Biodiversity

The variety of life, in all of its many manifestations.



Organisms at work



A tropical stream

Feeding and processing organic matter

A starting distinction

Organisms present and processes performed

Watch Alan Covich · 3:31

Today

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Biodiversity

Dimensions, measurement and knowledge gaps

2

History and geography

Evolution, extinction and spatial patterns

3

Ecosystem processes

Biogeochemical cycles, water and soils

4

Biological contributions

Diversity effects, mobile links and mutualisms

5

People and decisions

Health, benefits, valuation and trade-offs

Dimensions of biodiversity

Genetic Diversity

Variability within the genetic heritage of a species — the raw material for adaptation and resilience against environmental change.

Species Diversity

The variety of species present in a given habitat, reflecting the richness and complexity of local biological communities.

Ecosystem Diversity

The range of habitats and interacting communities — from forests to wetlands — each providing unique ecological services.

The dimensions overlap, but each describes a different aspect of life.

Genetic variation within species

Within populations

Alleles and genetic differences among individuals

Among populations

Variation across a species' geographical range

Ecological consequences

Differences in growth, fitness and responses to disturbance

Genetic variation provides material on which evolution can act.

Genome size and genetic diversity

Genome characteristics

- Amount of DNA
- Number of genes
- Number of chromosomes

Variation within a species

- Allelic diversity
- Heterozygosity
- Sequence differences

More DNA does not necessarily mean more genes.

Populations connect biodiversity and function

Individuals

Differ in traits, condition and genetic composition

Populations

Maintain local abundance, interactions and genetic variation

Species

Can persist globally while local populations disappear

Local population loss can remove an ecological contribution.

How much life remains undescribed?

~2M

~2 million

Species known to science

~8M

~8 million

Working estimate of eukaryotic species

Historical estimates reported by Gaston in 2010, with substantial uncertainty.

Gaston (2010), Chapter 2, Table 2.2 and pp. 29 - 31.

Taxonomy and sampling shape what we know

Multiple names

One species may have been described more than once

Cryptic species

Similar-looking organisms may belong to different species

Sampling bias

Large, common and accessible organisms receive more attention

Described species form a biased sample of existing biodiversity.

Ecological diversity across scales

Unit	What it describes
Habitat and ecosystem	Local environments and interacting biotic - abiotic systems
Ecoregion	Distinct communities and environmental conditions
Biome	Broad formations such as forests, grasslands and tundra
Biogeographic realm	Large regions shaped by evolutionary and geographical history

Boundaries often simplify ecological continua.

Spatial Dynamics and Biogeography



Preston's Area Effect

Larger areas support disproportionately more species. This species-area relationship is a cornerstone of conservation planning — protecting more land means protecting exponentially more biodiversity.

