *Innovative finance for conservation: Roles for ecologists and practitioners. Issues in Ecology Report No. 22*. Ecological Society of America. https://www.esa.org/wp-content/uploads/2020/11/ESA_IssuesInEcology_no.22.pdf

Rodrigues, A. S. L., Pilgrim, J. D., Lamoreux, J. F., Hoffmann, M., & Brooks, T. M. (2006). The value of the IUCN Red List for conservation. *Trends in Ecology and Evolution*, *21*(2), 71–76. https://doi.org/10.1016/j.tree.2005.10.010

Salafsky, N., Salzer, D., Stattersfield, A. J., Hilton-Taylor, C., Neugarten, R., Butchart, S. H. M., … Wilkie, D. (2008). A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. *Conservation Biology*, *22*(4), 897–911. https://doi.org/10.1111/j.1523-1739.2008.00937.x

Schleicher, J., Eklund, J., Barnes, M., Geldmann, J., Oldekop, J. A., & Jones, J. P. G. (2020). Statistical matching for conservation science. *Conservation Biology*, *34*(3), 538–549. https://doi.org/10.1111/cobi.13448

Schmeller, D. S., Arvanitidis, C., Böhm, M., Brummitt, N., Chatzinikolaou, E., Costello, M. J., … Belnap, J. (2017). Case studies of capacity building for biodiversity monitoring. In M. Walters & R. J. Scholes (Eds.) *The GEO handbook on biodiversity observation networks* (pp. 309–326). Springer Nature. https://doi.org/10.1007/978-3-319-27288-7

Schulze, A., Jansen, M. & Köhler, G. (2015). Tadpole diversity of Bolivia's lowland anuran communities: molecular identification, morphological characterisation, and ecological assignment. *Zootaxa*, *4016*(1).

Schwartz, M. W., Cook, C. N., Pressey, R. L., Pullin, A. S., Runge, M. C., Salafsky, N., … Williamson, M. A. (2018). Decision support frameworks and tools for conservation. *Conservation Letters*, *11*(2), e12385. https://doi.org/10.1111/conl.12385

Smith, R. K., Meredith, H. & Sutherland, W. J. (2018). Amphibian Conservation. In W. J. Sutherland, L. V. Dicks, N. Ockendon, S. O. Petrovan, & R. K. Smith (Eds.) *What Works in Conservation 2018* (pp. 9–66). Cambridge, UK: Open Book Publishers.

Snaddon, J., Petrokofsky, G., Jepson, P., & Willis, K. J. (2013). Biodiversity technologies: tools as change agents. *Biology Letters*, *9*, 20121029. https://doi.org/10.1098/rsbl.2012.1029

Stephens, K., Tolley, K. A. & da Silva, J. M. (2022). A decade of genetic monitoring reveals increased inbreeding for the Endangered western leopard toad, *Sclerophrys pantherina*. *Conservation Genetics*, *23*(5), 903-918. https://doi.org/10.1007/s10592-022-01463-5

Stephenson, P. J., Bowles-Newark, N., Regan, E., Stanwell-Smith, D., Diagana, M., Höft, R., Abarchi, H., Abrahamse, T., Akello, C., Allison, H., Banki, O., Batieno, B., Dieme, S., Domingos, A., Galt, R., Githaiga, C. W., Guindo, A. B., Hafashimana, D. L. N., Hirsch, T., … Thiombiano, A. (2017). Unblocking the flow of biodiversity data for decision-making in Africa. *Biological Conservation*, *213*, 355–340. https://doi.org/10.1016/j.biocon.2016.09.003

Sterrett, S. C., Katz, R. A., Brand, A. B., Fields, W. R., Dietrich, A. E., Hocking, D. J., … Campbell Grant, E. H. (2019). Proactive management of amphibians: Challenges and opportunities. *Biological Conservation*, *236*, 404–410. https://doi.org/10.1016/j.biocon.2019.05.057

Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L., & Waller, R. W. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, *306*(5702), 1783–1786. https://doi.org/10.1126/science.1103538

Sutherland, W. J., Pullin, A. S., Dolman, P. M., & Knight, T. M. (2004). The need for evidence-based conservation. *Trends in Ecology and Evolution*, *19*(6), 305–308. https://doi.org/10.1016/j.tree.2004.03.018

