

Land use changes in protected areas: Scenarios, driving forces and impacts on biodiversity

Maris Klavins, Janis Krumins

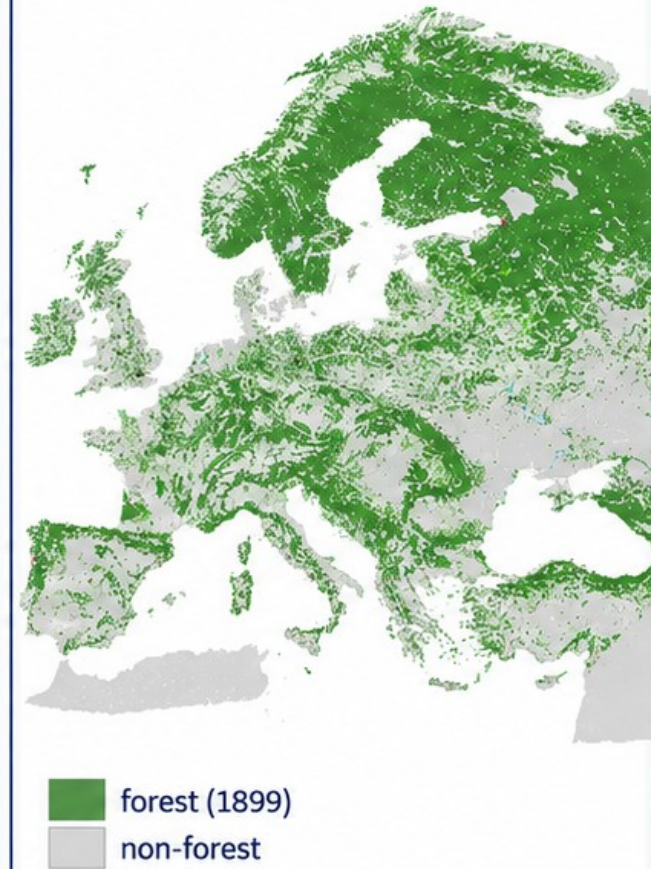
Europe-LAND



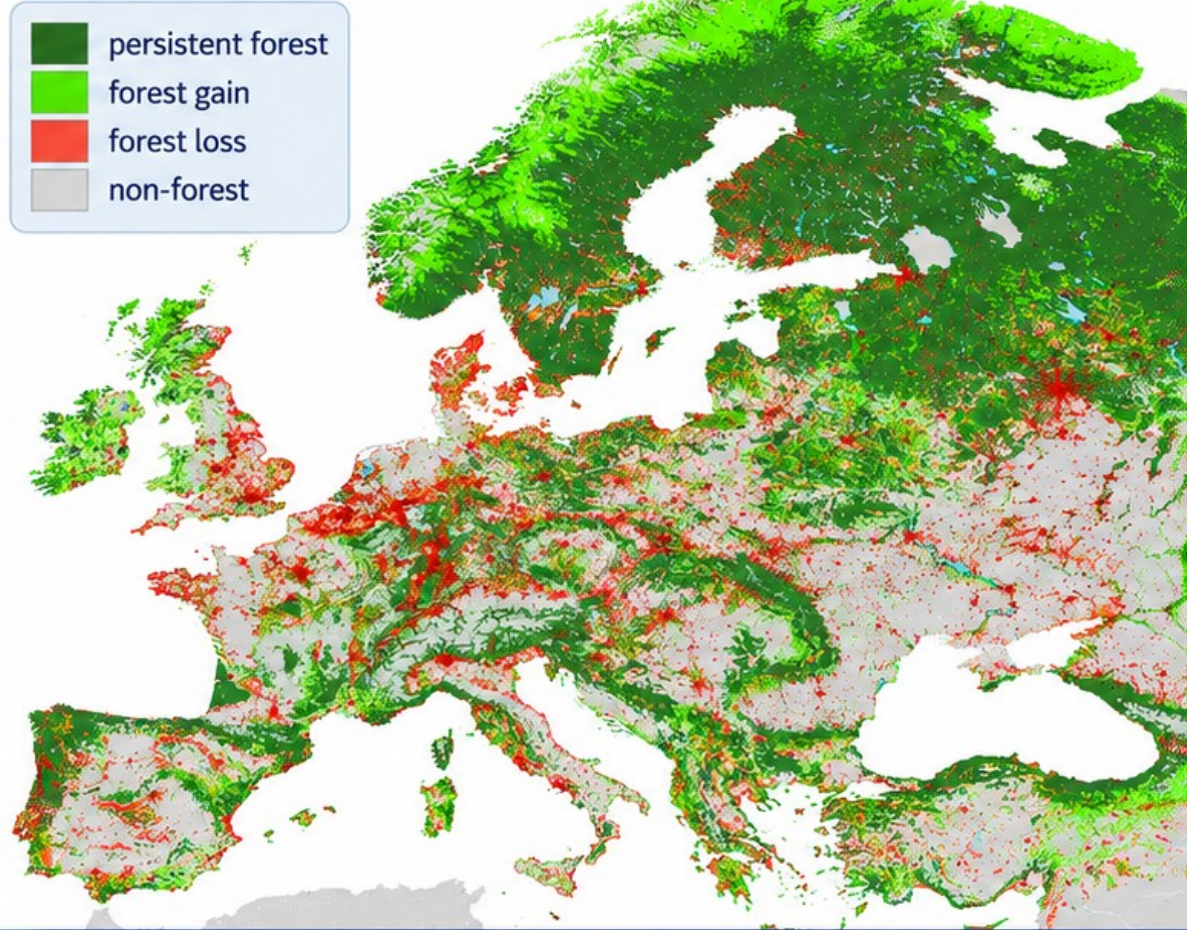
Our land is changing!