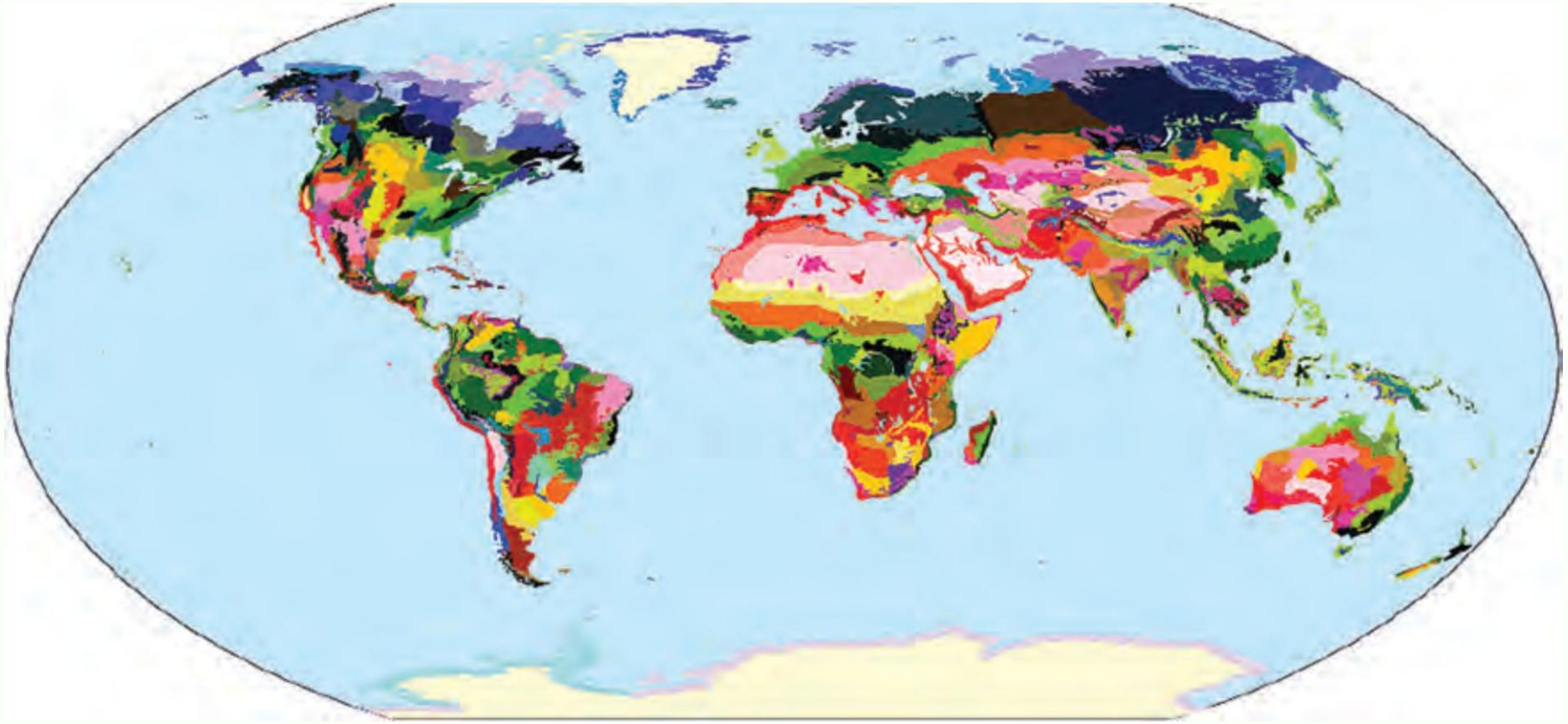
Diamond's Distance Effect

Geographic isolation reduces biodiversity. Islands and habitat fragments farther from source populations receive fewer colonizers and suffer higher extinction rates.

Ecological Niche vs. Physical Habitat

A species' **niche** encompasses its functional role and resource requirements, distinct from the physical habitat it occupies.

The geographical mosaic of ecoregions



Ecological classifications help represent different environments in conservation planning.

Gaston (2010), Fig. 2.1, after Olson et al. (2001). Original map.

Richness and evenness

	Community 1	Community 2
Species A	25	85
Species B	25	5
Species C	25	5
Species D	25	5

Richness = 4 in both

Evenness differs

Biodiversity Indexes

Shannon Index (H)

Measures species diversity based on relative abundance. Higher values indicate richer, more evenly distributed communities.

Pielou Index (J)

Evaluates **evenness** — how uniformly individuals are distributed across species in a sample.

Simpson Index (D)

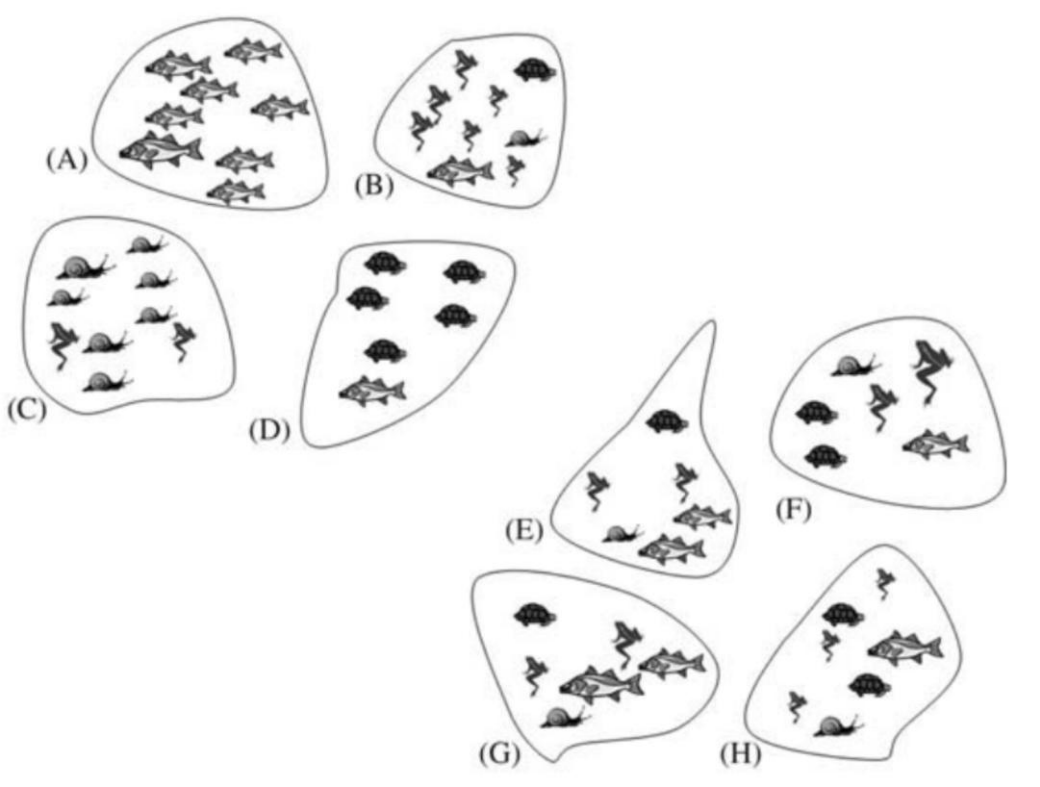
Quantifies ecological dominance. High values signal that one or few species dominate the community.

