Forecast-based action for conservation

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Forecast-based action for conservation

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Abstract

Extreme weather events pose an immediate threat to biodiversity, but existing conservation strategies have limitations. Advances in meteorological forecasting and innovation in the humanitarian sector provide a possible solution—forecast-based action (FbA). The growth of ecological forecasting demonstrates the huge potential to anticipate conservation outcomes, but a lack of operational examples suggests a new approach is needed to translate forecasts into action. FbA provides such a framework, formalizing the use of meteorological forecasts to anticipate and mitigate the impacts of extreme weather. Based on experience from the humanitarian sector, I suggest how FbA could work in conservation, demonstrating key concepts using the theoretical example of heatwave impacts on sea turtle embryo mortality, and address likely challenges in realizing FbA for conservation, including establishing a financing mechanism, allocating funds to actions, and decision-making under uncertainty. FbA will demand changes in conservation research, practice, and governance. Researchers must increase efforts to understand the impacts of extreme weather at more immediate and actionable timescales and should coproduce forecasts of such impacts with practitioners. International conservation funders should establish systems to fund anticipatory actions based on uncertain forecasts.

KEYWORDS

anticipatory action, biodiversity, climate change, conservation, ecological forecasting, extreme weather, forecast-based action, humanitarian

Acciones para la conservación basadas en pronósticos

Resumen: Los eventos climáticos extremos representan una amenaza inmediata para la biodiversidad, pero las estrategias actuales de conservación tienen limitantes. Los avances en los pronósticos meteorológicos y la innovación en el sector humanitario proporcionan una solución posible: las acciones basadas en pronósticos (ABP). El aumento en pronósticos ecológicos demuestra un enorme potencial para anticiparse a los resultados de la conservación, pero la falta de ejemplos operativos sugiere que se necesita una nueva estrategia para transformar los pronósticos en acciones. Las acciones basadas en pronósticos proporcionan este marco que formaliza el uso de pronósticos meteorológicos para anticipar y mitigar impacto del clima extremo. Con base en la experiencia del sector humanitario, hago una sugerencia de cómo las ABP podrían funcionar para la conservación mediante la demostración de conceptos clave usando el ejemplo teórico del impacto de las olas de calor sobre la mortalidad embrionaria de las tortugas marinas. También abordo los posibles retos para la conservación mediante la realización de las ABP, incluidos el establecimiento de mecanismos de financiamiento, la asignación de fondos para las acciones y la toma de decisiones durante la incertidumbre. Las ABP exigirán cambios en los investigación, práctica y gestión de la conservación. Los investigadores deben incrementar sus esfuerzos para entender el impacto del clima extremo a escalas temporales más inmediatas y viables. También deberán coproducir con los practicantes los pronósticos de dichos impactos. Los financiadores de la conservación internacional deberán establecer sistemas para financiar las acciones anticipadas con base en pronósticos inciertos.

PALABRAS CLAVE

acción anticipada, acción basada en pronósticos, biodiversidad, cambio climático, clima extremo, conservación, humanitario, pronósticos ecológicos

INTRODUCTION

Climate change is set to become a major driver of biodiversity loss in the 21st century (Nunez et al., 2019; Pereira et al., 2010; Urban, 2015). Even under best-case scenarios, greenhouse gas emissions to date have already committed Earth to substantial climate change (IPCC, 2022; Solomon et al., 2009), meaning its impacts on biodiversity will at best prevail for decades to come.

Research into the effects of climate change on biodiversity has largely focused on the gradual response of species to incremental climate change over centennial time scales (Parmesan & Yohe, 2003; Tulloch et al., 2020). However, the role extreme weather events play in biodiversity loss is of growing concern; under climate change scenarios, the frequency and severity of extreme weather is projected to increase (Stott, 2016). In combination, the "press" of incremental climate change and "pulses" of extreme weather mean ecological thresholds, or tipping-points, are breached more often (Harris et al., 2018).

