

Are humans a *transient agent of destruction* or a potential *persistent driver of biosphere net gain*?

Human activity is shifting Earth beyond its safe operating limits – in a similar manner to past biotic crises

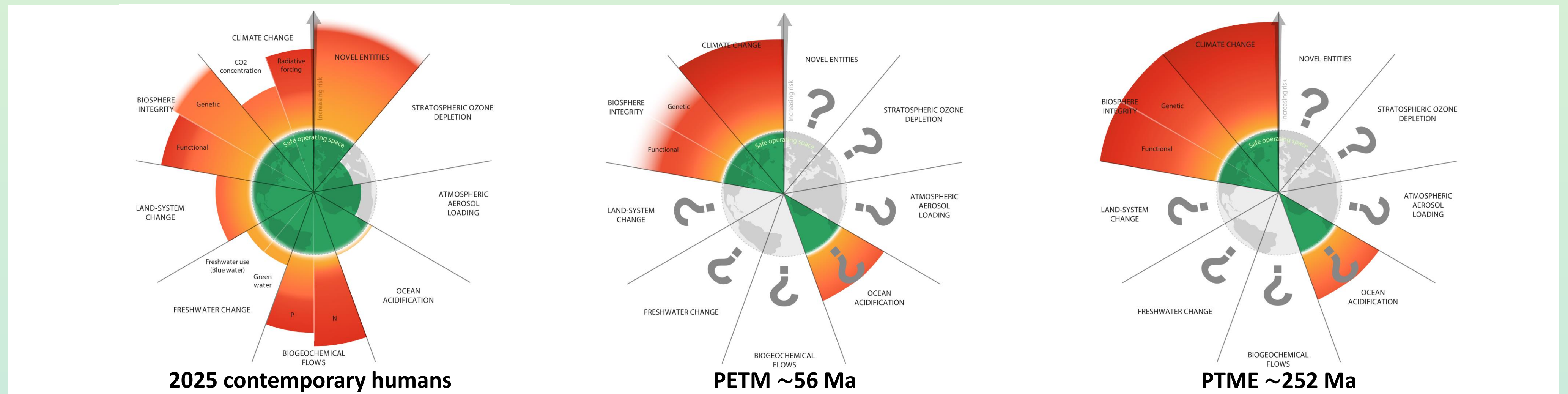


Fig. 1: The planetary boundaries framework¹ reveals that humans are pushing the Earth system beyond the safe limits of its recent past. Planet Earth has been pushed beyond the safe operating space for its biosphere many times in the deep

past^{e.g. 2}, with these intervals often driving biotic crises and even mass extinctions (see Figs. 2, 3). The modern (2025)¹ planetary boundary values are shown here next to estimates for the biosphere integrity boundary for the Palaeocene-

Eocene Thermal Maximum (PETM, ~56 million years ago) and the Permo-Triassic Mass Extinction (PTME, ~252 million years ago; see Fig. 3). We are already approaching and perhaps exceeding PETM-like impacts on the biosphere.

Disrupting agents of the biosphere

The biosphere has endured many disruptions throughout Earth history on timescales ranging from seconds to millions of years (Fig. 2). The drivers of each of these disruptions can be considered either *transient* or *persistent*.

Transient disruptors:

- originate outside the biosphere (e.g. massive volcanism, bolide impacts);
- operate over short timescales (typically $\sim 10^3$ to 10^6 years, sometimes $< 10^0$ years);
- are associated with rapid environmental change (e.g. temperature change, ocean oxygen concentration, ocean acidification and acid rain);
- drive temporary, sometimes massive, reductions to biodiversity, biomass, primary productivity, and ecological complexity.

Persistent disruptors:

- originate within the biosphere (e.g. oxygenic photosynthesis, flowering plants);
- operate over long timescales (typically $> 10^6$ to 10^9 years);
- are associated with the evolution of new ecological niches, habitats, and symbioses;
- drive monotonic increases in planetary habitability (e.g. biomass, biodiversity, or primary productivity), despite potential harm caused to the incumbent biosphere.

