AL-FARABI KAZAKH NATIONAL UNIVERSITY FACULTY OF BIOLOGY AND BIOTECHNOLOGY DEPARTMENT OF BIOTECHNOLOGY

Lecture 10

ECOLOGICAL RESEARCH METHODS

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Lecture Objective

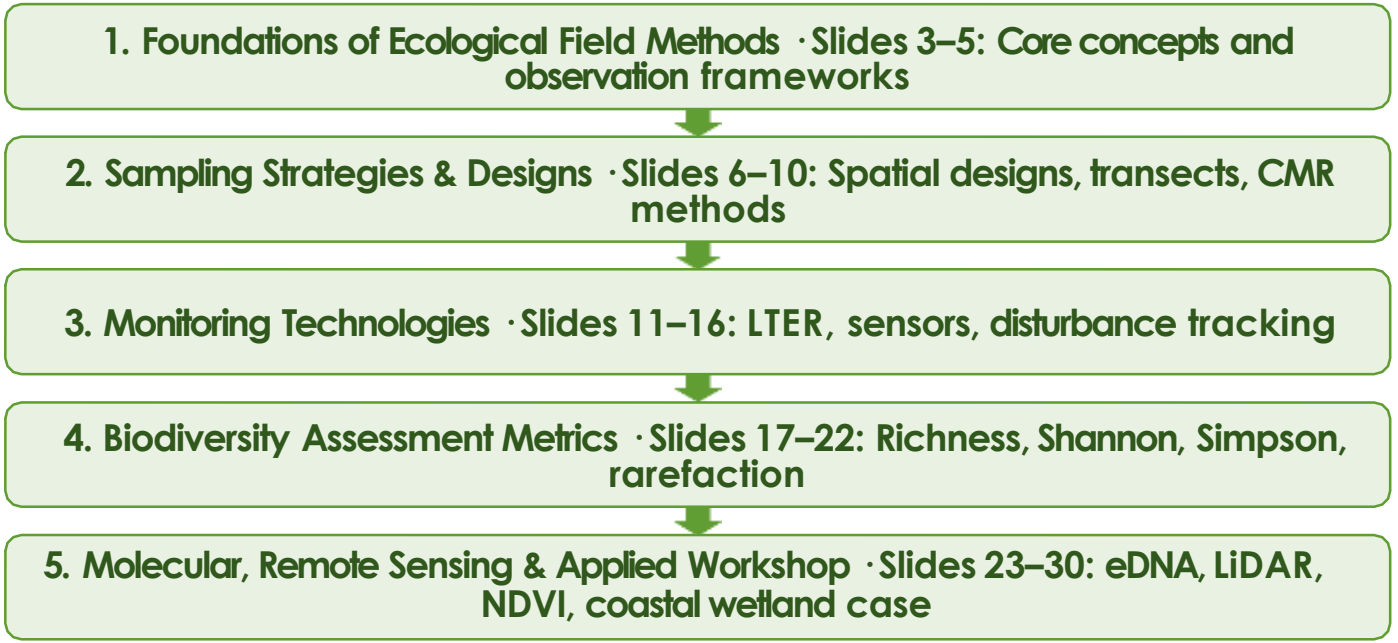
To introduce students to the fundamental methods of ecological research, including field observations, sampling techniques, environmental monitoring, biodiversity assessment, and ecological data analysis. To develop an understanding of how scientific methods are applied to investigate ecosystems and evaluate environmental changes.

Expected Learning Outcomes

By the end of this lecture, students will be able to:

1. Explain the fundamental principles and objectives of ecological research.
2. Identify different field and laboratory methods used in ecological studies.
3. Describe sampling techniques for assessing biodiversity and environmental conditions.
4. Apply basic methods of environmental monitoring and ecological data collection.
5. Interpret ecological data and evaluate environmental changes.6. Understand the importance of scientific methods in ecosystem assessment and conservation.