Rarefaction Method

Standardizes sample sizes to enable fair diversity comparisons across different habitats or studies.

SPATIAL SCALE

Local and regional diversity



Alpha

Diversity within a site

Beta

Differences among sites

Gamma

Diversity across the region

Dodds & Whiles (2020), Fig. 11.2.

BIODIVERSITY THROUGH TIME

Life has transformed its environment

Early microbial life

Life occupied Earth long before familiar plants and animals

Oxygenic photosynthesis

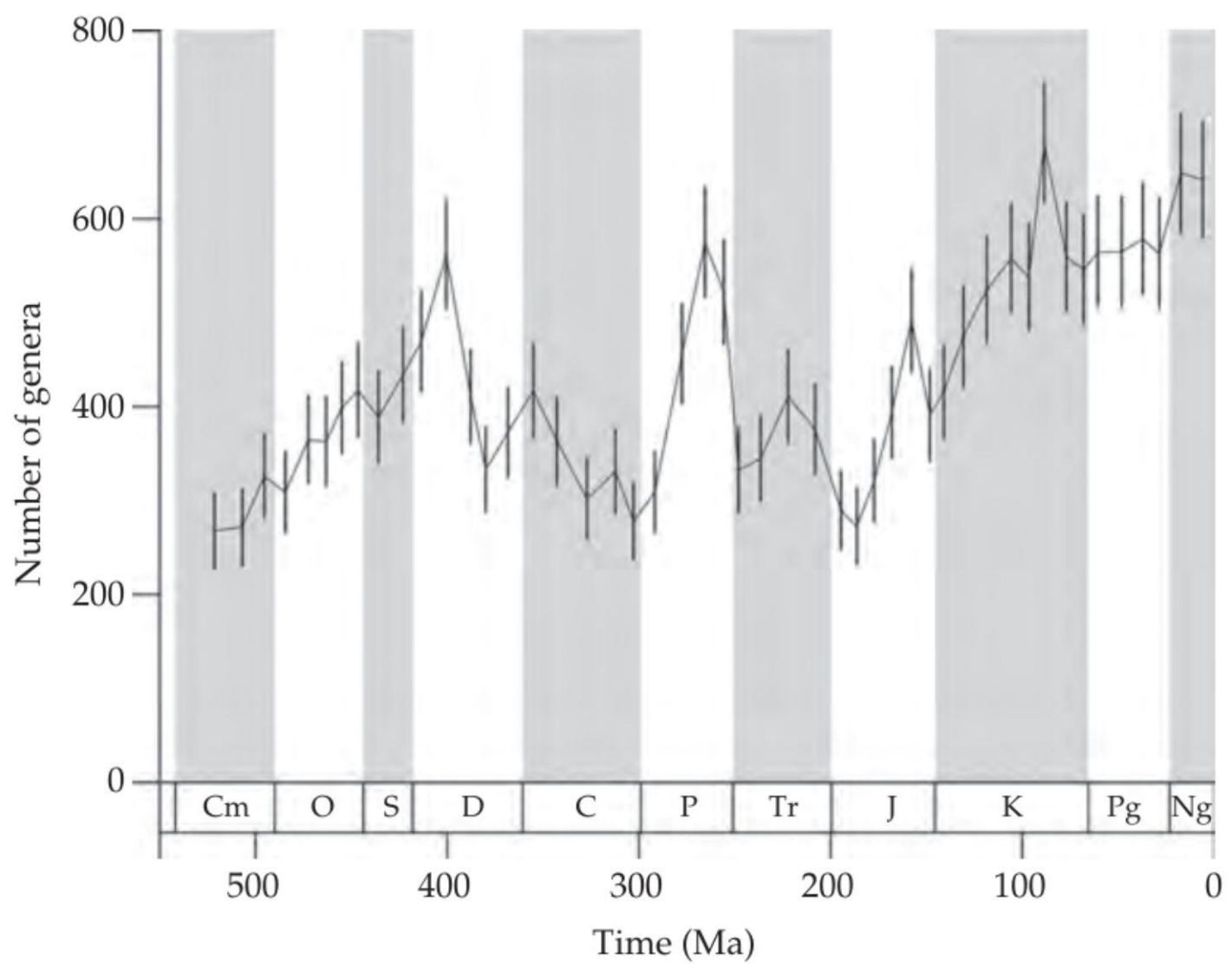
Organisms changed atmospheric conditions

Endosymbiosis

Cellular integration opened new evolutionary possibilities

Evolution changed both organisms and the conditions for life.

