Supplementary Material

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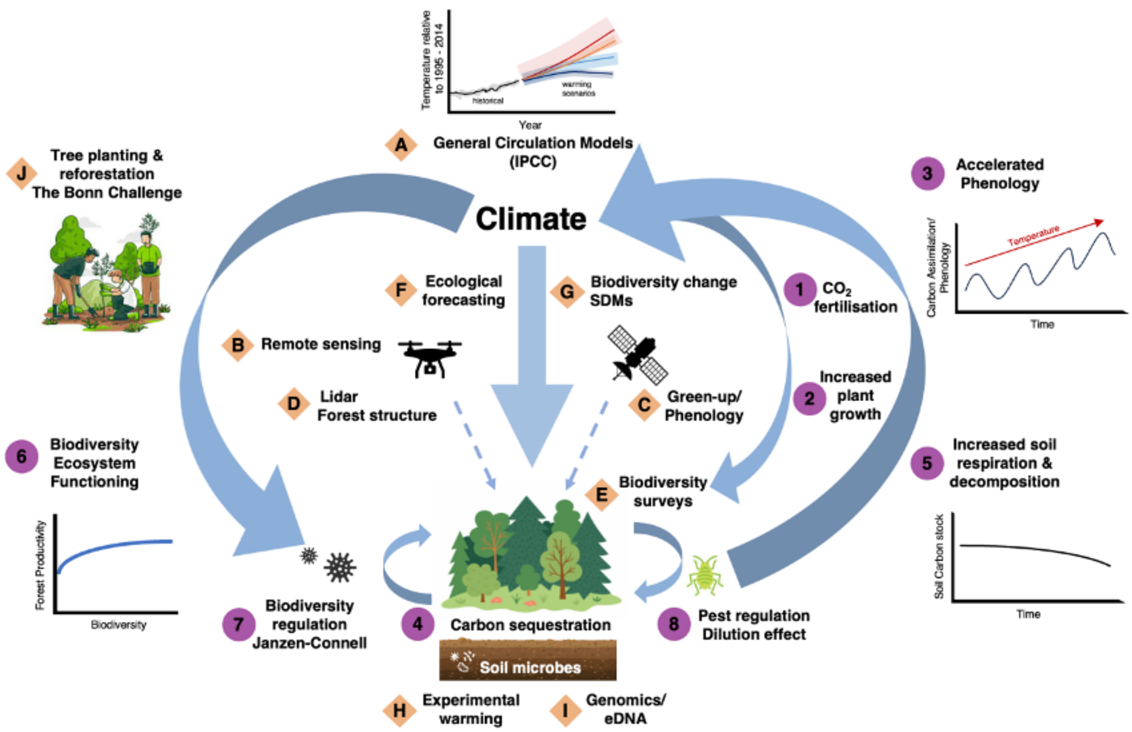
Glossary

Behavior: the way an organism acts, e.g., foraging, movement, social interactions
Biodiversity crisis: nature and biodiversity loss, encompassing the decline or disappearance of biological diversity, from genes to ecosystems.
Climate crisis: long-term shifts in the means and variances of temperatures and weather patterns (including shifts in seasonality, and incidences of extremes in climate variables as well as changes in spatial and temporal correlations among climate variables).
Climatic extreme events: rapid changes in climate that occur over a short window of time.
Climate variability: deviations from the long-term mean climate state.
Deforestation: intentional clearing of forested land.
Development time of pathogens: the progressive life history changes a pathogen undergoes in its lifetime.
Development time of vectors: the progressive life history changes a pathogen's vector (organism that transmits pathogens between humans and animals) undergoes in its lifetime.
Dilution / Amplification: when the presence of a species in a population either dilutes or amplifies the transmission of pathogens.
Ecosystem services: benefits humans obtain from nature, e.g., carbon sequestration, nutrient cycling, and flood regulation.
Extirpation: the loss of a species from a particular geographic area, local extinction.
Food web dynamics: changes in flow or structure of the food chains in an ecosystem.
Gradual climate change: slow and consistent changes in climate over time.
Infectious disease crisis: increasing frequency and prevalence of emerging infectious diseases in plants, animals, and people.
Migration: regular and repeated movements between different areas of an organism's home range.
Novel disease spread: transmission of a new disease through a population.
Parasite mediated competition: competition between two species driven by parasitism in one or both species.
Physiology: referring to the physiological mechanisms of an organism, e.g., cellular and metabolic processes.
Range shifts: a spatial change in the geographic distribution of a species.
Species decline: decrease in habitat, geographic range, or population sizes of a particular species.
Species introductions: the arrival of species into a new geographic area.
Spillover: contact of a host population with pathogen propagules from another host population as a result of high pathogen abundance in a population where the pathogen can be permanently maintained, reservoir population.
Temporal mismatch: misalignment of organismal processes or organisms in time. The temporal mismatch theory ties the fitness of an organism to the temporal synchrony of the offspring's energetic needs and food source.
Thermal mismatch: misalignment of temperature required for organismal processes. The thermal mismatch hypothesis suggests that smaller-bodied parasites will generally be favored over larger-bodied parasites due to their broader thermal niches and ability to quickly adapt to changing environmental conditions.