Agenda & Structure



Empirical Observation In Complex Systems

Natural vs. Anthropogenic Effects	Distinguishing human-driven change from natural ecosystem variability
Abiotic–Biotic Interactions	Climate, soil, and water drivers shaping producers, consumers, and decomposers
Ecosystems as Dynamic Networks	Nonlinear biological systems with feedback loops between species and environment
Unbiased Observation Design	Minimizing observer bias through rigorous protocols and controls
Standardized Field Methods	Ensuring reproducibility and comparability across studies and sites

Scale & Heterogeneity

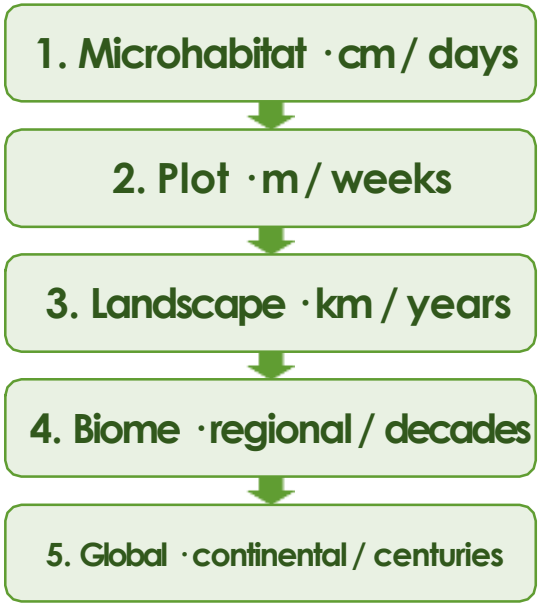
Microhabitat cm scale / days

Landscape
km scale / years

Global
continental / centuries

Biome
regional / decades

Plot
meters / weeks



Abiotic Vs. Biotic Measurements

SOIL CHEMISTRY
Soil probes, pH meters, and nutrient analysers measure organic matter, nitrogen, phosphorus, and moisture content as key abiotic drivers of ecosystem productivity.

MICROCLIMATE
Abiotic instruments include thermometers, pyranometers, and anemometers to record temperature, solar radiation, humidity, and wind speed across habitat gradients.

TROPHIC INTERACTIONS
Pitfall traps, mist nets, and trawl nets capture organisms across trophic levels, enabling assessment of species richness, guild structure, and predator-prey ratios.

ABUNDANCE & BIOMASS
Biotic sampling via quadrats, point-counts, and sweep nets quantifies species abundance, density, and biomass across vegetation layers and faunal guilds.



Spatial Sampling Designs

Method / metric	Meaning and application
RANDOM SAMPLING	Randomly placed sample locations suited for uniform or homogeneous habitats; minimizes selection bias across the study area.
SYSTEMATIC SAMPLING	Samples placed at fixed, regular intervals across the landscape; optimal for spatial mapping and detecting gradients.
STRATIFIED RANDOM SAMPLING	Habitat divided into distinct strata; proportional random samples drawn from each stratum to capture heterogeneity.

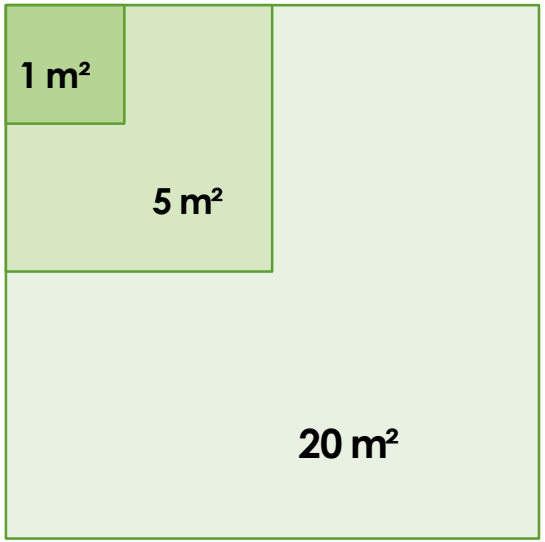
Plot-based Sampling: Quadrats & Nesting

NESTED QUADRAT DESIGN
Concentric frames (1 m², 5 m², 20 m²) placed within one plot simultaneously capture ground flora, shrub layer, and canopy trees.