Existing conservation strategies to mitigate the impacts of extreme weather broadly fall into two categories: long-term resilience building and short-term disaster response. Long-term resilience-building strategies seek to secure sufficient habitat to act as refugia during extreme weather. This has largely been realized through the strengthening and expansion of the global protected areas network (Hannah, 2010). Short-term disaster response involves the rescue and rehabilitation of wildlife after an extreme weather event.

These existing strategies have limitations. The expansion of protected areas is chronically underfunded and raises ethical concerns around the marginalization of local communities. Further, uncertainties in climate projections pose a scientific challenge in accurately identifying habitats for protection in future climates (Stoklosa et al., 2015), and a reliance on correlative ecological models means many predictions are unreliable under novel conditions (although process-based approaches show promise [Briscoe et al., 2019; Maino et al., 2016]). For short-term disaster response, the problem is that by this point, most impacts have already been realized and significant losses of biodiversity may have already occurred. Further, emergency mobilization of people and resources following a disaster can be disproportionately costly.

A new approach is needed to help mitigate the impacts of extreme weather on biodiversity. This approach should focus on shorter, more immediate time frames to minimize the uncertainties associated with climate projections, should be anticipatory rather than responsive, and—given the limited funding available for biodiversity conservation—must be cost-effective (Tulloch et al., 2020). I believe that recent advances in subseasonal to seasonal (S2S) (from days to months) meteorological forecasting, together with innovation from the humanitarian sector, may provide such a solution.

Meteorological forecasts at S2S time scales now provide reliable early warnings of many extreme weather events (White et al., 2017), including flooding, drought, and cyclones (Alfieri et al., 2018; Boult et al., 2020; Emerton et al., 2020). Early warnings present a window of opportunity in which anticipatory actions, triggered by forecasts, can mitigate the impacts of extreme weather. In theory, preparing for, rather than responding to extreme weather not only lessens impacts, but also reduces the costs involved (Coughlan De Perez et al., 2015). Lessened impacts demand fewer total resources, and sourcing and mobilizing people and equipment in advance has cost-saving efficiencies over scrambling resources for rapid response in the aftermath of a disaster (Braman et al., 2013).

Recognizing the potential benefits of acting before an event occurs based on forecast information, actors in the humanitarian sector are moving toward such an anticipatory approach. The International Federation of Red Cross and Red Crescent Societies (hereafter, Red Cross), the world's largest humanitarian network, call this movement "forecast-based action" (FbA). Other humanitarian actors use different terminology, but the concept is broadly defined as:

> [the] use of climate or other forecasts to trigger funding and action prior to a shock or before acute impacts are felt, to reduce the impact on vulnerable people and their livelihoods, improve the effectiveness of emergency preparedness, response and recovery efforts, and reduce the humanitarian burden (Wilkinson et al., 2018).

I make a case for the adoption of FbA in conservation as a means to further mitigate the impacts of extreme weather on biodiversity. I considered how FbA complements current themes in conservation research and how the humanitarian FbA approach could be translated to better protect biodiversity from extreme weather. I provide a framework and a theoretical example.

FBA and Ecological Forecasting

In conservation, FbA aligns with recent calls for ecology to become more anticipatory (Bradford et al., 2018) and follows thinking established under the ecological forecasting movement. Ecological forecasting describes the process of predicting the state of populations, habitats, ecosystem services, and functions in response to scenarios of climate, land use, human population, technology, and economic activity, with fully specified uncertainties (Clark et al., 2001). By Clark et al.'s (2001) broad definition, a huge volume of ecological research could be classified as ecological forecasting. However, FbA specifically aligns with ecological forecasting as defined by Dietze et al. (2018).

In a call for more decision-relevant forecasts, Dietze et al. (2018) outline a narrower vision for ecological forecasting that draws from practices established in predictive fields, such as meteorology. This vision moves away from predictions at centennial timescales and instead focuses on more actionable S2S timescales. In doing so, forecasts not only become more decision-relevant, but near-term forecasting also allows for more rapid iteration and improvement of forecast products (Houlahan et al., 2017; Hudson et. al., 2017). To further support decision-making, Dietze et al. (2018) recommend that forecasts be probabilistic in order to capture uncertainties and should be coproduced by forecast producers and users so that the resulting product is tailored to decision-makers' needs to improve uptake and application.

