UNIVERSITY of York

This is a repository copy of *Climate change mitigation and nature conservation both require higher protected area targets*.

White Rose Research Online URL for this paper: <u>https://eprints.whiterose.ac.uk/156278/</u>

Version: Accepted Version

Article:

Roberts, Callum Michael orcid.org/0000-0003-2276-4258, O'Leary, Bethan Christine orcid.org/0000-0001-6595-6634 and Hawkins, Julie Patricia (2020) Climate change mitigation and nature conservation both require higher protected area targets. Philosophical Transactions of the Royal Society London B. 2019.0121. ISSN 1471-2970

https://doi.org/10.1098/rstb.2019.0121

Reuse

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.



eprints@whiterose.ac.uk https://eprints.whiterose.ac.uk/

- 1 Climate change mitigation and nature conservation both require higher protected area targets
- 2 Callum M. Roberts^{1*}, Bethan C. O'Leary¹ and Julie P. Hawkins¹
- 3 ¹Department of Environment and Geography, University of York, York, YO10 5NG
- 4 *Corresponding author: <u>callum.roberts@york.ac.uk</u>

5 Citation: Roberts, C.M., B.C. O'Leary and J.P. Hawkins (2020) Climate change mitigation and nature

- 6 conservation both require higher protected area targets. Phil. Trans. R. Soc. B 375: 20190121.
- 7 http://dx.doi.org/10.1098/rstb.2019.0121
- 8

9 Abstract

- 10 Nations of the world have, to date, pursued nature protection and climate change mitigation and
- 11 adaptation policies separately. Both efforts have failed to achieve the scale of action needed to halt
- 12 biodiversity loss or mitigate climate change. We argue that success can be achieved by aligning
- 13 targets for biodiversity protection with the habitat protection and restoration necessary to bring
- 14 down greenhouse gas concentrations and promote natural and societal adaptation to climate
- 15 change. Success, however, will need much higher targets for environmental protection than the
- 16 present 10% of sea and 17% of land. A new target of 30% of the sea given high levels of protection
- 17 from exploitation and harm by 2030 is under consideration and similar targets are being discussed
- 18 for terrestrial habitats. We make the case here that these higher targets, if achieved, would make
- 19 the transition to a warmer world slower and less damaging for nature and people.
- 20

21 Keywords

- 22 Biodiversity conservation; Natural climate solutions; Nature-based solutions
- 23
- 24 The year 2009 was a watershed in the progress of climate change [1, 2]. At a meeting at the Royal
- 25 Society in London to examine the past and consider the future of tropical coral reefs, participants
- 26 realised that global emissions, which by then stood at 386ppm CO₂, had already exceeded the
- estimated 350ppm CO₂ tolerance of this ecosystem [1]. It was too late to simply reduce emissions; to
- secure a viable future for coral reefs some of the CO₂ already in the atmosphere would now have to
- 29 be recaptured [1]. This recognition moved debate from consideration of how to avoid future
- 30 problems, to the fixes required for those already existing, a conversation that still continues [3-5].
- 31 The Paris Agreement acknowledged this shift in perspective by incorporating carbon recapture in the
- 32 two more ambitious Representative Concentration Pathways, RCP 2.6 (a stringent mitigation/low
- emissions scenario) and RCP 4.5 (a stabilisation/moderate emissions scenario) [6], more recently
- 34 extended to include social and economic dimensions through Shared Socio-economic Pathways [7].
- 35 The most effective way to quickly capture sufficient CO₂ from the atmosphere is via photosynthesis,
- 36 so both RCPs include scenarios of mass reforestation and habitat restoration [4, 8]. But while climate
- 37 change and emissions reduction are now high on the political agenda, addressing the global and
- 38 accelerating deterioration of nature [9] is at least as urgent. In practice, however, biodiversity loss