SQUARE & RECTANGULAR QUADRATS
Fixed-frame plots used to census stationary organisms; rectangular forms suit elongated habitats and linear vegetation gradients.

MULTI-SCALE VEGETATION LAYER ASSESSMENT
Each nested scale targets a distinct stratum: 1 m for herbs/mosses, 5 m for shrubs, 20 m for overstorey trees, enabling stratified species richness comparisons.

CIRCULAR & IRREGULAR QUADRATS
Circular plots minimise perimeter-to-area ratio, reducing edge-effect bias; suited for tree basal area and shrub cover estimation.



Nested plots: areas shown to scale

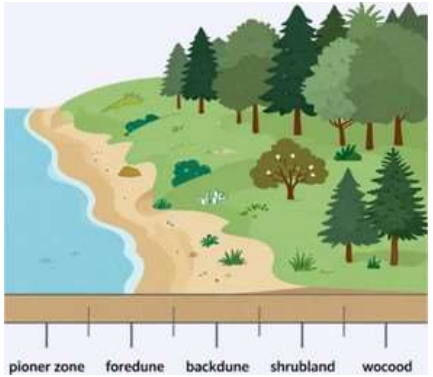
Line & Belt Transects

ENVIRONMENTAL GRADIENTS
Transects are oriented perpendicular to gradients (e.g., elevation, moisture, salinity) to capture species turnover. Gradient-aligned placement maximizes detection of community composition shifts.

LINE-INTERCEPT TRANSECT
Records all organisms or ground cover that physically touch or intercept a tape or line stretched across the study area. Ideal for estimating percent cover of vegetation along environmental gradients.

COASTAL DUNE ZONATION
Classic transect application: species composition shifts from pioneer halophytes at the shoreline through foredune grasses to shrub communities and woodland at the inland terminus.

BELT TRANSECT
Samples all organisms within a fixed-width corridor (e.g., 1–5 m) on either side of a central line. Captures both presence and abundance data across heterogeneous habitats.



Capture-mark-recapture (CMR) Method

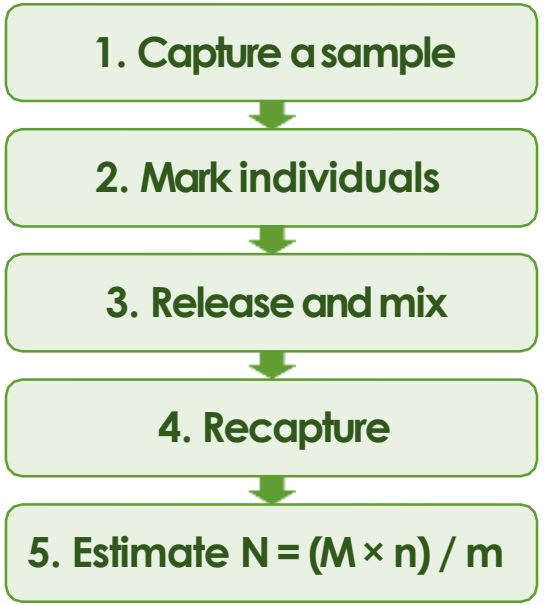
Initial Capture
Capture a sample of individuals from the population

Marking Individuals
Apply unique tags, bands, or dye to each captured animal

Release & Mixing
Release marked animals; allow full mixing with population

Recapture Sample
Conduct second capture; record marked vs. unmarked

Lincoln-Petersen Calculation
$N = (M \times n) / m$; estimate total population size



Non-invasive Wildlife Sampling

TRACK PLATES

Ink or sooted tracking plates record footprint impressions of passing fauna, allowing species identification and activity pattern analysis across survey sites. activity.

CAMERA TRAPS

Motion-activated cameras provide continuous photographic records of wildlife presence, behavior, and abundance with minimal human disturbance to natural

ACOUSTIC MONITORS

Passive acoustic recording units capture vocalizations of birds, bats, and amphibians continuously, enabling biodiversity assessment with zero behavioral impact. capture.

