TF1.3 Permanent marshes

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IUCN Global Ecosystem Typology 2.0

Descriptive profiles for biomes and ecosystem functional groups

David A. Keith, Jose R. Ferrer-Paris, Emily Nicholson and Richard T. Kingsford (editors)

INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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IUCN Red List of Ecosystems Thematic Group
Rue Mauverney 28
1196 Gland, Switzerland
rle-contact@iucn.org
www.iucn.org/resources/publications

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Executive summary

Ecosystems are critically important components of Earth's biological diversity and as the natural capital that sustains human life and well-being. Yet all of the world's ecosystems show hallmarks of human influence, and many are under acute risks of collapse, with consequences for habitats of species, genetic diversity, ecosystem services, sustainable development and human well-being. A systematic typology that encompasses all of Earth's ecosystems, representing the diversity of both ecosystem function and biodiversity, is essential for marshalling knowledge to inform effective action to sustain this critical natural capital. Accordingly, at the World Conservation Congress Marseille 2020, the IUCN membership voted strongly in favour of Motion 074, now Resolution 061, for adoption of the Global Ecosystem Typology to support global, regional and national efforts to assess and manage risks to ecosystems (WCC Resolution 061).

The IUCN Global Ecosystem Typology is a hierarchical classification system that, in its upper levels, defines ecosystems by their convergent ecological functions and, in its lower levels, distinguishes ecosystems with contrasting assemblages of species engaged in those functions. This report describes the three upper levels of the hierarchy, which provide a framework for understanding and comparing the key ecological traits of functionally different ecosystems and their drivers. An understanding of these traits and drivers is essential to support ecosystem management. By sharing research and management experiences about ecosystem functions, dependencies and responses to management, the typology can facilitate knowledge transfer that improves management outcomes for both biodiversity and ecosystem services.

The top level of the Global Ecosystem Typology divides the biosphere into **five global realms:** i) terrestrial; ii) subterranean; iii) freshwater (including saline water bodies on land); iv) marine; and v) the atmosphere.

The interfaces between these core realms are recognised as transitional realms, accommodating ecosystems, such as mangroves, that depend on unique conditions and fluxes between contrasting environments. At Level 2, the typology defines **25 biomes** – components of a core or transitional realm united by one or a few common major ecological drivers that regulate major ecological functions. These include familiar terrestrial biomes, such as tropical/subtropical forests and deserts, as well functionally distinctive groupings that fall outside the traditional scope of the biome concept, including lentic and lotic freshwater biomes, pelagic and deep sea benthic marine biomes, subterranean freshwater biomes, and several anthropogenic biomes. Ecosystems in this latter group are created by human activity, which continues to drive and maintain their assembly. Level 3 of the typology includes **108 Ecosystem Functional Groups** that encompass related ecosystems within a biome that share common ecological drivers and dependencies, and thus exhibit convergent biotic traits. Examples include temperate deciduous forests, annual croplands, seasonal upland streams, intertidal forests, epipelagic ocean waters, and deep sea trenches and troughs.

This report contains descriptive profiles for the 25 biomes and 108 Ecosystem Functional Groups in version 2.0 of the Global Ecosystem Typology, with a glossary and synopsis of the rationale and methods for development. The profiles describe the ecological traits and key drivers that distinguish groups of related ecosystems from one another, illustrated by exemplar images and diagrammatic models of ecosystem assembly, with indicative maps of global distribution and sources of further information. The descriptions, images and maps are also available on an interactive website https://global-ecosystems.org/.

Version 2.0 of the Global Ecosystem Typology is the outcome of critical review and input by an extensive international network of ecosystem scientists.