Trophic cascade: reciprocal changes in the food web as a result of the addition or removal of a top predator.
Urbanization: the process in which large numbers of people concentrate in proportionally small geographic areas.
Vector population: the vector species that occupy a particular geographical area.



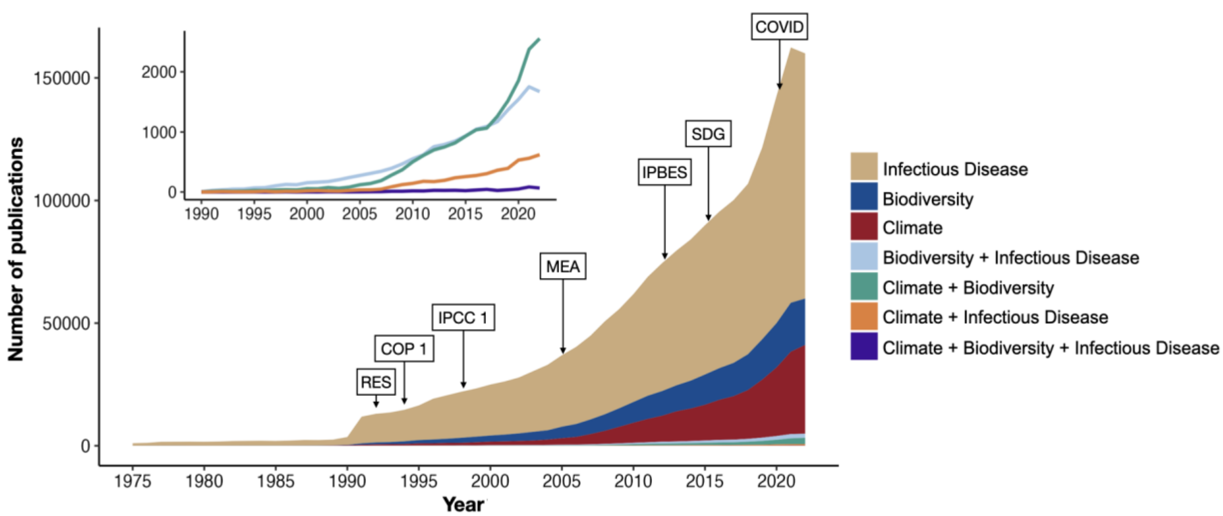
Appendix Figure 1: Schematic illustrating mechanisms underlying key pathways and feedbacks linking between biodiversity, disease dynamics and the climate system (numbers), and the research tools and data types that allow us to quantify them (letters). Climate determines rates of primary productivity (central arrow). Warming temperatures and CO_2 fertilisation (1) accelerate plant growth (2) and the timing of annual life cycle events (3). Increased plant growth sequesters atmospheric CO_2 (4), but warming soils elevate respiration and decomposition rates of soil microbes (5) which releases CO_2 back into the atmosphere. Increased biodiversity enhances ecosystem productivity (6), and thus rates of CO_2 fixation. Pests and disease can regulate and maintain biodiversity through Janzen-Connell effects (7) while biodiversity can modify disease outbreaks through the dilution effect (8). General climate circulation models (A) and synthesis reports from the Intergovernmental Panel on Climate Change (IPCC) provide projections of likely climate responses to variation in atmospheric CO_2 concentration. Remote sensing using satellites and drones (B) allows for real-time monitoring of plant phenological responses (C) to changes in climate and associated changes in vegetation structure (D). Remote sensed data and ‘on the ground’ biodiversity surveys (E) inform ecological forecasts (F) in combination with species distribution modelling (G). Experimental manipulations, such as experimental warming (H), and new genomic tools (I) that can detect evidence of selection provide quantitative measures of species' adaptive and plastic potential to environmental changes. Nature-based solutions (J), including tree planting (see The Bonn Challenge: https://www.bonnchallenge.org/), provide potential for win-win-win scenarios, but only if enacted thoughtfully. See Table 1 for citations. We use a terrestrial forest ecosystem as example to illustrate system complexity; equivalent schematics could be generated for marine and freshwater ecosystems. We do not show interactions with the socio-economic system, including feedbacks with public health policy, disease surveillance, clean energy pathways etc. which would add further complexity.

