Alarming consequences of ocean acidification

Meghan Miner Murray

Among the most horrifying consequences of anthropogenic climate change is the slow seep of CO_2 that is gradually turning oceans into a caustic soup. The topic of ocean acidification (OA) has come into public discourse only in the past 15 years, and new research continues to hone in on how these chemical reactions could play out.

Scientists in Michigan and Canada recently modeled deep ocean currents and found the calcium-rich seafloor, thought to be an important buffer against OA, is already beginning to dissolve at rates reflective of human-induced CO_2 levels (*P Natl Acad Sci USA* 2018; doi.org/10.1073/pnas.1804250115). These changes murk up an otherwise unperturbed and understudied ecosystem but also are slowly erasing important records. "Some climatic information is stored within these deep-sea sediments", explains lead author Olivier Sulpis (McGill University; Montreal, Canada). "If they dissolve, we're losing this information as well."

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Ocean acidification complicates recovery of already dwindling stocks of commercially valuable cod.

In Europe, commercially important and already-declining populations of young European eels (*Anguilla anguilla*) could lose their ability to find their way to rivers, an essential part of their life cycle. Tiago Grilo (MARE; Cascais, Portugal), lead author of a recent study on eel migration, says their disorientation is probably the result of an olfactory disruption mechanism related to OA (*Biol Lett* 2019; doi.org/10.1098/rsbl.2018.0627).

Tiny, 10-mm-long Atlantic cod larvae (*Gadus morhua*), one of the most commercially valuable and carefully regulated species in the North Atlantic, show some disturbing physiological changes given varying food availability under OA conditions (*Glob Change Biol* 2018; doi.org/10.1111/gcb.14554). Stressed fish seem to adapt by developing larger, stronger skeletons, but they also have weakened gills and organs, which could signal future trouble. Study coauthor Catriona Clemmesen-Bockelmann (GEOMAR Helmholtz Centre for Ocean Research; Kiel, Germany) says, "You have to look at several different responses on different levels in the cod larvae to really know what's going on".

Francis Chan, an Oregon State University (Corvallis, OR) researcher who studies OA exposure and impacts along the US West Coast, and who was not involved in any of the above studies, comments, "I see this grouping of work as an example of OA science '3.0'…1.0 was about this global problem, getting people to realize the chemistry is actually changing. And then 2.0 was kind of this rapid response: 'Does it matter biologically?' Now, I think some of these studies are dialing into the things that people actually care about: 'Does OA pose a reasonable threat?' And this is really important because I think decision makers are demanding – they need – ways to calibrate how big of a priority this is."

Canada's species recovery plans lack Indigenous involvement

Niki Wilson

Canada has laws and policies that require land managers to consult with Indigenous Peoples on recovery efforts for imperiled species. At the risk assessment stage, the Species at Risk Act (SARA) provides clear guidelines on how to involve Indigenous Peoples. However, according to a new study, when it comes to developing federal recovery plans that identify how to arrest or reverse the decline of species, there are no similarly clear consultation criteria, and this may affect the level of involvement of Indigenous Peoples (*Environ Sci Policy* 2019; doi.org/10.1016/j.envsci.2019.01.017).

Lead author Cassandra Hill (Carleton University; Ottawa, Canada) applied a six-point scoring system to all recovery documents written between 2006 and 2017 for species designated as threatened, endangered, or of special concern under SARA. A score of zero indicated no observable Indigenous participation, whereas high-level involvement, like coauthorship, scored a five. Scoring accuracy was tested with 10 randomly selected document authors. The resulting dataset was subject to a multi-step elimination process in which, for example, cases where Indigenous Peoples had declined involvement were removed from further statistical analysis.

Fifty-two percent of all recovery documents received a score of zero, whereas only 6.5% of documents received a score of five. Documents for species in Alberta, Saskatchewan, Manitoba, and Quebec had lower scores than those in other regions. Scores were also lower for taxa like mosses, arthropods, and amphibians, as opposed to iconic and economically valuable taxa like fish and mammals. Documents created by the Department of Fisheries and Oceans had higher scores than those authored by Parks Canada and Environment and Climate Change Canada.