HAIR SNARES & EDNA

Passive hair snare stations collect fur samples for genetic identification, enabling species detection and individual recognition without physical

Long-term Ecological Monitoring

30-YEAR TREND DATA

Time-series records of canopy growth, species turnover, and biomass accumulation spanning 30+ years.

LTER NETWORK & PERMANENT PLOTS

Permanent plots provide baseline data for tracking decadal ecosystem change and detecting long-term trends.

SUCCESSION & CLIMATE ADAPTATION

Monitoring vegetation succession and species range shifts driven by changing climate conditions over decades.

ECOSYSTEM BASELINE & DISTURBANCE

Baseline datasets enable separation of natural variability from anthropogenic disturbance signals over time.

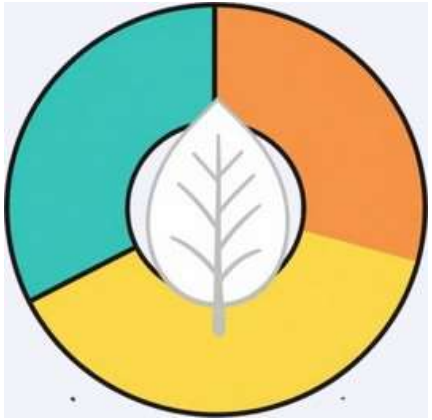
Bioindicators & Sentinel Species

AMPHIBIANS
Permeable skin and dual aquatic-terrestrial life stages make amphibians acutely sensitive to chemical contaminants, UV radiation, and habitat fragmentation. Population declines signal ecosystem-wide stress.

LICHENS
Highly sensitive to atmospheric pollutants, especially sulfur dioxide and nitrogen oxides. Lichen diversity and cover serve as reliable indicators of ambient air quality and long-range pollution deposition.

STRESS LINKAGES
Bioindicators are matched to specific stressors: lichens →air pollution; macroinvertebrates →water quality; amphibians →contaminants & UV. Monitoring these taxa enables early detection of environmental change.

MACROINVERTEBRATES
Benthic macroinvertebrates (e.g., EPT taxa) reflect freshwater ecosystem health. Community composition and biotic indices (BMWP, HBI) quantify organic pollution and habitat degradation.



Aquatic & Marine Sampling

SECCHI DISK

Measures water transparency and turbidity; disk lowered until invisible, recording euphotic zone depth as a proxy for primary productivity.

VAN DORN BOTTLES

Collect discrete water samples at precise depths; captures water chemistry, dissolved oxygen, and plankton for vertical profile analysis.

RESEARCH VESSEL DEPLOYMENT

Vessels coordinate multi-instrument casts: CTD rosettes, sediment grabs, and trawl nets to characterize full water- column ecology.

PLANKTON NETS

Fine-mesh tow nets (20-200 µm) dragged horizontally or vertically to concentrate phyto- and zooplankton for community composition analysis.

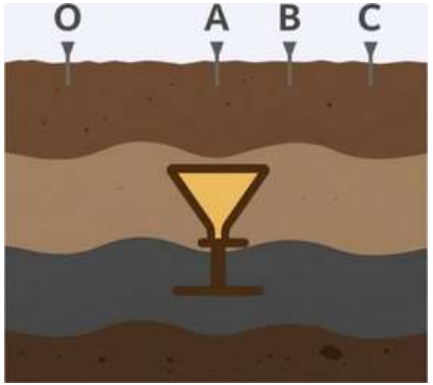
Soil & Sub-surface Ecosystem Methods

BERLESE-TULLGREN FUNNEL
Heat and light gradient drives microarthropods (mites, collembolans) downward through a mesh- lined funnel into a collection vial. Enables quantitative extraction of soil mesofauna from core samples.

SOIL CORING
Cylindrical metal corers extract intact vertical soil profiles. Layers are analyzed for organic matter, root biomass, nutrient gradients, and microbial communities at defined depth intervals.