Authors and affiliations

Professor David A. Keith, Lead author and editor	Centre for Ecosystem Science, University of NSW, Sydney, Australia; NSW Department of Planning, Industry and Environment, Sydney, Australia; IUCN Commission on Ecosystem Management, Gland, Switzerland
Dr Jose R. Ferrer-Paris, Map development	Centre for Ecosystem Science, University of NSW, Sydney, Australia; IUCN Commission on Ecosystem Management, Gland, Switzerland
Associate Professor Emily Nicholson, Peer-review editor	Centre for Integrative Ecology, Deakin University, Burwood, Victoria, Australia; IUCN Commission on Ecosystem Management, Gland, Switzerland
Professor Richard T. Kingsford, Governance, author and editor	Centre for Ecosystem Science, University of NSW, Sydney, Australia
Professor Alicia T.R. Acosta	Department of Science, Roma Tre University, Rome, Italy
Dr Andrew H. Altieri	Department of Environmental Engineering Sciences, University of Florida, Gainesville, USA
Dr Angela Andrade	Conservation International Colombia, Bogota, Colombia; IUCN Commission on Ecosystem Management, Gland, Switzerland
Professor Alexandre M.B. Anesio	Department of Environmental Science, Aarhus University, Denmark
Professor Angela H. Arthington	Australian Rivers Institute, Griffith University, Australia
Professor Stefan Bertilsson	Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
Professor Malcom Beveridge	University of Stirling, Stirling, Scotland
P. Bhanumati	National Statistical Office, Ministry of Statistics and Programme Implementation, New Delhi, India
Professor Thomas S. Bianchi	Department of Geological Sciences, University of Florida, Gainesville, USA
Associate Professor Melanie J. Bishop	Department of Biological Sciences, Macquarie University, Sydney, Australiia
Dr Lucie M. Bland	Lucie Bland Book Coach and Editor, Melbourne, Australia
Dr Patrick Bogaart	United Nations Statistics Division, The Hague, Netherlands
Dr David Brankovits	Marine Biology Department, Texas A&M University, Galveston, USA
Dr Neil A. Brummitt	Department of Life Sciences, Natural History Museum, London, England
Dr Paul E. Carnell	Centre for Integrative Ecology, Deakin University, Burwood, Australia
Dr Jane A. Catford	Department of Geography, King's London, England
Dr Michael A. Chadwick	Department of Geography, King's College London, England
Dr Alan Channing	School of Earth & Ocean Sciences, Cardiff University, Wales

Associate Professor Jeremy T. Claisse	Biological Sciences, California State Polytechnic University, Pomona, USA
Professor Richard T. Corlett	Xishuangbanna Botanical Garden, Chinese Academy of Sciences, Yunnan, China
Professor Tasman P. Crowe	School of Biology and Environmental Science, University College Dublin, Ireland
Dr Nick A. Cutler	School of Geography, Politics & Sociology, Newcastle University, England
Dr Katherine A. Dafforn	Department of Earth and Environmental Sciences, Macquarie University, Sydney, Australia
Associate Professor Ian Donohue	School of Natural Sciences, Department of Zoology, Trinity College Dublin, Dublin, Ireland
Professor David Eldridge	University of NSW, Australia
Associate Professor Franz Essl	Department of Botany and Biodiversity Research, Unversity of Vienna, Vienna, Austria; Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, South Africa
Professor Andrés Etter	Departamento de Ecología y Territorio, Pontificia Universidad Javeriana, Bogotá, Colombia
Dr Don Faber-Langendoen	Conservation Science Division, NatureServe, Arlington, USA; SUNY College of Environmental Science and Forestry, Syracuse, USA
Dr Ulla Fernandez-Arcaya	Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Palma, Spain
Dr Louise B. Firth	School of Biological and Marine Sciences, University of Plymouth, England
Professor Janet Franklin	Department of Botany, University of California, Riverside, USA
Dr Lila García	Provita, Caracas, Venezuela
Dr Vasilis Gerovasileiou	Hellenic Centre for Marine Research (HCMR), Institute of Marine Biology, Biotechnology and Aquaculture (IMBBC), Heraklion, Crete, Greece
Professor David Gibson	School of Biological Sciences, Southern Illinois University, Carbondale, USA
Professor Paul S. Giller	School of Biological, Earth and Environmental Sciences, University College Cork, Ireland
Dr Brett C. Gonzalez	Smithsonian National Museum of Natural History, Washington DC, USA
Dr Edward J. Gregr	Institute for Resources, Environment, and Sustainability, University of British Columbia, Vancouver, British Columbia, Canada; SciTech Environmental Consulting, Vancouver, British Columbia, Canada
Professor Richard Harper	School of Veterinary and Life Sciences, Murdoch University, Perth, Australia
Dr Justin C. Havird	Department of Biology, Colorado State University, Fort Collins, USA
Dr Sylvia E. Hay	Centre for Ecosystem Science, University of NSW, Sydney, Australia