Suzuki, N., Olson, D. H. & Reilly, E. C. (2008). Developing landscape habitat models for rare amphibians with small geographic ranges: A case study of Siskiyou Mountains salamanders in the western USA. *Biodiversity and Conservation*, *17*(9), 2197–2218. https://doi.org/10.1007/s10531-007-9281-4

Tapley, B., Michaels, C. J., Gumbs, R., Böhm, M., Luedtke, J., Pearce-Kelly, P., & Rowley, J. J. L. (2018). The disparity between species description and conservation assessment: A case study in taxa with high rates of species discovery. *Biological Conservation*, *220*, 209–214. https://doi.org/10.1016/j.biocon.2018.01.022

Thomas, A. C., Howard, J., Nguyen, P. L., Seimon, T. A., & Goldberg, C. S. (2018). eDNA Sampler: A fully integrated environmental DNA sampling system. *Methods in Ecology and Evolution*, *9*(6), 1379–1385. https://doi.org/10.1111/2041-210X.12994

Toivonen, T., Heikinheimo, V., Fink, C., Hausmann, A., Hiippala, T., Järv, O., … Di Minin, E. (2019). Social media data for conservation science: A methodological overview. *Biological Conservation*, *233*, 298–315. https://doi.org/10.1016/j.biocon.2019.01.023

Urban, M. C., Bocedi, G., Hendry, A. P., Mihoub, J.-B., Pe'er, G., Singer, A., Bridle, J. R., Crozier, L. G., De Meester, L., Godsoe, W., Gonzalez, A., Hellmann, J. J., Holt, R. D., Huth, A., Johst, K., Krug, C. B., Leadley, P. W., Palmer, S. C. F., Pantel, J. H., … Travis, J. M. J. (2016). Improving the forecast for biodiversity under climate change. *Science*, *353*(6304), 1113. https://doi.org/10.1126/science.aad8466

Venter, O., Fuller, R. A., Segan, D. B., Carwardine, J., Brooks, T., Butchart, S. H. M., … Watson, J. E. M. (2014). Targeting global protected area expansion for imperiled biodiversity. *PLoS Biology*, *12*(6), e1001891. https://doi.org/10.1371/journal.pbio.1001891

Vieites, D. R., Wollenberg, K. C. & Andreone, F. (2009). Vast underestimation of Madagascar's biodiversity evidenced by an integrative amphibian inventory. *Proceedings of the National Academy of Sciences*, *106*(20), 8267–8272. https://doi.org/10.1073/pnas.0810821106

Walls, S. C. (2014). Identifying monitoring gaps for amphibian populations in a North American biodiversity hotspot, the southeastern USA. *Biodiversity and Conservation*, *23*, 3341–3357. https://doi.org/10.1007/s10531-014-0782-7

Wilson, K. A., Auerbach, N. A., Sam, K., Magini, A. G., Moss, A. S. L., Langhans, S. D., … Meijaard, E. (2016). Conservation research is not happening where it is most needed. *PLoS ONE*, *14*(3), e1002413. https://doi.org/10.1371/journal.pbio.1002413

Wright, A. D., Bernard, R. F., Mosher, B. A., O'Donnell, K. M., Braunagel, T., DiRenzo, G. V., … Campbell Grant, E. H. (2020). Moving from decision to action in conservation science. *Biological Conservation*, *249*, 108698. https://doi.org/10.1016/j.biocon.2020.108698

Xie, J., Towsey, M., Zhang, J., & Roe, P. (2016). Acoustic classification of Australian frogs based on enhanced features and machine learning algorithms. *Applied Acoustics*, *113*, 193–201. https://doi.org/10.1016/j.apacoust.2016.06.029

Zipkin, E. F., Thorson, J. T., See, K., Lynch, H. J., Grant, E. H. C., Kanno, Y., … Royle, J. A. (2014). Modeling structured population dynamics using data from unmarked individuals. *Ecology*, *95*(1), 22–29. https://doi.org/10.1890/13-1131.1

Zippel, K. (2002). Conserving the Panamanian Golden Frog: Proyecto Rana Dorada. *Herpetological Review*, Vol. 33, pp. 11–12.

