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PERSPECTIVE

Environmental policies to cope with novel disturbance regimes–steps to address a world scientists' warning to humanity

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1. The challenge of novel disturbance regimes

A recent warning to humanity signed by >15 000 scientists identified global environmental threats that require urgent policy response from world leaders (Ripple *et al* 2017). Here, we document challenges and propose solutions related to ongoing shifts in natural disturbance regimes, which are both a cause and a consequence of major environmental perils. We propose the development of new disturbance management plans based on novel policies for land management, biodiversity conservation, and ecosystem restoration, which accommodate forecasted disturbance regime shifts and expected ecosystem responses.

Wildfires, storms, insect and pathogen outbreaks, and other climatically-enhanced events are becoming unprecedented in their frequency, extent, intensity, and the places and times of occurrence worldwide (Seidl *et al* 2017). Associated with these shifting disturbance regimes are increases in ecosystem susceptibility to disturbance through land-use modification such as intensive agriculture, large-scale industrial forestry, and fire exclusion, coupled with increases in disturbance agents promoted by more extreme weather (Sommerfeld *et al* 2018). Whereas many species and ecosystem functions across terrestrial ecosystems rely on periodic natural disturbances (Johnstone *et al* 2016), ecological resilience can be compromised when current disturbance regimes diverge from the conditions under which species evolved and communities assembled (Johnstone *et al* 2016).

The impacts of changing disturbance regimes can be further complicated by climate change and by interactions between disturbances. Interactions occur when one disturbance modifies the capacity of an ecosystem to withstand, or to recover after, further disturbance (Buma 2015, Burton *et al* 2020). For instance, windstorms and beetle outbreaks alter the structure of woody fuels and may modify the intensity and impact of subsequent wildfires (Cannon *et al* 2017). Disturbance interactions can produce unexpected consequences, for example by generating disproportionally large ecological effects following comparatively small changes in one of the interacting disturbances (Burton *et al* 2020). Under climate change, some disturbance regimes may shift towards the poles (Burton and Boulanger 2018), yet uneven expansion and retraction of the location and extent of disturbances is likely to produce unprecedented disturbance interactions. For example, the climatically-induced expansion of the area affected by wildfires and bark beetle outbreaks in boreal and mountain forests can result in some areas being subject to both types of disturbances, with unknown consequences (Burton and Boulanger 2018). In addition, climate change is increasing disturbance interactions by making disturbances more frequent and severe and by altering post-disturbance conditions (Enright *et al* 2015). For instance, reduced seed production and seedling recruitment resulting from increasing drought prevalence increases the vulnerability of ecosystems to multiple fires at short intervals and thus increases the likelihood of drastic alterations in vegetation cover and community composition (Enright *et al* 2015). Consequently, whereas climate change is already expected to produce large-scale regime shifts in the coming decades (Trisos *et al* 2020), the occurrence of unprecedented disturbances and disturbance interactions will likely make such transitions even faster and more widespread.

Policies to manage ecological disturbances traditionally involve reactive approaches, such as extensive post-disturbance (salvage) logging and reforestation after disturbance (Müller *et al* 2019). Such approaches neglect the importance of disturbances in sustaining key ecological functions (Pausas and Keeley 2019), the unexpected consequences of accelerating changes in disturbance regimes (Enright *et al* 2015), and the potential disturbance interactions involving human activities (Leverkus *et al* 2018), which can produce further unanticipated effects and increase the risk of ecosystem collapse (Lindenmayer and Sato 2018). An example of the latter is the elimination of key habitat structures, such as veteran and hollow-bearing trees by salvage logging (Lindenmayer and Sato 2018, Müller *et al* 2019). Current land management policies based on 20th century experience are unable to accommodate the new demands associated with changing disturbance regimes in the 21st century. For instance, conservation policies based solely on protected areas face new challenges, as the occurrence of novel disturbances can affect large parts of the distribution of a species or ecosystem (as exemplified by the 2019–20 Australian wildfires; Ward *et al* 2020). In addition, ecosystem restoration strategies often rely on the questionable assumption that target areas will benefit from environmental conditions stable enough to eventually support mature forests. By not considering the novel risks arising from disturbances, such strategies are unlikely to achieve their goals, and they may consume valuable time and resources that could be more effectively employed elsewhere.