Professor J. Tim Hollibaugh	Department of Marine Sciences, University of Georgia, Athens, USA
Professor Grant C. Hose	Department of Biological Sciences, Macquarie University, Australia
Professor Thomas M. Iliffe	Marine Biology Department, Texas A&M University, Galveston, USA
Professor Kenneth Irvine	IHE Delft Institute for Water Education, Delft, Netherlands
Professor Leland J. Jackson	Department of Biological Sciences, University of Calgary, Calgary, Canada
Associate Professor Mary Kelly-Quinn	School of Biology and Environmental Science, University College Dublin, Ireland
Dr Tytti Kontula	Finnish Environment Institute, Helsinki, Finland
Professor Christian H. Körner	Department of Environmental Sciences, University of Basel, Basel, Switzerland
Megan Lamson	University of Hawaii, Hilo, USA
Dr Caroline E. R. Lehmann	Royal Botanic Garden Edinburgh, Edinburgh Scotland; School of GeoSciences, University of Edinburgh, Edinburgh, Scotland
Dr Christy Linardich	International Union for Conservation of Nature Marine Biodiversity Unit, Department of Biological Sciences, Old Dominion University, Virginia, USA
Dr Arild Lindgaard	Norwegian Biodiversity Information Centre, Trondheim, Norway
Professor Javier Loidi	Department of Plant Biology and Ecology, University of the Basque Country, Spain
Professor Ralph Mac Nally	School of BioSciences, The University of Melbourne, Melbourne, Australia
Dr Alejandro Martínez	Molecular Ecology Group, Water Research Institute, National Research Council of Italy, Verbania, Italy
Dr Matt McGlone	Manaaki Whenua – Landcare Research, Lincoln, New Zealand
Dr Sarah E. McSweeney	Department of Geography, The University of Melbourne, Melbourne, Australia
Dr Justin Moat	Royal Botanic Gardens Kew, England
Dr Nicholas J. Murray	College of Science & Engineering, James Cook University, Townsville, Australia
Dr Jeanne L. Nel	Sustainability Research Unit, Nelson Mandela University, Port Elizabeth, South Africa; Wageningen Environmental Research, Wageningen University, Wageningen, The Netherlands
Professor Robert J. Orth	Biological Sciences Department, Virginia Institute of Marine Science, Gloucester Point, USA
Professor R. Toby Pennington	Geography, University of Exeter, Exeter, England; Royal Botanic Garden Edinburgh, Edinburgh, Scotland
Dr Nathalie Pettorelli	Zoological Society of London, London, England

Associate Professor Patricio Pliscoff	Department of Ecology and Institute of Geography, Pontifica Universidad Católitica de Chile, Santiago, Chile
Associate Professor Beth A. Polidoro	School of Mathematical and Natural Sciences, Arizona State University, Glendale, USA
Professor Imants G. Priede	Institute of Biological and Environmental Sciences, University of Aberdeen, Scotland
Professor Mark C. Rains	School of Geosciences, University of South Florida, USA
Dr Eva Ramirez-Llodra	Norwegian Institute for Water Research, Gaustadalléen, Oslo, Norway; REV Ocean, Lysaker, Norway
Dr Catherine A. Reidy Liermann	Huxley College of the Environment, Western Washington University, USA
Associate Professor Belinda J. Robson	Environmental & Conservation Sciences, Murdoch University, Perth, Australia
Associate Professor Sergio Rossi	Department of Biological and Environmental Sciences and Technologies, Università del Salento, Lecce, Italy
Dr Dirk J. Roux	Scientific Services, South African National Parks, George, South Africa; Sustainability Research Unit, Nelson Mandela University, George, South Africa
Dr Jessica A. Rowland	Centre for Integrative Ecology, Deakin University, Burwood, Victoria, Australia
Professor Jeremy Russell-Smith	Bushfire and Natural Hazards CRC, Charles Darwin University, Darwin Australia
Dr Ryan R. Rykaczewski	Ecosystem Sciences Division, NOAA Pacific Islands Fisheries Science Center, Honolulu, USA
Dr Troy S. Sakihara	Department of Land and Natural Resources, Hawaii, USA
Dr Scott R. Santos	Department of Biological Sciences, Auburn University, Auburn, Alabama, USA
Dena M. Sedar	Hawaii State Parks, Honolulu, USA
Barbara Seidel	The Nature Conservancy, Honolulu, USA
Dr Lynne Shannon	Department of Biological Sciences, University of Cape Town, South Africa
Monica Sharma	Consultant to the United Nations, New Delhi, India
Professor Charles R.C. Sheppard	Department of Life Sciences, University of Warwick, Coventry, England
Professor Martin J. Siegert	Grantham Institute – Climate Change and the Environment, Imperial College London, UK
Dr Jonathan S. Stark	Australian Antarctic Division, Hobart, Australia
Professor Iain M. Suthers	Centre for Marine Science & Innovation, University of New South Wales, Sydney, Australia
Professor Tracey T. Sutton	Department of Marine and Environmental Sciences, Nova Southeastern University, Florida, USA