- 39 receives far less attention and global actions to reverse it have been largely ineffective [9]. It is now
- 40 widely recognised that synergies between climate change and biodiversity conservation mean that
- 41 the two agendas must be pursued concurrently to meet societal and environmental goals, such as
- 42 the UN's Sustainable Development Goals, Convention on Biological Diversity's Aichi Targets, and the
- 43 Paris Agreement [9]. This recognition is now also reflected in global social movements aimed at
- 44 driving political action [10].
- 45 While reducing emissions remains fundamental, mitigation is also essential [4]. Conserving and
- 46 restoring natural habitats is among the most cost-effective emissions mitigation strategies available
- 47 but while clear synergies exist between the objectives of biodiversity protection and carbon capture,
- 48 there is also a risk that if conservation and climate change mitigation agendas are mis-aligned, one
- 49 could easily undermine the other.
- 50 The last decade has seen a surge in research on the benefits and costs of nature-based solutions to
- 51 climate change mitigation and adaptation and, as much of it acknowledges, there are trade-offs
- among outcomes [4]. For example, habitats that store the most carbon, or are best for flood control,
- or for pollution mitigation, are not necessarily the most diverse, intact, or natural. Hence the single-
- 54 minded pursuit of a narrow goal, such as carbon storage or reduced consumption of fossil fuels,
- 55 might well lead to policies antithetical to wildlife protection. An example of the former would be
- 56 establishment of large-scale, low diversity plantations with the potential to sequester large amounts
- 57 of CO₂ in repeatedly harvested timber but which could potentially hasten the disappearance of
- threatened species by co-opting space and blocking dispersal [11]. An example of the latter would be
- 59 increased land conversion to facilitate crops for biofuels to reduce reliance on fossil fuels at the
- 60 overall expense of carbon emissions and biodiversity [12]. It is critical to avoid such "bio-
- 61 perversities" in any climate mitigation policies [13].
- 62 The numerous co-benefits from wildlife and habitat protection for climate mitigation and adaptation
- 63 must be embedded in revised global ambitions. Climate solutions must promote conservation, while
- 64 conservation efforts must work to counter climate change. Natural or restored habitats perform
- 65 functions that are crucial in mitigating climate change and promoting societal adaptation. For
- 66 example, wetlands, peat bogs and rainforests are often intense carbon sinks [14-16] while intact,
- 67 vigorous wetlands and coral reefs form natural, self-repairing breakwaters that can protect coasts
- against sea level rise better than man-made defences [17]. Unfished mesopelagic fish populations
- 69 promote carbon sequestration in the deep sea [18] and protecting marine animals and ecosystems
- can benefit carbon storage and prevent release of carbon already locked away [5, 19]. Natural and
 restored forested landscapes promote water retention and counter flooding while regulating climate
- 72 and rainfall at local, regional and continental scales [20], while protected habitats in agricultural
- 73 landscapes sustain populations of natural pollinators, predators that control pests, and facilitate
- 74 seed dispersal [21, 22].
- 75 Existing global conservation targets (the 'Aichi targets') agreed through the Convention on Biological
- 76 Diversity (CBD) [23], and later incorporated into the Sustainable Development Goals [24], run until
- 77 2020. The Aichi targets have spurred governments to act and there have been some successes, but
- 78 global biodiversity continues to decline [9]. Attention is now turning to the post-2020 agenda and,
- 79 with the urgency of climate change well-recognised [25], there is a need to align conservation and
- 80 climate change agendas so that both may see greater success and fulfil their essential roles in
- 81 achieving the Sustainable Development Goals. The post-2020 CBD targets need a rapid increase in

- 82 ambition and action. For nature to substantially contribute to climate change mitigation higher
- 83 coverages of intact ecosystems will be essential because of the reliance of ecosystem service
- 84 delivery, including carbon sequestration and storage, on biodiversity and the crucial need to leave
- 85 existing carbon stores intact. Moreover, given that many ecosystems are already degraded, ensuring
- 86 continued provision of ecosystem services requires not only the precautionary protection of
- 87 currently intact habitats, but also large-scale habitat restoration.