Search Strategy and Selection Criteria

We conducted a series of literature searches via the Web of Science Core Collection, accessed through the University of Toronto September 28, 2023. We searched for papers published between 1975-2022 inclusive which mention terms relating to climate change, biodiversity and infectious disease in the title, author keywords, or abstract of each paper. We identified climate change literature using the search terms ‘climate change’ OR ‘global change’ OR ‘global warming’ OR ‘climate variability’; the biodiversity literature using the terms ‘biodiversity’ OR ‘biological diversity’ OR ‘species richness’ OR ‘genetic diversity’ OR ‘phylogenetic diversity’ OR ‘species diversity’; and the infectious disease literature using the terms ‘infectious disease’ OR ‘parasit*’ OR ‘pathogen*’ OR (‘infect*’ AND (‘parasit*’ OR ‘host’)). We use these sets to terms to identify papers associated with only one set of drivers (e.g. climate change NOT (biodiversity OR infectious disease)), in pairs (e.g. (climate change AND biodiversity) NOT infectious disease), and in triplet (climate change AND biodiversity AND infectious disease). For each search we restricted to primary research articles and review papers, excluding book chapters, conference proceedings, and data papers. We did not restrict by language but note that we did not include non-English terms in our searches.

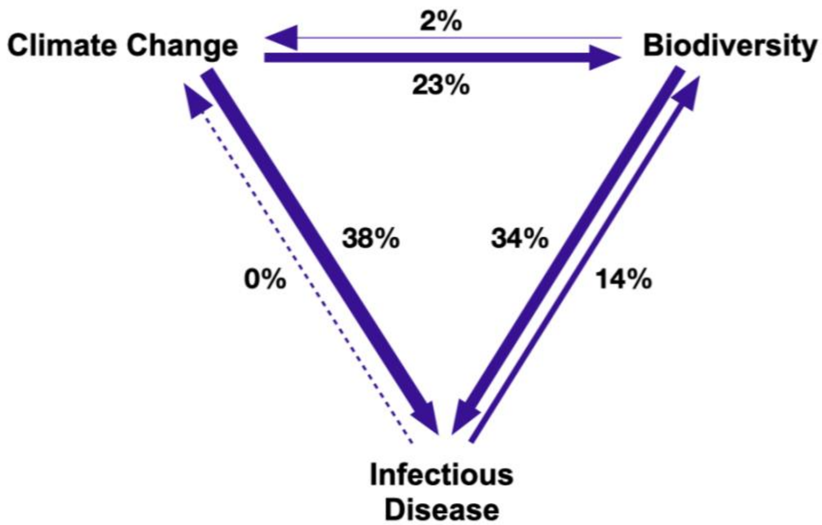
For publications at the intersection of climate change, biodiversity, and infectious disease, the literature is predominantly from the ecological and environmental sciences, with over 90% of articles included in the Web of Science subject categories "Ecology", "Environmental Sciences", "Biodiversity Conservation", "Plant Sciences", "Forestry", "Entomology", "Evolutionary biology", or "Zoology. For our most permissive search (papers including any terms reflecting climate change, biodiversity, or infectious disease), the literature is more evenly distributed across WOS subject categories, with the most frequent categories "Microbiology" (8.29%), "Environmental Sciences" (7.01%), "Biochemistry & Molecular Biology" (6.98%), "Immunology" (6.90%), and "Ecology" (6.27%). We included the number of papers in each research category in the most inclusive WOS search climate change OR biodiversity OR infectious disease and the number of papers in each research category in the least inclusive WOS search climate change AND biodiversity AND infectious disease as tables in Github (https://github.com/CBD-Working-Group/CBD_synthesis_figures/tree/main/WOS_trends/WOS_Sept28_2023/Research_categories).

