Beware the lone killer

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Why are harlequin frogs disappearing across the American tropics? A resifting of the evidence backs up the conclusion that global warming is a key conspirator in the losses.

Around the world, amphibians are vanishing, even from seemingly pristine areas — and among the factors that studies have tied to the disappearances are disease and climate change. Because of the climate link, frogs have become a symbol of extinction risk from global warming, their charm radiating hauntingly from front covers of magazines and newspapers from *Nature* and *Newsweek* to *The Washington Post* and *The New York Times*, their urgent message reaching millions. Awareness of the frogs' plight and its significance increased in January 2006, when we and a dozen colleagues presented evidence that climate change is loading the dice for disease outbreaks leading to disappearances of harlequin frogs (the genus *Atelopus*) across Central and South America[1]. A new study by Lips *et al.*[2], however, has challenged this link, claiming instead that the dramatic losses can be chalked up to what the authors say is a lone killer: the chytrid fungus *Batrachochytrium dendrobatidis*. Is there, as one journalist suggested, a "cautionary tale"[3] here about leaving behind the caveats pertaining to scientific findings while their definitive elements continue to reverberate? We think not. Resifting the evidence in this "scientific equivalent of the board game Clue"[4], we deduce that global warming is a key factor in the extinction crisis.

Just as viewers of the 1985 comedy film version of Clue saw different endings depending on the theatre they attended, readers who want to know why harlequin frogs are vanishing find different answers depending on the journal article they peruse. In the board game, known as Cluedo in Europe, the cards defining the answer to a murder mystery are kept in a secret case-file envelope, and the players trying to crack the case move about the rooms of a Gothic mansion in search of clues. The science in the case of the missing harlequin frogs, like this board game, involves deductive reasoning and dice rolling. But the scientists use computers, of course, to roll the dice tens of thousands of times. Following such an approach, we found that the disappearances of harlequin frogs have come on the heels of unusually warm years much more often than chance alone would dictate[1,5]. Disagreeing with this result, Lips *et al.* have shown their cards[2].

But in this game the stakes are high for everyone. What matters is not who the winner is, but what the truth is about why the frogs are vanishing. Global warming has long been a suspect in the disappearances, and it may conspire with various other culprits, such as landscape alteration, pollution and the presence of exotic species[5]. The science, therefore, must go beyond the game of Clue, in which only a single killer is identified. Around the world, climate change is stirring up ecology in diverse ways, amplifying the risk of extinction for many plants and animals, and threatening the integrity of the living systems that are vital to human well-being[6].

Humanity must decide whether this is a crisis in the here and now, demanding prompt action, or just a nebulous problem for the future. Some experts fear that the unvarnished truth will frighten people into inaction. We believe that the facts, combined with an inspiring vision of the solutions, can transform wait-and-see attitudes into cries for action. Journalistic balancing acts such as talk of a new "climate centrism"[7] are among the most dangerous games ever invented. If the frogs, who do not give a croak about the left or the right, had a voice in the matter, they would not sing praise to a false middle ground.

L A COLOMA

Onore's harlequin frog (*Atelopus onorei*) of the Andes mountains in Ecuador is among the scores of *Atelopus* species that have vanished in recent decades[1].

MULTIPLE SUSPECTS

Does the case of the missing harlequin frogs attest to the urgency of reducing greenhouse gas concentrations? Sifting through the evidence in the case, we consider existing clues as we search for new ones. We follow the game of Clue in spirit, but we go beyond it as well, visiting several 'mansions' far from the American tropics (by secret-passage travel, of course, to reduce our carbon footprint). As in the game, we also watch the other players to see where they go and where they do not go.

According to the paradigm put forward by Lips *et al.* the chytrid fungus operates alone, invading healthy amphibian communities and causing immediate die-offs, irrespective of changes in the physical environment. But had they taken account of some clues from Australia[8], they might have questioned whether this is the whole story. Frogs in Queensland experienced increasing developmental instability,

which is evidence of stress, at least two years before they suffered chytrid-related declines. What's more, the major die-offs there coincided with dramatic regional warming that mirrored the global trend.