Humans are acting fast – like a *transient disruptor*

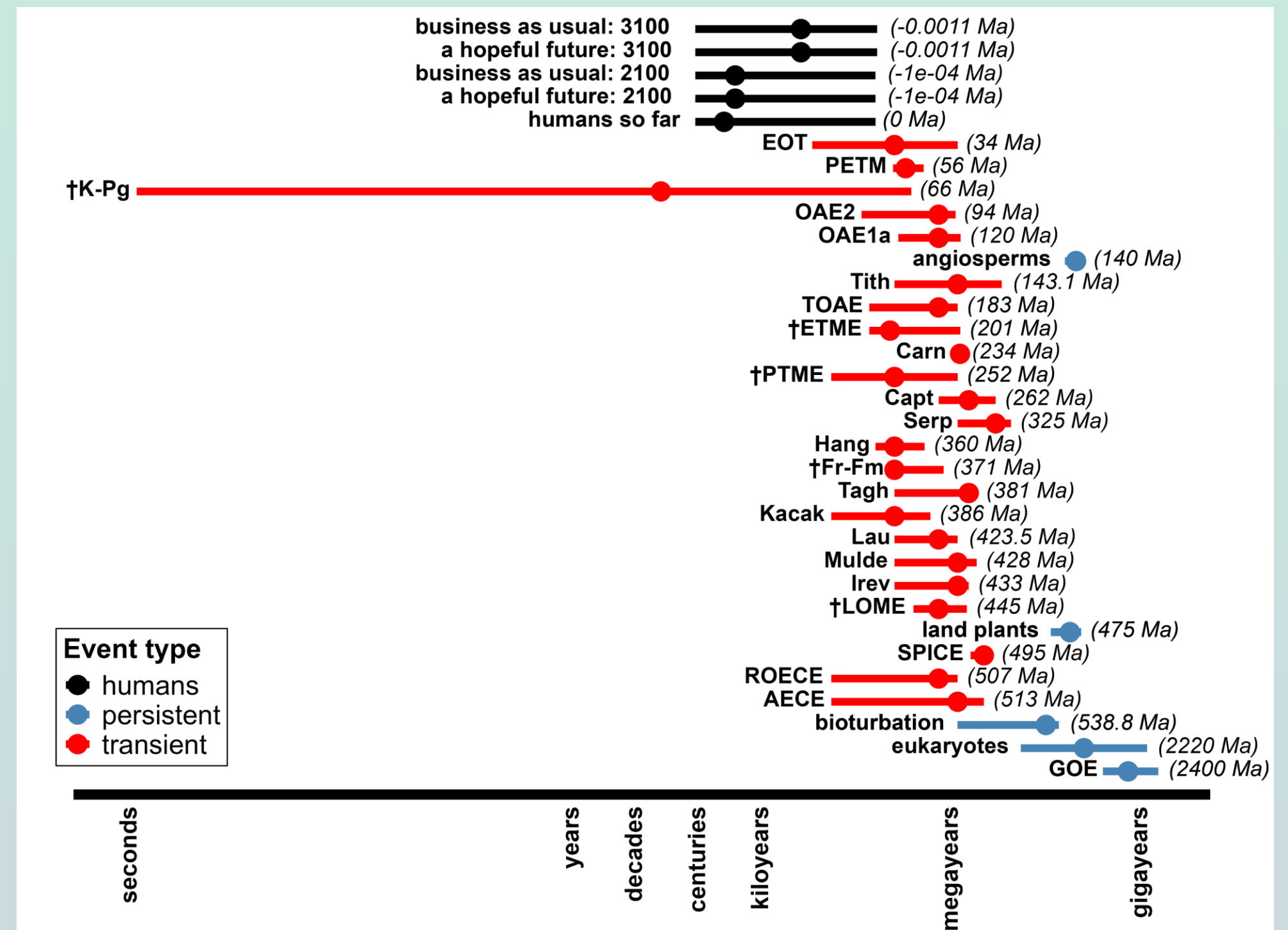
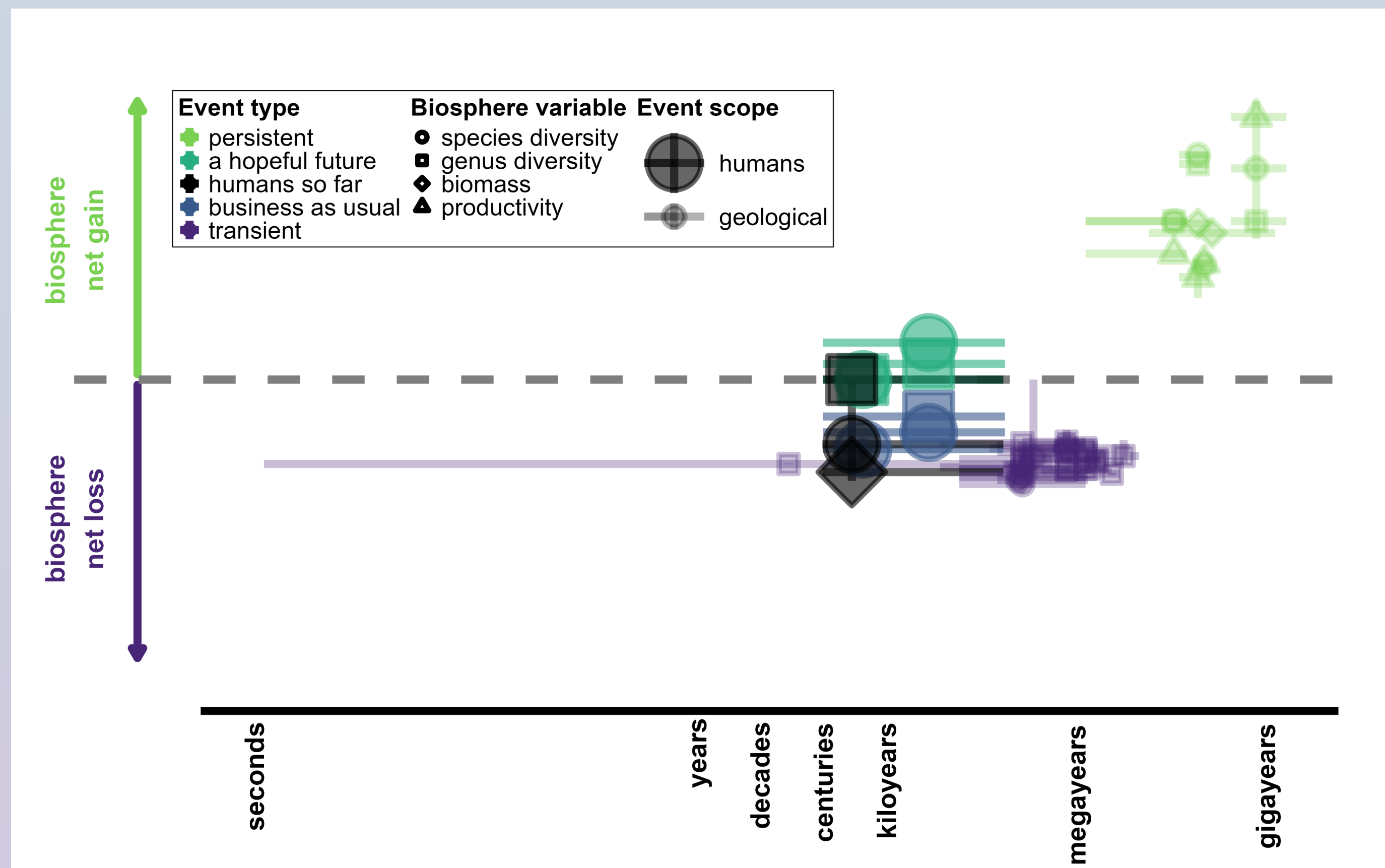


