

## BOOK OF ABSTRACTS

This Book of Abstracts provides a comprehensive overview of the session content and is structured into three main sections:

- I. **Session Description** – an introduction to each session, including its objectives and expected outputs
- II. **Session Program** – a detailed schedule for each session, including speakers and timing
- III. **List of Abstracts** – a complete compilation of all accepted abstracts

### I. SESSION DESCRIPTION

ID: T2b

#### Advancing ecosystem condition assessment: novel methods and integrated approaches

##### Hosts:

	Name	Organisation	E-mail
Host (s):	Fernando Santos-Martín	Universidad Rey Juan Carlos	<a href="mailto:fernando.santos@urjc.es">fernando.santos@urjc.es</a>
Co-host(s):	Philip Roche	INRAE	<a href="mailto:philip.roche@inrae.fr">philip.roche@inrae.fr</a>
	Balint Czucz	NINA	<a href="mailto:balint.czucz@nina.no">balint.czucz@nina.no</a>

##### Abstract:

Ecosystem condition refers to the overall quality of an ecosystem, described by its biotic, abiotic and landscape characteristics and the interactions between them, reflecting its capacity to provide ecosystem services. Methods and metrics for quantifying ecosystem condition can also contribute to operationalising the related concepts of ecosystem integrity, ecosystem health, and ecological resilience, central to current policy discourses. Recent technological advances in remote sensing, data analytics, and process-based modelling can now enable more accurate, scalable, and integrative measurements of ecosystem state and function.

This session will focus on innovative methodologies and emerging approaches for assessing ecosystem condition across biophysical, socio-economic, and governance dimensions. We seek contributions presenting novel indicators, remote sensing techniques, analytical models, and integrative frameworks that operate across multiple spatial and temporal scales. By presenting cutting-edge methodologies and case studies, the session aims to showcase how these approaches can enhance our understanding of ecosystem condition and strengthen the link to management strategies and policy implementation.

##### Goals and objectives of the session:

- Present and critically evaluate innovative methodologies and tools for ecosystem condition assessment.
- Facilitate exchange of experiences and perspectives from research, policy, and practice.
- Examine the integration of new approaches into decision-making and policy development.
- Identify methodological challenges, data requirements and priorities for advancing ecosystem condition science.

##### Planned output / Deliverables:

- Documented case studies and best practices applying new approaches in diverse contexts.
- Synthesis of methodological strengths, limitations, and applicability criteria
- Establishment of a collaborative network to facilitate on-going methodological development and knowledge sharing beyond the conference.
- Identification of research gaps and priorities for future methodological development.

##### Related to ESP Working Group:

TWG 2 – Biodiversity & Ecosystem services

## II. SESSION PROGRAM

**Room:** A3

**Date of session:** Wednesday 20, May 2026

**Time of session:** 09:00 – 16:30

**Part 1. Time of session:** 09:00 – 10:30

Time	First name	Surname	Organization	Title of presentation
9.00–9.05	Fernando	Santos	RJC University (Spain)	Session T2b Welcome and introductions
9.05–9.15	Philip	Roche	INRAE (France)	Towards a Minimum Set of Ecosystem Condition Indicators: A SEEA-EA Aligned Framework
9.15–9.25	Ivaylo	Ananiev	Academy Sciences (Bulgaria)	Assessing freshwater ecosystem condition by applying a spatially explicit minimum set
9.25–9.35	Dan E.	Kanmegne	Federal Statistical Office (Germany)	Advancing ecosystem condition accounts in Germany through remote sensing
9.35–9.45	Paula	Rendon	RJC University (Spain)	Integrating national and international ecosystem typologies for condition assessment
9.45–9.55	Xavier	Lecomte	INRAE (France)	The Human Pressure Index: A Lens for Policy and Action
9.55–10.05	Emily	Bank	LHU (Germany)	Reference levels for agroecosystem condition: Determination, operationalization
10.05–10.15	Joeri	Morpurgo	Leiden University (Netherlands)	Retrieval and analysis of temporal remote sensing and land-use data on ecosystem condition
10.15–10.30	Fernando	Santos	RJC University (Spain)	Q&A session

**Part 2. Time of session:** 11:00 – 12:30

Time	First name	Surname	Organization	Title of presentation
11.00–11.05	Balint	Czúcz	NINA (Norway)	Session T2b Welcome and introductions
11.05–11.15	Joana	Seguin	LHU (Germany)	How are ecosystem condition indicators currently applied in ecosystem services assessments?
11.15–11.25	Philip	Roche	INRAE (France)	Condition Matters: An Operational Framework for Integrating Ecosystem Condition
11.25–11.35	Sylvie	Campagne	IEFER (France)	Prospective scenarios of management impact on ecosystem services considering ecosystem condition
11.35–11.45	Eva	Malta-Pinto	CIBIO (Portugal)	Towards the integration of biological invasions in ecosystem service accounting

11.45–11.55	Branimir	Hackenberger Kutuzović	Osijek University (Croatia)	Functional–Ecological Characterization of Soils
11.55–12.05	Wickson	Kibasa	Wildlife Research Institute (Tanzania)	Assessment of Land Use Land Cover Change Impacts on Habitat Quality and Wildlife Connectivity in the Protected Area
12.05–12.15	Jacopo	Di Stefano	Trento University (Italy)	Downscaling the Environmental Sustainability Gap Framework
12.15–12.30	Balint	Czúcz	NINA (Norway)	Q&A session

