Comment

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Resisting the carbonization of animals as climate solutions

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Large animal conservation and rewilding are increasingly considered to be viable climate mitigation strategies. We argue that overstating animal roles in carbon capture may hinder, rather than facilitate, effective climate mitigation and conservation efforts.

Global climate change and biodiversity loss are the most important environmental crises today, generating support for nature-based solutions to climate change[1]. Until recently, natural climate solutions have focused on vegetation restoration and tree planting; however, large animal conservation and rewilding are increasingly cited as viable climate mitigation strategies through their potential to sequester carbon[2–4]. Here, we urge that the capacity of animals to prevent global warming should not be overstated for three reasons: (1) animal impacts on carbon balance are highly uncertain and context-dependent; (2) carbon sequestration benefits of rewilding are unlikely to be meaningful on relevant timescales for mitigating peak global warming; and (3) monetizing animals as carbon offsets generates many practical and ethical dilemmas. The current state of unverified and inflated economic valuations, selective media reporting, and carbon-focused ecosystem management could result in bio-perverse outcomes and distract from the urgent need to reduce fossil fuel emissions.

The uncertain roles of animals in climate mitigation

Despite representing ~0.3% of Earth's biomass, wild animals can exert oversized impacts on ecosystem carbon cycling via diverse mechanisms[5]. For example, recent modelling efforts suggest that African forest elephants (*Loxodonta cyclotis*) may increase above-ground carbon stocks by ~7.5% through engineering habitat and promoting growth of carbon-rich plants[3]. This research, among other studies, has generated the argument that global rewilding can expand nature-based solutions to prevent climate warming beyond 1.5–2 °C[4]. Yet, the prospect of leveraging animals for globally significant carbon capture should be met with caution (Fig. 1a). A recent study[4] estimated that conservation and rewilding of nine key animal groups could result in a net uptake of 6.41 Pg CO_2 yr^{-1}, ~64% of the Paris Agreement's natural climate solutions target. However, despite emphasis of rewilding terrestrial and marine megafauna, this estimate attributes ~90% of carbon capture benefits to conserving marine fish populations[4].

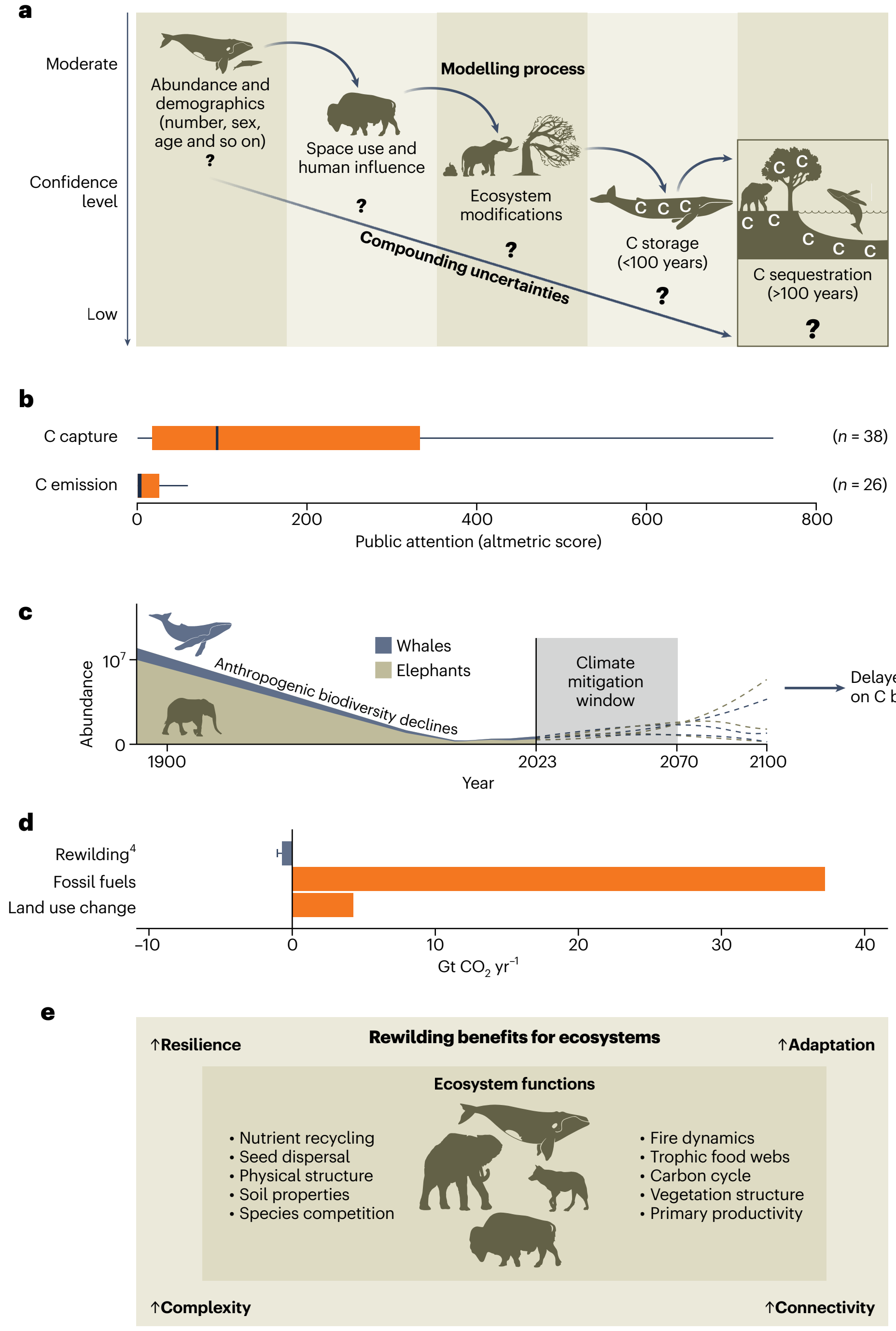
Media outlets have also skewed attention heavily towards large animals' positive roles in carbon capture (Fig. 1b). Yet, animal impacts on carbon cycling are extremely variable and context-dependent among species and environments[5,6] (Table 1). For example, unlike forest elephants, savanna elephants (*Loxodonta africana*) can decrease above-ground carbon stocks by ~65% through herbivory, trampling and tree toppling[7]. Muskox (*Ovibos moschatus*) may similarly increase carbon storage in Arctic mire, but decrease carbon storage in tundra shrubland[5]. Herbivore impacts on carbon balance are further convoluted by the presence or absence of predators. For example, predation by wolves may enhance carbon storage in boreal forest but reduce carbon storage in grasslands due to the variable impacts of their prey[5,6].