88 Providing greater space for recovery of intact, vibrant nature is not altruistic conservation, but is, we 89 argue, an indispensable act of self-preservation, producing a cascade of benefits that will help 90 maintain the habitability of the biosphere as the climate changes, thereby securing the wellbeing of 91 generations to come. In truth, the goals of protecting 10% of marine habitats and 17% of those on 92 land by 2020 (Aichi Target 11) were political and never considered sufficient to save nature, even 93 without climate change, or to enable nature to contribute substantially to climate change mitigation. 94 Based on the species-area relationship, regarded as one of ecology's few universal laws, protection 95 of so little habitat will condemn thousands of species to extinction if habitat outside them is 96 converted, degraded or lost. It is this logic that underpins calls for 'Nature Needs Half' [26], together 97 with an understanding that ecosystem processes and services of the scale needed to sustain the 98 wellbeing of life on Earth require large wildlife populations and huge expanses of intact and restored 99 habitat.

- 100 Since the current Convention on Biological Diversity targets were agreed, new research has shown 101 that future conservation success will depend on greatly increased coverage of fully and strongly 102 protected areas and restored habitats. For example, in the oceans, a synthesis of 144 studies asked 103 how much protected area coverage was needed to achieve, optimise or maximise benefits for six 104 core environmental and/or socioeconomic objectives [27]. The goals were representation of 105 biodiversity; ensuring ecological connectivity among protected sites; avoidance of population 106 collapse; avoidance of adverse, fisheries-induced evolution; enhancement of fisheries yield; and 107 meeting the needs of multiple stakeholder groups. The results consistently indicated that protecting 108 several tens-of-percent of the sea is required to meet goals with average and median values of 37% 109 and 35%, greatly exceeding the 5% or so of the ocean that is currently protected and the 10% target 110 (http://www.mpatlas.org).
- 111 Climate change adds a new dimension to the question of how much protected area coverage is 112 needed to assure conservation of wild nature. Climate change is already reducing wildlife population 113 sizes and forcing range shifts as conditions alter [28, 29]. Protected areas counter such stresses by 114 building up populations, and connectivity of populations and habitats is emerging as a key property 115 in securing species persistence and resilience to rapid change [5]. Hence networked protected areas, especially where embedded within well-managed land- or seascapes, provide crucial stepping stones 116 117 to accommodate range shifts and, where no further movements are possible, refuges of last resort 118 [5]. Analyses suggest that adequate levels of population viability and connectivity can be achieved 119 only with MPA coverages of 30% or more [27]. We are not aware of comparable analyses for 120 terrestrial ecosystems, but figures are unlikely to be lower [30], given the more limited capacity for 121 dispersal on land than in the sea [31].
- Policies that target single objectives can lead to unintended consequences and a lack of alignment
 between goals as we argue above [11-13]. However, protected areas, with their multiple benefits to
 wildlife and human societies, offer a low-tech and cost-effective nature-based tool to simultaneously

- 125 pursue climate change mitigation and adaptation and staunch biodiversity loss [5, 32]. Of course,
- 126 methods matter and the ability of protected areas to achieve multiple goals depends on factors such
- 127 as level of protection, public engagement, governance, location, size, staff and budget but we have a
- 128 large body of experience on how to effectively design and deliver protected areas [33, 34] and
- restoration programmes [35]. To date, much effort in marine protected area establishment has
- 130 focussed on remote and more intact ecosystems [36] which, while important in delivering planetary
- 131 benefits, is insufficient to address other immediate human needs. Extending benefits to more people
- 132 will require greater protection efforts in populous regions in both sea and land.
- 133 Over the past decade, we have gained a much clearer scientific understanding of the role of natural
- ecosystems in human wellbeing and planetary processes, and the scale of the challenge from rapid
- climate change. Given the plight of natural ecosystems and humanity's reliance on them for our
- survival, there is an urgent need to increase protection targets set by the Convention on BiologicalDiversity to secure sufficient space for nature to thrive and adapt in our fast-changing world. This is
- 138 so important because protected habitats must be part of frontline defence in efforts to mitigate
- 139 climate change and to promote ecosystem and societal adaptation against its effects. Our goals need
- 140 to coalesce in a joined-up strategy for planetary survival. For marine habitats, there is growing
- 141 consensus that at least 30% of the sea should be protected by 2030 [36] and a similar level of
- ambition is justified on land [37-39], with protection targeted to achieve ecological representation
- and connectivity to support and restore nature and its wealth of services. For the next phase of
- 144 reshaping global conservation ambitions, our focus must shift from saving nature, to harnessing the
- 145 benefits of nature to save ourselves.
- 146