Forest change in Europe, 1899 – 2019

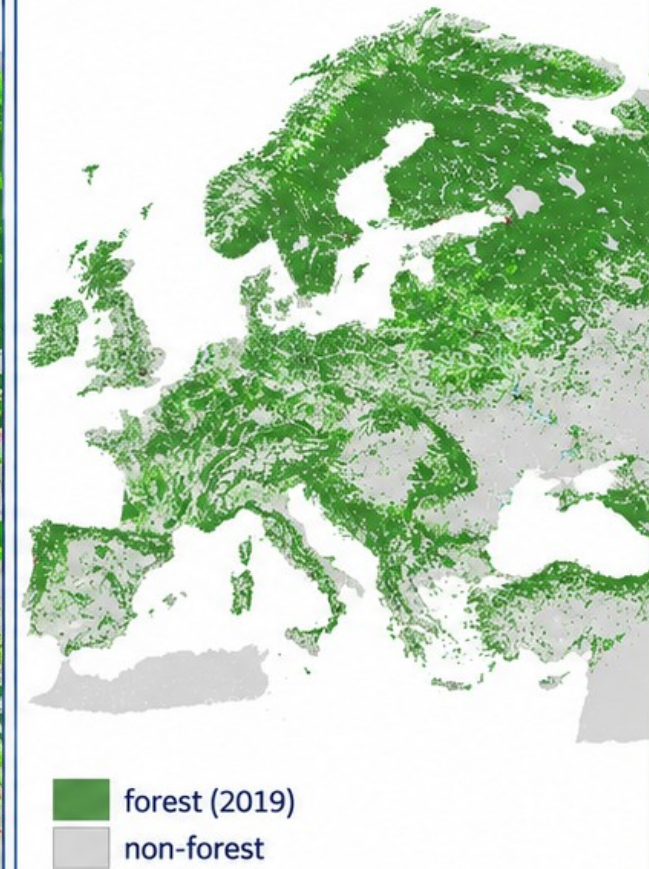
1899 forest extent



Forest change, 1899 – 2019



2019 forest extent



Key messages

1

Overall forest extent increases over time.

Forest cover in Europe is larger in 2019 than in 1899.

2

Forest becomes more spatially consolidated in many regions.

Notable expansion and increased connectivity, especially in northern and northeastern Europe.

3

Strong forest dynamics remain in northern Europe.

Both forest gain and loss occur in boreal regions, reflecting ongoing land-use and environmental changes.