Professor Stephen E. Swearer	School of BioSciences, The University of Melbourne, Australia
Dr Teemu Tahvaneinan	Department of Environmental and Biological Sciences, University of Eastern Finland, Joensuu, Finland
Dr Aleks Terauds	Australian Antarctic Division, Hobart, Australia
Mark G. Tozer	NSW Department of Planning, Industry and Environment, Sydney, Australia
Associate Professor Oscar Venter	Ecosystem Science and Management Program, University of Northern British Columbia, Prince George, Canada
Dr Kate E. Watermeyer	Centre for Integrative Ecology, Deakin University, Burwood, Victoria, Australia
Professor James E. M. Watson	Wildlife Conservation Society, Bronx, New York, USA; Centre for Biodiversity and Conservation Science, University of Queensland, Brisbane, Australia
Dr Richard Williams	CSIRO, Melbourne, Australia
Dr Susan K. Wiser	Manaaki Whenua – Landcare Research, Lincoln, New Zealand
Dr Ryan Woodland	Center for Environmental Science, University of Maryland, Solomons, USA
Professor Kenneth R. Young	Department of Geography and the Environment, University of Texas, Austin, USA
Dr Irene Zager	Provita, Caracas, Venezuela; IUCN Commission on Ecosystem Management, Gland, Switzerland

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IUCN peer reviewers
Dr Sean N. Porter (South African Association for Marine Biological Research, Durban, South Africa)
Professor Neil D. Burgess (UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), England; Copenhagen University, Copenhagen, Denmark)

Copy editor
Dr Lucie M. Bland

Final proofreader
Diwata Hunziker

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Glossary of selected terms and acronyms used in ecosystem descriptions

Allochthonous energy	Energy imported into an ecosystem from external sources in the form of organic material.
Ambient environment	Non-resource environmental factors that modify the availability of resources or the ability of organisms to acquire them.
Aphotic	A zone where light intensity is too low to support photosynthesis.
Autochthonous energy	Energy captured from abiotic sources in situ by autotrophs living within an ecosystem.
Autotroph	An organism that fixes carbon from its surroundings, manufacturing complex energy-storing organic compounds, generally using energy from light (photosynthesis) or inorganic chemical reactions (chemosynthesis). Autotrophs are primary producers in trophic webs.
Basin fill	Unconsolidated to moderately consolidated subterranean sediments that bear aquifers. They are composed of gravel, sand, silt and clay deposited on antecedent alluvial fans, pediments, flood plains and playas.
Biofilm	Periphyton. A complex layer composed of algae, cyanobacteria and heterotrophic microbes embedded in a mucopolysaccharide matrix cohering to submerged aquatic surfaces. Important food source for aquatic animals.
Biogenic	A structure created by living organisms (e.g. a coral reef, tunnels in soils or sediment).
C_3	The most common photosynthetic pathway in plants based only on the Calvin cycle with associated energy loss to photorespiration and dependence on daytime CO_2 uptake. This pathway is dominant in environments with abundant moisture and cool temperatures.
Cauliflory	An arrangement of flowers and fruits in which they are borne directly on the main stems of a tree.
C_4	A photosynthetic pathway with a supplementary C-fixation pathway that minimises photorespiration, reduces CO_2 demand and increases water use efficiency, often dominating in warm and dry environments.
CAM	A specialised C_4 photosynthetic pathway in which CO_2 uptake and fixation occur during the night, followed by internal release in daytime when light-dependent photosynthesis can take place. Stomatal closure occurs during the day, reducing moisture loss and enabling survival in very hot and dry conditions.
Chemoautotroph	An organism that fixes carbon from its surroundings using energy from inorganic chemical reactions.
C:N ratio	Carbon-to-nitrogen ratio in biological tissues. Reflects differences in tissue composition related to nitrogen availability and capture as well as woodiness in plants (Pérez-Harguindeguy et al., 2013).
C:N:P (Redfield) ratio	The consistent ratio of Carbon-to-Nitrogen-to-Phosphorus in marine phytoplankton of deep seas, related to a homeostatic protein-to-ribosomal RNA ratio present in both prokaryotes and eukaryotes-
Dimicitic lakes	Lakes with waters that mix from top to bottom twice per year, before and after surface freezing in winter.
Disturbances	Sequences or 'regimes' of environmental events that destroy living biomass, liberate and redistribute resources and trigger life history processes in some organisms (e.g. fires, floods, storms, mass movement).

