tem services, their use of the term in their paper's title is potentially misleading. Failing to integrate fire as an ecological process within an ecosystem services–disservices framework can promote a biased perspective of wildfire. An example of the risks of such a perspective is the historical fire-suppression policy that largely ignored the various socioecological roles of fire, indirectly fostering catastrophic fires over the past decades (the so-called "Fire Paradox"; Silva *et al.* 2010). Improved communication of ecosystem services and disservices can help to guide decision making in fire management policy and land-use planning.

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Abson DJ, Von Wehrden H, Baumgärtner S, *et al.* 2014. Ecosystem services as a boundary object for sustainability. *Ecol Econ* **103**: 29–37.

Adams MA. 2013. Mega-fires, tipping points and ecosystem services: managing forests and woodlands in an uncertain future. *Forest Ecol Manage* **294**: 250–61.

Bowman DMJS, Balch JK, Artaxo P, *et al.* 2009. Fire in the Earth system. *Science* **324**: 481.

Costanza R, De Groot R, Braat L, *et al.* 2017. Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosystem Services* **28**: 1–16.

Haines-Young R and Potschin M. 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. https://bit.ly/2ZKcKOU. Viewed 20 May 2019.

Keeley JE, Baer-Keeley M, and Fotheringham CJ. 2005. Alien plant dynamics following fire in Mediterranean-climate California shrublands. *Ecol Appl* **15**: 2109–25.

Pausas JG and Keeley JE. 2019. Wildfires as an ecosystem service. *Front Ecol Environ* **17**: 289–95.

Pettorelli N, Schulte to BühneH, Tulloch A, *et al.* 2018. Satellite remote sensing of ecosystem functions: opportunities, challenges and way forward. *Remote Sens Ecol Conserv* **4**: 71–93.

Potschin M and Haines-Young R. 2016. Conceptual frameworks and the cascade model. In: Potschin M and Jax K. (Eds). OpenNESS Ecosystem Services Reference Book. EC FP7 Grant Agreement no 308428. www.openness-project.eu/library/reference-book. Viewed 20 May 2019.

Sil Â, Fernandes PM, Rodrigues AP, *et al.* 2019. Farmland abandonment decreases the fire regulation capacity and the fire protection ecosystem service in mountain landscapes. *Ecosystem Services* **36**: 100908.

Silva JS, Rego F, Fernandes P, and Rigolet E (Eds). 2010. Towards integrated fire management – outcomes of the European project Fire Paradox. Research report 23. Joensuu, Finland: European Forest Institute.

Vaz AS, Kueffer C, Kull CA, *et al.* 2017. Integrating ecosystem services and disservices: insights from plant invasions. *Ecosystem Services* **23**: 94–107.

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Wildfires misunderstood

Rain is a natural process that provides a range of services to humans but certainly not all rainfall events (eg those generating floods) are beneficial to human societies. Biodiversity can also deliver a variety of services, even though there are species capable of harming humans. Likewise, the vast majority of life depends (directly or indirectly) on sunlight, yet we can get sunburn and develop skin cancer after overexposure. In the same way, wildfires can offer a range of ecosystem services (Pausas and Keeley 2019) but obviously not all fires, and not all fire regimes, provide services to humankind; indeed, wildfires can have negative (even catastrophic) impacts on society. For instance, if we build houses in a fire-prone (or flood-prone) area, then the inhabitants of those houses are likely to suffer negative impacts when a wildfire (or a major rainfall event) occurs. Similarly, when we substantially increase fuel loads and landscape homogeneity (eg due to a fire exclusion policy, or with a massive and poorly managed tree plantation), the impact of wildfires – especially under novel climatic conditions – can be catastrophic (eg the case of the 2017 fires in Portugal and Chile; Bowman *et al.* 2019).

In more general terms, negative impacts to humans (disservices) often occur when we perturb the historical fire regime: that is, when one or some of the fire regime parameters (ie frequency, seasonality, spread pattern, or intensity) are altered

(Keeley and Pausas 2019). This is because human societies have adapted to historical fire regimes, or have modulated the fire regime for their own benefit (cultural fire regimes); however, recent abrupt fire regime changes due to modern anthropogenic factors (eg mismanagement, global warming) lead to fire regimes that adversely impact biodiversity and the services they provide (for a few examples, see Keeley and Pausas [2019]). This is why we previously suggested that perturbations to the historical fire regime feed back to the functioning of the ecosystem and reduce these services in the same way that major anthropogenic changes in a rainfall regime reduce the services that precipitation provides to humans (Pausas and Keeley 2019). Thus, the idea that wildfires can provide ecosystem services stands firmly, even though there are currently some socially unsustainable fire regimes; these negative impacts are well-known and emphasized by the media.