Undoubtedly, some relevant papers were missed because of our choice of search terms (e.g., we did not include more general terms such as “temperature”, “abundance”, or “disease” because these are often used in contexts other than the three pressures of focus in this synthesis); however, the overall proportion of papers that intersect axes of each global pressure is unlikely to be greatly impacted by their exclusion – few papers consider pairwise terms, fewer still consider all three, and those that do tend to focus on a single study system.



Appendix Figure 2: Number of publications retrieved for different combinations of search terms associated with biodiversity, climate change, and infectious disease research. Literature trends are based on Web of Science searches for terms related to climate change, biodiversity, and infectious disease. Major events related to the study of climate change, biodiversity, or infectious disease are indicated: The Rio Earth Summit (RES) in 1992; the first Convention of Biological Diversity (COP 1) in 1994; the first Intergovernmental Panel on Climate Change (IPCC 1) meeting in 1998; Millennium Ecosystem Assessment (MEA) published in 2005; the formation of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2012; the Sustainable

Development Goals (SDG) published in 2015; and SARS-CoV-2 (COVID) became pandemic in 2020. Literature reflecting pairwise and three-way combinations of search terms are highlighted in the inset.



Appendix Figure 3: Number of publications that discuss mechanistic links between biodiversity, climate change, and infectious disease. Mechanistic links describe a process by which one global pressure drives another. Mechanisms were identified through our reading of the literature, including the papers cited in Appendix Table 1, and are consistent across the main text figures. Arrows illustrate the direction of mechanistic links between pressures; arrow width is weighted by relative number of publications (percent of the 128 publications is noted next to each arrow), as a proxy for research effort.

Figure Methods

The mechanisms listed in the Glossary are consistent across all figures and tables. These mechanisms were identified through reading studies from the literature searches as well as others cited throughout the paper.

Appendix Figure 2 is the number of publications retrieved from the literature searches described above per year. The inset figure zooms in on the interaction publications (Climate + Biodiversity, Climate + Infectious Disease, Biodiversity + Infectious Disease, and Climate + Biodiversity + Infectious Disease). The script and data to recreate *Appendix Figure 2* is available on GitHub (https://github.com/CBD-Working-Group/CBD_synthesis_figures)

Appendix Figure 3 is a summary of the subset of climate change, biodiversity, and infectious disease literature search papers that discuss these global pressures in more depth than a single mention in the abstract, introduction, or conclusion. When summarizing which studies connected which global pressures, we scored a paper if it discussed a process by which one of the global pressures could impact another. For example, if a paper discussed how disease can lead to species decline and affect the biodiversity of an ecosystem it would be counted in the Disease –> Biodiversity path. The same paper could describe another process that links Biodiversity –> Disease and would be counted in that arrow as well.

The width of each arrow in *Appendix Figure 3* is the number of publications scored by the process described above divided by the number of papers in the Climate change –> Biodiversity path (it was the second lowest pathway, the first was infectious disease to climate change which had one paper and was marked with a dashed arrow).

Figure 3

Figure 3 is another summary of the subset of climate change, biodiversity, and infectious disease literature search papers that discuss these global pressures in more depth than a single mention in the abstract, introduction, or conclusion. *Figure 3* provides the background of the studies that identify mechanisms between two global pressures. The intention was to identify if there were common mechanisms within types of studies, ecosystems, or taxa. However, we found that the mechanisms that link climate, biodiversity, and disease are not easily sorted out by taxa or ecosystems.