Hill and her colleagues suggest many reasons why Indigenous Peoples may not be involved in species recovery plans, such as issues around manpower, obstacles to sharing knowledge, and a lack of trust due to previously insufficient consultations. The authors make "clear and achievable recommendations" to improve future consultation and tracking, says ethnoecologist Jonaki Bhattacharyya of the University of Victoria (Victoria, Canada), who works with Indigenous Peoples on land-relationship planning. According to Hill, recommendations include "the need for specific guidelines on how to involve Indigenous Peoples [as well as] more transparency as to how people were included in the [formation] of the documents".

Brazil's poisoned river

Richard Kemeny

While rescue workers continue to excavate bodies from the toxic mud released by the catastrophic collapse of a tailings dam near Brumadinho, Brazil, the chemical-laced sediment is creeping down the Paraopeba River, slowly and indiscriminately killing all life within. The environmental legacy of the country's second major dam collapse in just 3 years will be profound and long-lasting, and its true extent may not be known for years.

On the morning of January 25, almost 12 million cubic meters of mining refuse breached the dam and tore into the surrounding area at over 70 km per hour. The initial surge wiped out over 112 hectares of native forest, around half of which were in environmentally protected areas. The sludge soaked into the land and flowed into the Paraopeba, where it continues to travel downstream.

Videos released shortly after the event showed fish dying on river banks, flapping around in dark orange mud. A recent report from SOS Mata Atlântica (São Paulo, Brazil), an environmental NGO, documented low levels of dissolved oxygen and worrying amounts of toxicity in the river. Concentrations of certain metals such as manganese, chromium, and copper far exceeded what is considered safe by legislation. The state government has banned the use of the water. "The fact is that biological life, for at least 300 [river] kilometers, is eliminated", says Adriano Paglia, a professor of ecology at the Federal University of Minas Gerais (UFMG; Belo Horizonte, Brazil).

The affected stretch of the Paraopeba "is an important source of water for all sorts of flora and fauna, beyond just fish and aquatic species", Paglia continues. "Various species of birds, amphibians, even mammals, which at some point approach the water to hunt and feed, have already gone. That's what we expect." Researchers from UFMG are now trying to determine how much of the wildlife has vanished and what impact this might have. Under the difficult conditions, progress is slow.

The state-sponsored geological service Geociências do Serviço Geológico do Brasil (CPRM; Belo Horizonte, Brazil) is also monitoring the river. Regular rainfall has caused pulses in river discharge, helping to push the sediment along. Daily bulletins report the slow but steady progress of the effluent toward the Retiro Baixo hydroelectric dam, the outflow of which drains into the major São Francisco River. Paglia says that although the dam will likely halt the bulk of the sediment, he ultimately doesn't trust that it will stop it all. The monitoring continues.

Snails nibbling on seedlings may shape forests

Jake Buehler

In temperate forests, the most recognizable herbivores are large mammals like deer, or perhaps seasonal armies of caterpillars that devour young leaves. These animals have a visible impact on forest plant communities, but new research suggests that forests may also be modified by woefully underestimated actors: snails (*J Ecol* 2019; doi.org/10.1111/1365-2745.13150).

Giant trees like oak and ash start as vulnerable seedlings that may fall victim to snails, the forest's most unassuming vegetarians. After observing an accumulation of these mollusks in the seedling-rich aftermath of a forest fire, Claudia Stein (Auburn University at Montgomery; Montgomery, AL) investigated the dietary preferences of seedling-eating snails and their ecological influence. Stein and her colleagues took understory western

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Neohelix alleni feeding on a tree-of-heaven seedling.

whitelip snails (*Neohelix alleni*) from Ozark oak–hickory woodlands in Missouri and offered them the leaves of seedlings from six local tree and shrub species. The researchers gauged relative preference by weighing the leaves before and after snail exposure. The snails clearly preferred tree-of-heaven (*Ailanthus altissima*), the only invasive species offered.

To see if the snails' preferences translated to impacts on live seedlings, the team set up a field-based experiment. They planted seedlings of the six species in grids that either had special fencing (excluding or retaining snails) or were open to the forest. They also excluded or allowed deer access. After a year, the team looked at how the plants were faring. They found that the snails' palates influenced seedling establishment, with the three preferred species having higher biomass in the absence of snails. Deer had a negligible impact. The scientists also observed that, in surrounding forest, the plants the snails preferred were also low in number, perhaps due to this selective grazing. More research is needed, but if snails keep certain seedling populations low, fewer of those trees may reach full size. "I think our results truly suggest that snails – by shaping the seedling community – have an effect on forest composition", comments Stein.