147

148 References

149 [1] Veron, J. E. N., Hoegh-Guldberg, O., Lenton, T. M., Lough, J. M., Oburae, D. O., Pearce-Kelly, P.,

150 Sheppard, C. R. C., Spalding, M., Stafford-Smith, M. G. & Rogers, A. D. 2009 The coral reef crisis: the

- critical importance of <350 ppm CO₂. *Marine Poll Bull* **58**, 1428-1436.
- 152 (DOI:10.1016/j.marpolbul.2009.09.009).
- 153 [2] Solomon, S., Plattner, G. K., Knutti, R. & Friedlingstein, P. 2009 Irreversible climate change due to
- 154 carbon dioxide emissions. *Proc Natl Acad Sci U S A* **106**, 1704-1709. (DOI:10.1073/pnas.0812721106).
- 155 [3] Anthony, K., Bay, L. K., Costanza, R., Firn, J., Gunn, J., Harrison, P., Heyward, A., Lundgren, P.,
- Mead, D., Moore, T., et al. 2017 New interventions are needed to save coral reefs. *Nat Ecol Evol* **1**,
- 157 1420-1422. (DOI:10.1038/s41559-017-0313-5).
- 158 [4] Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W.
- H., Shoch, D., Siikamäki, J. V., Smith, P., et al. 2017 Natural climate solutions. *PNAS* **114**, 11645.
 (DOI:10.1073/pnas.1710465114).
- 161 [5] Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P., Duarte, C. M., Lubchenco, J., Pauly, D.,
- 162 Sáenz-Arroyo, A., Sumaila, U. R., Wilson, R. W., et al. 2017 Marine reserves can mitigate and
- 163 promote adaptation to climate change. *PNAS* **114**, 6167-6175. (DOI:10.1073/pnas.1701262114).
- 164 [6] van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C.,
- 165 Kram, T., Krey, V., Lamarque, J.-F., et al. 2011 The representative concentration pathways: an
- 166 overview. *Clim Change* **109**, 5. (DOI:10.1007/s10584-011-0148-z).
- 167 [7] Rogelj, J., Popp, A., Calvin, K. V., Luderer, G., Emmerling, J., Gernaat, D., Fujimori, S., Strefler, J.,
- 168 Hasegawa, T., Marangoni, G., et al. 2018 Scenarios towards limiting global mean temperature
- 169 increase below 1.5 °C. *Nat Clim Change* **8**, 325-332. (DOI:10.1038/s41558-018-0091-3).
- 170 [8] Williamson, P. 2016 Emissions reduction: Scrutinize CO₂ removal methods. *Nature* **530**, 153-155.
- 171 (DOI:10.1038/530153a).
- 172 [9] IPBES. 2019 Summary for policymakers of the global assessment report on biodiversity and
- ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and EcosystemServices. IPBES secretariat, Bonn, Germany.
- 175 [10] Shah, D. 2019 Viewpoint: Extinction Rebellion: radical or rational? *Br J Gen Pract* **69**, 345.
- 176 (DOI:10.3399/bjgp19X704357).
- 177 [11] Cannell, M. G. R. Environmental impacts of forest monocultures: water use, acidification,
- 178 wildlife conservation, and carbon storage. In *Planted Forests: Contributions to the Quest for*
- 179 Sustainable Societies (eds. J. R. Boyle, J. K. Winjum, K. Kavanagh & E. C. Jensen), pp. 236-262.
- 180 [12] Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes,
- 181 D. & Yu, T.-H. 2008 Use of U.S. croplands for biofuels increases greenhouse gases through emissions
- 182 from land-use change. *Science* **319**, 1238. (DOI:10.1126/science.1151861).
- 183 [13] Lindenmayer, D. B., Hulvey, K. B., Hobbs, R. J., Colyvan, M., Felton, A., Possingham, H., Steffen,
- 184 W., Wilson, K., Youngentob, K. & Gibbons, P. 2012 Avoiding bio-perversity from carbon
- 185 sequestration solutions. *Conserv Lett* **5**, 28-36. (DOI:10.1111/j.1755-263X.2011.00213.x).
- 186 [14] Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I. & Marbà, N. 2013 The role of coastal
- 187 plant communities for climate change mitigation and adaptation. *Nat Clim Change* **3**, 961-968.
- 188 (DOI:10.1038/NCLIMATE1970).
- 189 [15] Gamfeldt, L., Snä, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M. C.,
- 190 Fröberg, M., Stendahl, J., Philipson, C. D., et al. 2012 Higher levels of multiple ecosystem services are
- 191 found in forests with more tree species. *Nat Commun* **4**, 1340. (DOI:10.1038/ncomms2328).