RHIZOSPHERE SAMPLING
Root-zone soil is carefully separated from bulk soil for targeted microbial and chemical analysis. Reveals mycorrhizal associations, exudate chemistry, and root-microbe interaction zones.

LYSIMETRY
Lysimeters isolate soil volumes to collect percolating water for chemical analysis. Measures nutrient leaching, contaminant transport, and water retention dynamics across soil horizons.



Disturbance & Succession Monitoring

BIOMASS & SPECIES TRACKING

Repeated measures of biomass, species composition, and soil chemistry document ecosystem recovery trajectories post-disturbance.

CHRONOSEQUENCE STUDIES

Chronosequences substitute space for time, sampling sites of known post-disturbance age to reconstruct long- term successional dynamics.

PRIMARY VS SECONDARY SUCCESSION

Primary succession begins on bare substrate; secondary follows disturbance retaining soil seed banks and organic matter.

Automated Environmental Sensor Networks

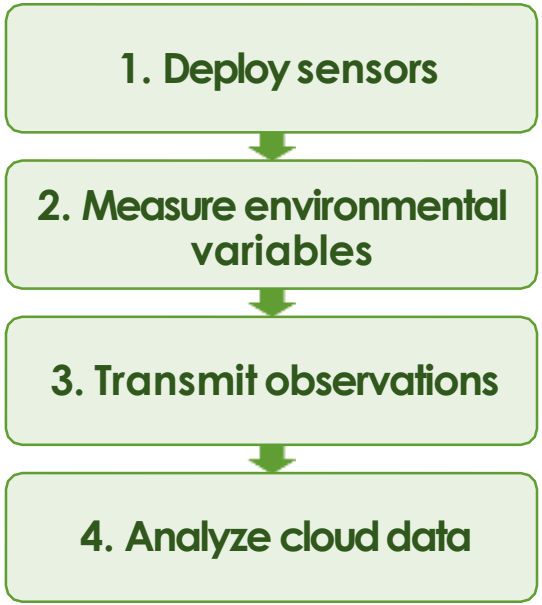
Sap Flow Measurement
Heat dissipation probes quantify water transport in plant stems, linking physiology to ecosystem flux

Cellular Data Streaming to Cloud
Sensor nodes transmit real-time data via cellular or LoRa networks to cloud platforms for remote analysis

IoT Sensor Arrays
Networked in-situ sensors deployed across study sites for continuous, high-frequency data capture

Hydrology Sensors
Water level loggers, soil moisture probes, and conductivity meters monitor hydrological dynamics

Microclimate Monitoring
Temperature, humidity, light, and wind sensors track fine-scale climatic variation within ecosystems



Alpha, Beta & Gamma Diversity

Method / metric	Meaning and application
ALPHA DIVERSITY	Local species richness within a single habitat or community; measured by species counts, Shannon index, or Simpson index at the plot level.
BETA DIVERSITY	Species turnover between distinct habitats or along environmental gradients; quantified by Whittaker's $\beta = \gamma / \bar{\alpha}$ or Sørensen dissimilarity.
GAMMA DIVERSITY	Total regional species diversity across all habitats in a landscape; represents the cumulative pool from which local communities are drawn.

Measuring Species Richness & Abundance

RELATIVE ABUNDANCE
The proportional representation of each species within a community. Calculated as the count of individuals of one species divided by the total count of all individuals across all species.

SPECIES RICHNESS
The total number of distinct species recorded within a defined area or community. Richness is the simplest biodiversity metric but does not account for how individuals are distributed among species.

ABUNDANCE DISTRIBUTION
Rank-abundance curves plot species from most to least dominant. Steep curves indicate low evenness; shallow curves indicate equitable distribution across species in the assemblage.

COMMUNITY COMPOSITION
The identity and proportional representation of species in a community. Two communities may share equal richness yet differ substantially in abundance distribution and dominant taxa.



Shannon-wiener Diversity Index

SAMPLE CALCULATION
Community: 3 spp. (n=50,30,20; N=100). p_1=0.50, p_2=0.30, p_3=0.20 →H' = −(0.50ln0.50 + 0.30ln0.30 + 0.20ln0.20) = 1.03 nats.