2. Elaborating disturbance management plans

To adapt ecosystem management to novel disturbance types and interactions, we argue that new biodiversity conservation, ecosystem restoration, and land management policies for the coming decades (such as the post-2020 Convention on Biological Diversity (CBD) global biodiversity framework and the Strategy of the UN Decade on Ecosystem Restoration, but also national and regional policies) are essential to promote the development of strategic disturbance management plans. Such plans would define management goals and specific actions based on the risks associated with changing disturbance regimes. The proposed disturbance management plans would include: anticipatory actions to be conducted independently of the occurrence of particular disturbance events (points 1–6 below and in figure 1), a range of compatible post-disturbance actions that would address long-term management objectives (point 7), and educational strategies (point 8, not depicted in the figure).

2.1. Mapping disturbance regime shifts

This refers to identifying ecosystems vulnerable to disturbance regimes that are beyond the bounds of their historical variability (point 1 in figure 1). This demands comparing the characteristics of past disturbances with those of recent and projected future disturbances, including disturbance type, intensity, recurrence, seasonality, extent, patchiness, and recovery rates. Spatially-explicit disturbance projections should also identify the potential for novel disturbance interactions. Novel interactions can produce strong, unexpected ecological effects (Buma 2015, Seidl *et al* 2017), yet mapping shifts of combined disturbance regimes has only recently been attempted (e.g. for forests of western Canada; Burton and Boulanger 2018). Regional projections of disturbance regime shifts would define the subsequent decisions and actions.

2.2. Maintaining intact ecosystems

In the absence of observed or expected disturbance regime shifts, the least human-modified ecosystems (point 2 in figure 1) are likely to be those best-adapted to local disturbance regimes (Johnstone *et al* 2016). Their conservation can be achieved through commonly applied methods, such as establishing protected areas and preventing habitat fragmentation. However, such measures may need to be intensified, as relatively intact ecosystems with stable disturbance regimes may become rare and expanding human pressure for resources can degrade ecosystems even without disturbance regime shifts. Additionally, natural disturbance regimes should be maintained; this requires avoiding introducing new disturbances (e.g. logging in intact forests), and allowing the occurrence of natural disturbances (e.g. generally avoiding fire suppression in fire-maintained ecosystems).

2.3. Promoting resilience

Management actions should prioritize increasing ecological resilience, primarily in heavily altered ecosystems (point 3 in figure 1). Ensuring the presence of disturbance-adapted plant species with strong regeneration capacity at a landscape level may speed the recovery of vegetation and ecological functions after subsequent disturbance. Moderate levels of disturbance (e.g. prescribed fire or variable canopy retention during logging operations) can be applied at shifting locations across landscapes to maintain or increase the abundance of disturbance-adapted species. Such a mosaic approach enhances the landscape-scale availability of secondary forests, which contain biodiversity repositories of different successional stages (Arroyo-Rodríguez *et al*