**Part 3. Time of session:** 15:00 – 16:30

Time	First name	Surname	Organization	Title of presentation
15.00–15.05	Philip	Roche	INRAE (France)	Session T2b Welcome and introductions
15.05–15.15	Chiaria	Cortinovis	Trento University (Italy)	Urban ecosystem condition as a conceptual challenge: revealing the different perspectives behind existing indicators
15.15–15.25	Joanna	Lipsa	Wrocław University (Poland)	Developing an integrated 2D–3D indicator for urban ecosystem condition assessment
15.25–15.35	Michał	Krupiński	CBK (Poland)	Satellite–based Urban Sprawl Monitoring through Copernicus Data
15.35–15.45	Linda	Widiachristy	Wageningen (Netherlands)	Go with the flow: exploring spatial mismatches of ecosystem service in new planned cities of the Global South
15.45–15.55	Yana	Rueva	Salzburg University (Austria)	Cooling Effects of Tropical Forests Under Extreme Heat: Remote Sensing Analyses Across Elevation Gradients
15.55–16.05	Harini	Santhanam	MANIPAL (India)	Decoupling the spatio–temporal axis of reversal from ecosystem disservices to services of seismic events
16.05–16.30	Philip	Roche	INRAE (France)	Q&A session

### III. LIST OF ABSTRACTS

*The first author is the presenting author unless indicated otherwise*


#### 1. Towards a Minimum Set of Key Ecosystem Condition Indicators: A SEEA-EA Aligned Framework for European Ecosystems

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Standardised assessment of ecosystem condition is essential for tracking environmental change, supporting evidence-based policy, and enabling international comparability. A minimum set of ecosystem condition indicators represents a pragmatic compromise between scientific comprehensiveness and operational feasibility. This work, conducted within Work Package 3 of the SELINA project, aimed to derive a minimum set of key ecosystem condition indicators per ecosystem type, aligned with the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) framework.

We conducted a systematic literature review to identify spatially explicit ecosystem condition indicators operationalised in recent scientific applications. This review was complemented by an extensive expert-based evaluation involving ecosystem type expert groups. We assessed indicators for eight ecosystem types: Agroecosystems, Forests, Urban ecosystems, Wetlands, Heath- and Shrub lands, Grasslands, Rivers and Lakes, and Marine and Coastal ecosystems. Indicators were evaluated against criteria including data availability, ecological validity, sensitivity to change, and pan-European applicability. A key methodological advancement was the operationalisation of a clear separation between condition indicators, describing the ecological state of ecosystems (abiotic, biotic, and landscape characteristics), and pressure indicators, describing anthropogenic drivers.

Minimum indicator sets were proposed for each ecosystem type, constrained to variables currently available in spatially explicit formats with European-wide coverage. The literature review revealed a predominance of remote sensing as a tool for producing spatially explicit indicators, with biases towards structural and physical state indicators and limited coverage of compositional and functional attributes. Common data gaps across ecosystem types included biodiversity indicators (particularly species richness and abundance), functional state metrics, and soil-related variables. Expert consultations highlighted persistent tensions between minimum and comprehensive indicator sets, and the importance of ecosystem-specific adaptations within a harmonised framework.

These minimum indicator sets are intended not as static endpoints, but as starting points for iterative refinement as data infrastructure, scientific knowledge, and monitoring capacities improve. The next step is to implement those minimum sets to map ecosystem condition at local to European levels.

**Keywords:** Ecosystem condition, SEEA-EA, ecosystem accounting, minimum indicators, biodiversity monitoring, remote sensing, Human Pressure Index

## 2. Assessing freshwater ecosystem condition by applying a spatially explicit minimum set of indicators: a case study of Ogosta river basin

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A minimum set of ecosystem condition indicators represents a pragmatic compromise between scientific comprehensiveness and operational feasibility, designed to capture essential ecosystem characteristics while remaining implementable across diverse contexts with existing resources and data infrastructure (Nickolson et al., 2025). In this study we applied the approach developed in SELINA (Science for Evidence-based and sustainable decisions about NATural capital) approach for selection of a minimum set of indicators for freshwater ecosystems and applied it in a case study located in the upper part of Ogosta river basin. The freshwater ecosystems in the case study are essential for people living in this area, as well as for other ecosystem types such as croplands, forests, and grasslands. They also maintain various ecosystem services. Due to heavy rainfall in 1964 and the following breakdown of a tailing dam, a serious spill and pollution with heavy metals in the water and soils occurred. Therefore, assessing the condition of the ecosystem is essential. We followed the MAES methodology for the mapping process, and additionally added up-to-date data sources for 3 ecosystem types. For ecosystem condition, we applied approach from the SEEA-EA framework by selecting proper variables by checking for data, applying a list of conceptual and practical criteria, and finally creating a Minimum Set of Indicators. The results are presented in the form of ecosystem extent and ecosystem condition maps.