Diversity through geological time



Species disappear throughout evolutionary history

Diversification takes geological time and changes composition

Extinction and recovery

Background extinction

Species disappear throughout evolutionary history

Mass extinction

Large disruptions reorganise biological diversity

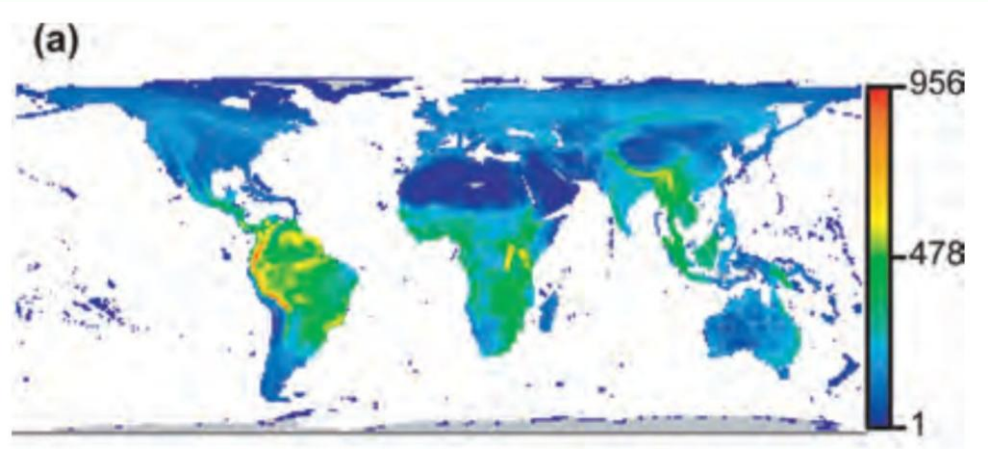
Recovery

Diversification takes geological time and changes composition

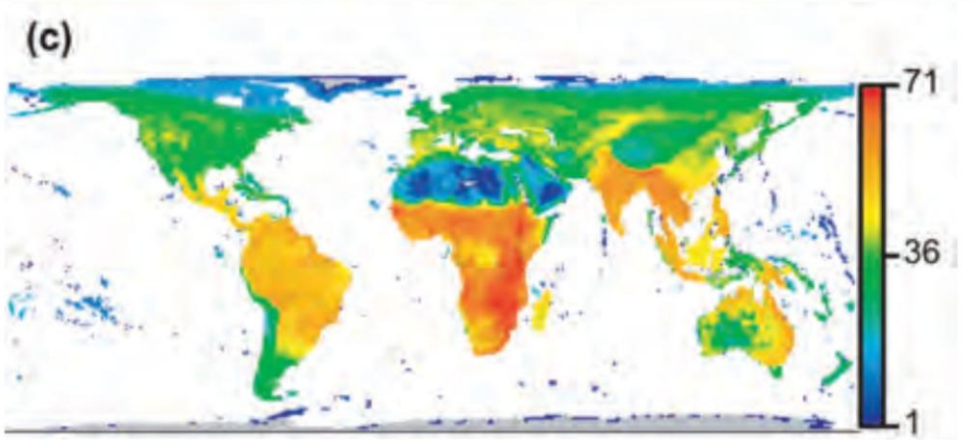
Recovery of richness does not recreate the lost species and interactions.