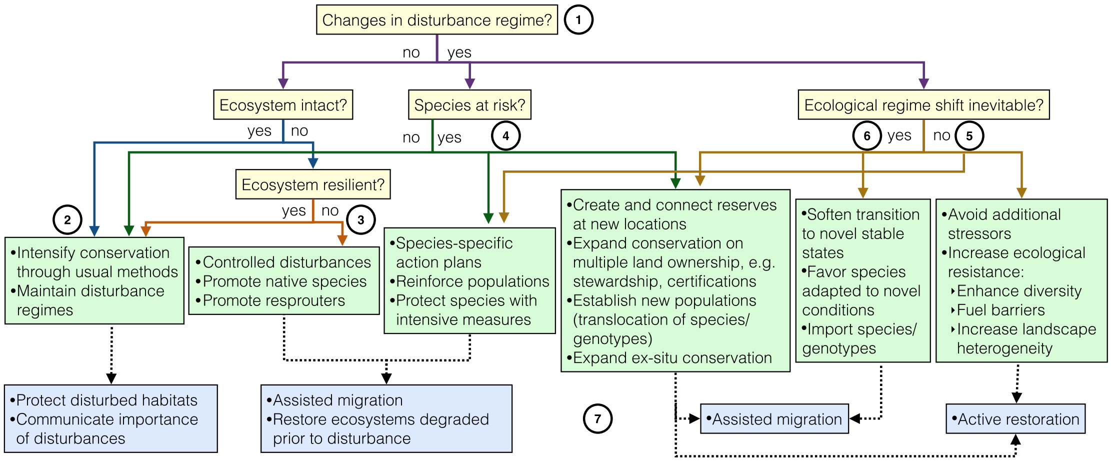

Figure 1. Schematic representation of disturbance management plans. New plans would evaluate changes in the frequency, intensity and extent of disturbances, the state of ecosystems, and risks to species and ecosystems (yellow boxes), and propose anticipatory actions that are independent of particular disturbance events (green boxes) and potential post-disturbance actions (blue boxes). Anticipatory actions are associated (dotted lines) with compatible post-disturbance actions to pursue long-term management objectives. The key elements of these plans (points 1–7, plus one point on education) are described in the text. Lines are colored for clarity of presentation.

2017). This approach additionally increases heterogeneity in composition and structure and reduces fuel loading, thereby promoting disturbance-stabilizing feedbacks (Pausas and Bond 2020). Reforestation efforts should aim to increase species diversity while ensuring the presence of species that are likely to thrive under recurrent disturbances and future climate. As an example, enhanced resistance and resilience to disturbances in wood-production coniferous forests can result from underplanting with native broadleaved species (Astrup *et al* 2018)—particularly resprouters.

2.4. Devoting focused conservation efforts to rare species and susceptible ecosystems

Where changes in disturbance regimes are anticipated, targeted conservation strategies are needed for species that are rare or sensitive to novel disturbances (point 4 in figure 1). Protected areas are under increasing risk of novel disturbances that may threaten the existence of rare and declining species and ecosystem types. Focused conservation actions should ensure these areas maintain disturbance regimes that can sustain these species and ecosystems (Ward *et al* 2020). This may require extreme measures in some cases, which, however, may be less costly and more effective than *ex-situ* conservation programs. Examples include restricting human access to some natural habitats (e.g. as done to prevent disturbance to the relict Wollemi pine, *Wollemia nobilis,* in Australia), maintaining cattle grazing and burning in nutrient-poor heathlands with a special flora (as in some parts of Western Europe), and managing landscape heterogeneity to promote 'safe sites' that may act as disturbance refugia (Ward *et al* 2020). In some cases, translocating populations from areas with higher historical disturbance frequencies may be necessary—even more so than in response to climate change alone (Hoegh-Guldberg *et al* 2008). This is because novel disturbances may have more dramatic and immediate effects on populations than gradual changes in temperature and precipitation, and thereby preclude natural migrations to more suitable areas. To establish novel locations for populations, enhancing conservation programs under multiple types of land ownership and governance will be key. This may include voluntary conservation programs on private land (Farmer *et al* 2017) but also further integration of conservation actions into natural resource management (e.g. through forestry certification programs; Gustafsson *et al* 2012). New global conservation targets should also continue expanding *ex-situ* conservation programs to safeguard many of the planet's biota and allow their translocation or potential re-introduction in the future.

2.5. Preventing regime shifts

In cases where changes in climate and disturbance regimes are not expected to necessarily produce ecological regime shifts (point 5 in figure 1), conservation and restoration efforts should seek to maintain current stable states. For instance, although old-growth forests may possess substantial inertia in the face of climate change (Noss 2001), many stands are not adapted to novel climatic and disturbance conditions, which may increase their susceptibility to collapse. By identifying the mechanisms and thresholds of change that maintain stable states and those that drive ecosystem shifts (Pausas and Bond 2020), the cumulative effects of multiple stressors could be mitigated. For instance, although repeated wildfires in Australian mountain ash forests constitute an important stress, post-fire logging should be avoided to maintain the current forest estate (Lindenmayer and Sato 2018). In some cases, intensive actions (see point 4) may be needed. Efforts to increase ecological resistance to natural disturbance are also critical. Novel ecosystem management policies should seek to reduce the incidence and severity of disturbances, especially in cases where human actions such as fire exclusion, intensive past land uses, or even-aged silviculture have left ecosystems vulnerable to uncharacteristically severe disturbances. Examples include increasing species diversity in homogeneous tree plantations to enhance resilience to multiple disturbances (Astrup *et al* 2018, Pausas and Keeley 2019), adding deciduous trees as green fire breaks in boreal industrial conifer landscapes (Astrup *et al* 2018), and prescribed burning or grazing to replace the ecological role of wildfires (Pausas and Keeley 2019). In addition, broadening the scale of restoration actions to landscapes, for instance by creating mosaics with patches of heterogeneous management, can help spatially diversify the risks of uncertain future disturbances.