Fig. 2: Timescales (\log_{10}) of human disruption alongside transient and persistent disruptors in Earth history, with oldest at the bottom and near-future at the top. Each line represents the range of timescales over which the disruptor acted on the biosphere with each point indicating the main timescale of impact. Dagger-marks (†) indicate the 'Big 5' mass extinctions. The age of each event in millions of years ago (Ma) is in parentheses.

Humans are degrading the biosphere – like a *transient disruptor*



Most contemporary anthropogenic impacts on the biosphere are *negative*, resembling past *transient disruptors* in both timescale and magnitude (Fig. 3). Humans are currently degrading wild biomass and wild biodiversity (Fig. 3) through mechanisms including rapid temperature change, deforestation, ocean deoxygenation and acidification, similar to past biotic crises². For example, human-driven deforestation is probably on par with forest biomass loss in the Permo-Triassic Mass Extinction (~252 million years ago)³.

If humans can reinvent our interactions with the biosphere (e.g. with new technology or by re-valuing sustainable land management) we may be able to support the evolution of new species, new ecological niches, and greater productivity and biomass.

Fig. 3: Timescales and calculated impacts of human disruption alongside transient and persistent disruptors in Earth history. Both axes are \log_{10} scales with the x-axis in years and the y-axis in % change of biosphere variable.