THE H' FORMULA
$H' = -\Sigma (p_i \times \ln p_i)$, where p_i = proportion of individuals belonging to species i in the community.

KEY TERMS DEFINED
S = total species richness; $p_i = n_i/N$ (relative abundance); ln = natural logarithm; H' increases with richness and evenness.

INTERPRETING H' VALUES
H'=0: single species (no diversity). H' 1–2: moderate diversity. H'>3: high diversity. Max H' = ln(S) when all species equally abundant.

Species 1
n = 50; p = 0.50

Species 2
n = 30; p = 0.30

Species 3
n = 20; p = 0.20

$H' = -\Sigma p_i \ln(p_i)$
≈ 1.03 nats

Biodiversity Metrics: Simpson's Diversity Index

Method / metric	Meaning and application
INVERSE SIMPSON INDEX	1/D: effective number of equally abundant species. Ranges from 1 (complete dominance) to S (perfect evenness). Preferred for intuitive interpretation.
SIMPSON'S INDEX (D)	$D = \Sigma [n_i(n_i-1)] / [N(N-1)]$ where n_i = count of species i, N = total individuals. D ranges 0-1; higher D = greater dominance.
GINI-SIMPSON INDEX	1 − D: probability that two randomly selected individuals belong to different species. Ranges 0-1; higher values indicate greater diversity.
SIMPSON VS. SHANNON: DOMINANCE SENSITIVITY	Simpson's D weights dominant species more heavily than Shannon's H'. Shannon is sensitive to rare species; Simpson reflects community evenness and dominant species control.

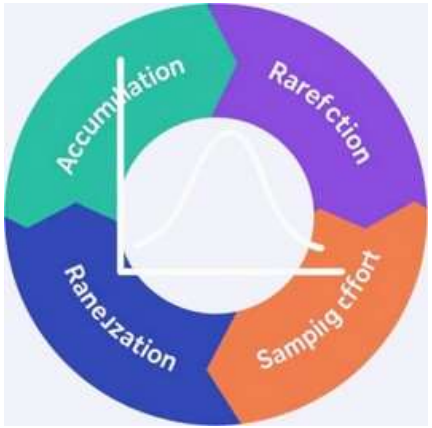
Species Accumulation Curves & Rarefaction

STANDARDIZATION
Corrects for unequal sample sizes across communities. Rarefaction curves enable fair cross-site biodiversity comparisons by normalizing richness estimates to a shared baseline.

ACCUMULATION CURVE
Plots cumulative species detected against increasing sampling effort. The curve rises steeply at first, then flattens as new species become rarer, indicating sampling completeness.

SAMPLING EFFORT
Determines the minimum effort needed for reliable richness estimates. Asymptote of the accumulation curve signals sufficient sampling; used to optimize field survey design.

RAREFACTION METHOD
Interpolates species richness to a common, smaller sample size. Allows statistically valid comparisons of diversity across sites with unequal sampling effort.



Functional & Phylogenetic Diversity

TRAIT-BASED APPROACHES

Functional traits such as leaf area, root depth, and body size are measured to assess how communities respond to and affect their environment.

FUNCTIONAL DIVERSITY

Measures the range of ecological roles and functional traits present in a community, reflecting how species contribute to ecosystem processes.

BEYOND SPECIES COUNTS

Integrating functional and phylogenetic metrics reveals evolutionary history and ecological complementarity beyond simple species richness.

PHYLOGENETIC DIVERSITY

Quantifies the evolutionary distances among species in a community using branch lengths on a phylogenetic tree as a diversity measure.