Clues from Italy again imply that the chytrid is not a lone killer[9]. Findings from Umbria, which Lips *et al.* also disregarded, indicate that this fungus was common in frogs, in a previously unknown form that did not cause disease, for at least several years before it flared up in an epidemic of chytridiomycosis. And when it did, during the 2003 heat wave, a parasitic mesomycetozoean protist, *Amphibiocystidium ranae*, also went on the march in the same host populations. This observation agrees with the evidence that shifting climatic conditions may give an edge to various frog pathogens[5,9].

Likewise, other studies that we cited in a brief overview[5] point to climate change as an important factor in the amphibian crisis. Lips *et al.* however, paid them no heed. For instance, data from the south of England show that rising temperatures are degrading toads' body condition, along with their reproductive success and survivorship[10]. This finding, which hints at an increasing susceptibility to disease, has been called a "smoking gun"[11] for the impacts of global warming on amphibians.

Is there danger in the air? As Sherlock Holmes said in "The Adventure of the Speckled Band", "We have not a moment to lose." Departing the area where the toads were studied[10], which lies just north of the chalky Purbeck Hills in south Dorset, and not far from where Clue originated, we head northeast to Cambridge.

Arriving there, we go to the library that houses the work of Lips *et al.* The study is also freely available online[2]. But regardless of how one accesses it, beware deception by the seemingly obvious. Some of the moves in a game of Clue may confound the other players — making them believe, for example, that a certain card is in the secret envelope when actually it is not. Even the most intelligent players can become confused.

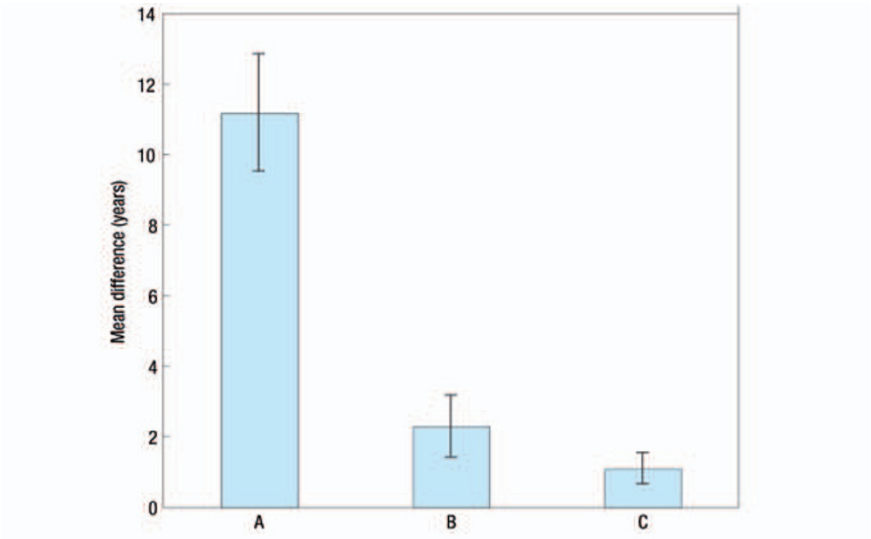

Figure 1 Mean difference between the reported date of decline of each harlequin frog species and the last year in which it was observed. The three means (A–C) are for three different data sets adapted from Table 1 of Lips *et al.*[2]; error bars show standard error. Lips *et al.* claimed that a large time gap (A) revealed a great deal of sampling error in data representing the last year of observation of the various species. The use of last observations, however, is appropriate only for species that have disappeared. For this subset of species, the mean difference is relatively small (B), and it is even smaller after some striking errors in Table 1 are corrected (C).