Additionally, current predictions of rewilding impacts on carbon balance often focus on above-ground carbon[3,4]; however, animals can influence carbon balance via numerous diverse mechanisms[5]. For example, savanna elephants can increase below-ground carbon through deposition of organic carbon in dung while escalating carbon emissions by stimulating decomposition[8]. Animals can also influence carbon balance through indirect effects on fire regimes and soil-carbon persistence[9]. Ultimately, animals can promote the capture or release of carbon in different settings, exhibiting a high degree of variability, particularly in response to rapidly changing environments[6]. Increased carbon storage is not an inevitable outcome of healthy, functional ecosystems: current scientific knowledge indicates there is no straightforward answer when predicting wildlife impacts on carbon balance.

The reality of scaling animal impacts on carbon balance

Given the uncertainty and context-dependency of animals' roles in carbon capture at the ecosystem level, scaling estimates globally bestows an incredible challenge. On land, only ~11% of areas available for rewilding are formally protected[4]. The remaining spaces introduce numerous social barriers (for example, human–wildlife conflict), complicating carbon capture outcomes[6,10]. These challenges are especially true for apex predators and will be particularly (and unjustly) pertinent to the Global South. Rewilding objectives may also counteract revegetation efforts and convolute carbon capture goals. For example, a recent meta-analysis[11] found that herbivory reduced vegetation stocks by a mean of 89% at restoration sites globally. Consequently, even with sufficient investment, attaining the necessary spatial scale and restoration outcomes to make carbon benefits meaningful for climate mitigation may be unrealistic.

For wildlife conservation and rewilding to meaningfully contribute to climate mitigation, they must also align with the goal of achieving net-zero CO_2 emissions by the mid–late twenty-first century[1]. Even if current biodiversity declines are halted, and large animal population growth is rapidly initiated, most species will take several generations, spanning decades to centuries, to reach their carrying capacity (Fig. 1c). Large animals give birth infrequently and to few young, and population growth is further slowed by apex predator rewilding, human exploitation (for example, poaching) and increasing extreme climate events (for example, fire, flooding). Where animal influence is mediated through tree biomass (for example, forest elephants), responses are further delayed by slow tree demographics. Thus, animal effects



Modelling animal impacts on carbon has high uncertainty

Public attention is biased towards studies suggesting carbon capture

Rewilding at scale will take time and has an unknown future

Rewilding should not distract from rapidly phasing out fossil fuels

Rewilding and large animal conservation should focus on diverse impacts of animals beyond carbon