Supplemental information

Table S1: Example amphibian survey and monitoring programmes

Programme	Partners	Objectives	Methods	Geography/ Time	References
Agile Frog	NGOs, Jersey zoo, Jersey government	Prevent the extinction of the agile frog in Jersey	Pond survey of adult frogs; tadpole release and monitoring	Jersey/late 1980-present	https://www.gov.je/Environment/LandMarine Wildlife/ColdBlooded/pages/frogs.aspx; Ward et al., 2016
Amphibian Research and Monitoring Initiative (ARMI)	US Dept. Interior, US Geological Survey; other US Depts., academia, States	Monitor amphibians on public lands and determine factors affecting their status	Diverse survey and research methods used	US-wide with a focus on US federal and state lands/2000 to present	Adams et al., 2013; ARMI, 2020 ; Grant et al., 2016
Atelopus Survival Initiative	National and international individuals, groups and institutions	Improve the conservation status of harlequin toads		Range-wide plan for the next 20 years (2021-2041)	https://www.atelopus.org/the-initiative
British Columbia, Canada amphibian conservation and restoration database	British Columbia Ministry of the Environment, Canada	Track amphibian conservation and restoration actions inclusive of inventory and monitoring programmes	Any	Any	Leigh Anne Isaac, Personal Communication (BC Ministry of Environment, herpetofaunal expert)
Corroboree Frog Recovery Program	Australian Government, Zoos, NGOs	Secure the survival of the northern and southern corroboree frog in Australia, annually monitor wild populations	Survey number of calling males	Alpines of New South Wales and the Australian Capital Territory/2003 to present	https://www.corroboreefrog.org.au/

Programme	Partners	Objectives	Methods	Geography/ Time	References
FrogID	Australian Museum	Understand the true species diversity, distribution and breeding habitats of Australian frogs	Anuran call surveys; citizen science	Australia/ 2017-2021	https://www.frogid.net.au/
Frogwatch USA	AZA		Citizen science; frog calls	US wide/1998-2014	www.aza.org/frogwatch
Golden Mantella	Malagasy NGOs, zoos	Address fundamental questions around species dispersion, migration and colonisation	Distribution, site occupancy, capture-mark-recapture	Mangabe-Ranomena-Sahasarotra New Protected Area, Madagascar/2012-present	Edwards et al., 2022; Piludu et al., 2015
Greater Yellowstone Inventory and Monitory Network's Amphibian Monitoring Program	US Dept. Interior, US National Park Service, US Geological Survey; academia	Annually monitor native amphibian species and their habitats across 300 wetland sites in 30 watershed units	Visual observations, Dip net surveys	Yellowstone National Park, Grant Teton National Park; Wyoming, USA/2005 to present	Gould et al., 2019; Hossack et al., 2015; Ray et al., 2016, 2020.
Idaho Amphibian and Reptile iNaturalist Project	Idaho State Univ. Herpetology Laboratory; iNaturalist; citizen scientists	Improve species occurrence and distribution data in Idaho by collecting observations using iNaturalist, a mobile application	Crowdsourcing (iNaturalist) observations and purposive surveys	Idaho, USA/2016 to present	Peterson, 2020
Long-Term Ecological Research Program (LTER or PELD)	Brazilian government, National Institute for Research in the Amazon	Establish permanent research sites integrated in a network for the development and monitoring of long-term ecological research	Temporal dynamics of amphibians; visual and acoustic surveys	PELD Amazon/ early 1990-present	https://ppbio.inpa.gov.br/
Mountain Chicken Recovery Programme	NGOs, zoo, academia, governments	To have healthy mountain chicken populations across their former year-2000 ranges on each of Montserrat and Dominica by 2034	Visual population surveys; screening the animals for disease	Montserrat and Dominica/2014-present	https://www.mountainchicken.org/