For FbA to work effectively in conservation, there must be instances in which forecastable conservation impacts can be mitigated by anticipatory action (Hobday et al., 2018). The growth of ecological forecasting in the literature suggests that many ecological outcomes are indeed forecastable (Lewis et al., 2022) (Table 1). However, Tulloch et al. (2020) found that most ecological forecasts in Australia target impacts on production (agriculture) and human health, not conservation (also Table 1). Of those that focus on conservation, most consider impacts at centennial timescales, which, as previously discussed (Dietze et al., 2018), do not best represent management needs. The mismatch between existing ecological forecasts and management-relevant forecasts for conservation may be explained by a limited understanding of users' needs. Only 20% of ecological forecasting publications identify an end user (Lewis et al., 2022), demonstrating a clear need for a framework to standardize the development and implementation of conservation-relevant forecasts. This is, where I believe, FbA comes in.

APPLYING FA IN CONSERVATION

FbA complements ecological forecasting, providing a standardized framework by which ecological forecasts could be routinely translated into conservation action (Figure 1).

There are a number of practical and scientific considerations required to realize FbA in conservation. To aid understanding of the concepts presented here, I provide a theoretical example in which FbA is used to minimize the impacts of extreme heat on sea turtle embryo mortality. Sea turtles lay eggs in sandy beaches throughout the tropics. Nest temperatures determine hatching success (i.e., if temperatures exceed thermal tolerance limits, the developing embryos die) (Laloë et al., 2017). As climate change increases the frequency and severity of heatwaves, hatching success is expected to decline, threatening the survival of sea turtles.

Following the FbA approach (Figure 1), early warnings of extreme heat could be used to trigger early action to prevent nests overheating and minimize embryo mortality (Figure 2). First, identify risks: heatwaves occurring during incubation threaten hatching success.

Second, identify actions: a local charity targeting sea turtle conservation installs canopies to shade nests and prevent overheating and in extreme cases, excavates and artificially incubates eggs until hatching. These actions require time to assemble supplies and train personnel.

Third, identify forecasts: in collaboration with the conservation organization, forecast producers identify possible heatwave forecast products.

Fourth, hindcast evaluation: forecast producers evaluate the ability of forecasts to correctly identify heatwave events that cause sea turtle embryo mortality. Hindcast evaluation identifies forecast probability thresholds (i.e., degree of certainty that triggers action) and determines how often thresholds are likely to be breached and thus the frequency of triggering and costs of FbA over time. Forecasts with high uncertainty issued several months in advance can trigger the procurement and prepositioning of supplies, location of turtle nests, and training of required personnel, such that when the heatwave nears and forecasts become more certain, canopies can be installed or nests excavated rapidly.

Fifth, develop a protocol: forecasts, thresholds, actions, and responsibilities are documented in an early action protocol (EAP) that is submitted to a funding organization's advisory committee for approval (see below).

Sixth, monitor and take action: once approved, forecasts are monitored for breaches in the predefined thresholds, upon which, funds are automatically released to the conservation organization to install canopies or excavate nests.

Based on experiences in the humanitarian sector, FbA could be implemented in conservation. The humanitarian sector parallels conservation in several ways: humanitarian activities are challenge focused—including efforts to minimize impacts of extreme weather—and humanitarian actors have traditionally employed both long-term resilience building (often in the form of infrastructure development, e.g., flood defenses [Bischiniotis et al., 2020]) and short-term disaster response strategies to mitigate the impacts of extreme weather. As with establishing protected areas, infrastructure development relies on uncertain science to identify appropriate sites (Lawrence et al., 2013). Further, short-term humanitarian response risks impacts and expenses that could have been avoided given appropriate preparation (Braman et al., 2013).