**Keywords:** Freshwater Ecosystems, Ecosystem Condition, SEEA-EA, Minimum Set of Indicators, River basin


## 3. Advancing ecosystem condition accounts in Germany through remote sensing

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The ecosystem condition account is a pillar within the System of Environmental-Economic Accounting (SEEA EA) framework, that provides biophysical characteristics underpinning an ecosystem's capacity to supply services. In Germany, the federal statistical office has developed several ecosystem service accounts including crop production, forest growth and carbon



storage. Yet, the methodology relies heavily on aggregated statistical inputs and model-based coefficients, limiting the spatial and temporal sensitivity of condition assessments. This contribution proposes a remote sensing-based approach to monitor ecosystem service within the SEEA -EA.

The methodology relies on harmonized Earth observation (EO) time series from Landsat and Sentinel missions. To establish the link between the German ecosystem services and the ecosystem condition variables derived from EO, several machine learning models including Random Forest (RF), Support Vector Machines (SVM) and Convolutional Neural Networks (CNNs) were assessed via a supervised classification. The Predictors including among others vegetation indices, phenological metrics, tree cover density and land surface temperature, were assessed and ranked by their importance to each of the ecosystem services. The models were tuned using ecosystem service accounts for the year 2015 and 2018 to reach an overall accuracy higher than 0.9. Then, the service account for the year 2021 was used for the validation. As part of the final step, a spatial error assessment was carried to visualize the distribution of the classification error and detect clusters and evidence of spatial autocorrelation in the error. Error maps were generated for each service together with a report stating whether or not the error is randomly distributed.

This approach produced a spatial explicit and annually consistent layers that could be aggregated by ecosystem type or administrative units, allowing to display the variation of ecosystem service supply within aggregated units. Moreover, it could complement existing service accounts by enhancing spatial details and transparency through the spatial error assessment.

**Keywords:** Ecosystem service monitoring, Ecosystem condition assessment, Remote sensing, Spatial error assessment, SEEA-EA (System of Environmental-Economic Accounting)

#### 4. Integrating national and international ecosystem typologies for condition assessments: Principles for typology design and policy alignment

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This study presents an overview of the integration of national, European and global ecosystem typologies used in European countries to support ecosystem condition assessments and policy reporting obligations. The aim is to understand the development and integration of ecosystem typologies for assessing ecosystems at national level, both under obligatory EU reporting requirements and beyond, in support of the European Union (EU) implementation of the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA). Based on the review of literature and a comprehensive survey, the progress in ecosystem typologies development, condition assessment and data sources were identified for thirty-one countries (EU27 countries, United Kingdom, Switzerland, Norway and Israel). Additionally, the study provides an overview of European/global ecosystem typologies, habitat classifications and land-cover classification systems, tracing their evolution and highlighting their role in addressing global environmental challenges. National level typologies, constituting around 52% of the typologies identified, were found to be compatible with at least one international typology, such as the European Nature Information System (EUNIS) or the land-cover typology of Coordination of Information on the Environment (CORINE) and the ecosystem typology applied by the EU Mapping and Assessment of Ecosystems and their Services (MAES) initiative. The study discusses principles for designing condition-enabled ecosystem typologies, emphasising the use of ecologically homogeneous classes supported by functional definitions, that are also practical operationalizable at appropriate spatial and temporal scales. It also highlights the crucial role of crosswalks in linking different typologies for international comparability. The integration of national, European/global ecosystem typologies is essential for advancing ecosystem assessment and management efforts, considering their growing relevance in policy- and decision-making within countries and international bodies, such as the United Nations and the EU.

**Keywords:** ecosystem typologies, ecosystem condition assessment, ecosystem accounting, environmental policy

#### 5. The Human Pressure Index: A Lens for Policy and Action Transforming cumulative pressure frameworks into actionable tools for policy, governance and ecosystem resilience – a European Application


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Cumulative anthropogenic pressures are a major driver of biodiversity loss, yet they remain poorly operationalised in ecosystem accounting and policy-relevant assessments. Within the System of Environmental-Economic Accounting (SEEA),



pressure flows are addressed in the SEEA Central Framework (SEEA-CF), while ecosystem condition is captured in SEEA Ecosystem Accounting (SEEA-EA). However, spatially explicit and harmonised representations of cumulative pressures are still lacking, limiting their integration into ecosystem condition assessments and decision-making.

To address this gap, we develop a pressure-based conceptual framework aligned with SEEA ecosystem condition accounts, bridging pressure concepts from the SEEA-CF with condition assessment in SEEA-EA. We operationalise this framework through the Human Pressure Index (HPI), a harmonised, spatially explicit index for European terrestrial ecosystems, integrating land use, pollution and invasive alien species pressures, and structured according to IPBES direct drivers of biodiversity loss.

We assess the ecological relevance of the HPI through comparisons with the Biodiversity Intactness Index (BII) and the Global Human Modification (GHM) index. Results reveal a strong, nonlinear decline in biodiversity intactness with increasing cumulative pressure, and highlight the complementarity between diffuse functional pressures captured by the HPI and structural modification metrics represented by GHM.