Programme	Partners	Objectives	Methods	Geography/ Time	References
National Amphibian Survey	NGOs, UK government, academia	Determine trends in the occurrence and relative abundance of frogs, toads and newts in the UK	Trapping; capture-mark-recapture; citizen science	UK wide/2007-present	https://amphibian-survey.arc-trust.org/
North American Amphibian Monitoring Program (NAAMP)	US Dept. Interior, Geological Survey, Citizen science, academia, States, NGOs	Monitor calling amphibian populations	Anuran call surveys from roads	Eastern and central USA/1997 to 2015	Cosentino et al., 2014; NAAMP, 2020; Villena Carpio et al., 2016
Ranita de Darwin	NGOs, zoo, academia, governments	Long-term monitoring of southern Darwin's frog (*Rhinoderma darwinii*) populations	Visual surveys; capture-recapture	4 sites across South Chile (Contulmo, Neltume, Chiloé, Melimoyu)/2014-present	https://www.ranitadedarwin.org/
Rescue of Endangered Venezuelan Amphibians (REVA)	ASA, Amphibian Ark, NGOs, Zoo	Monitoring and conservation strategies to rescue endangered species	Visual encounters; audio surveys; captive breeding; reintroductions	Venezuelan Andes/ 2018-present	https://revafrog.home.blog/
Sierra Nevada Amphibian Monitoring Program	US Dept. Agriculture, US Forest Service	Long-term multi-scale monitoring of amphibians on national forest lands in the Sierra Nevada	Randomised, unequal probability, rotating panel design; visual observations; capture-mark-recapture; egg mass surveys	Sierra Nevada Range, California: >2200 sites, 124 basins/2002 to 2009	Brown et al., 2012, 2013, 2014
US Dept. Defense Partners in Amphibian and Reptile Conservation (DoD PARC)	US Dept. Defense (Army, Air Force, Navy and Marine Corps)	Species inventory of 415 DoD properties (sites)	Literature, database searches; observations using variable methods	US-wide; 2013 to 2016	Petersen et al., 2018

Abbreviations: Dept: Department; Univ: University; NGOs: non-governmental organisations

Table S1 references:

Adams, M. J., Miller, D. A. W., Muths, E., Corn, P. S., Campbell Grant, E. H., Bailey, L. L., … Walls, S. C. (2013). Trends in amphibian occupancy in the United States. *PLoS ONE*, *8*(5), e64347. https://doi.org/10.1371/journal.pone.0064347

ARMI. (2020). Amphibian Research and Monitoring Initiative. US Geological Survey. Retrieved 18th January, 2021 from https://armi.usgs.gov/

Brown, C., Kiehl, K. & Wilkinson, L. (2012). Advantages of long-term, multi-scale monitoring: assessing the current status of the Yosemite toad

(*Anaxyrus (=Bufo) canorus*) in the Sierra Nevada, California, USA. *Herpetological Conservation and Biology*, *7*(2), 115–131.

Brown, C. & Olsen, A. R. (2013). Bioregional monitoring design and occupancy estimation for two Sierra Nevadan amphibian taxa. *Freshwater Science*, *32*(3), 675–691. https://doi.org/10.1899/11-168.1

Brown, C., Wilkinson, L. R. & Kiehl, K. B. (2014). Comparing the status of two sympatric amphibians in the Sierra Nevada, California: Insights on ecological risk and monitoring common species. *Journal of Herpetology*, *48*(1), 74–83. https://doi.org/10.1670/12-103

Campbell Grant, E. H., Miller, D. A. W., Schmidt, B. R., Adams, M. J., Amburgey, S. M., Chambert, T., Cruickshank, S. S., Fisher, R. N., Green, D. M., Hossack, B. R., Johnson, P. T. J., Joseph, M. B., Rittenhouse, T. A. G., Ryan, M. E., Waddle, J. H., Walls, S. C., Bailey, L. L., Fellers, G. M., Gorman, T. A., … Muths, E. (2016). Quantitative evidence for the effects of multiple drivers on continental-scale amphibian declines. *Scientific Reports*, *6*, 25625. https://doi.org/10.1038/srep25625

Chandler, R. B., Muths, E., Sigafus, B. H., Schwalbe, C. R., Jarchow, C. J., & Hossack, B. R. (2015). Spatial occupancy models for predicting metapopulation dynamics and viability following reintroduction. *Journal of Applied Ecology*, *52*(5), 1325–1333. https://doi.org/10.1111/1365-2664.12481