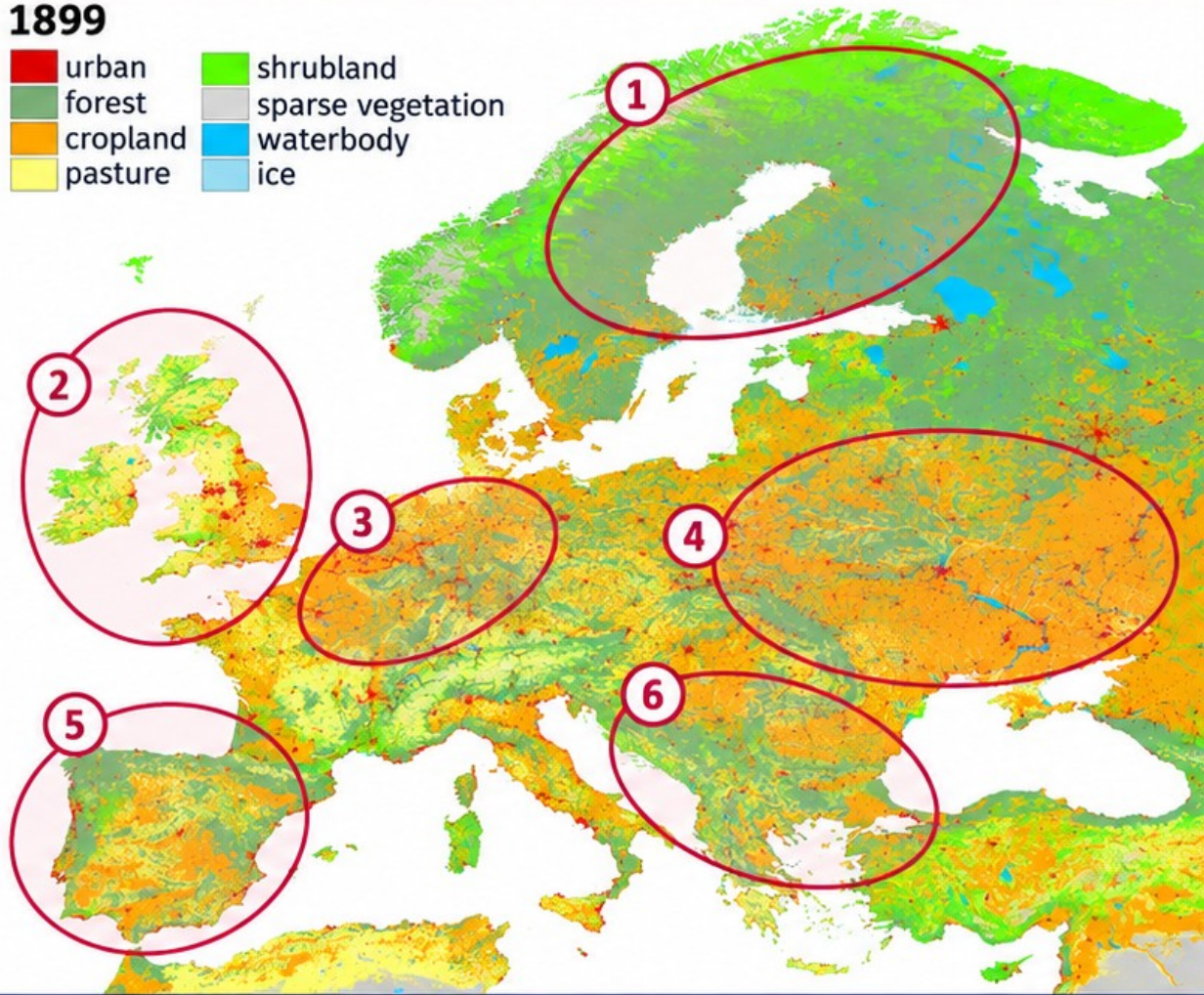
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Local forest loss persists despite the long-term expansion trend.