Stein explains that previous work has revealed how snails modify grassland ecosystems, but this is the first examination of their role in forest settings. Next, she wants to see if native snails prefer native or invasive plants, and if similar feeding impacts exist in different forest ecosystems.

Reality check for Australia's species recovery plans

Virginia Gewin

Australia's species recovery plans need to address seemingly intractable problems, such as habitat destruction and climate change, to effectively prevent extinctions, say the authors of two new papers. A policy piece (*Conserv Lett* 2019; doi.org/10.1111/conl.12633) calls into question the most high-profile goal of Australia's 2015 Threatened Species Strategy – to cull two million feral cats (*Felis catus*) by 2020 – that, the authors argue, relies on a weak scientific basis. No reliable estimate of the number of feral cats existed when the target was set; furthermore, it's difficult to accurately measure the number of cats killed, and the target hasn't been linked to any expected measurable increases in threatened species populations.

Killing cats runs the risk of distracting attention away from other threats to biodiversity, especially widespread and ongoing habitat loss, says lead author Tim Doherty, a conservation ecologist at Deakin University (Melbourne, Australia).

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Feral cats are a problem, but species recovery plans must focus on habitat loss and climate change too.

"We acknowledge cats are a big problem, but we need to be looking at all threats and have a more holistic, balanced conservation approach", he urges. For example, he points out, the focus on feral cats does nothing to help threatened invertebrates or fish.

Any realistic species conservation plan must also tackle climate change. In a recent study (*Conserv Biol* 2018; doi.org/10.1111/cobi.13270), scientists reviewed 100 recovery plans for Australian terrestrial threatened species – 50 flora and 50 fauna – and found that 57 plans listed climate change as a current or potential threat. Only 22 identified recovery actions to address climate change-specific risks. Reintroduction, translocation, or assisted colonization was recommended in 36 recovery plans, but only four specified that the actions may be necessary to counter climate change-related threats.

In addition to more funding, there needs to be a national strategy to implement evidence-based actions in the field, monitor recovery efforts, and update recovery plans accordingly, says Malin Hoeppner, a conservation biologist at Macquarie University (Sydney, Australia). Take the Bramble Cay melomys (*Melomys rubicola*), a small rodent, recently declared extinct, that lived on an atoll north of Australia and was the first documented mammal extinction attributed to anthropogenic climate change. A recovery plan for the species was published in 2008 but offered no strategies to reduce the climate threats.

While the 2015 Threatened Species Strategy is the closest thing to a national strategy at the moment, there is no accountability or coordination among responsible parties, explains Hoeppner. "Many recovery teams are doing excellent work but there are a lot of threatened species – so many that [some], especially the smaller species, are being forgotten", she adds.

Medical journals tackle health and climate change

Jennie Dusheck

The impact of global warming on the health, survival, and population dynamics of plants and animals has hardly escaped the notice of journals that cover ecological topics. Medical journals have been slower to address the likely consequences of catastrophic climate change on human health.

But physicians are jumping into the fray. In 2017, the medical journal *The Lancet* launched *The Lancet Planetary Health*, an open-access journal that publishes research at the interface of human health and the living and physical environment. This February, *The British Medical Journal* (*BMJ*) joined in, inviting authors to submit articles for a special series on human health in the age of climate change.

In an editorial titled "Challenges for health in the Anthropocene epoch", *BMJ* invited submissions for a series of papers – in *BMJ*, *BMJ Open*, and *BMJ Global Health* – that will be published between September and December of 2019 (doi.org/10.1136/bmj.l460).

Pauline Scheelbeek, assistant professor of nutritional and environmental epidemiology at the London School of Hygiene and Tropical Medicine (London, UK), one of three authors of the editorial, noted the timeliness of the series in an email interview. Scientific understanding of how the environment affects human health is growing rapidly. But, she noted, "in terms of more pragmatic, 'on the ground' implementation (eg what a GP could recommend to their patients, etc), there is still a lot of ground to cover".

According to Scheelbeek and her coauthors, protecting human health involves keeping planetary conditions within a "safe operating space". Solutions, they wrote, include increasing the resilience of populations to catastrophic changes by implementing early warning systems for extreme heat, floods, and infectious disease outbreaks, as well as designing water, sanitation, and other infrastructure to withstand extreme events.