Species and families show different maps

Bird species

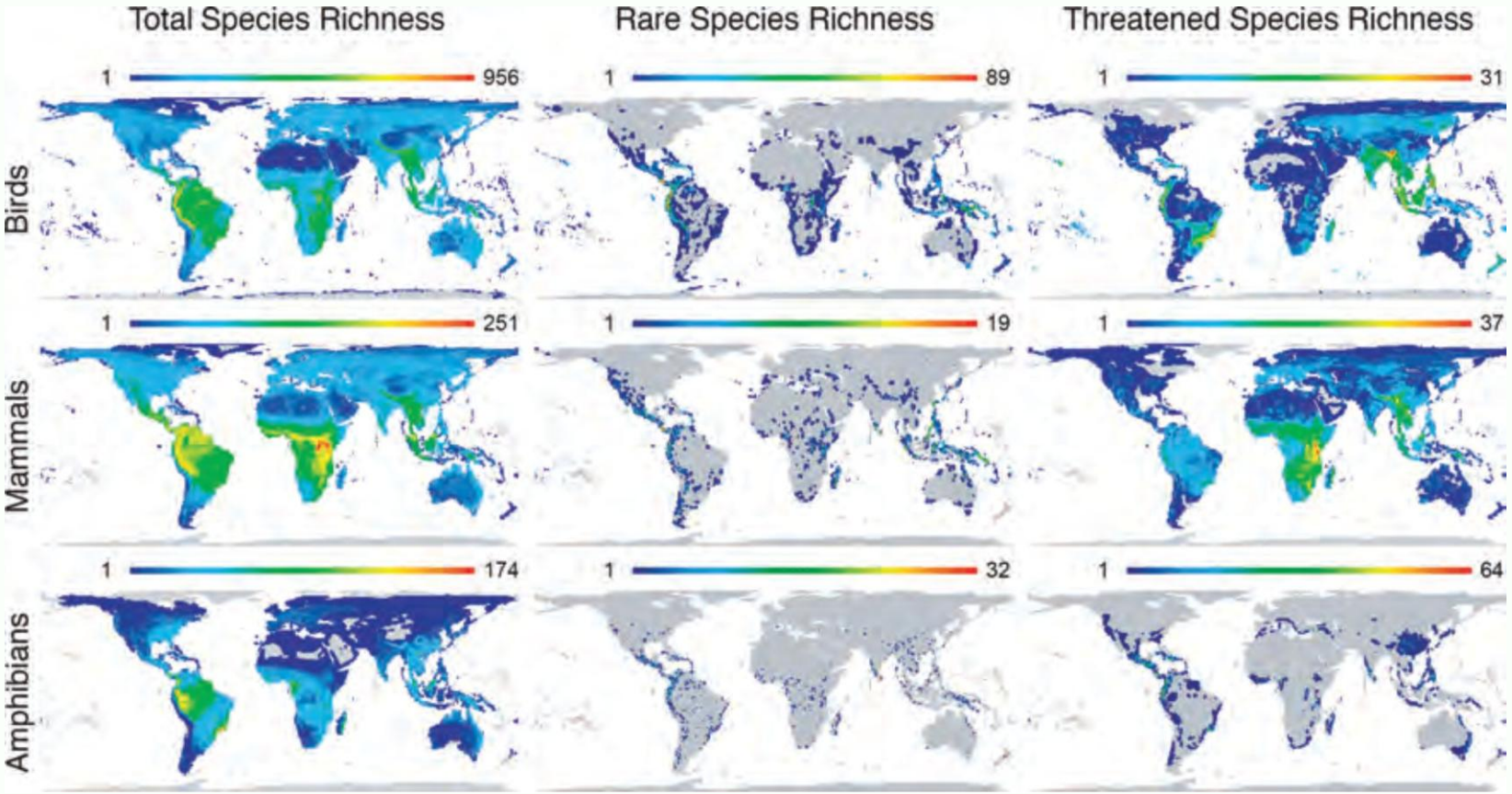


Bird families



The taxonomic level changes the geographical pattern.

Richness, rarity and threat



Total richness, restricted ranges and threat identify overlapping but different priorities.

Terrestrial, marine and freshwater diversity

System	Pattern highlighted in the chapter	Relevant explanation
Marine	High diversity of major taxonomic groups	Long evolutionary history in the sea
Terrestrial	Many described species	Habitat heterogeneity and geographical isolation
Freshwater	High diversity relative to occupied area	Isolation among basins and water bodies

The ranking depends on the biological unit being counted.

Biogeographic history shapes regional richness

Tropical realms

The richest region changes with the taxon and rank

Indo-Pacific seas

A major centre of marine richness and endemism

Freshwater basins

Distinct histories support diverse regional assemblages

Mountain building, climate history and dispersal leave geographical signatures.

The latitudinal diversity gradient

Speciation

Regions differ in the rate at which new species arise

Extinction

Regions differ in the persistence of existing lineages

Range movement

Immigration and expansion alter regional diversity

Energy, climatic variation and topography can influence all three.

Altitude and depth create strong gradients

Changing conditions

Temperature, resources and habitat area vary

Observed patterns

Richness can decline or peak at intermediate positions

Extreme environments

Distinct communities persist where sampling is difficult

A short vertical distance can represent a large environmental change.

CONSERVATION IMPLICATIONS

What a biodiversity assessment needs

A defined target

The dimension, organisms and spatial scale

An appropriate baseline

The period and conditions used for comparison

An account of uncertainty

Sampling gaps, taxonomy and historical evidence

Human activities are changing biodiversity while we are still documenting it.

Ecosystem functions and services

How organisms influence processes and human well-being

Processes, services and benefits

Concept	Meaning	Example
Ecosystem process	An ecological activity or transformation	Retention of soil and sediment
Ecosystem service	An ecological contribution people use or experience	Less sediment reaching a water intake
Benefit	A resulting gain in human well-being	Lower water-treatment requirements

A service connects ecosystem functioning to a beneficiary.

MILLENNIUM ECOSYSTEM ASSESSMENT

Common groups of ecosystem services

Provisioning

Food, timber, fresh water and other products

Regulating

Contributions to climate, water and biological regulation

Cultural

Recreation, education, aesthetic and spiritual experiences

The MEA also includes supporting services, such as nutrient cycling.

A range of ecosystem functions

Process	What changes
Production and consumption	Organic matter and energy transfer
Decomposition and nutrient cycling	Organic matter and nutrient availability
Water regulation and soil retention	Water flow, storage and sediment transport
Pollination and seed dispersal	Reproduction, gene flow and recruitment
Predation and scavenging	Consumer populations and carcass processing

Şekercioğlu (2010), Chapter 3, Table 3.1 and sections 3.1 - 3.5.