TABLE 1 Examples of operational ecological forecasts

Forecast product	Type[a]	Early action	Availability	Reference
Bayesian state space model is used to forecast Brucellosis prevalence in Yellowstone bison several years into the future	explicit	Used to inform adaptive management decisions (hunting, culling, or vaccination) of Yellowstone bison to minimize the spread of Brucellosis to livestock.	not publicly available	Thompson Hobbs et al. (2015)
Flying-Fox Heat Stress Forecaster uses 72-h heatwave forecasts to identify camps where flying-foxes are likely to experience heat stress.	proxy	Email alerts direct human resources to camps at risk. Sprinklers are used to cool camps and flying-foxes which have fallen to the ground are rescued.	https://www.animalecologylab.org/ff-heat-stress-forecaster.html	Ratnayake et al. (2019)
GrassCast uses seasonal precipitation forecasts to predict rangeland productivity across the Great Plains and southwest United States.	proxy	GrassCast is used to guide the management of livestock grazing, but could equally be used to infer the conservation implications of varying rangeland productivity.	https://grasscast.unl.edu/	Hartman et al. (2020)
The Food and Agriculture Organizations's Desert Locust Watch combines meteorological forecasts with monitoring data (location and abundance) to predict the movement trajectories and development rates of locusts in the Horn of Africa.	proxy	Management of locusts is hindered by the vast areas over which surveillance is required. The Desert Locust Watch helps to identify at-risk regions so that monitoring and management efforts can be better targeted.	http://www.fao.org/ag/locusts/	Cressman (2013)
Monitoring of the Oceanic Niño Index and Atlantic Multidecadal Oscillation can indicate Amazonian fire season severity 3–5 months in advance.	proxy	Advance information about fire risk provides time to appropriately allocate fire-fighting resources or implement targeted burning restrictions.	https://www.ess.uci.edu/~amazonfirerisk/	Chen et al. (2011)
NOAA use a hydrodynamic model incorporating satellite imagery and wind direction to forecast harmful algal blooms in the coming days at a number of locations across the United States.	proxy	Algal blooms can kill marine species, cause shellfish poisoning (making shellfish harmful to eat), and may induce respiratory irritation in people. NOAA's early warnings allow health officials to close beaches and shellfish beds, and issue advice to nearby residents.	https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-forecasts/	Wynne et al. (2013)
Coral Reef Watch uses the Predictive Ocean Atmosphere Model for Australia to forecast seasonal sea surface temperatures and potential coral bleaching events up to 2 months ahead of time.	proxy	Advanced warning of bleaching events allows for the prepositioning of management and monitoring equipment, implementation of management strategies (limiting other stressors, e.g., pollution, sedimentation, and fishing), and the collection of data.	https://coralreefwatch.noaa.gov/satellite/bleachingoutlook_cfs/	Spillman et al. (2013)
The U.S. National Phenology Network use temperature forecasts and growing degree day models to predict when economically important insects and invasive plants will reach critical life stages.	proxy	Phenological models allow the timing of management activities to coincide with peak organism susceptibility, reducing chemical use, saving time and money, and minimizing nontarget impacts.	https://www.usanpn.org/data/forecasts/	Crimmins et al. (2020)

[a]For definition of forecast types, see main text ("Forecast Types").