Lips *et al.* were soon called out[12], however, for violating a sacred rule of deductive logic: avoid circularity. Hypothesizing that the chytrid's arrival spells immediate doom for many harlequin frogs, the authors used the estimated date of their decline to infer when the chytrid arrived at the various places that have been studied. They envisaged these shock-and-awe arrivals as a consequence of the microbe's introduction in several places, followed in each case by a wavelike spread, which they mapped by simply adding smaller waves until the patterns made sense. The result is an untested, and perhaps untestable, model of pathogen spread, and only one of various possibilities. Contrary to the authors' claims, this colourful montage demonstrates nothing.

CARTOONBOOK

1949 first edition of Clue.

And even if the chytrid is spreading in a wavelike fashion, what does this tell us? Who can say that such dynamics are incompatible with the occurrence of climate-linked epidemics? Indeed, researchers studying the ebola virus in Africa have found evidence for both kinds of patterns[13]. Because a wavelike spread does not necessarily indicate a lone killer, Lips *et al.* may be "riding the wave"[2] to the wrong conclusion.

FALSE ACQUITTAL

As we continue our search in the library, something odd makes its presence known. And it is not the smoke of strong Indian cigars — the starting point of an important clue in "The Adventure of the Speckled Band". In this case, the evaluation of our analyses by Lips *et al.* does not smell quite right.

The authors claimed to refute the link between unusually warm years and frog disappearances: by adding random error to the data, they said, they were able to make the patterns go away[2]. It was quickly pointed out, however, that this approach is invalid[12]. By adding enough error to the relevant data, one could make some of the most harmful things on Earth appear harmless — even the energy policies of the Bush administration.

Lips *et al.* added error to data indicating the year in which each frog species was observed for the last time. We had used these data as an index of the timing of sudden population declines leading to disappearances, and we found that large-scale temperature tended to peak the year before the last observation[1,5]. Lips *et al.* argued, however, that the declines often took place long beforehand, and they used this to justify their addition of error. Examining, for such cases, data that they presented in their Table 1, they calculated an average gap of 11.2 years between the estimated date of decline and the last year of observation.

This suggestion is astonishing from a biological standpoint. Irrespective of the paradigm that one embraces, the recent catastrophic declines have often led to rapid disappearances. Species with small geographic ranges, which are especially vulnerable to extinction and account for a large proportion of the missing harlequin frogs, should therefore be expected to disappear quickly. So why would they often still persist more than a decade after such a catastrophe?

The answer is that they generally do not. Lips *et al.* erred in their calculations, in part because they included species that, by their own criteria, have not gone missing. We explicitly focused on disappearances[1]. Although some of the species that still survive have indeed declined seriously, one cannot assume that all of the reported declines are equally catastrophic and due to the same causes. And most significantly, the last year of observation of a species that is still surviving tells us little other than when researchers last visited its habitat.

In our original paper[1], we repeated the analysis, adding the species that had declined severely and had gone missing for five years or more but were later rediscovered in small numbers. Substituting, for these species, the last year in which each was observed before it disappeared temporarily, we again found a tendency for the disappearances to follow unusually warm years.

The focus by Lips *et al.* on a set of species that is inappropriate to the task at hand explains most, but not all, of the erroneous 11.2-year gap (Fig. 1). Another part of this false discrepancy reflects some large errors in their Table 1. We have not fully reviewed the data in this Table . In many cases, their origin is mysterious, even when they supposedly came from our own publications. Nevertheless, some of the errors are striking. For example, Costa Rica's Central Cordillera harlequin frog (*Atelopus senex*) was seen for the last time in 1986, yet Lips *et al.* claimed that it was found as recently as 2004. Perhaps Professor Plum, who in the *Clue* book series was notoriously absent-minded, would have done no better.

So what happens when a player makes a false accusation? In the present case, this means laying the blame on the chytrid fungus and calling for the acquittal of global warming without sound basis. According to the official rules of Clue, that player is sidelined for the rest of the game. But plenty remains to be investigated, and Lips and colleagues have done some valuable detective work in the past — showing, for example, that the chytrid does belong in the line-up wherever frogs go missing. We would therefore be willing to waive the rules (but not let the wave rule) if Lips *et al.* concede that this fungus is not a lone killer and that climate change, along with several other forms of environmental deterioration, is a key factor in many cases.

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