The *BMJ* series also comes in the midst of a widely acknowledged global health transition from communicable diseases to non-communicable diseases (NCDs). In the view of experts such as those at the World Health Organization, environmental contributors like air pollution are the major drivers of heart and lung diseases (https://bit.ly/2UdJb5u). In 2016, air pollution caused 5.6 million deaths from NCDs; it was the primary risk factor for all NCDs in many parts of the world, and second only to tobacco smoke in others.

Millions for mining gold without mercury

Adrian Burton

A US$180-million program was launched February 18 with the aim of reducing the use of mercury in artisanal and small-scale (A/SS) gold mining. Financed by the Global Environment Facility (GEF; Washington, DC) – a partnership founded in 1992 between member nations, international institutions, civil society organizations, and the private sector to address global environmental issues and assist nations in delivering sustainable development initiatives – the Global Opportunities for the Long-term Development of the Artisanal and Small-scale Gold Mining Sector program aims to facilitate A/SS miners' access to mercury-free gold extraction technologies. This should not only help safeguard their health but also reduce the serious environmental damage caused by mercury-based gold extraction methods.

Some 15 million people work in the A/SS mining sector, mostly in low-income countries. Although responsible for one-fifth of the world's gold supply, they usually make a humble living selling the small amounts of gold they extract. This process commonly involves mixing gold-containing soil with mercury to form a gold–mercury amalgam, which is then heated to vaporize the mercury, leaving the gold behind. This is the largest of all mercury emissions sources and puts some 1000 tons of the toxin into the air every year. Liquid mercury also reaches rivers and groundwater, which poisons ecosystems, drinking water, and food sources. Large-scale mining operations have not used mercury for decades but the technologies employed – and there are several – remain beyond the financial reach of most A/SS miners. The new fund will help them acquire the necessary hardware. "One objective of [the program] is to support miners' access to finance through a number of potential models such as revolving fund loans, loan guarantees, and working with existing national and local banks. This will ensure miners have the capital they need to get new mercury-free technologies", explains Gustavo Fonseca, GEF Director of Programs.

The new program will also work with the political and commercial institutions of partnering African, Asian, and South American nations to promote miners' rights and safety, and improve their access to gold markets. "The program will connect miners to markets through partnerships with refiners, jewelers, banks, and other end-users of gold", continues Fonseca. "Cutting out the middle man means better profits for miners."

"The health effects of mercury on miners and their families can be staggering", says Louisa Esdaile (Flinders University; Adelaide, Australia). "Mercury pollution is causing health and environmental crises in many areas. Anything that moves [A/SS] gold mining toward other extraction methods is very welcome."

Leaving ground cover saves amphibians

Lesley Evans Ogden

Amphibians are in trouble globally, and over 80% of species in rapid decline depend on forest habitats. Yet less than a quarter of the Earth's forest landscapes have escaped clearing, alteration, or fragmentation effects. Clear-cutting is well known to contribute to amphibian declines, but less frequently discussed are the repercussions of replanting. How do plantation forests affect amphibians? New research experimentally investigated this question in a tract of Florida's Withlacoochee State Forest (*Ecol Appl* 2019; doi.org/10.1002/eap.1870).

Lead author Christopher Haggerty (University of South Florida; Tampa, FL) and his two colleagues built 30 experimental enclosures, placing 10 in each of three forest types that had been cut in the past. In pine plantation, partially regenerated pine forest, and fully regenerated pine forest, Haggerty's team tested the influence of ground cover microhabitat on desiccation risk, behavior, and survival of over 900 juvenile Southern toads (*Anaxyrus terrestris*). They released the toads into the center of the cross-shaped enclosures and observed where they went, what habitats they selected, and how well they survived.

C Haggerty

Runway enclosure for testing toad microhabitat selection, situated in fully regenerated pine forest.

What they discovered is that toads' 24-hour desiccation rates and 72-hour mortality rates were significantly higher in the pine plantation than in naturally regenerated pine forest. They attributed these increased drying and mortality rates to lower measured soil moisture.

In a naturally regenerating system, Haggerty says, "the canopy tends to remain relatively open, which encourages growth for herbaceous plants". In high-intensity silviculture, roller chopping and scalping eliminate this shrubby ground cover, drying out the upper layer of soil. "Ground cover in forests may be more important to juvenile amphibians than the canopy", he says, and these results may help us to better understand and mitigate drought-related declines in other amphibians like the imperiled striped newt (*Notophthalmus perstriatus*). Retaining patches of ground cover within highly managed forests may provide refugia for amphibians threatened by the warming and drying effects of climate change.