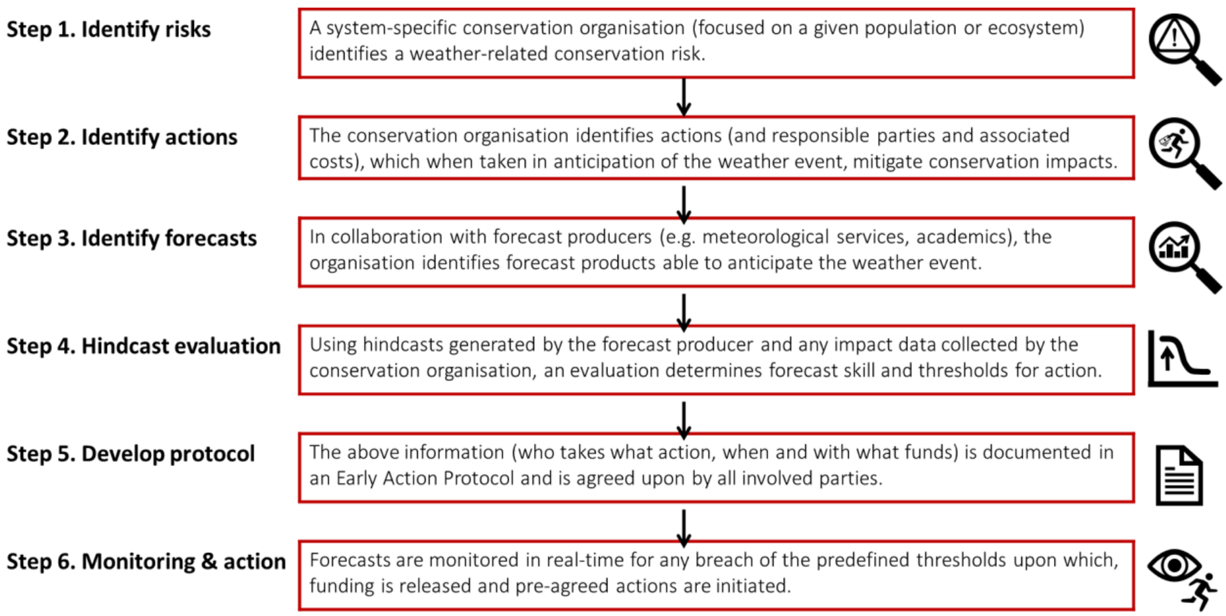

FIGURE 1 The development of forecast-based action in conservation: translating forecasts into conservation action.

FIGURE 2 A theoretical example of forecast-based action applied to sea turtle conservation. Early warnings of temperatures exceeding thermal tolerance limits of developing sea turtle embryos trigger deployment of resources and personnel to protect nests. Canopies are installed to shade nests and prevent overheating or eggs are excavated and artificially incubated until hatching. Graphic by Cara Gallagher, based on Red Cross media.

Establishing a Funding Mechanism

A fundamental challenge for FbA is raising funds before impacts occur to allow for anticipatory action. Instead of responding to emergency appeals in the aftermath of a disaster, donors are instead asked to provide support based on uncertain forecasts of future impact.

For the Red Cross, this meant extending the scope of their long-established Disaster Relief Emergency Fund (DREF), which was initially set up to provide immediate financial support for the Red Cross's National Societies in the aftermath of a disaster. In 2017, the DREF was extended to include "FbA by the DREF," a dedicated (funds earmarked to support only FbA, rather than responsive action), sustainable (no donations predesignated, so funds can be used where needed), and scalable (fundraising is scaled up for FbA in line with the expected mainstreaming of the approach) financial mechanism to fund FbA.

A comparable financial mechanism is required to support FbA in conservation. Although individual, system-specific conservation organizations (hereafter, the implementing organization) could establish their own FbA financing solutions, an international, cross-organizational approach is preferable in order to prepare for extreme weather that transcends national boundaries and has multispecies impacts and to ensure that funds are available wherever needed, regardless of the financial means of affected countries or organizations. For instance, although a charity targeting turtle conservation in Turkey could establish their own FbA fund, in the event that a heatwave affects multiple species across the Mediterranean basin, having cross-organizational oversight would prevent the duplication of efforts, allow identification of gaps, and likely prove more cost-effective.

Potential organizations to host the fund (hereafter, the host organization) should be international in scope and respected enough to draw significant and growing investment. The host organization must be committed to providing ongoing financial support to a given program (as opposed to time-limited, project grants) because the FbA approach inherently demands a long-term perspective to demonstrate benefits (MacLeod et al., 2021). As such, the host should seek to diversify conservation donors, drawing investment from public and private sectors to avoid economic shocks that affect government allocation and tourism (Fletcher et al., 2020) and would otherwise limit the implementation of FbA.