Overall, the HPI provides a policy-ready and SEEA-EA-compatible tool for mapping and monitoring cumulative human pressures, supporting European biodiversity and restoration policies, including the EU Biodiversity Strategy for 2030, the Nature Restoration Law and the Zero Pollution Action Plan.

**Keywords:** Cumulative anthropogenic pressures; Pressure-based conceptual framework; IPBES drivers; SEEA Ecosystem Accounting; Ecosystem Condition Assessment; Environment Policy Impact Assessment

## 6. Reference levels for agroecosystem condition: Determination, operationalization and comparison in a German case study

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Ecosystems in good condition are fundamental for a sustainable supply of ecosystem service bundles that ensure human well-being. Acknowledging this, policies globally increasingly emphasize the need to monitor and report on ecosystem condition (EC), which requires a sound conceptual base and reliable assessment and quantification methods.

While trends over time can be monitored through EC variables in absolute values, a reference is required for comparison to derive an indicator that evaluates the EC as 'good' or 'bad', ultimately. However, reference conditions or levels are still little used in EC assessments, as conceptual and practical uncertainties remain. Anthropogenically influenced ecosystems, such as agroecosystems, are especially challenging, as they cannot be compared to a natural state.

To address this challenge, here, reference levels were tested and compared for a set of agroecosystem condition variables in a case study in Germany. Precisely, the method was the following: 1) reference levels were determined through two different approaches - data-driven, analysing ambient distribution, and literature-based, using, e.g. policy or expert thresholds, (ii) the reference levels were applied to rescale the EC variables, and (iii) the resulting indicators were compared to highlight the influence of the two methods on the final EC assessment.

Preliminary results show no clear trend between the approaches. For some EC variables, both methods produce similar reference levels and thus comparable indicator distributions. For others, reference levels differ substantially, resulting in sensitive indicator fluctuations. The data-driven method is easier to apply and readily integrated into automated assessments but holds more uncertainties for non-normally distributed data or non-linear relationships. The literature-based method requires more research effort but can provide more ecologically meaningful reference levels.

In conclusion, this research a) provides comprehensive lists of literature-based reference levels for exemplary agroecosystem condition variables and b) contributes to improving guidance for applying reference levels in agroecosystems.


**Keywords:** Reference condition, Reference sites, Ambient distribution, Literature values, SEEA-EA

## 7. Retrieval and analysis of temporal remote sensing and land-use data on ecosystems made easy with the R package More Urban Spatial Tools

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Assessing urban ecosystems requires the integration of heterogeneous spatial datasets, including remote sensing products and land-use information. Although many open-source datasets are available, they are rarely combined in a consistent and comparable manner across space and time, limiting robust assessment of ecosystem services and biodiversity. We present MUST (More Urban Spatial Tools), an R package that facilitates streamlined data retrieval and basic assessment of the state of urban green infrastructure over time. MUST integrates remote sensing-based information (through Google Earth Engine) with land-use data (Open Street Maps and Ohsome) to provide annually resolved UGI indicators from 2017 to the present at a spatial resolution of 10 × 10 m. Moreover, it leverages the Consolidated Urban Green Infrastructure Classification, allowing for the rapid creation of globally standardized maps. By enabling standardized, reproducible workflows for multi-source data integration, MUST lowers technical barriers and supports more consistent temporal analyses of urban green infrastructure. These maps can form both the basis for governmental policies and research efforts.

**Keywords:** data, remote sensing, land use, ecosystem conditions, harmonisation

## 8. How are Ecosystem Condition indicators currently applied in Ecosystem Services assessments? – Insights from a systematic literature review

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The integrated assessment of Ecosystem Services (ES) is crucial for highlighting human dependence on a functioning, biodiversity-rich environment. As pressures on ecosystems increase, recent initiatives, including the MAES (Mapping and Assessment of Ecosystems and their Services) initiative, underscore the necessity of incorporating Ecosystem Condition (EC) indicators into ES assessments. The successful implementation of frameworks and reporting strategies such as the Kunming-Montreal Global Biodiversity Framework (GBF), the Nature Restoration Regulation (NRR), and the System of Environmental Economic Accounting Ecosystem Accounting (SEEA EA) calls for robust indicators to facilitate integrated assessment and monitoring. These indicators are vital for informing EU and national policies about the state and temporal changes in ecosystem assets, condition, and related services.

Within the scope of the EU Horizon project SELINA (Science for evidence-based and Sustainable decisions about natural capital), we conducted a systematic literature review to evaluate how EC indicators are used in ES assessments in the recent scientific literature. Our review documented 929 EC indicators linked to one or more ES and examined 707 ES indicators. We observed a predominant focus on terrestrial ecosystems, with marine and less intensively managed ecosystems notably underrepresented. Our findings also identified a prevalent use of chemical state EC indicators, while landscape and functional state metrics remained underutilized. Moreover, a significant portion of the EC indicators exhibited misclassification, blurring the conceptual clarity between condition, pressure, extent, and services indicators. In this presentation, we will share the key findings and identified gaps from our review, aiming to stimulate the discussion on advancing EC-enabled ES assessments. By addressing these gaps, we can enhance our understanding of EC and strengthen the link to better informed management strategies and policy implementation.