However, the difficulty in understanding the role of wildfires in providing ecosystem services still persists (eg the letter by Sil *et al.*), in contrast to the wide acceptance of the services provided by other natural processes. The root of the problem lies with discerning wildfires as natural processes that shape biodiversity, ecosystems, and societies (*fire blindness* as described in Pausas and Lamont 2018). For instance, in relation to fire, some researchers consider only "fire protection" as a service (Haines-Young and Potschin 2018), while in many ecosystems, protection from fire is, in fact, a perturbation that generates more problems to humans and biodiversity than frequent wildfires (Allen *et al.* 2002; Boisramé *et al.* 2017; Walker *et al.* 2018); understanding the variability of fire regimes is key in this regard.

Similarly, wildfires are often categorized as natural disasters like volcanic eruptions, earthquakes, and tsunamis; in so doing, the intrinsic ecological and evolutionary feedbacks between wildfires and biodiversity can be overlooked (Bond *et al.* 2005; He *et al.* 2019). These misunderstandings are not rare in our society and have a historical basis (Pausas and Bond 2019), but they make it difficult to establish a coherent fire management policy in many fire-prone regions. For instance, failing to understand the concept of perturbations to the fire regime (Keeley and Pausas 2019) may promote the notion that all fires are problematic and should be eliminated from the system, and this is far from true (Boisramé *et al.* 2017). This is the context in which our paper's emphasis on the ecosystem services provided by wildfire is especially important. Extrapolating the social consequences of wildfires in anthropogenic environments (eg tree plantations, semi-urban areas) to natural ecosystems is also a source of confusion; each of these settings often requires different fire management approaches. Fortunately, ecologists across the world are currently investigating the important role of wildfires, and we are getting closer to coexisting with, and benefiting from, wildfires. Our challenge is how to maintain the ecosystem services provided by fire in the era of anthropogenic climate change.

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Allen CD, Savage M, Falk DA, *et al.* 2002. Ecological restoration of southwestern Ponderosa pine ecosystems: a broad perspective. *Ecol Appl* **12**: 1418–33.

Boisramé G, Thompson S, Collins B, *et al.* 2017. Managed wildfire effects on forest resilience and water in the Sierra Nevada. *Ecosystems* **20**: 717–32.

Bond WJ, Woodward FI, and Midgley GF. 2005. The global distribution of ecosystems in a world without fire. *New Phytol* **165**: 525–38.

Bowman DMJS, Moreira-Muñoz A, Kolden CA, *et al.* 2019. Human–environmental drivers and impacts of the globally extreme 2017 Chilean fires. *Ambio* **48**: 350–62.

Haines-Young R and Potschin M. 2018. Common International Classification of Ecosystem Services (CICES) v5.1 and guidance on the application of the revised structure. www.cices.eu. Viewed 18 Aug 2019.

He T, Lamont BB, and Pausas JG. 2019. Fire as a key driver of Earth's biodiversity. *Biol Rev*; https://doi.org/10.1111/brv.12544.

Keeley JE and Pausas JG. 2019. Distinguishing disturbance from perturbations in fire-prone ecosystems. *Int J Wildland Fire* **28**: 282–87.

Pausas JG and Bond WJ. 2019. Humboldt and the reinvention of nature. *J Ecol* **107**: 1031–37.

Pausas JG and Keeley JE. 2019. Wildfires as an ecosystem service. *Front Ecol Environ* **17**: 289–95.

Pausas JG and Lamont BB. 2018. Ecology and biogeography in 3D: the case of the Australian Proteaceae. *J Biogeogr* **45**: 1469–77.

Walker RB, Coop JD, Parks SA, *et al.* 2018. Fire regimes approaching historic norms reduce wildfire-facilitated conversion from forest to non-forest. *Ecosphere* **9**: e02182.