Dan Greenberg (Simon Fraser University; Burnaby, Canada), a doctoral amphibian researcher unaffiliated with the study, says there are "a bucket-load of papers" on the effects of habitat modification on amphibians but few that dig into the mechanisms and microenvironment. According to Greenberg, that makes this paper, which takes a ground-level frog's eye view, "quite cool".

Guitar industry could change its tune to sustainability

Ken Ferguson

Acoustic guitar players often claim that the best-sounding instruments are made of exotic woods – hardwoods that primarily grow in tropical regions – but perhaps less well known among guitarists is that many of these species are increasingly overexploited in their native ranges. However, new findings suggest that exotics used in guitar making could be replaced with more sustainable substitutes without diminishing tonal appeal (*J Acoust Soc Am* 2018; doi.org/10.1121/1.5084735). "Historically, some of the finest high-end guitars were made of exotic woods, which were still plentiful up to about the first half of the 20th century", explains Samuele Carcagno, a senior research associate at Lancaster University (Lancaster, UK) and the lead author of the study. "This very likely helped build their reputation as acoustically 'superior' woods, even though the acoustic qualities of these high-end guitars may have been due to other factors."

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The backs and sides of the six guitars used in the trials were constructed of different woods.

To test the role of back/side-plate wood type on acoustic guitar sound quality, Roger Bucknall, a coauthor of the study and renowned UK luthier, built six identical acoustic guitars, three with back/side plates made of different exotic hardwoods and three made of common hardwoods. Fifty-two experienced acoustic guitar players were then asked to evaluate each of the guitars and rate them based on factors like sound quality and playability while wearing welder's goggles to prevent visual identification of the instruments. Analysis of the evaluations revealed that the guitarists were unable to discern any substantial differences in sound quality among the guitars, indicating that, in some aspects of guitar construction at least, sustainable woods could conceivably be substituted for exotics with minimal effects on an instrument's acoustic properties.

"The impact that the guitar industry has on endangered woods is small compared to that of others, such as the furniture industry, and even if we could convince all guitar buyers to opt for alternative and sustainable woods the direct impact on deforestation would be relatively minor", notes Carcagno, "but an increased awareness of the issue of endangered woods in our society could motivate people to make more critical choices when buying not only guitars but also other products that may impact endangered woods, and to motivate policy makers to enact regulations to protect these species."

Interior proposes "streamlining" information requests

Tom Oates

On December 28, the US Department of the Interior (DOI) announced, in the Federal Register, proposed revisions to its regulations implementing the Freedom of Information Act (FOIA). "The proposed rule was published between Christmas and New Year's, during the government shutdown [December 22 to January 25], with a public comment period set to end on January 28", says Meg Townsend of The Center for Biological Diversity (Portland, OR). "We weren't able to reach anybody [at DOI] with questions, and the timing in itself was suspect", she continues. "It was an added challenge because they didn't include text of the proposed rule. They just outlined what the changes would be. And even still, nobody has been able to get a straight answer about the timeline for the final rule."

Passed by Congress in 1967, FOIA mandates transparency in the US federal government. Each agency is empowered to develop its own regulations to implement FOIA, with the Office of Information Policy at the Department of Justice providing guidance to fully comply with the letter and the spirit of the law.

DOI's proposed revisions were prompted by an "unprecedented surge in FOIA requests and litigation" since 2016, exacerbated by increased legal action resulting from DOI's non-response to initial FOIA requests. The revisions would give DOI the ability to deny requests it deems "unreasonably burdensome" and to impose new standards for compliance and charging of fees. "A lot of the language is very vague. It makes what had been pretty clear, pretty opaque", adds Townsend.

"I'm concerned because [the proposed changes claim to] streamline burdensome FOIA requests", says Kevin Emmerich of Basin & Range Watch (Beatty, NV). "Even before this, it's already been difficult to get the Bureau of Land Management [BLM; an agency within DOI] to grant a FOIA request. Many people don't understand how meaningful FOIA is. It's very instrumental to us in formulating substantive comments on Draft Environmental Impact Statements."

"FOIA has already been getting more difficult to use", agrees Laura Cunningham of the Western Watersheds Project (Cima, CA). "I'd like to [submit a FOIA request to] the BLM on their large pinyon–juniper treatments in the Bodie Hills [of California]. They're claiming the trees are unnaturally expanding their range, although these are native trees. If Interior is going to enact more stringent rules, it'll just lead to more lawsuits", she warns.