**Keywords:** EC-enabled ES assessments, indicators, proxies, variables, link

## 9. Condition Matters: An Operational Framework for Integrating Ecosystem Condition into Ecosystem Service Capacity Matrices

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Ecosystem service (ES) capacity matrices are widely used for ES assessment due to their operational simplicity, yet they typically assign uniform capacity scores to ecosystem types without accounting for local variations in ecosystem condition. This methodological gap creates systematic assessment errors, particularly when matrices are applied across heterogeneous landscapes. We present a novel framework for integrating ecosystem condition into capacity matrices through ecosystem-specific condition thresholds, directly operationalizing the SEEA EA conceptual linkage between condition and service capacity.

Our approach characterizes ecosystem condition through two composite indices: structural condition (integrating vegetation cover, productivity, and canopy height from remote sensing data) and biological condition (combining



biodiversity intactness, soil organic carbon, and natural habitat proportion). We classify ecosystem services into five functional groups based on their empirically-documented dependencies on these condition components, and develop allocation tables linking condition states (low, medium, high) to adjusted capacity values.

We present a study case application to a 430-km<sup>2</sup> study area in the Hauts-de-France region demonstrates that condition-adjusted capacity assessments differ from unadjusted matrices by 0.58–0.81 units on average (12–16% of capacity range), with maximum local differences reaching 2.1 units (42% of range). Validation against six independent reference datasets shows correlation improvements ranging from 0.035 to 0.132 (mean 0.078), with all improvements statistically significant. This framework provides practitioners with a reproducible, scalable method for refining ES assessments using readily available spatial datasets, bridging the gap between condition monitoring and service capacity estimation. The approach has direct applications in natural capital accounting, land-use planning, and environmental impact assessment.

**Keywords:** Ecosystem condition, capacity matrix, ES mapping, remote sensing, natural capital accounting

## 10. Prospective scenarios of management impact on ecosystem services considering ecosystem condition

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We face the challenge of optimising management actions under constrained budgets to preserve or restore ecosystem and their condition. Ecosystem services (ES) assessment has emerged as a valuable framework for evaluating these management actions, yet current ES models rarely integrate explicit ecosystem condition (EC) evaluation despite the recognised dependence of ES on EC. Our study aims to analyse whether integrating EC assessment into ES models can improve the evaluation of the impact of management actions in degraded areas, and whether such integration provides conservation managers with more robust decision-making tools.

We developed an ES framework that explicitly integrates both ecosystem condition and land use change to assess management action impacts on ES capacity in a French wetland area. The model incorporates a capacity matrix, structural and biological condition indices, and habitat area data to quantify ES values. The analysis is carried out for the situation under current conditions and for two management scenarios derived from the wetland management plans of the site. Our results demonstrate how alternative management scenarios differentially affect ES portfolios, with certain actions enhancing specific services while diminishing others. These results can inform decision-making, either confirming current management actions or recommending a change in actions according to local objectives. Our approach offers a replicable framework where assessing management effectiveness is critical for sustained support and adaptive management.

**Keywords:** capacity matrix, structural and biological condition indices, land-use change, wetland

## 11. Towards the integration of biological invasions in ecosystem service accounting: linking invasion by alien species with shifts in forest ecosystem condition

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Biological invasions are increasingly recognised as a major driver of biodiversity loss and ecosystem change, yet their integration into ecosystem service assessment frameworks remains limited. In an era of accelerating global transport of goods, trade and human mobility, invasion by introduced alien species plays a central role in moving ecosystems into novel states by modifying their abiotic and biotic composition, structure, and/or functioning, which together define ecosystem condition. Because ecosystem condition underpins the capacity of ecosystems to deliver services, failing to assess and quantify shifts in condition driven by biological invasions might constrain the accurate accounting of the real impacts they can have on ecosystem service supply.

This presentation introduces a methodological approach designed as a first step towards addressing this gap. Using a structured literature synthesis combining systematic review and meta-analysis, we compiled empirical evidence on the effects of alien species invasions on multiple dimensions of ecosystem condition in European forests. Reported impacts are organised across five condition dimensions (abiotic quality, composition, structure, functioning, and landscape characteristics) and analysed in relation to invasive species groups, forest types, and biogeographic regions to identify



consistent directional shifts and their main ecological and contextual predictors. Preliminary results are presented and discussed in relation to their implications for ecosystem service supply capacity and ecological resilience. This study highlights the relevance of integrating biological invasions into ecosystem service assessments and natural capital accounting to support effective risk management, restoration planning, and adaptation under ongoing global social-ecological change.

**Keywords:** Biological invasions, forest ecosystems, ecosystem condition, ecosystem services, integrative accounting

## 12. Functional-Ecological Characterization of Soils: Foundation for Ecotoxicological Classification

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Healthy and productive soils are essential for sustainable food production and ecosystem services. The EU Soil Strategy 2030 recognizes soil biodiversity as a key indicator of sustainable soil use, yet significant knowledge gaps exist in understanding functional diversity of soil fauna and its relationship to soil health. This project addresses these gaps by developing a novel functional-ecological characterization framework for soils based on soil invertebrate communities and their ecosystem functions.