Dystrophic	Waters with low levels of dissolved nutrients, high acidity, brown colouration and low light penetration due to tannins, organic acids and undecayed plant matter, usually originating from peaty substrates.
Emergent	A large tree, emerging above the height of a main forest canopy.
Engineer	Ecological or ecosystem engineers are organisms that directly or indirectly alter the biotic or abiotic structure of ecosystems and resource availability, making it suitable for habitation by other organisms (Jones et al., 1994).
Epicormic resprouting	New shoots on trees emerging from meristematic tissues beneath the bark on large stems and trunks, usually after death of canopy foliage.
Ericoid leaves	Small, sclerophyllous leaves with thick cuticles and typically crowded on the branchlets; resembling those of heather.
Euphotic	A zone with abundant light that can support photosynthesis.
Heterotroph	An organism that cannot manufacture its own food by carbon fixation and therefore derives its intake of nutrition from other sources of organic carbon, mainly plant or animal matter. In the food chain, heterotrophs are secondary and tertiary consumers. Heterotrophs are consumers in trophic webs, including decomposers, detritivores, herbivores and predators.
LAI	Leaf Area Index, the projected area of leaves as a proportion of the area of land compared to which it is measured. Useful in remote sensing for describing vegetation density (Pérez-Harguindeguy et al., 2013).
Leaf sizes	Terms describing leaf size follow Raunkiaer (1934) except 'Notophyll'.

Size class	Leaf area
Megaphyll	>164,025 mm^2
Macrophyll	18,225–164,025 mm^2
Mesophyll	2,025–18,225 mm^2
[Notophyll	2,025–4,500 mm^2]
Microphyll	225–2,025 mm^2
Nanophyll	25–225 mm^2
Leptophyll	<25 mm^2

Mass movement	Bulk movements of soil and/or rock debris down slope or vertically downwards in response to gravity.
Mesophotic	A zone of moderate light intensity that can support photosynthesis.
Meromictic lakes	Lakes with waters that rarely mix from top to bottom, and thus remaining semi-permanently stratified into stable layers with contrasting temperature and hydrochemistry and biota.
Monomictic lakes	Lakes with waters that mix from top to bottom once per year, regardless of whether the surface freezes in winter, although the seasonal timing of mixing depends on whether surface freezing occurs.
Peat	A deposit of partially decayed organic matter in the upper soil horizons.
Periphyton	Biofilm. A complex layer composed of algae, cyanobacteria and heterotrophic microbes embedded in a mucopolysaccharide matrix cohering to submerged aquatic surfaces. Important food source for aquatic animals.
Photoautotroph	An organism that fixes carbon from its surroundings using energy from light.
Phreatic	Related to groundwater or aquifers.
Polymicitic lakes	Lakes with waters that mix continuously from top to bottom, and thus are never vertically stratified, usually due to their shallow depth.

Primary productivity*	The amount of chemical energy (expressed as carbon biomass) that autotrophs create in a given length of time.
Resources	Five fundamental resources in the environment that are essential to sustaining all life: water, nutrients, oxygen, carbon and energy.
Ruderal	Plants with a combination of life-history traits that enable colonisation of open post-disturbance environments. Traits and related trade-offs include rapid growth, high fecundity, wide propagule dispersal, short life-span, high demands for nutrients and intolerance of competition.
Sclerophyll	Plants or vegetation bearing leaves hardened by an abundance of woody tissue (sclerenchyma) and thick cuticles. Typically associated with environments that experience limited nutrients or water or cold stress.
Secondary productivity	Biomass of heterotrophic (consumer) organisms generated in a given length of time, driven by the transfer of organic material between trophic levels.
Serotinous	Refers to seedbanks that are held in woody fruits retained on the parent plant for later release, which may occur spontaneously or en masse in response to fire or adult mortality.
Semelparous	Plant life cycle with a single reproductive episode before death.
SLA	Specific Leaf Area, the ratio of area of a fresh leaf to its dry mass. Positively related to plant relative growth rate (Pérez-Harguindeguy et al., 2013).
Succulent	Having tissues (usually leaves or stems of plats) engorged with water, as a mechanism for drought tolerance or salt dilution.
Ultramafic	Rocks and derivative soils with low silica content, also low in Potassium, but with high concentrations of Magnesium and Iron.
Xeromorphic	Plants and animals possessing traits that enable them to tolerate drought by storing water, enhancing uptake and reducing loss. Example traits include nocturnal activity, deep roots, etc.