eDNA Metabarcoding Pipeline

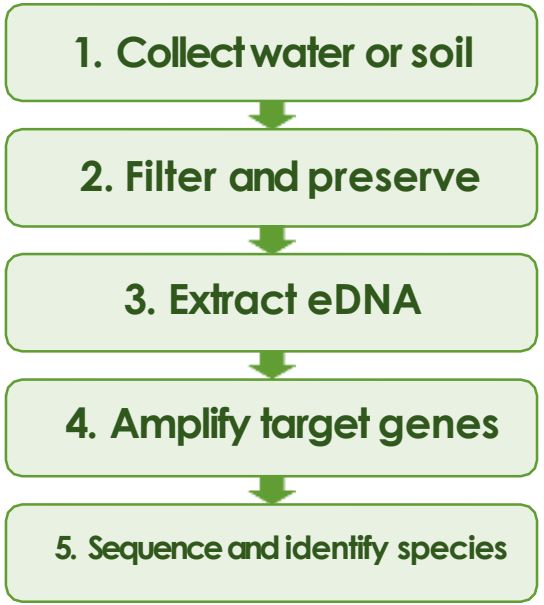
Water / Soil Collection
Collect water or soil samples from target environment

Filtration & Preservation
Filter samples; preserve on membrane for transport

DNA Extraction
Lyse cells and isolate environmental DNA from matrix

PCR Amplification
Amplify target gene regions using universal primers

Sequencing & Species ID
Sequence amplicons; match reads to reference database



Remote Sensing In Ecosystem Ecology

VEGETATION MAPPING

Spectral signatures distinguish plant communities, detect invasive species, and map canopy density across large spatial extents with high temporal frequency.

SATELLITE & AERIAL IMAGERY

Multispectral and hyperspectral satellite sensors capture reflected radiation across visible, near-infrared, and shortwave bands for landscape-scale analysis.

MULTI-SPECTRAL BAND COMPOSITION

False-color composites combine spectral bands to highlight photosynthetic activity, moisture stress, and ecosystem degradation pat ter ns.

LAND COVER CLASSIFICATION

Supervised and unsupervised classification algorithms assign pixels to land cover categories such as forest, wetland, cropland, and urban surfaces.

Vegetation Indices: NDVI

FALSE-COLOR NDVI MAPPING
Multi-spectral satellite bands are composited into false-color maps; color gradients (red = degraded, green = healthy) reveal spatial patterns of vegetation stress.

NDVI FORMULA
NDVI = (NIR − Red) / (NIR + Red); values range from −1 to +1, where higher values indicate denser, healthier vegetation.

PHOTOSYNTHETIC ACTIVITY QUANTIFICATION
Healthy vegetation strongly absorbs red light and reflects near-infrared (NIR); NDVI captures this contrast to measure canopy greenness and productivity.

HEALTHY VS. DEGRADED VEGETATION
NDVI > 0.5 indicates dense healthy canopy; NDVI < 0.2 signals bare soil, drought stress, or land degradation; enables large-scale ecosystem health monitoring.

Near-infrared reflectance
NIR

Red reflectance
Red

NDVI = (NIR − Red) / (NIR + Red)

LiDAR & 3d Canopy Profiling

CANOPY LAYER MAPPING
Point cloud classification separates canopy returns by height thresholds. Canopy height models (CHM) and leaf area index (LAI) are derived, quantifying light penetration, biomass distribution, and species stratification.

LIDAR PULSE TIMING
LiDAR emits rapid laser pulses that travel to vegetation and ground surfaces. Return travel time is precisely measured to calculate distance, enabling centimeter-level vertical resolution of forest structure.

GROUND TOPOGRAPHY
Ground returns filtered from vegetation points generate bare-earth digital elevation models (DEMs). Terrain slope, drainage patterns, and microtopography are mapped even beneath dense forest canopy cover.

3D FOREST STRUCTURE
Millions of return points are compiled into dense 3D point clouds. These models reveal overstory, midstory, and understory canopy layers, capturing vertical habitat complexity across large forest areas.



Acoustic Ecology & Ecoacoustics

PASSIVE RECORDING NETWORKS

Autonomous recording units (ARUs) deployed across habitat grids collect continuous long-term soundscape data. Networks enable spatially replicated monitoring with minimal observer disturbance across large ecological areas.

BIOPHONY & GEOPHONY

Biophony captures biological sound sources (bird calls, insect stridulation, amphibian choruses); geophony records abiotic sounds such as wind, rain, and water flow forming the natural soundscape baseline.