Our approach focuses on functional groups of soil organisms rather than taxonomic classifications alone, investigating how functional diversity relates to soil biotic potential, stability, and resistance to environmental stressors. Field sampling across five major soil types in continental Croatia under different land uses (cropland, forest, grassland) provides baseline data on taxonomic and functional diversity of macrofauna, mesofauna, and microbial communities during different seasons.

Laboratory microcosm and field mesocosm experiments examine secondary biotic potential using standardized barley cultivation in both defaunated and intact soils. Stability tests investigate functional-ecological status under varying temperature and moisture regimes simulating climate change scenarios, while resistance experiments assess responses to model pollutants (arsenic, cadmium, imidacloprid). Measurements integrate soil fauna biomass and functional traits, microbial enzyme activity, plant physiological parameters, and physicochemical soil properties.

Preliminary results demonstrate significant impacts of soil composition, management practices, and abiotic factors on invertebrate biomarkers and ecosystem functions. Advanced computational methods including machine learning for organism identification, dynamic energy budget modeling, and Bayesian inference for in silico experiments enable prediction of functional-ecological responses to environmental changes.

This holistic approach aims to establish standardized methods for functional-ecological soil classification, providing science-based indicators for soil health monitoring aligned with EU legislation and supporting evidence-based decisions for sustainable soil management and protection.

**Acknowledgement:** The results presented in the paper are an output from the research project IP-2022-10-3233 „Functional-ecological characterization of soils - foundation for ecotoxicological classification”.

**Keywords:** soil biodiversity, functional ecology, ecotoxicology, ecosystem functions, soil health

## 13. Assessment of Land Use Land Cover Change Impacts on Habitat Quality and Wildlife Connectivity in the Protected Area: A Case Study of Lake Manyara National Park, Tanzania


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Rapid land use land cover change (LULC) is a major driver of biodiversity loss and ecosystem fragmentation in protected areas, undermining conservation outcomes. This study assessed the impacts of LULC on habitat quality and wildlife connectivity in and around Lake Manyara National Park (LNMP), Tanzania, a critical ecosystem supporting diverse species and functioning as a corridor within the northern circuit. Multi-temporal satellite imagery (2005,2015,2025) was analyzed



using ArcGIS 10.2 to quantify LULC dynamics, complemented by spatial modeling of habitat quality and connectivity spatial modeling to evaluate habitat quality and connectivity Least-cost path and corridor modelling techniques were applied, alongside the InVEST habitat quality model to assess anthropogenic threats. Results indicate notable expansion of agricultural land (+6.72%) and settlements (+3.97%) in the 10 km buffer zone, largely at the expense of grassland (-10.46%) and forest cover (-1.6%), leading to increased fragmentation. Within LMNP, water bodies expanded (+3.78%), forest cover declined (-5.92%), grassland decreased (-1.1%), while woodland increased (+7.22%). Wildlife corridors showed narrowing and discontinuity, within Lake Manyara's expansion, inundating farmland, settlements and dispersal areas. Social surveys revealed that 35.8% of respondents had no formal education, 29.4% primary, 26.8% secondary, and 8.1% tertiary. Urban growth was identified as the dominant driver (42.3%), followed by logging (20%) and farming expansion (13.9%). Other drivers (23.8%) included hydrological and climatic factors such as lake expansion, increased rainfall, flooding. Livestock pressure and localized tree felling. Population growth, particularly in Esilalei (57% increase from 2005 to 2025), further intensified land pressure. Habitat quality analysis confirmed a decline in suitable wildlife habitats over the study period. These findings highlight the complex interplay of human and environmental forces shaping LULC change and emphasizing the need for integrated land-use planning, community-based conservation, and protection of ecological corridors to sustain habitat integrity and wildlife connectivity in and around protected areas in Tanzania and similar ecosystems elsewhere.

**Keywords:** Land use change, habitat quality, wildlife connectivity, Hydrological change

#### 14. Downscaling the Environmental Sustainability Gap Framework: Evidence from the Chicamocha Canyon, Colombia

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In an era of unprecedented anthropogenic pressure, dominant economic indicators like GDP fail to account for natural capital depletion, often encouraging unsustainable development. The Environmental Sustainability Gap (ESGAP) framework addresses this deficiency by evaluating environmental performance against absolute, science-based standards. While ESGAP has proven effective at national levels, its adaptability to sub-national regions, where ecological specificities and governance challenges are often most crucial, remains largely unexplored. This paper bridges that gap by downscaling the ESGAP framework to the Chicamocha Canyon in Colombia, a significant yet threatened ecological region.

Using the Strong Environmental Sustainability Index (SESI), we assessed the region's natural capital across four essential functions: source, sink, life support, and human health & welfare. We selected 13 context-specific indicators which address critical environmental issues, including forest utilization rates, water stress, soil erosion and salinization, water contamination, biodiversity levels, and human welfare metrics like drinking water quality, indoor air pollution, and protected area coverage.