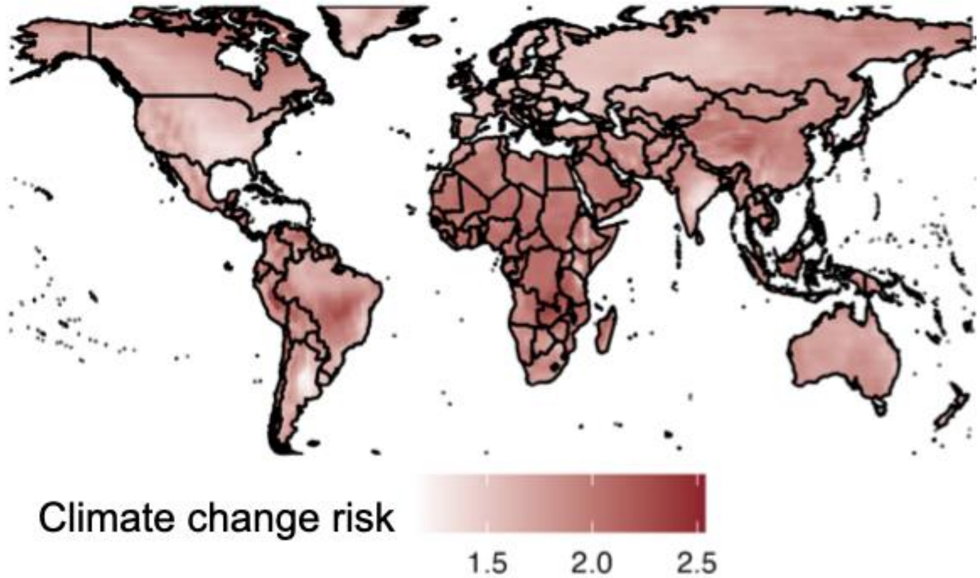
To score the 128 number of papers that were included in the summary, we designated each study a publication type based on the study's focus: theory was assigned to theoretical publications, literature was assigned to publications synthesizing or reviewing existing literature, and empirical was assigned to observation or experimental studies. We identified the focal habitat of each study to the closest corresponding ecosystem: terrestrial, marine, freshwater, and agricultural; studies with a human focus rather than an ecosystem focus were scored as 'anthropogenic,' and theoretical studies were denoted as 'in silico.' We also identified the focal organism of each study (Taxon). For theoretical studies the organism used to parameterise the model was listed. For general studies that covered a broad range of organisms the taxon was denoted as 'animal.' The mechanisms that were described as links between either climate change, biodiversity, or infectious disease in each publication were assigned to the mechanisms discussed in this synthesis (*Figure 2*). When a mechanism described in a study did not match any of the mechanisms discussed in this synthesis, we identified the most related mechanism. For example, studies that describe general increases in temperature and precipitation were included in the 'gradual climate change' mechanism, whereas studies on extreme heatwaves were included in 'climatic pulse events.' Each line represents a single study out of the total 128 scored for each column of the figure. The script and data to recreate *Figure 3* are available on GitHub (https://github.com/CBD-Working-Group/CBD_synthesis_figures).

Figure 4

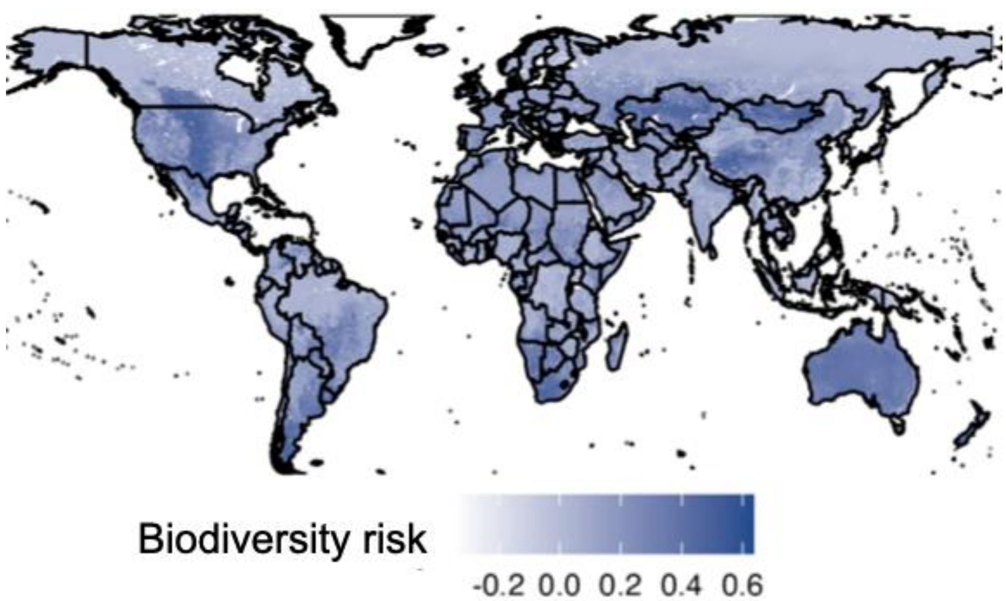
Figure 4 shows three ways to geographically overlap climate risk, biodiversity risk, and infectious disease risk data to highlight areas that could potentially have interactions between two or three of the global pressures.