- 192 [16] Page, S. E., Rieley, J. O. & Banks, C. J. 2011 Global and regional importance of the tropical
- 193 peatland carbon pool. *Glob Chang Biol* **17**, 798-818. (DOI:10.1111/j.1365-2486.2010.02279.x).
- 194 [17] Beck, M. W. & Lange, G.-M. 2016 Managing coasts with natural solutions: guidelines for
- measuring and valuing the coastal protection services of mangroves and coral reefs (Technical
- 196 Report). WAVES, World Bank, Washington, D.C.
- 197 [18] O'Leary, B. C. & Roberts, C. M. 2018 Ecological connectivity across ocean depths: implications
- 198 for protected area design. *Glob Ecol Conserv* **15**, e00431. (DOI:10.1016/j.gecco.2018.e00431).
- 199 [19] Wilmers, C. C., Estes, J. A., Edwards, M., Laidre, K. L. & Konar, B. 2012 Do trophic cascades affect
- 200 the storage and flux of atmospheric carbon? An analysis for sea otters and kelp forests. *Front Ecol*
- 201 Environ 10, 409-415. (DOI:10.1890/110176).
- 202 [20] Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., Gutierrez, V.,
- Noordwijk, M. v., Creed, I. F., Pokorny, J., et al. 2017 Trees, forests and water: cool insights for a hot
 world. *Glob Environ Change* 43, 51-61. (DOI:10.1016/j.gloenvcha.2017.01.002).
- 205 [21] Lentini, P. E., Martin, T. G., Gibbons, P., Fischer, J. & Cunningham, S. A. 2012 Supporting wild
- 206 pollinators in a temperate agricultural landscape: maintaining mosaics of natural features and
- 207 production. *Biol Conserv* 149, 84-92. (DOI:10.1016/j.biocon.2012.02.004).
- 208 [22] Bianchi, F. J. J. A., Booij, C. J. H. & Tscharntke, T. 2006 Sustainable pest regulation in agricultural
- 209 landscapes: a review on landscape composition, biodiversity and natural pest control. *Proc Royal Soc*
- 210 B 273, 1715-1727. (DOI:10.1098/rspb.2006.3530).
- [23] Convention on Biological Diversity. 2010 COP Decision X/2. Strategic plan for biodiversity 2011–
 2020. (<u>https://www.cbd.int/decision/cop/?id=12268</u> accessed: 1 October 2019)
- [24] United Nations. 2015 Transforming our world: the 2030 Agenda for Sustainable Development.
 A/RES/70/1.
- 215 [25] IPCC. 2018 Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of
- 216 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the
- 217 context of strengthening the global response to the threat of climate change, sustainable
- 218 development, and efforts to eradicate poverty. World Meteorological Organization, Geneva,
- 219 Switzerland, 32 pp.
- 220 [26] Wilson, E. O. 2016 Half-earth: our planet's fight for life, Liveright; 272 p.
- 221 [27] O'Leary, B. C., Winther-Janson, M., Bainbridge, J. M., Aitken, J., Hawkins, J. P. & Roberts, C. M.
- 222 2016 Effective coverage targets for ocean protection. *Conserv Lett* **9**, 398-404.
- 223 (DOI:10.1111/conl.12247).
- 224 [28] Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J. & Cheung, W. W. L.
- 225 2018 Preparing ocean governance for species on the move. *Science* **360**, 1189.
- 226 (DOI:10.1126/science.aat2360).
- 227 [29] Chen, I. C., Hill, J. K., Ohlemüller, R., Roy, D. B. & Thomas, C. D. 2011 Rapid range shifts of
- species associated with high levels of climate warming. *Science* **333**, 1024.
- 229 (DOI:10.1126/science.1206432).
- 230 [30] Svancara, L. K., Brannon J., R., Scott, M., Groves, C. R., Noss, R. F. & Pressey, R. L. 2005 Policy-
- driven versus evidence-based conservation: a review of political targets and biological needs.
- 232 *BioScience* **55**, 989-995. (DOI:10.1641/0006-3568(2005)055[0989:pvecar]2.0.co;2).
- 233 [31] Kinlan, B. P. & Gaines, S. D. 2003 Propagule dispersal in marine and terrestrial environments: a
- community perspective. *Ecology* **84**, 2007-2020. (DOI:10.1890/01-0622).