Townsend is also certain that the proposed revisions will draw lawsuits. DOI was unresponsive to requests for comment.

Australian businesses lagging on climate risk disclosure

Claire Miller

Wildfires. Unprecedented floods. Record heatwaves and drought. Australia's summer of 2019 has been hard to ignore, even for climate skeptics. But as food prices rise and infrastructure buckles, it's surprising to Will van de Pol (a legal researcher at Market Forces, an environmental finance group; Melbourne, Australia) that the country's largest climate risk-exposed companies continue to defy regulators and investors by failing to take climate risks to their businesses seriously. "We're not the worst of the worst on [climate risk] disclosure", van de Pol explains. "But our economy is highly exposed to the transition risks of climate change, and the physical risks are also hitting home, so we should be leading the pack on this issue."

Since early 2017, the Australian Prudential Regulation Authority (APRA) has warned that climate change is a foreseeable and material risk, and that companies would be more closely monitored. Last September, the Australian Securities and Investments Commission (ASIC) concluded that many companies were breaking the law by failing to adequately consider and disclose climate risk. And in February, a Market Forces report entitled "Investing in the Dark" (https://bit.ly/2N-FLvjw) found that of the 72 "high-risk" companies analyzed, barely half (57%) identified climate change as a material business risk. What's more, only 32% disclosed detailed discussion of specific climate risks and opportunities, and just 14% provided comprehensive scenario analyses demonstrating the company's future viability in a 2°C warming pathway, as set out in the 2015 UNFCCC Paris Agreement.

The problem, says van de Pol, is that the regulators are not backing their strong words with enforcement. "I think corporations are being allowed to get away with boilerplate or superficial references to the climate risk", he continues. "We did find an increase in the number of companies willing to talk about climate risk as an issue but very few willing to do the hard work to translate that into a detailed assessment of the risk to their business and details about what they are doing to manage that risk."

He's hoping that this past summer, and a February Royal Commission report on the banking sector that excoriated regulators for failing to enforce governance rules, might help to focus minds. "It's terrible to think it would take something like what we've seen recently to drive this home. The IPCC's special 1.5°C report in October was really sobering as well, and I hope this is a wake-up call to investors and regulators to ensure companies are really shifting."

"One thing after another" weakens ecosystem health

Christie Wilcox

Understanding how disturbance shapes ecosystems is fundamental to ecology. And it makes sense that frequent damaging events would cause more harm than infrequent ones. But frequently disturbed habitats are usually more recently disturbed, too. "Both disturbance frequency and time since last disturbance are extremely important and occur in concert, but we need to test them separately if we want to know the actual driver of change", says Jessica Haghkerdar (University of St Andrews; St Andrews, UK). "Streams are a good study system for disturbance and recovery questions because they are subject to frequent disturbances, including floods and droughts."

So, with the help of her master's advisor Hamish Greig and research assistant Jack McLachlan, Haghkerdar set up 15 anchored mesocosms in a brook in Edinburg, Maine, to determine whether community composition varies depending on disturbance frequency. Each was constructed with plastic corrugated roofing material as the base and filled with a gravel substrate that invertebrates could colonize. The gravel was churned by hand to simulate a bed-moving flood at different frequencies (eg every 3 days, every 7 days) over a 1-month period, with all mesocosms receiving their last disturbance on the same day. Then, all were left undisturbed for 9 days (so they had the same recovery time) before the final collections for invertebrate counts occurred.

H Greig

Stream mesocosms used in the experiment.

There were clear differences in the communities depending on disturbance frequency, with the most frequently disturbed mesocosms containing the smallest number of invertebrate families and the fewest overall individuals (*Ecol Evol* 2019; doi.org/10.1002/ece3.4968). The strength of this result surprised Haghkerdar, as a 9-day period represents "a substantial opportunity for a patch in a stream to be recolonized". The loss of whole families from the most disrupted mesocosms was also somewhat unexpected and underscores just how strong the effect of disturbance frequency was.

The findings suggest that ecosystems can have barriers to recovery even after disturbances cease. And because of that, "our work suggests that disturbance history needs to be considered when examining effects of further disturbances on a community", says Haghkerdar. It may also help guide conservation decision making, as "the stressors that residents have already been put through, plus the ability to respond to disturbance cues, can have a big effect on responses".