Climate change risk is measured as the standard Euclidean distance across multiple climate metrics between a baseline (1995-2014) and future (2080-2099) period under the Shared Socioeconomic Pathway (SSP) 2-4.5 scenario;[198] Biodiversity is represented as the inverse of the Biodiversity Intactness Index (1- BII), which reflects the proportional loss of species richness in a given area relative to minimally-impacted baseline sites in 2005;[199] Infectious disease risk is represented by mammal zoonotic host richness,[200] a measure of both biodiversity and zoonotic infectious disease burden.

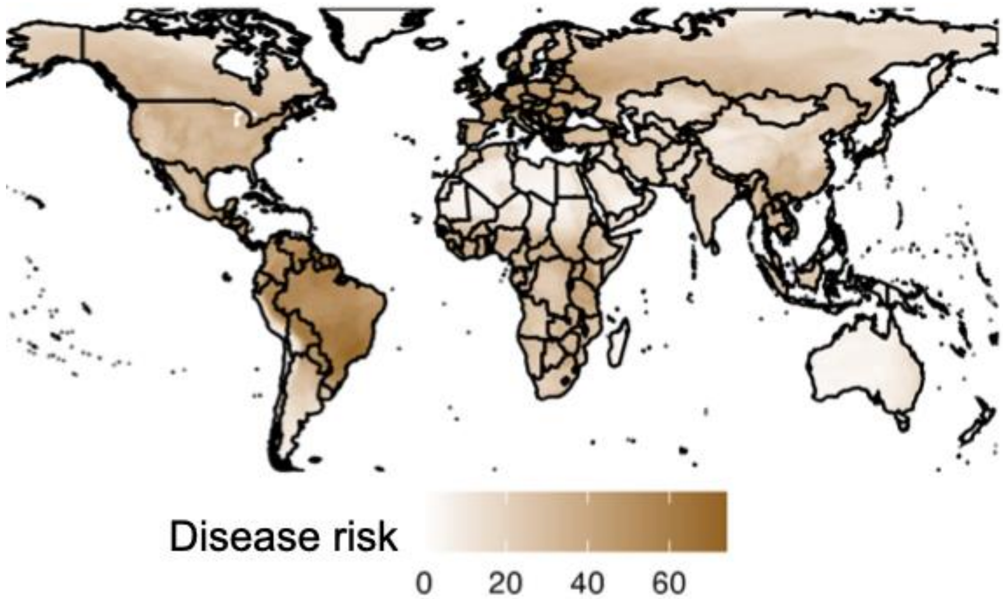
The data above were visualized on maps individually (Appendix figures 4-6). To create *Figure 4A* we calculated the upper 20% quantile of each dataset to highlight geographic areas of 'high risk' for each global pressure. Each cell on the map was assigned a color based on the global pressure(s) that had data in the upper 20% quantile or was an area of 'high risk' using the 'colors3d' function in the *colormap* R package (version 0.0.0.9). To create *Figure 4B*, the additive overlapping data map, the data were normalized between 0 and 1 using min-max normalization. To create *Figure 4C*, the multiplicative overlapping map, the data were rescaled between 1 and 2 using min-max normalization and then adding 1. Below are the individual maps for climate risk, biodiversity risk, and infectious disease risk. The script and data to recreate *Figure 4* and the individual data maps are available on GitHub (https://github.com/CBD-Working-Group/CBDmapping).



Appendix Figure 4. Climate change risk map measured as the standard Euclidean distance across multiple climate metrics between a baseline (1995-2014) and future (2080-2099) period under the Shared Socioeconomic Pathway (SSP) 2-4.5 scenario.

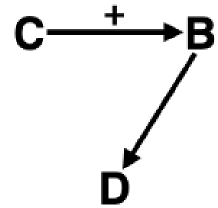
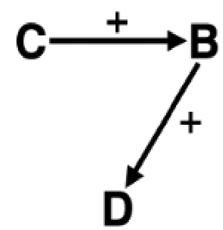
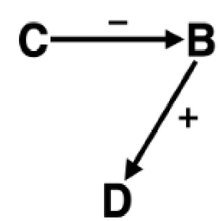


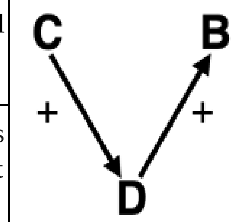
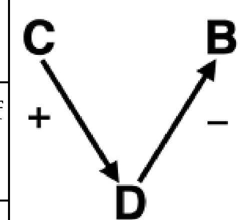
Appendix Figure 5. Biodiversity risk map shown as the inverse of the Biodiversity Intactness Index (1- BII), which reflects the proportional loss of species richness in a given area relative to minimally impacted baseline sites in 2005.