*Descriptive profiles use ordinal descriptors (high, medium, and low) of productivity (such as for Net Primary Productivity), unless otherwise stated. For terrestrial and transitional realms, these descriptors are based on estimates from an ensemble of global vegetation models (Cramer et al., 1999; Kicklighter et al., 1999; Huston & Wolverton, 2009). For marine surface systems, they are based on estimates of chlorophyll a concentration for the upper 30 m of the water column (Sarmiento et al., 2004; Huston and Wolverton, 2009):

- High: >2,000 g dry mass $m^{-2}.yr^{-1}$ for terrestrial and transitional ecosystems; >8 $mg.m^{-3}$ chlorophyll a concentration for marine ecosystems.
- Medium: 500–2,000 g dry mass $m^{-2}.yr^{-1}$ for terrestrial and transitional ecosystems; 0.1–8 $mg.m^{-3}$ chlorophyll a concentration for marine ecosystems.
- Low: <500 g dry mass $m^{-2}.yr^{-1}$ for terrestrial and transitional ecosystems; <0.1 $mg.m^{-3}$ chlorophyll a concentration for marine ecosystems.

Table 4 Methods and source data for indicative maps of each Ecosystem Functional Group (EFG)

EFG	DESCRIPTION
T1.1 / T1.2 / T2.1 / T2.2 / T2.6 / T3.4 / T4.1 / T5.1 / T5.2 / T5.3 / T5.4 / T5.5 / T6.5 / T7.5	Major and minor occurrences were initially identified using consensus land-cover maps (Tuanmu & Jetz, 2014) and then cropped to selected terrestrial ecoregions (Dinerstein et al., 2017) at 30 arc second spatial resolution. Ecoregions were selected if: i) their descriptions mentioned features consistent with those identified in the profile of the EFG; and ii) if their location was consistent with the ecological drivers described in the profile.
S2.1 / T1.4 / T2.3 / T2.4 / T3.1 / T3.2 / T4.2 / T4.3 / T4.4 / T4.5 / T6.4 / TF1.2 / TF1.3 / F1.6 / TF1. 7	Terrestrial ecoregions containing major or minor occurrences of this ecosystem functional group were identified by consulting available ecoregion descriptions (Dinerstein et al., 2017), global and regional reviews, national and regional ecosystem maps, locations of relevant examples, and proofed by expert reviewers. Consequently, they are coarse-scale indicative representations of distribution, except where they occupy small ecoregions. Ecoregions were mapped at 30 arc seconds spatial resolution.
T1.3	The distribution of tropical montane rainforest was approximated from a model of environmental suitability based on climatic variables and cloud cover (Wilson & Jetz, 2016). Occurrences were aggregated to half degree spatial resolution and cells reclassified as major occurrences (>25% of cell area) and minor occurrences (< 25% of cell area).
T2.5	Remote sensing estimates of canopy height were used as a direct indicator of the distribution of this group of tall forest ecosystems (Armston et al., 2015: Tang et al., 2019). We selected all areas with tree canopies taller than 40 m, and clipped to the spatial extent of temperate climate types (Beck et al., 2018). Mapped occurrences were then aggregated to half degree spatial resolution and reclassified as major occurrences (>20% of cell area) and minor occurrences (< 20% of cell area).
T3.3	Major and minor occurrences were identified using consensus land-cover maps (Tuanmu & Jetz, 2014; Latifovic et al., 2016), then cropped to selected terrestrial ecoregions at 30 arc seconds spatial resolution (Dinerstein et al., 2017; CEC, 1997). Ecoregions were selected if they contained areas mentioned or mapped in published regional studies (Loidi et al., 2015; Luebert & Pliscoff, 2017), or if: i) their descriptions mentioned features consistent with those identified in the profile of the Ecosystem Functional Group; and ii) if their location was consistent with the ecological drivers described in the profile.
T6.1	Areas of permanent snow where identified from consensus land-cover maps (Tuanmu & Jetz, 2014), glacier inventories (Raup et al., 2007; NSIDC, 2005–2018) and the Antarctic Land Cover map for 2000 (Hui et al., 2017). A composite map was created at 30 arc seconds spatial resolution in geographic projection, occurrences were then aggregated to half degree spatial resolution and reclassified as major occurrences (cells with > 22% snow coverage) and minor occurrences (cells with at least one occurrence).
T6.2	Known locations of prominent ice-free rock in glacial and alpine environments were selected from global geographical gazeteers (GeoNames, 2020), glacier inventories (Raup et al 2007; NSIDC, 2005–2018) and the Antarctic Land Cover map for 2000 (Hui et al., 2017). Further areas with mixed occurrence of barren and snow/ice cover were identified from the Circumpolar Arctic Vegetation Map (Raynolds et al., 2019), the USGS EROS LandCover GLCCDB, version 2 (Loveland et al., 2000) and a 1-km consensus land-cover map (Tuanmu & Jetz, 2014). A composite map was created at 30 arc seconds spatial resolution in geographic projection, occurrences were then aggregated to half degree cells. Cells containing at least one known location were designated as major occurrences, while those mapped as mixed barren and snow/ice cover were designated as minor occurrences if snow/ice covered at least 2.5% of the cell area.
T6.3	Areas corresponding to the tundra climatic zone according to the Köppen-Geiger classification system (Beck et al., 2018) were first identified. Additional areas were then selected in high latitudes corresponding with low annual solar radiation (values <1800 in Beckmann et al., 2014). A union of these maps was created at 30 arc seconds spatial resolution in geographic projection, occurrences were then aggregated to half degree spatial resolution and reclassified cells as major occurrences (>80% of cell area) and minor occurrences (30%-80% of cell area).