- [32] Leverington, F. J., Laemos Costa, K., Pavese, H., Lisle, A. & Hockings, M. 2010 A global analysis of
- protected area management effectiveness. *Environmental Management* **46**, 685-698.
- 237 (DOI:10.1007/s00267-010-9564-5)).
- 238 [33] Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., Craigie, I., Darling, E.
- 239 S., Free, C. M., Geldmann, J., et al. 2017 Capacity shortfalls hinder the performance of marine
- 240 protected areas globally. *Nature* **543**, 665-669. (DOI:10.1038/nature21708).
- 241 [34] Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., Barrett, N. S.,
- 242 Becerro, M. A., Bernard, A. T. F., Berkhout, J., et al. 2014 Global conservation outcomes depend on
- 243 marine protected areas with five key features. *Nature* **506**, 216-220. (DOI:10.1038/nature13022).
- [35] Bayraktarov, L., Saunders, M. I., Abdullah, S., Mills, M., Beher, J., Possingham, H. P., Mumby, P. J.
- 245 & Lovelock, C. E. 2016 The cost and feasibility of marine coastal restoration. *Ecol Appl*.
- 246 (DOI:10.1890/15-1077).
- [36] IUCN. 2016 Motion 053 Increasing marine protected area coverage for effective marinebiodiversity conservation.

249 (<u>https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_050_EN.pdf</u> accessed:
 250 1 October 2019)

- 251 [37] Baillie, J. & Zhang, Y.-P. 2018 Space for nature. *Science* **361**, 1051.
- 252 (DOI:10.1126/science.aau1397).
- 253 [38] Dinerstein, E., Vynne, C., Sala, E., Joshi, A. R., Fernando, S., Lovejoy, T. E., Mayorga, J., Olson, D.,
- Asner, G. P., Baillie, J. E. M., et al. 2019 A global deal for nature: guiding principles, milestones, and
- targets. *Science Advances* **5**, eaaw2869. (DOI:10.1126/sciadv.aaw2869).
- 256 [39] Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., Hahn, N.,
- 257 Palminteri, S., Hedao, P., Noss, R., et al. 2017 An Ecoregion-Based Approach to Protecting Half the
- 258 Terrestrial Realm. *BioScience* **67**, 534-545. (DOI:10.1093/biosci/bix014).

259 Funding

- 260 The author's received no specific funding for this work. We appreciate the invitation for C.M.R. to
- attend the Sackler Forum on Climate Change and Ecosystems which helped develop ideas in this
- 262 paper.