Fig. 1 | Five key messages regarding why animal roles in mitigating climate change should not be overstated. a, Modelling animal impacts on carbon has high uncertainty: predicting rewilding outcomes for carbon capture is confounded by compounding uncertainties and will vary dramatically by ecosystem and taxa worldwide. **b**, Public attention is biased towards studies suggesting carbon capture: we found that research suggesting net carbon release by animals is far less shared by media outlets and the public (altmetric scores from ref. 9 supplementary literature). **c**, Rewilding at scale will take time and has an unknown future: solutions to global warming are needed within the next 30 years, beyond the feasible scope of animal population restoration to climate-relevant levels. **d**, Rewilding should not distract from rapidly phasing out fossil fuels: even in optimistic restoration scenarios, animal impacts on carbon balance are negligible compared with the need to reduce emissions from fossil fuel consumption and land use change linked to food systems (rewilding estimates from ref. 4; fossil fuel and land use change estimates from Our World in Data, 2022). **e**, Rewilding and large animal conservation should focus on diverse impacts of animals beyond carbon: animals provide a diverse array of ecosystem functions. Focusing attention primarily on carbon impacts may lead to bio-perverse outcomes that disrupt ecosystem adaptation and resilience. Whales in **a**,**c** and **e** credit: KBelka/iStock/Getty Images Plus. Elephants in **a** and **c**, bison in **a** and **e**, and wolf in **e** reproduced from PhyloPic, CC0 1.0 UNIVERSAL (https://creativecommons.org/publicdomain/zero/1.0/).

Table 1 | Overview of the carbon impacts of African elephants (*Loxodonta* spp.) and great whales, the most popularly endorsed animals for climate change mitigation and carbon monetization

Mechanism of carbon capture	Confidence	Context-dependency	Summary
African elephants (*Loxodonta* spp.)			
Abundance and rewilding potential	Moderate	High	Estimating elephant abundance is difficult (particularly for forest elephants) but possible with moderate confidence[3,4]. The rewilding potential of savanna and forest elephants is highly uncertain due to increased poaching, habitat loss, human–wildlife conflict and climatic factors[6].
Carbon storage in bodies	Moderate	Low	Estimating carbon stored in elephants is straightforward and comparable across species and ecosystems[3,4]. Uncertainty stems from estimating elephant abundance, population growth and demography.
Respiration and enteric emissions	Moderate	Low	Estimating carbon release (CO_2 and CH_4) by elephants is relatively straightforward and similar across species and ecosystems[3,4]. Uncertainty stems from estimating elephant abundance, population growth and demography.
Impacts on above-ground carbon stocks	Low	High	Elephants can impact above-ground carbon via diverse mechanisms[3,5,7,8]: tree toppling, seed dispersal, altered fire regimes and so on. Research is still limited, but studies show variable impacts that are context-dependent by ecosystem (for example, savanna, forest) and population density[3,6–8].
Impacts on below-ground carbon stocks	Low	High	Elephants can impact below-ground carbon via diverse mechanisms[5,8]: dung, soil trampling, vegetation destruction and so on. Research is limited, but shows potentially variable impacts by ecosystem type and population density[5–8].
Great whales			
Abundance and rewilding potential	Moderate	High	Abundance varies dramatically by species and sub-populations and is difficult to accurately estimate (particularly pelagic species)[6,12]. Uncertainty in abundance is the largest source of error in quantifying whale ecological functions. Slow maturation, low fecundity and increasing anthropogenic threats lead to long timescales and, in some regions, high uncertainty[6,12].
Carbon storage in bodies	Moderate	Low	Estimating carbon in whale bodies is straightforward and similar across species and ecosystems[4,12]. Uncertainty stems from estimating whale abundance, population growth and demography.
Respiration and enteric emissions	Low	Low	Estimating CO_2 release by whales is difficult but can be done with low confidence[4,12]. No research has examined CH_4 emissions, although studies must account for methane oxidation prior to reaching the ocean surface.
Whale falls	Moderate	High	Whales can export carbon to the deep sea via sinking carcasses[12]. Uncertainty and context-dependency stem from estimating abundance, mortality rate and the number of whales that die over the deep ocean[6,12].
Whale pump	Low	High	Whales can increase ocean primary productivity by feeding at depth and returning to the surface, where they release nutrients for phytoplankton uptake[12]. Uncertainty and context-dependency stem from differences in species and location, the source of carbon, the degree and longevity of stimulation of phytoplankton productivity, and estimates of carbon transport through detritus to the deep ocean, which are probably very small for most species and orders of magnitude lower than the 1% of global ocean productivity included in economic models[6,12].