The results reveal a state of severe environmental unsustainability, with an overall SESI score of 19.25 out of 100. This alarming metric reflects deep structural failures: the "source" function is critically impaired by deforestation and soil erosion; the "sink" function is overwhelmed by ionic and nutrient pollution; "life support" capacities have collapsed due to freshwater pollution and biodiversity loss. Human welfare is directly compromised, with over 70% of local municipalities lacking safe drinking water. Environmental degradation stems from agriculture, mining, and uncontrolled grazing. These activities cumulatively drive deforestation, water pollution, and soil erosion, overwhelming the canyon's fragile vegetation and regenerative capacity.

Ultimately, this research validates the ESGAP framework as a scalable tool for regional authorities. By providing a scientifically rigorous, data-driven diagnosis, it translates the abstract principle of strong sustainability into a practical instrument for policy.

#### 15. Urban ecosystem condition as a conceptual challenge: revealing the different perspectives behind existing indicators


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The topic of ecosystem condition is more and more prominent in the scientific and policy debate. While methods and indicators for condition assessment in some ecosystem types start to become consolidated, the same cannot be said for urban ecosystems. Attempts to define and assess urban ecosystem condition so far have adopted a broad range of methods, variables, and indicators that -taken together- appear incoherent. We argue that such incoherence reflects major disagreements in the conceptualization of urban ecosystems and their condition.



To reveal the disagreements and their implications, we search the scientific literature to answer five key questions: i) what is the urban ecosystem that should be analysed?, ii) how should the boundaries of the system be identified?, iii) what factors should be considered to define its condition?, iv) what are the relationships between urban ecosystem condition and services?, and v) how can reference levels for “good conditions” be defined? We then consider variables and reference levels used to assess urban ecosystem condition in key guidance documents and recent publications, mapping their position with respect to the key questions.

For all questions, we found quite different and often contrasting answers, either explicitly stated in the definition of theoretical frameworks or implicitly derived from existing applications. Alternative perspectives emerged from the tension between an exclusively ecological focus on nature (“ecology in the city” paradigm) and a socio-ecological-technological approach capturing human-nature interactions (“ecology of/for the city”). However, positions on system boundaries and values associated with condition assessment go beyond this simplistic dichotomy, revealing diversified perspectives.

The mapping of existing variables and reference levels helps to clarify their conceptual underpinnings and reciprocal relationships. The results call for the definition of a more coherent and robust framework for the assessment of urban ecosystem condition, able to meaningfully support evidence-based decision-making.

**Keywords:** ecosystem condition, urban ecosystems, reference levels, indicators, SEEA-EA

## 16. Developing an integrated 2D–3D indicator for urban ecosystem condition assessment: a spatial framework for comparing conventional and enhanced approaches

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Urban ecosystems are dynamic systems where changes in landscape structure influence ecosystem condition and the capacity to provide ecosystem services. Despite growing availability of geospatial data, urban ecosystem assessments remain largely based on two-dimensional (2D) land cover, potentially overlooking vertical spatial structure. This study aims to develop an integrated urban ecosystem condition indicator combining biotic, abiotic, and landscape-related metrics derived from both 2D and 3D spatial data. The indicator will enable comparison of conventional 2D assessments with 2D–3D assessments across multiple spatial units, evaluating how inclusion of 3D spatial information affects urban ecosystem condition and its capacity to support ecosystem services over long-term periods. The case study focuses on Wrocław, Poland. Long-term landscape analyses using satellite imagery (Landsat, Sentinel) and detailed national vector data (BDOT10k) will provide a baseline for horizontal changes in land cover composition and spatial configuration. To extend this framework, 3D data from airborne laser scanning and photogrammetric sources will be incorporated to characterise the vertical structure of vegetation and built-up areas. Height- and volume-based indicators will be combined with landscape metrics to construct a composite urban ecosystem condition indicator capturing biotic, abiotic, and landscape dimensions. The indicator will be applied across multiple spatial units to systematically compare 2D-based and integrated 2D–3D assessments. It is hypothesised that 3D indicators will reveal spatial patterns of urban ecosystem condition that remain underestimated or overlooked in conventional 2D analyses. The study is expected to provide transparent, scalable, and policy-relevant approaches for urban ecosystem condition assessment, supporting urban planning, ecosystem services management, and evidence-based decision-making.

**Keywords:** urban ecosystem condition, 3D spatial indicators, landscape structure, GIS and remote sensing, ecosystem services assessment

## 17. Satellite-based Urban Sprawl Monitoring through Copernicus Data

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Our research addresses the critical need for automated, scalable solutions to monitor urban sprawl in South America, leveraging Copernicus Earth Observation data and end-user-driven methodologies. Presented initiative focuses on developing operational tools for automated processing of Sentinel satellite imagery, tailored to governmental stakeholders responsible for land-use planning and sustainable development. By integrating user requirements through iterative feedback loops, the project aims to deliver spatially explicit indicators of urban expansion, land cover transitions, and

infrastructure encroachment on peri-urban ecosystems.

Key components include the deployment of machine learning algorithms for high-resolution land cover classification and change detection, optimized for South American urban contexts. Demo cases are co-designed with local partners, targeting cities experiencing rapid sprawl to validate the robustness of the tools under diverse geographic and socioeconomic conditions. Capacity-building workshops equip end-users with skills to interpret EO-derived metrics, such as impervious surface growth and green space fragmentation, directly applicable to SDG 11 (Sustainable Cities) monitoring frameworks. The project emphasizes knowledge transfer, fostering long-term adoption of Copernicus data through open-access tools and standardized workflows. Outcomes will include operational protocols for integrating EO analytics into national urban planning systems, enhancing evidence-based policymaking for resilient city development.