TF1 Palustrine wetlands biome

Okavango Delta, Botswana.
Source: Richard Kingsford (with permission)

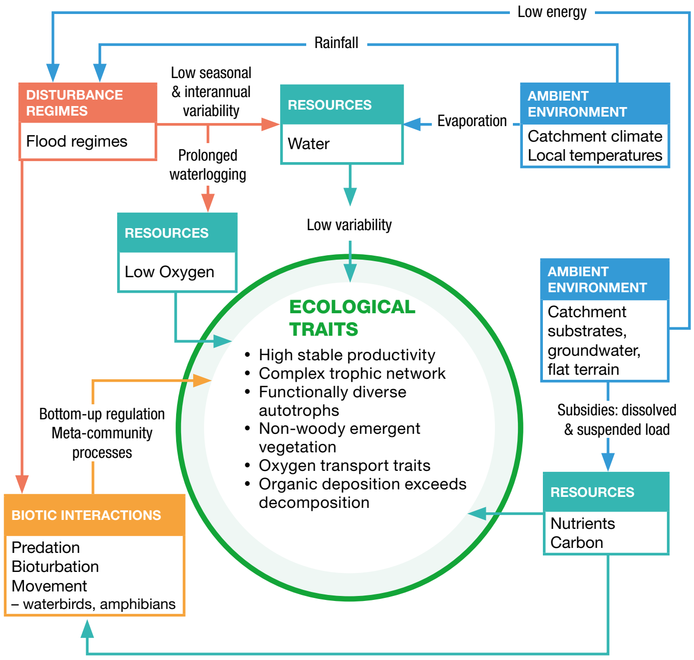
At the interface of terrestrial and freshwater realms, the Palustrine wetlands biome includes vegetated floodplains, groundwater seeps, and mires with permanent or intermittent surface water. Although water and light are abundant at least periodically, saturation of the soil may result in oxygen deprivation below the ground. This suppresses microbial activity and, in many systems, production exceeds decomposition, resulting in peat accumulation. The water regime influences resource availability and productivity and thus regulates these ecosystems from the bottom-up. Interactions among catchment precipitation, local evapotranspiration, and substrate and surface morphology regulate run-on, runoff, infiltration, and percolation. This results in water regimes that vary from permanent shallow standing water or near-surface water tables to seasonally high water tables to episodic inundation with long inter-annual dry phases. As a consequence of their indirect relationships with climate, wetland biomes are traditionally classified as 'azonal'. Spatial heterogeneity is a key feature of palustrine wetlands. At landscape scales, they function as resource sinks and refuges with substantially higher productivity than the surrounding matrix. Fine-scale spatial variation in the water regime often produces restricted hydrological niches and intricate mosaics of patch types with contrasting structure and biotic composition. Autotrophs dominate complex trophic webs. Amphibious macrophytes are the dominant autotrophs, although epibenthic algae are important in some systems. Amphibious plants have specialised traits enabling growth and survival in low-oxygen substrates and often engineer habitats for heterotrophs. Microbial decomposers and invertebrate detritivores are most abundant in surface soils. A range of microscopic and macroinvertebrates with sedentary adult phases (i.e. crustaceans) have obligate associations with Palustrine wetlands, which also provide important foraging and breeding sites for macroinvertebrate and vertebrate herbivores and predators that disperse more widely across the landscape, including waterbirds.