Current confidence in predicting animal impacts on carbon balance is low and influenced by limited research, inflated assumptions, and compounding uncertainties in modelling and scaling processes. Context-dependency is generally high, varying by species, ecosystem, trophic structure and anthropogenic pressures.

on carbon balance can range from years (for example, herbivory) to centuries (for example, seed dispersal). Although these timeframes are valuable to consider for long-term carbon balance[9], rewilding is unlikely to meet immediate climate mitigation needs (Fig. 1d).

The dilemma of commodifying animals for carbon markets

A recent study[3] suggested that climate mitigation services by wildlife are valuable enough to attract carbon offset investors. In a case study, the authors valued African forest elephant populations at US$20.8 billion (US$10.3–29.7 billion) for their carbon services, or ~US$1.8 million per elephant[3]. Great whales have similarly been proposed for carbon monetization, with one estimate reaching US$1 trillion globally, or US$2 million per whale[2], despite a lack of scientific consensus regarding whale impacts on carbon cycling[12]. These monetization estimates have been widely criticized due to concerns about the legitimacy of such evaluations and the consequences of their public acceptance[12].

The first major concern pertains to properly assessing animal impacts on carbon sequestration given their variability and context-dependency. The Verified Carbon Standard requires emissions reduction or removal to be real, measurable, permanent, unique and additional. To our knowledge, the proposed carbon services of forest elephants and great whales do not pass this standard, as the assumptions lack field verification or measurement. In addition, carbon markets currently grapple with issues of additionality and the 'time value' of carbon, both relevant for assessing animal impacts on carbon. Indeed, directly linking carbon offset investments to rewilding outcomes and subsequent carbon benefits presents an extreme challenge. Moreover, it is critical to account for temporality in carbon outcomes, given that carbon capture in the present holds more value than the future. This is particularly important considering that the more immediate impacts of rewilding (for example, herbivory) may reduce carbon stocks[11], while the more positive impacts on carbon balance (for example, seed dispersal) may be delayed. Carbon offset markets are moving faster than the science they depend on. As a result, overstating animal impacts on climate mitigation may lead to misguided investments and ineffective mitigation strategies.

Ethical concerns also arise when commodifying animals in pursuit of climate mitigation. Besides moral issues around reducing wildlife to market values, we must also consider animals that do not enhance or may increase carbon emissions through natural ecosystem roles (for example, savanna elephants). In one extreme example, the killing of fin whales (*Balaenoptera physalus*) in Iceland has been promoted as a carbon service. Overemphasizing carbon storage undermines the diverse and vital ecological roles of animals[9], and relentless market optimization towards a single carbon goal risks perverse outcomes[13]. These problems are already apparent in the 'carbonization' of trees, which, despite the clearer and more direct carbon benefits, faces many criticisms[14] due to tree planting in inappropriate ecosystems (that is, grasslands), exclusion of local communities in carbon deals, challenges around additionality and leakage, and carbon offset purchasing by major fossil fuel emitters, thus delaying the necessary transition from a fossil fuel economy. Ambiguity around carbon baselines (for example, avoided deforestation credits) has also raised doubts about the genuine climate benefits of high-profile projects[10], undermining the credibility of biosphere-based climate mitigation strategies. All of these issues would probably be repeated for animal-focused climate mitigation, and are likely to be amplified because the science is younger, more uncertain and more context-dependent. Failure to deliver promised climate mitigation benefits risks eventual blowback and diminishing the wider benefits of conservation and rewilding.

The imperative for conservation beyond carbon

While the contribution of wildlife conservation and rewilding to global carbon capture may not be viable on relevant timescales, animals fulfil indispensable roles in restoring and sustaining diverse ecosystems. Accordingly, conservation and rewilding are paramount for reversing biodiversity loss and increasing ecosystem adaptation to climate change[9]. For example, many plant species rely on animal dispersal to track climate change, which has been reduced by ~60% globally through defaunation[15]. Simultaneously, animals contribute to the complexity of food webs, habitats, microclimates and nutrient cycles (including carbon) that promote ecosystem biodiversity, resiliency and resistance to abrupt environmental change[9] (Fig. 1e).

Ultimately, we strongly endorse trophic rewilding as an approach to protecting and restoring biodiversity. While rewilding may support climate mitigation in some circumstances, we caution that unverified and inflated economic valuations, selective media reporting, and a narrow management focus on carbon could result in perverse outcomes and reputational risk from failed carbon capture, and distract from the urgent need to reduce fossil fuel emissions. We cannot afford to make this mistake: ecosystems, humans and wildlife could suffer as a result.

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Competing interests

The authors declare no competing interests.