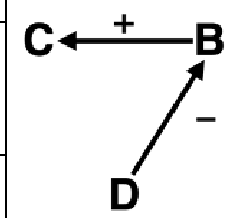
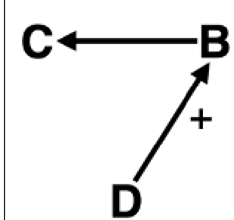
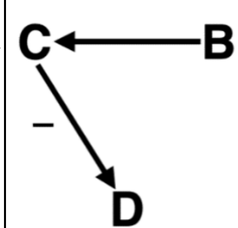


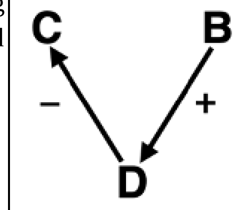
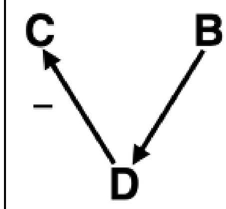
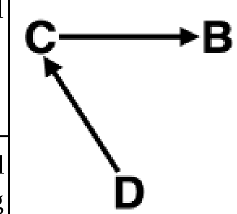
Appendix Figure 6. Infectious disease risk is represented by mammal zoonotic host richness, which is a measure of both biodiversity and infectious disease.

Table 1. Case studies illustrating mechanistic links connecting climate, biodiversity, and infectious disease. A) Climate → Biodiversity → Infectious disease **B)** Climate → Infectious disease → Biodiversity **C)** Infectious disease → Biodiversity → Climate **D)** Biodiversity → Climate → Infectious disease **E)** Biodiversity → Infectious disease → Climate **F)** Infectious disease → Climate → Biodiversity. Each pathway is discussed in further details in section **Mechanistic Links.**

A) Climate → Biodiversity	**Biodiversity → Disease**	**Case Study**	**Pathway**
Precipitation & Food web dynamics	Dilution / Amplification	Elevated precipitation increases resource production, which in turn increases reservoir species richness and abundance, amplifying Lyme disease.[1-6]	
		Addition of host species with low reservoir competence to a community with low species richness reduces *Borrelia burgdorferi* infection in nymphal ticks, and thus Lyme disease prevalence.[7,8]	
	Vector population	Drought induced changes in water depth and patchiness, disrupting aquatic food webs, and control of larval mosquitoes by fish.[9] The increase in mosquito populations[10] and the concentration of avian hosts around remaining watering holes[11] increases West Nile virus transmission.	
Temporal mismatch	Migration	Climate induced shifts in the phenology of milkweed, leading to changes in Monarch butterfly migration, which acts as a filter for diseased individuals—disease prevalence is higher at the end of breeding season than at overwintering sites.[12]	
Gradual climate change & Species introductions	Novel disease spread	Permafrost melt releases active bacteria and viruses from thawing carcasses, leading to anthrax outbreaks.[13,14]	
Migration / Range shifts	Spillover	Change in migratory behavior of harp seals following increased sea ice melt, increased opportunities for disease spillover and outbreaks of phocine distemper.[15-17]	
	Dilution / Amplification	Sea ice melt alters the migration of caribou, a seasonal disease escape strategy. Increased contact between geographically separated ungulate species, facilitating spillover of diseases into communities that were previously isolated.[15]	
		Extreme wetness and dryness decrease richness of insect-pollinated plants, reshaping the distribution of their pollinators.[18] Increased length of pollinator foraging distances, and floral trait variation drive increases in pathogen transmission and disease intensity.[19]	