2.6. Managing transitions to alternative states

New landscape management policies should acknowledge that climate change and shifting disturbance regimes may inevitably drive abrupt ecosystem transitions to alternative states (Trisos *et al* 2020) (point 6 in figure 1). In such cases, promoting current ecosystems through traditional restoration activities (e.g. through reforestation with the existing suite of species) might not only fail but also preclude the establishment of new species while wasting time and resources. Promoting species that would thrive in an alternative state—but maintaining pockets of the original state when possible—may help soften transitions to maximize ecosystem functions and biodiversity within the possibilities imposed by novel climate and disturbance regimes. Specific actions to achieve this may include promoting some already existing species at certain sites, improving habitat connectivity to enhance natural migrations, and translocating species that are better adapted to novel disturbance regimes (i.e. importing species to target areas; Hoegh-Guldberg *et al* 2008). Some of the actions proposed in point 4 above also apply to this case (figure 1).

2.7. Taking advantage of positive disturbance effects

Disturbance management plans would outline potential post-disturbance management actions (point 7 in figure 1) aligned with compatible anticipatory measures. Ideally, post-disturbance actions would build on potential opportunities from natural disturbances to address long-term management goals. First, it should be recognized that vegetation cover in disturbed areas usually regenerates naturally (Pausas and Keeley 2019). Based on evaluations such as those proposed in figure 1, and on observed processes after particular disturbances, it can be decided whether active post-disturbance restoration may be necessary; otherwise, avoiding actions in recently-disturbed areas might help reduce additional impacts from well-intended human activities. However, natural disturbances also provide new management possibilities to enhance biodiversity. These may include the restoration of previously degraded ecosystems, such as the redistribution of sediment in highly degraded river systems and the recovery of fire- or herbivore-dominated grassland ecosystems (Pausas and Keeley 2019). Active restoration, where needed, should preferably target vegetation types that are better adapted to current or projected future climate and disturbance regimes (Hoegh-Guldberg *et al* 2008, Pausas and Keeley 2019). Additionally, disturbances provide opportunities to develop novel conservation strategies that protect the habitats characterized by early successional ecosystems and their associated biodiversity (Leverkus *et al* 2019). For instance, schemes to pay landowners for retaining patches of deadwood after windthrows would both promote deadwood-associated communities and secure the income of affected stakeholders. Establishing protected areas within disturbed ecosystems may help communicate their high ecological value.

2.8. Expanding education programs about disturbances

Finally, education programs are needed to foster a dynamic view of ecosystems, including appreciation of the ecological importance of natural disturbances, alternative states, and their associated biodiversity (Thorn *et al* 2020). Besides their obvious destructive effects, natural disturbances may also enrich biodiversity in less-known ways—e.g. through pulses in deadwood availability in forests and increased recruitment and regeneration opportunities (Pausas and Keeley 2019). Moving away from static and idealized conceptualizations of ecosystems—such as the classical perspective that old and stable ecosystems are the sole target for conservation and that any disturbance is purely destructive—should help society: (a) differentiate between the effects of natural disturbance regimes from those of novel disturbances, (b) accept novel approaches for ecosystem management (e.g. prescribed burns and managed wildfires), and (c) avoid common requests for intensive post-disturbance interventions in the name of ecological restoration. Such shifts in paradigms are also needed in the conservation community to promote the many values of species-rich open (non-forest) vegetation and novel ecosystems (Pausas and Keeley 2019, Pausas and Bond 2020).

Crisis-style, post-hoc decision-making has historically characterized post-disturbance management. We suggest that, besides reducing greenhouse emissions to decrease the climatic drivers of shifting disturbance regimes, new-generation management plans be established prior to disturbances. These should outline anticipatory measures and guidelines for appropriate post-disturbance management actions. We acknowledge that no disturbance plan will work perfectly, as future disturbance regimes and ecological responses to them are dynamic, and sometimes unpredictable. Uncertainty should be clearly identified to recognize the range of actions that could be taken. Some of the ideas we propose are not without risk, such as the translocation of species and genotypes to areas where they were previously absent. For this reason, we need research on shifts in disturbance regimes, the coupled impacts of interacting disturbances and climate change, and the effectiveness and risks of associated management actions. This will improve long-term planning to maximize biodiversity and ecosystem functioning in a changing world.