From Funds to Action

Once a funding mechanism is established, the next challenge is to allocate funds to anticipatory action. Access to the Red Cross's FbA by the DREF depends on the approval of an EAP. These protocols are developed by Red Cross National Societies for a particular hazard. For instance, the Mozambique Red Cross Society has two approved EAPs, one for tropical cyclones and one for flooding, and another in development for drought (IFRC, 2021). An EAP defines "who takes action when, where and with what funds" (Wilkinson et al., 2018). This includes details on the forecast products used, trigger thresholds for action, what actions will be taken, and who is responsible. Upon approval of an EAP by the Red Cross's advisory group (see below), the release of funds for anticipatory action is guaranteed (i.e., not dependent on a decision-making process) and automatic (i.e., once a trigger threshold is breached, funds are released to the implementing national society), preventing potential delays.

A comparable process would be required in conservation, formalizing the allocation of funds from the host organization to the implementing organization (Figure 3). The host organization should establish guidelines for the development and submission of conservation EAPs. Implementing organizations, such as the local turtle conservation charity, could subsequently propose EAPs for consideration by the host organization's advisory group. Following the Red Cross's model, the advisory group should include a scientific advisory committee, which provides advice on the latest scientific developments in forecasting and risk analysis to ensure the EAP is efficient and credible, and a validation committee, which assesses the EAP for coherence with other disaster management activities, cost-effectiveness, and alignment with strategic priorities.

Conservation EAPs could target a single species, community, or area and may vary in spatial extent from local to national or regional scales, depending on the scope and capacity of the implementing organization. The funding requested should reflect the scale and severity of the conservation impacts the EAP aims to mitigate.

Once the EAP has been approved by the advisory group, funds should be released to the implementing organization upon any breach of the trigger thresholds to allow for rapid implementation of the agreed anticipatory actions. All EAPs should be subject to periodic review by the advisory group to ensure they reflect the latest advances in forecasting and continue to address the most urgent conservation challenges posed by extreme weather.

Following the humanitarian model, multiple host organizations may offer funding for FbA in conservation; each host supports multiple implementing organizations and each implementing organization potentially proposes a number of EAPs targeting different conservation risks.

Forecast Types

Operational ecological forecasts fall into two broad categories: those that explicitly forecast an ecological quantity, often through the use of a process-based model, and proxy forecasts that rely on meteorological forecasts as a proxy for ecological outcomes (Table 1).

Explicit ecological forecasting is comparable to impact-based forecasting in the humanitarian sector. Impact-based forecasting focuses on what the weather will do, rather than what the weather will be. It aims to directly forecast the impacts of extreme weather in order to allow for more targeted interventions (ARRCC et al., 2020). Impact-based forecasting often depends on process-based or machine learning approaches to anticipate impacts, but it is hindered by the poor availability of accurate impact data (Boult et al., 2022).

A similar challenge exists for explicit ecological forecasting. For many ecological systems, continuous monitoring data of ecological quantities are unavailable. This limits the development and validation of data-hungry process-based models to a limited number of well-studied systems (Boult & Evans, 2021).

Conversely, continuous, long-term meteorological data are widely available, and, as a result, proxy ecological forecasts exist for a broad range of systems (Table 1). For example, 72-h heatwave forecasts predict heat stress in flying foxes (*Pteropus* spp.) in Australia (Ratnayake et al., 2019), and the National Oceanographic and Atmospheric Administration's Coral Reef Watch uses seasonal sea surface temperate forecasts to anticipate coral bleaching events on the Great Barrier Reef (Spillman et al., 2013). However, by their nature, proxy data are further removed from the conservation outcome, and their use may introduce additional uncertainty in decision-making.