ACOUSTIC COMPLEXITY INDICES

Indices such as ACI, ADI, and BIO quantify soundscape diversity from spectrogram data. High acoustic complexity correlates with greater biodiversity, enabling rapid, non-invasive ecosystem health assessment from audio recordings.

ANTHROPHONY & NOISE POLLUTION

Anthrophony encompasses human-generated sounds (traffic, machinery, aircraft). Separating anthrophony from biophony enables assessment of anthropogenic disturbance impacts on wildlife communication and behavior.

Ecological Data Integration & Modeling

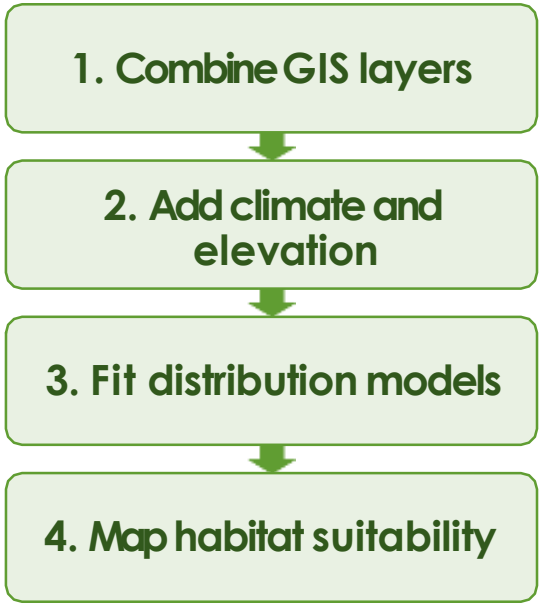
Climate & Elevation Gradients
Integrating temperature, precipitation, and topographic rasters as model covariates

Occurrence Points & SDM Output
Georeferenced field records converge into probability maps of species dist r ibut ion

GIS Spatial Integration
Layering climate, elevation, land cover, and species data in geographic information systems

MaxEnt Modeling
Maximum entropy algorithm predicting habitat suitability from presence-only data

Species Distribution Models (SDMs)
Correlating species occurrence records with environmental predictor variables



Workshop Assignment

Scenario Overview
500-hectare coastal wetland threatened by agricultural runoff and invasive species. Design a comprehensive monitoring protocol.

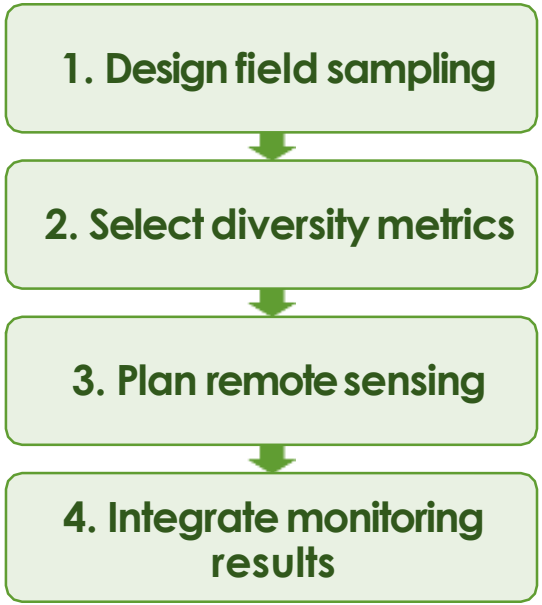
Sampling Design
Select and justify a spatial sampling strategy (random, systematic, or stratified) suited to wetland heterogeneity.

Biodiversity Metrics
Choose two biodiversity indices (e.g., Shannon- Wiener, Simpson's) and describe your measurement approach for wetland communities.

Remote Sensing
Select one remote sensing or sensor technology (NDVI, LiDAR, IoT sensors) for abiotic and canopy health monitoring.

Deliverables
Written protocol report with sampling map, metric rationale, and technology justification submitted for peer review.

Assessment Criteria
Evaluated on scientific rigor, design appropriateness, metric selection rationale, and clarity of monitoring plan.



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