Everlasting Swamp, Clarence River floodplain, Australia.
Source: John Spencer/OEH

TF1.3 Permanent marshes

BIOME: TF1 PALUSTRINE WETLANDS
REALM: TRANSITIONAL FRESHWATER-TERRESTRIAL

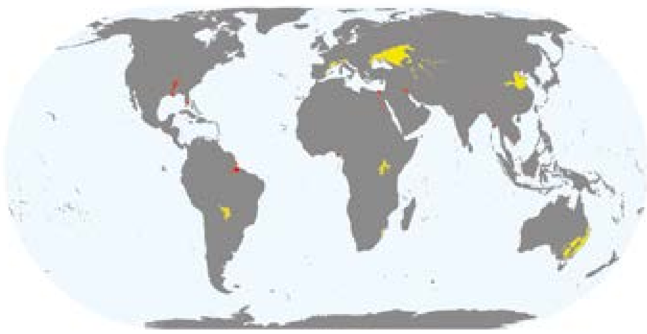
Contributors: R.T. Kingsford, J.A. Catford, M.C. Rains, B.J. Robson, D.A. Keith



ECOLOGICAL TRAITS: These shallow, permanently inundated freshwater wetlands lack woody vegetation but are dominated instead by emergent macrophytes growing in extensive, often monospecific groves of rhizomatous grasses, sedges, rushes, or reeds in mosaics with patches of open water. These plants, together with phytoplankton, algal mats, epiphytes, floating, and amphibious herbs, sustain high primary productivity and strong bottom-up regulation. Although most of the energy comes from these functionally diverse autotrophs, inflow and seepage from catchments may contribute allochthonous energy and nutrients. Plant traits, including aerenchymatous stems and leaf tissues (i.e. with air spaces), enable oxygen transport to roots and rhizomes and into the substrate. Invertebrate and microbial detritivores and decomposers inhabit the water column and substrate. Air-breathing invertebrates are more common than gill-breathers, due to low dissolved oxygen. The activity of microbial decomposers is also limited by low oxygen levels and organic deposition continually exceeds decomposition. Their aquatic predators include invertebrates, turtles, snakes and sometimes small fish. The emergent vegetation supports a complex trophic web, including insects with winged adult phases, waterbirds, reptiles, and mammals, which feed in the vegetation and also use it for nesting (e.g. herons, muskrat, and alligators). Waterbirds include herbivores, detritivores, and predators. Many plants and animals disperse widely beyond the marsh through the air, water and zoochory (e.g. birds, mammals). Reproduction and recruitment coincide with resource availability and may be cued to floods. Most macrophytes spread vegetatively with long rhizomes but also produce an abundance of wind- and water-dispersed seeds.

KEY ECOLOGICAL DRIVERS: These systems occur in several geomorphic settings, including lake shores, groundwater seeps, river floodplains and deltas, always in low-energy depositional environments. Shallow but perennial inundation and low variability are maintained by frequent floods and lake waters, sometimes independently of local climate. This sustains high levels of water and nutrients, but also generates substrate anoxia. Substrates are typically organic. Their texture varies, but silt and clay substrates are associated with high levels of P and N. Salinity is low but may be transitional where wetlands connect with brackish lagoons (FM1.2, FM1.3). Surface fires may burn vegetation in some permanent marshes, but rarely burn the saturated substrate, and are less pervasive drivers of these ecosystems than seasonal floodplain marshes (TF1.4).

DISTRIBUTION: Scattered throughout the tropical and temperate regions worldwide.



Reference:
Grace, J.B., Wetzel, R.G. (1981). 'Habitat Partitioning and Competitive Displacement in Cattails (Typha): Experimental Field Studies'. *The American Naturalist* 118(4): 463–474.