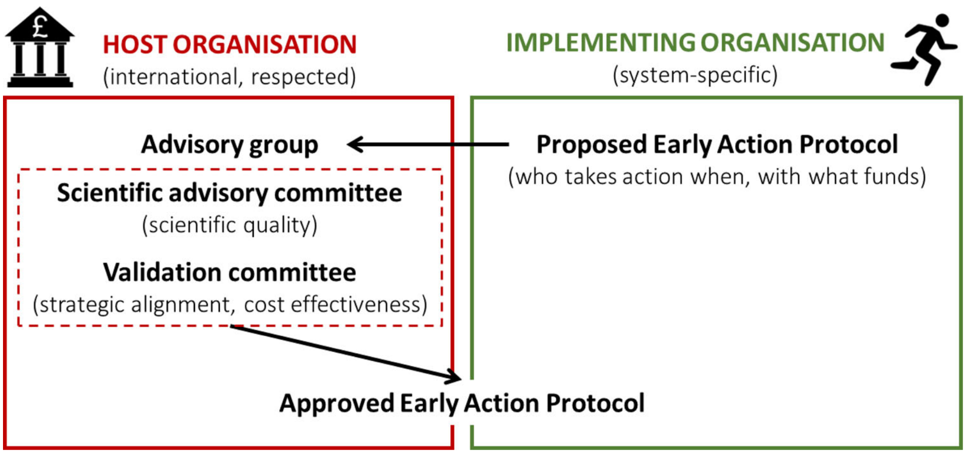

FIGURE 3 Framework for assigning funds to forecast-based action (FbA) in conservation. The host organization raises funds and distributes them to implementing organizations for FbA, dependent on the approval of an early action protocol (EAP). The implementing organization submits their proposed EAP to the host organization's advisory committee. The scientific advisory committee assess the EAP for scientific credibility and the validation committee consider how the EAP aligns with conservation priorities and existing activities. Once approved, the EAP becomes a joint agreement between the host and implementing organization.

Choosing whether to pursue an explicit ecological forecast or use a proxy depends on the availability of ecological data and the skill of proxy forecasts (i.e., the ability of a forecast product to correctly delineate the occurrence of a hazard). Often, proxy forecasts based on simple meteorological thresholds may be sufficient to anticipate the impacts of extreme weather and improve conservation outcomes (Bradford et al., 2018). In other situations, particularly those in which the relationship between extreme weather and conservation outcomes is complex, data collection should be prioritized to allow for the development of explicit forecasts.

In the case of sea turtle embryo mortality, a lack of data on long-term hatching success prevents the development of an explicit forecast, but air temperature data are widely available. The relationship between air temperature and sand temperature is well understood (Laloë et al., 2014) and thus these temperatures can be used as proxies for heat-induced embryo mortality.

Action Amisdt Uncertainty

The future is uncertain and even the best forecasts can be wrong. Using forecasts to inform anticipatory action, therefore, presents four possible outcomes: forecasted event occurs (hit), forecasted event does not occur (false alarm), event occurs but was not forecasted (miss), and no event occurs and no event was forecasted (correct negative). Misses may result in negative impacts that could have been prevented with anticipatory action, whereas false alarms can mean resources are unnecessarily depleted (Coughlan De Perez et al., 2015). Interventions triggered by false alarms may also negatively affect conservation outcomes if there is a risk associated with intervention (e.g., excavating turtle nests results in the mortality of some embryos). Moreover, incorrect delineation of extreme weather threatens the credibility of the FbA program and may deter potential future donations.

Uncertainties arise through a number of aspects of FbA systems. First, each forecast product has different skill in correctly identifying the occurrence of a disaster that depends on the underlying forecast methodology, data used, and assumptions made. Moreover, skill can vary regionally and between seasons (Boult et al., 2020). The skill of a given forecast can be measured using a number of categorical verification scores; the false-alarm rate is most commonly applied in humanitarian FbA (Coughlan De Perez et al., 2015). Second, uncertainty is introduced in the identification of thresholds for action. Triggering anticipatory action requires defining a danger-level threshold (e.g., nest temperatures above 33°C [Laloë et al., 2014]) and the probability of occurrence threshold (e.g., a 60% probability that the danger-level threshold will be breached). Third, there is a trade-off between increasing the lead time in which a forecast is issued to allow for a greater range of anticipatory actions and the risk of a false alarm because uncertainty increases with lead time (Bischiniotis et al., 2019).