Biogeochemical cycles connect living and physical systems

Reservoirs

Atmosphere, water, soil, rocks and organisms

Transformations

Photosynthesis, respiration, decomposition and microbial reactions

Transfers

Movement of elements between reservoirs

Changes in one part of a cycle can affect other ecosystems.

Photosynthesis and atmospheric conditions

Oxygen

Oxygenic photosynthesis transformed atmospheric conditions

Atmospheric chemistry

Oxygen participates in reactions that alter compounds

Climate feedbacks

Biological activity affects carbon and water exchanges

Ecosystems influence the physical conditions on which life depends.

Carbon stocks and carbon fluxes

Carbon stock

Amount present at a given time

Examples: vegetation, soil and peat

t C ha^{-1}

Carbon flux

Transfer or net change through time

Examples: uptake, respiration and release

t C ha^{-1} yr^{-1}

The carbon balance depends on the pool, boundary and time interval.

Nutrients support life and can cause overload

Element	Biological role and cycling	Consequences of human alteration
Nitrogen	Microbes fix and transform nitrogen	Excess inputs can promote eutrophication
Phosphorus	Weathering and organisms affect availability	Runoff and erosion transfer phosphorus to water
Sulfur	An essential component of biological molecules	Excess emissions can contribute to acid deposition

The amount, form, location and rate of input determine the effect.

Four attributes of hydrologic services

Attribute	What a beneficiary may need
Quantity	Enough water for a specified use
Quality	Acceptable sediment, nutrient, salinity or pathogen levels
Location	Water at the intake, field, habitat or river reach
Timing	Availability during the required season or flow period

An improvement in one attribute can constrain another.

Water moves through vegetation and soils

Interception and infiltration

Vegetation and soil alter how rainfall enters the system

Storage and release

Soils, wetlands and channels modify flow pathways and timing

Evaporation and transpiration

Plants and surfaces return water to the atmosphere

Hydrologic services include water supply, damage mitigation and cultural uses.

Forest cover and hydrologic outcomes

Potential contributions	Sediment retention and changes in flow pathways
Important conditions	Rainfall, soil, topography and catchment scale
Management effects	Roads, compaction, drainage and tree water use

Natural forests and plantations can have different outcomes (refer to the article of today Hua et al.2022).

Soils support multiple ecosystem functions

Contribution	Underlying processes or properties
Water regulation	Retention, infiltration and gradual release
Plant support and nutrition	Root anchorage, nutrient retention and delivery
Decomposition and fertility	Organic matter transformation and nutrient recycling
Element cycling and storage	Carbon and nutrient pools linked to biological activity

Soil properties emerge from physical, chemical and biological interactions.

Soil loss connects land to downstream ecosystems

At the source

Loss of topsoil, nutrients and productive capacity

During transport

Sediment and associated materials move through catchments

Downstream

Deposits affect water quality, reservoirs and coastal habitats

Soil can be lost rapidly and take much longer to rebuild.

Functional roles and species identity

Dominant species

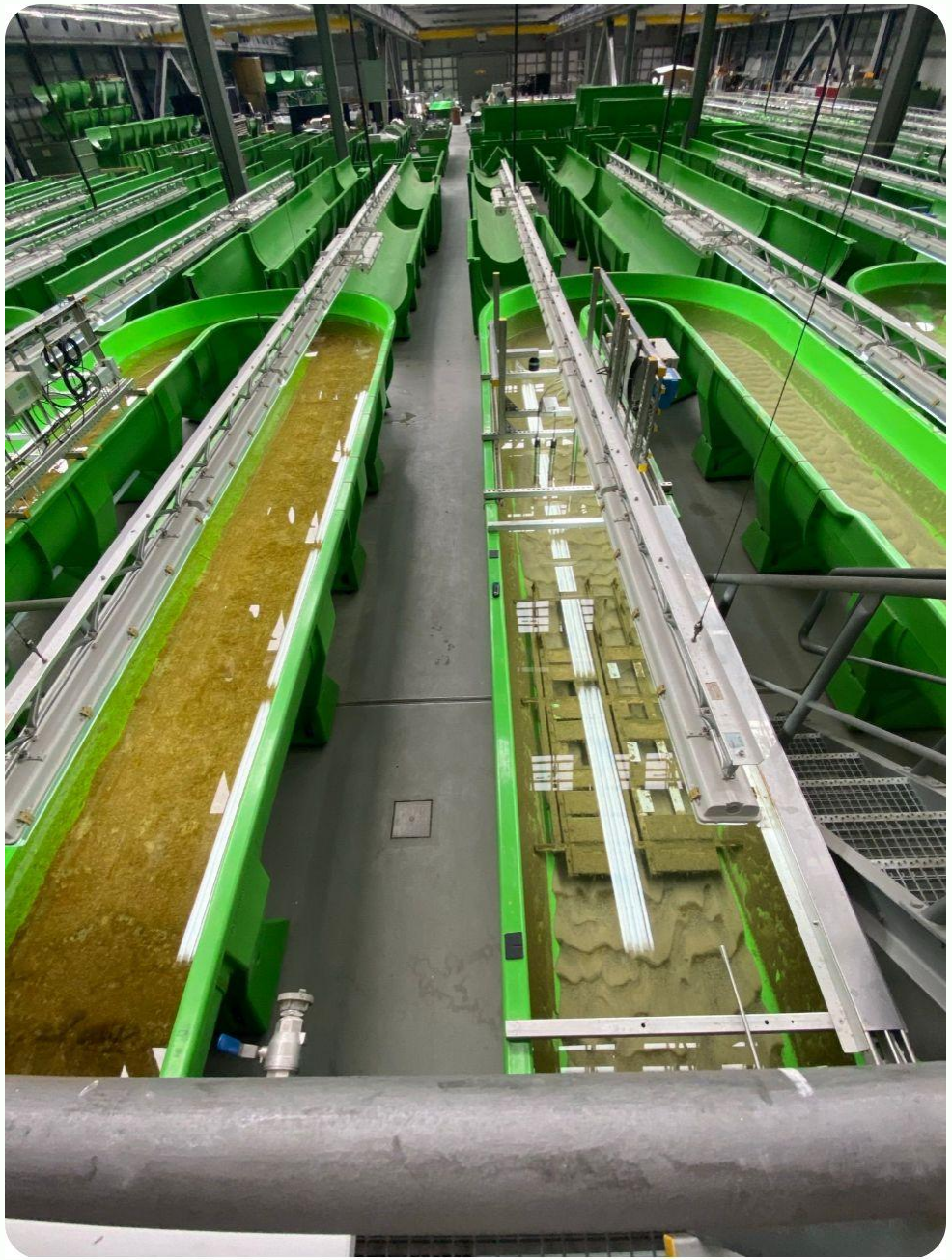
Large abundance or biomass can drive a process