B) Climate → Disease	Disease → Biodiversity	Case Study	Pathway
Novel disease spread & Spillover	Trophic cascade	Severe storms and warmer water are associated with amoebiasis outbreaks in sea urchins.[20] Mass mortality of sea urchins releases kelp forests from predation,[21,22] increasing local species richness.[23]	
Thermal mismatch	Parasite mediated competition	Shorter winters favor temperature dependent growth of *Geomyces destructans*,[24] which is linked to White Nose Syndrome (WNS) in bats.[25] WNS reduces the abundance of dominant bat species in the community,[26] favoring less dominant bat species.	
	Extirpation	Cold-adapted and warm-adapted amphibian hosts are more susceptible to *Batrachochytrium dendrobatidis* (*Bd*) fungus at relatively warm and cool temperatures, respectively.[27] *Bd* infection has caused amphibian population declines and extirpation.[28,29]	
		Climate related shifts in habitat suitability for white pine blister rust resulted in a decline in prevalence in arid regions and an increase in colder regions—causing extirpation.[30]	
Temperature & Physiology	Species decline	Temperature dependent virulence of *Vibrio spp.*,[31] which are associated with coral bleaching and disease.[32] Coral declines are associated with fish biodiversity loss.[33]	
		Warming temperatures increase the occurrence and severity of Ranavirus,[34] a disease linked to mass mortality events and population declines in the common frog.[35]	
Behavior		Drought increased foraging distances in the blue orchard bee, resulting in the increase of parasitism rates by the blister beetle and subsequent species decline.[36,37]	
Development time of pathogens	Extirpation	Decreased larval development times of the lung-dwelling nematode, *Umingmakstrongylus pallikuukensis*, of muskoxen (*Ovibos moschatus*) increases infection pressure,[38] which cascades to elevated predation risk from polar bears.[39]	
Novel disease spread & Spillover		Shifts in timing of end of the dry season when Ebola outbreak risk is highest.[40-42] Mortality induced changes in local primate community assemblages.[43,44]	

C) Disease → Biodiversity	**Biodiversity → Climate**	**Case Study**	**Pathway**
Species decline / Extirpation	Ecosystem services	The loss of keystone and mesopredators due to Sea star wasting disease (SSWD) reduces kelp forest resilience.[45,46] Loss of kelp forest could reduce potential to capture and store (blue) carbon.[47,48]	
		Eelgrass wasting disease and loss of eelgrass beds[49,50] may reduce potential carbon sequestration.[51]	
		The chestnut blight fungus, native to East Asia, effectively removed a dominant forest tree in the Eastern US.[52,53] The death and decay of mature American chestnuts resulted in a pulse of released carbon and removed an important carbon sink.[54]	
		Haplosporidium nelsoni (MSX) influences shellfish populations, and epizootic outbreaks have led to large population declines.[55] Oyster beds provide a range of ecosystem services, including habitat for fish, water filtration, and shoreline protection.[56,57]	
	Trophic cascade	Rinderpest reduced herbivore density in the Serengeti. Decreased grazing released vegetation from top-down control and increased fires, shifting the habitat to a net carbon source.[58,59]	
Parasite mediated competition	Ecosystem services	Foliar fungal pathogens increase plant biodiversity by reducing above ground plant biomass.[60] Reduced biomass may decrease ecosystem services, including carbon sequestration; however, more diverse grasslands are suggested to sequester more carbon.[61]	
D) Biodiversity → Climate	**Climate → Disease**	**Case Study**	**Pathway**
Agrobiodiversity& Microclimate	Development time of pathogens	Height differences in more genetically diverse rice crop plantings modified temperature and humidity conditions, likely inhibited spore germination and mycelium growth of fungal blast (*Magnaporthe grisea*), reducing disease pressure.[62]	

E) Biodiversity → Disease	**Disease → Climate**	**Case Study**	**Pathway**
Species introductions & Novel disease spread	Ecosystem services	Introduced non-native species and their pathogens, i.e., *Cryptococcus fagisuga* causing beech bark disease,[63] can result in tree damage and death, reducing forest biomass and potential carbon sequestration capabilities.[64]	
Dilution / Amplification		Tree diversity has a hump-shaped relationship with pest diversity (at low tree diversity pests are amplified and at high tree diversity pests are diluted).[65] Mountain pine beetle infestation reduces forest biomass and carbon sequestration capabilities.[66]	
F) Disease → Climate	**Climate → Biodiversity**	**Case Study**	**Pathway**
Behavior	Ecosystem services	Parasitic plants, such as *Striga hermonthica*—a parasite of sorghum-–may modify their microclimate via high transpiration rates.[67] Forest microclimate influences soil microbial composition, impacting primary productivity, and plant communities.[68]	
	Climate-induced biodiversity decline (various mechanisms)	The mitigation strategies used at the emergence of COVID-19 (travel bans, social distancing, suspended industrial production) also mitigated climate change by decreasing daily CO_2 emissions.[69-71]	

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