Cosentino, B. J., Marsh, D. M., Jones, K. S., Apodaca, J. J., Bates, C., Beach, J., Beard, K. H., Becklin, K., Bell, J. M., Crockett, C., Fawson, G., Fjelsted, J., Forys, E. A., Genet, K. S., Grover, M., Holmes, J., Indeck, K., Karraker, N. E., Kilpatrick, E. S., … Willey, A. (2014). Citizen science reveals widespread negative effects of roads on amphibian distributions. *Biological Conservation*, *180*, 31–38. https://doi.org/10.1016/j.biocon.2014.09.027

Edwards, W. M., Bungard, M. J., Rakotondrasoa, E. F., Razafindraibe, P., Andriantsimanarilafy, R. P., Razafimanahaka, J. H., & Griffiths, R. A. (2022). Predicted impact of climate change on the distribution of the Critically Endangered golden mantella (*Mantella aurantiaca*) in Madagascar. *Herpetological Journal, 32*, 5-13. https://doi.org/10.33256/32.1.513

Gould, W. R., Ray, A. M., Bailey, L. L., Thoma, D. P., Daley, R., & Legg, K. (2019). Multistate occupancy modeling improves understanding of amphibian breeding dynamics in the Greater Yellowstone Area. *Ecological Applications*, *29*(1), e01825. https://doi.org/10.1002/eap.1825

NAAMP. (2020). North American Amphibian Monitoring Program. US Geological Survey. Retrieved November 18, 2020 from https://www.usgs.gov/centers/eesc/science/north-american-amphibian-monitoring-program

Petersen, C. E., Lovich, R. E. & Stallings, S. (2018). Amphibians and reptiles of United States Department of Defense installations. *Herpetological Conservation and Biology*, *13*(3), 652–661.

Peterson, C. (2020). Using crowdsourced data for conservation: The Idaho Amphibian and Reptile iNaturalist Project. *Abstracts of the 9th World Congress of Herpetology, Dunedin, New Zealand*. Retrieved from https://web.archive.org/web/20200107102716/http://wchnz.com/wch2020/programme/programme

Piludu, N., Dubos, N., Razafimanahaka, J. H., Razafindraibe, P., Randrianantoandro, J. C., & Jenkins, R. K. (2015). Distribution, threats and conservation of a Critically Endangered amphibian (*Mantella aurantiaca*) in Eastern Madagascar. *Herpetology Notes*, *8*, 119-123.

Ray, A. M., Gould, W. R., Hossack, B. R., Sepulveda, A. J., Thoma, D. P., Patla, D. A., ... Al-Chokhachy, R. (2016). Influence of climate drivers on colonization and extinction dynamics of wetland- dependent species. *Ecosphere*, *7*(7), e01409. https://doi.org//10.1002/ecs2.1409

Ray, A. M., Patla, D. A. & Peterson, C. (2019). Taking the pulse of wetlands: What are we learning from the amphibian vital sign? *Yellowstone Science*, *27*(1), 52–54. https://www.nps.gov/articles/short-taking-the-pulse-of-wetlands.htm

Villena, O. C., Royle, J. A., Weir, L. A., Foreman, T. M., Gazenski, K. D., & Campbell Grant, E. H. (2016). Southeast regional and state trends in anuran occupancy from calling survey data (2001–2013) from the North American amphibian monitoring program. *Herpetological Conservation and Biology*, *11*(2), 373–385.

Ward, R., Liddiard, T., Goetz, M., & Griffiths, R. A. (2016). Head-starting, re-introduction and conservation management of the agile frog on Jersey, British Channel Isles. In: Soorae, P. S. (ed.) (2016). Global Re-introduction Perspectives: 2016. Case-studies from around the globe. Gland, Switzerland: IUCN/SSC Reintroduction Specialist Group and Abu Dhabi, UAE: Environment Agency-Abu Dhabi. xiv + 276 pp.

Automated audio recording unit © Jessica Deichmann

Researcher, Víctor Vargas García, monitoring high elevation amphibians, including the Acancocha water frog (*Telmatobius jelskii*) in the Peruvian Andes. This species is classified as Near Threatened on the Red List. © Jessica Deichmann