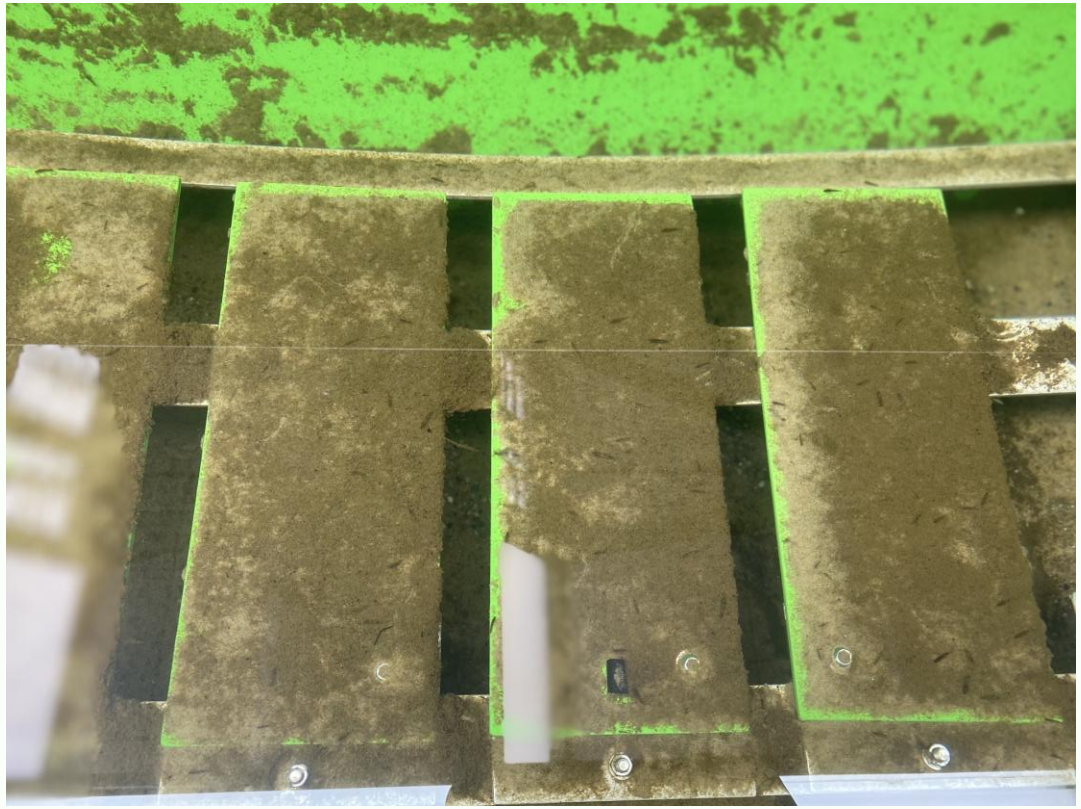
Keystone species

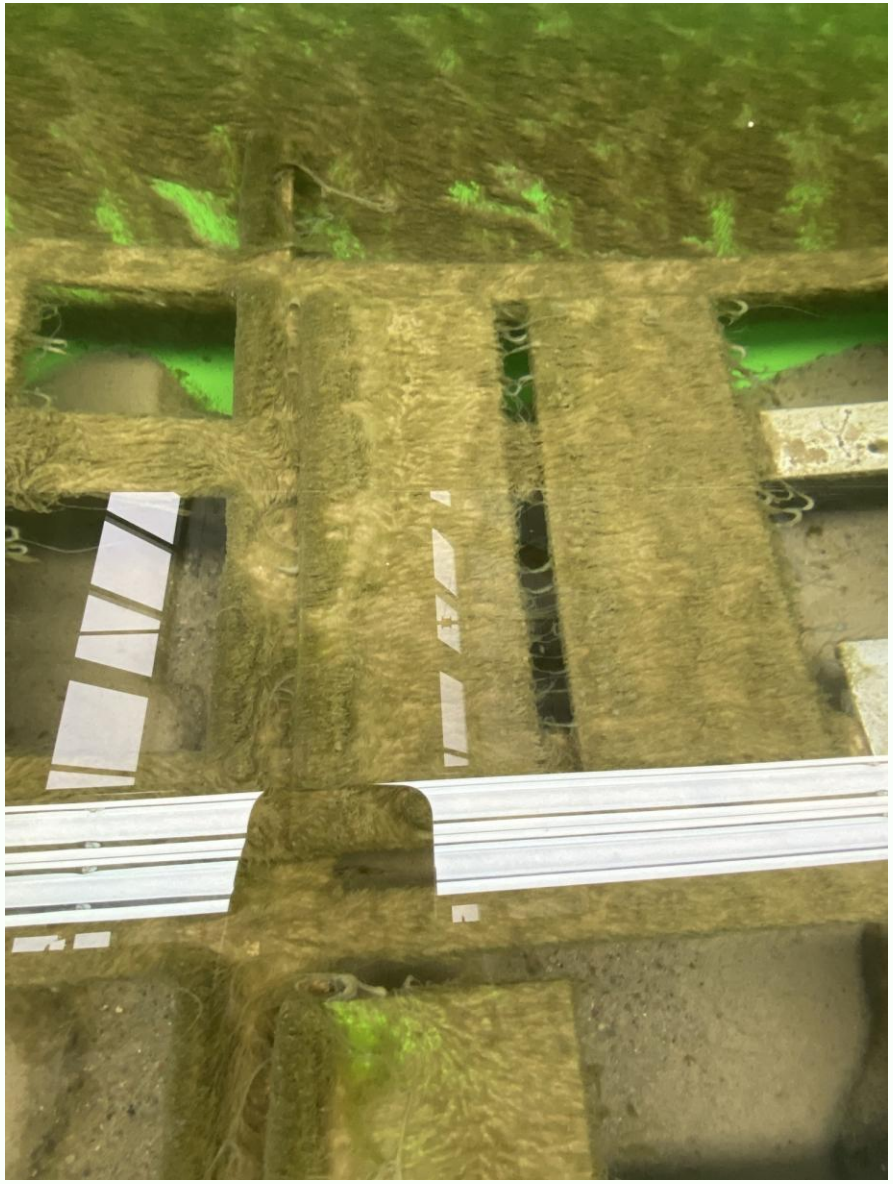
Effects are large relative to abundance

Other species

Contributions may emerge under different conditions







VALUING ECOSYSTEM SERVICES

Why ecosystem services enter decisions

Visible returns

Markets record some products and revenues

Uncounted consequences

Ecological losses can impose costs elsewhere or later

Comparison

Valuation helps assess alternative land-use outcomes

The global value of ecosystem services

US$125 trillion per year

Estimated global service flows in 2011

Values expressed in 2007 US dollars

Method: biome areas combined with estimated values per unit area

Costanza et al. (2014), Global Environmental Change 26, 152–158. doi:10.1016/j.gloenvcha.2014.04.002

Interpreting a global valuation

What it expresses

The scale of human dependence on ecosystem services

What shapes the estimate

Biome areas, valuation methods and transfer assumptions

For local decisions

Compare a specific ecological change and its beneficiaries

Global totals support awareness. Local choices need local evidence.

Diverse values of nature

Instrumental

Nature contributes to human purposes and well-being

Intrinsic

Nature has worth in itself

Relational

Meaningful relationships, identity and responsibilities

Pascual et al. (2023), Nature 620, 813–823. doi:10.1038/s41586-023-06406-9

A wetland, several reasons to conserve it

Flood regulation

An instrumental contribution to people's safety

Wildlife persistence

An intrinsic reason to protect living organisms

Belonging and care

Relational values connecting communities and place

Decision question: whose values enter the conservation objective?

A conservation interpretation of both chapters

Biological change

Which genes, populations, species or communities change?

Ecological mechanism

Which process responds, and under what conditions?

Conservation outcome

Which objective or human benefit does the evidence address?