Within the project, one of selected cities was Santiago de Chile. CBK PAN has developed an automatic approach for automatic classification of series of Sentinel-2 images, focused on identification of areas covered by artificial materials (buildings, roads, asphalt surfaces). University de Chile has provided the local reference databases.

**Keywords:** remote sensing, Copernicus, urban sprawl

## 18. Go with the flow: exploring spatial mismatches of ecosystem service in new planned cities of the Global South

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By 2050, more than half of the world's urban population will reside in the Global South, prompting the construction of new planned, purportedly "green" cities. While ensuring a sustainable delivery of ecosystem services (ES) is key to such a green status, these cities may struggle to achieve it, as their fixed structures thwart the adaptation strategies commonly adopted to overcome spatial mismatches between ES supply and demand. Assessing the cost of the spatial gap between supply and demand is critical in improving ES delivery, but methods commonly used to do this generally disregard spatial flow, namely, how people access ES given landscape characteristics. This study uses ES spatial flow to assess spatial mismatches in Nusantara, Indonesia's new capital city. Three ES essential for the functioning of new cities, such as freshwater supply, recreation, and food provision, are evaluated. We integrate various InVEST models, projected population in 2045, and origin-destination Cost Matrix analysis to measure how ES flow from supply to demand across the landscape. Mismatches are quantified using a locally optimal selection 'greedy' algorithm in Python. Our findings show that service realization is greatly influenced by proximity to service origin, particularly for ES dependent on transport networks. Districts with higher proportions of intact natural areas do not inherently ensure greater ES supply, underscoring how critical ES flow dynamics within the city are. Nonetheless, despite the ample supply of greenery within the city, all ES assessed display significant mismatches, with food supply showing the largest deficits, and recreation the smallest. By explicitly modelling ES flows, this study highlights the need to protect not only core supply areas but also the pathways that enable service delivery. Integrating flow-based ES assessments into early planning stages can offer deeper and more robust insights into new-city development in ecologically sensitive areas

**Keywords:** ES flow, spatial mismatch, new planned city, supply, demand

## 19. Cooling Effects of Tropical Forests Under Extreme Heat: Remote Sensing Analyses Across Elevation Gradients During the 2023–2024 El Niño in Amistosa, Costa Rica


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Global-scale deforestation in the last century has significantly altered the Earth's energy balance. Historically, most research has focused on the biogeochemical impacts, such as a decrease in carbon sequestration. Lately, there has been increased attention to the biogeophysical effects, such as changes in the latent and sensible heat fluxes caused by deforestation. Forests act as heat regulators, benefitting local communities, where previous studies have shown that tropical forests have the strongest net cooling effect. However, the variability of forest-induced cooling in mountainous environments and during extreme warming events remains poorly understood. Filling this gap is crucial, since mountains cover nearly one-third of Earth's land surface, and the frequency of extreme events is expected to increase with global warming. This study evaluates the spatial and temporal dynamics of forest-mediated cooling relative to the adjacent pastures and agricultural



areas in the Amistosa region of Costa Rica. Land surface temperature (LST) time series of multiple thermal satellite sensors are evaluated for forests and open lands during the El Niño event in 2023-2024 and compared to the previous two years as a reference. Specifically, the study assesses: (i) how forest-induced cooling responded to the extreme warming associated with the 2023–2024 El Niño, and (ii) how the cooling varies between 0 and 1800m above sea level. The final results support the identification of priority areas for conservation and restoration that will maximise the benefits of forests in terms of heat regulation, as a climate adaptation measure.

**Keywords:** heat stress, climate regulation, biophysical cooling, land cover change, surface energy dynamics

## 20. Decoupling the spatio-temporal axis of reversal from ecosystem disservices to services of seismic events

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Seismic events are the largest group of natural processes that are perceived to produce ecosystem disservices (ED) globally. However, the value of their disservices on the short-term are disproportionately assessed as 'large' compared to their long-term enablement to ecological successions that mark the temporal transformation of seismically-affected landscapes. We hypothesise that the seismic intensity (I) negatively correlates with short-term regulatory and cultural ecosystem services (ES), while positively correlating with the large-scale and long-term provisioning, cultural and regulatory ES. We explored this in the context with global examples based on, the nature and intensity of the seismic footprint and its geomorphological effects. Further we determine the turnover axis (T) from a largely ED model to an ES-recovered model. Using well-documented global reports on the impacts of large and small seismic events, we tried to understand the factors affecting the coupling of the successional values attributable to I and T. Using a Pareto optimality scoring approach to classify the impacts of I on T for provisioning, regulatory and/or cultural ES provided a new methodology to decouple the ED-ES axis in the context of seismic events. These inferences are valuable to plan the Nature Based Solutions in diverse seismic environments and to position sustainable development across the ES – DS – human continuum.

**Keywords:** Seismic, Ecosystem services, Ecosystem disservices, NbS, Sustainable development, human continuum