Data availability statement

No new data were created or analysed in this study.

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References

Arroyo-Rodríguez V, Melo F P L, Martínez-Ramos M, Bongers F, Chazdon R L, Meave J A, Norden N, Santos B A, Leal I R and Tabarelli M 2017 Multiple successional pathways in human-modified tropical landscapes: new insights from forest succession, forest fragmentation and landscape ecology research *Biol. Rev.* **92** 326–40

Astrup R, Bernier P Y, Genet H, Lutz D A and Bright R M 2018 A sensible climate solution for the boreal forest *Nat. Clim. Change* **8** 11–12

Buma B 2015 Disturbance interactions: characterization, prediction, and the potential for cascading effects *Ecosphere* **6** 70

Burton P J and Boulanger Y 2018 Characterizing combined fire and insect outbreak disturbance regimes in British Columbia, Canada *Landscape Ecol.* **4** 1997–2011

Burton P J, Jentsch A and Walker L R 2020 The ecology of disturbance interactions *Bioscience* **70** 854–70

Cannon J B, Peterson C J, O'Brien J J and Brewer J S 2017 A review and classification of interactions between forest disturbance from wind and fire *For. Ecol. Manage.* **406** 381–90

Enright N J, Fontaine J B, Bowman D M J S, Bradstock R A and Williams R J 2015 Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes *Front. Ecol. Environ.* **13** 265–72

Farmer J R, Ma Z, Drescher M, Knackmuhs E G and Dickinson S L 2017 Private landowners, voluntary conservation programs, and implementation of conservation friendly land management practices *Conserv. Lett.* **10** 58–66

Gustafsson L *et al* 2012 Retention forestry to maintain multifunctional forests: a world perspective *Bioscience* **62** 633–45

Hoegh-Guldberg O, Hughes L, Mcintyre S, Lindenmayer D B, Parmesan C, Possingham H P and Thomas C D 2008 Assisted colonization and rapid climate change *Science* **321** 345–6

Johnstone J F *et al* 2016 Changing disturbance regimes, ecological memory, and forest resilience *Front. Ecol. Environ.* **14** 369–78

Leverkus A B, García Murillo P, Jurado Doña V and Pausas J G 2019 Wildfires: opportunity for restoration? *Science* **363** 134–5

Leverkus A B, Lindenmayer D B, Thorn S and Gustafsson L 2018 Salvage logging in the world's forests: interactions between natural disturbance and logging need recognition *Glob. Ecol. Biogeogr.* **27** 1140–54

Lindenmayer D B and Sato C 2018 Hidden collapse is driven by fire and logging in a socioecological forest ecosystem *Proc. Natl Acad. Sci.* **115** 5181–6

Müller J, Noss R, Thorn S, Bässler C, Leverkus A B and Lindenmayer D 2019 Increasing disturbance demands new policies to conserve intact forest *Conserv. Lett.* **12** e12449

Noss R F 2001 Beyond Kyoto: forest management in a time of rapid climate change *Conserv. Biol.* **15** 578–90

Pausas J G and Bond W J 2020 Alternative biome states in terrestrial ecosystems *Trends Plant Sci.* **25** 250–63

Pausas J G and Keeley J E 2019 Wildfires as an ecosystem service *Front. Ecol. Environ.* **17** 289–95

Ripple W J, Wolf C, Newsome T M, Galetti M, Alamgir M, Crist E, Mahmoud M I Laurance W F and 15364 scientists from 184 Countries 2017 World scientists' warning to humanity: a second notice *Bioscience* **67** 1026–8

Seidl R *et al* 2017 Forest disturbances under climate change *Nat. Clim. Change* **7** 395–402

Sommerfeld A *et al* 2018 Patterns and drivers of recent disturbances across the temperate forest biome *Nat. Commun.* **9** 4355

Thorn S, Seibold S, Leverkus A B, Michler T, Müller J, Noss R F, Stork N, Vogel S and Lindenmayer D B 2020 The living dead—acknowledging life after tree death to stop forest degradation *Front. Ecol. Environ.* **18** 505–12

Trisos C H, Merow C and Pigot A L 2020 The projected timing of abrupt ecological disruption from climate change *Nature* **580** 496–501

Ward M *et al* 2020 Impact of 2019–2020 mega-fires on Australian fauna habitat *Nat. Ecol. Evol.* **4** 1321–6