Another source of uncertainty, rarely discussed in humanitarian FbA, is that associated with the effectiveness of actions. In conservation, anticipatory actions for a given risk may be unclear or untested, introducing further uncertainty. However, implementing organizations are best placed to identify appropriate actions and, in some instances, are already undertaking these actions under resilience-building initiatives (in which case, FbA helps target these activities at times or locations of most need). If appropriate actions are unknown, implementing organizations may find guidance through Conservation Evidence (Sutherland et al., 2019).

Uncertainty has the potential to confound the use of ecological forecasts (Houlahan et al., 2017), but in the humanitarian sector, the collaboration between humanitarian actors, forecast producers, and meteorological scientists helps in the navigation of uncertainty.

A promising approach used to align forecasts (and their associated uncertainties) with anticipatory actions is action-based forecasting (Coughlan De Perez et al., 2016). Rather than choosing actions based on the skill of forecasts, action-based forecasting flips this approach. Humanitarian actors begin by identifying anticipatory actions for an extreme event. For each action, local decision-makers define the lead time required for each action and their willingness to act in vain (false-alarm rate). The lead time and false-alarm rate provide the criteria against which to assess possible forecast products and trigger thresholds. Where forecasts present more uncertainty (due to low skill or longer lead times), they are used to trigger low-cost, low-regret actions.

In the turtle example, the procurement of supplies and training of personnel represent low-cost, low-regret actions, by which I mean, if these actions are triggered by a false alarm, supplies and trained personnel will not be wasted because they will be prepared for a subsequent heatwave. Conversely, installing canopies and excavating nests are high-cost, high-regret actions because the costs of deployment cannot be recuperated. High-cost, high-regret actions should, therefore, only be triggered with a high degree of forecast certainty. Currently under consideration in the humanitarian sector is the use of multiple trigger windows to account for varying forecast uncertainties and differing risks associated with actions. So, although triggering the installation of canopies and excavation of nests based on long-lead seasonal temperature forecasts presents high uncertainty and a greater risk of acting in vain, these forecasts could trigger the procurement and training of personnel. Then, when short-lead heatwave forecasts identify the spatial and temporal extent of heatwaves with greater certainty, supplies and personnel can be rapidly deployed.

Following the action-based forecasting approach—determining the lead time required for each action (i.e., procurement and training may take several weeks, whereas canopies can be installed in a day) and the willingness to act in vain—may prove useful in conservation, particularly in cases for which sufficient monitoring and impact data are unavailable (Boult et al., 2022). Working together with forecasting experts and decision scientists to coproduce EAPs that carefully align anticipatory actions with forecast thresholds, accounting for uncertainties and potential conservation risks associated with intervention, will help realize FbA in conservation.

CONCLUSION

FbA provides a framework through which forecasts can be translated into anticipatory conservation action and has the potential to make conservation planning more actionable, reduce the impacts of extreme weather on biodiversity, and improve the cost-effectiveness of conservation spending.

Although there will be many instances in which FbA cannot mitigate the impacts of extreme weather on biodiversity, either because forecast skill is insufficient at the required lead times or because anticipatory actions are not feasible, FbA provides an additional tool in conservation's arsenal against climate change, complementing existing long-term resilience-building approaches and minimizing the need for short-term disaster response.

Realizing FbA in conservation will require a change of practice by researchers, practitioners, and funders. More research is required into the impacts of extreme weather and climate change at more immediate, S2S time scales, and researchers should seek to coproduce conservation-relevant forecasts alongside practitioners to better meet decision-making needs. Practitioners should consider how conservation outcomes and spending may be improved if forecasts were used to trigger or direct anticipatory action. Often, this may not mean implementing novel actions or training new personnel, but rather directing existing activities and resources to locations or times of greatest risk.

Initially, I recommend a small number of demonstration projects targeting a range of species, regions, and hazards. Based on experiences gained through pilot projects, potential host organizations should explore the establishment of financial mechanisms to support FbA. Regardless of whether FbA as outlined here is adopted across the sector, long-term investment is required to support the development of conservation-relevant forecasts and to establish anticipatory conservation action programs (though I argue that FbA provides a standardized framework to do this) to better protect biodiversity from the effects of increasingly frequent and severe extreme weather events.

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