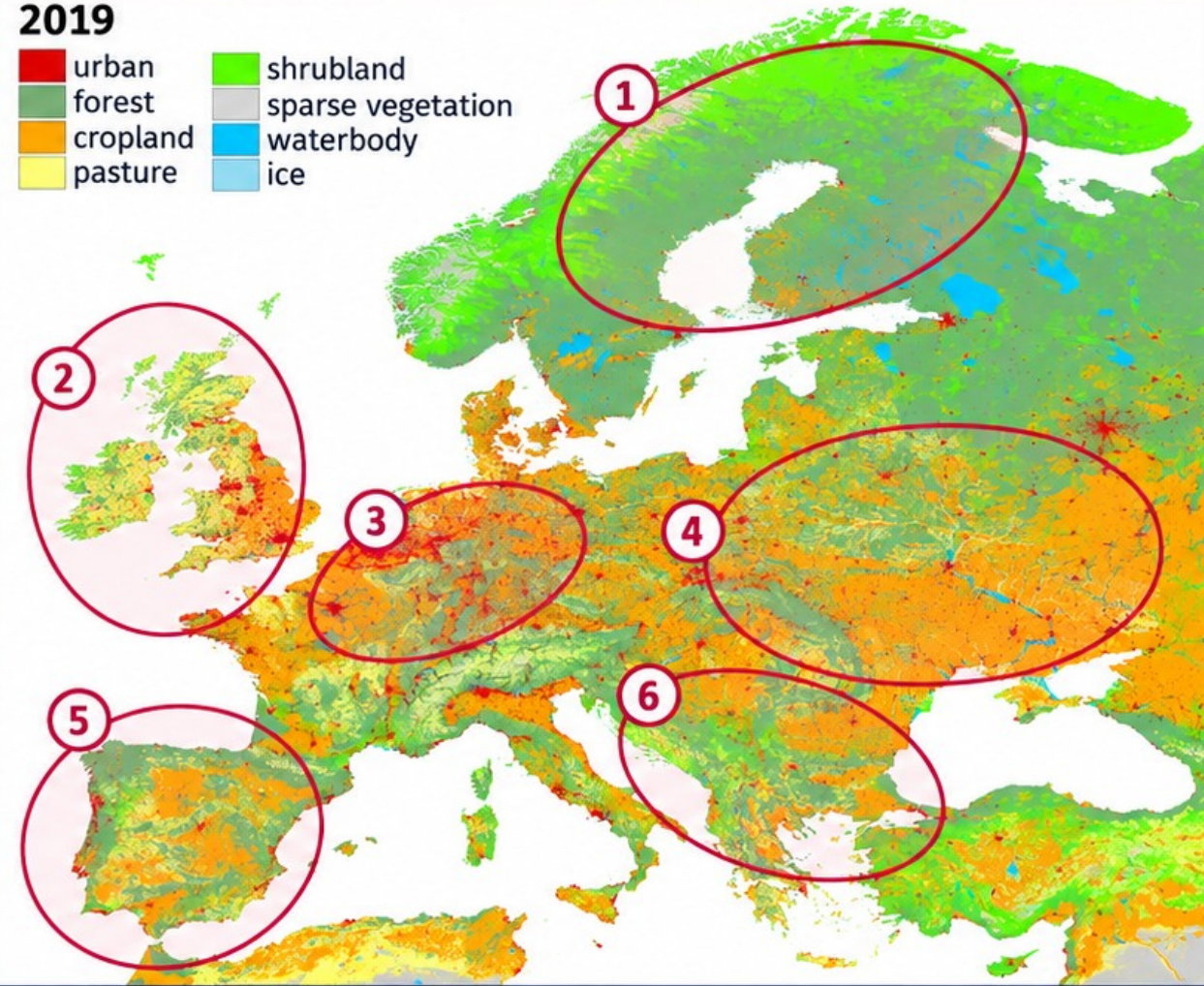
Forest loss remains visible in parts of central Europe, western Europe and southern Europe.

Major land-cover change areas, 1899–2019

1899



2019



Key change areas (highlighted on both maps)

- | | |
|--|--|
| 1 Scandinavia / northern Europe – forest–shrubland reorganization, stronger forest consolidation. | 4 Central and eastern European agricultural belt – cropland redistribution and forest gain in places. |
| 2 British Isles and western France – agricultural restructuring. | 5 Iberian Peninsula – forest–shrubland shifts. |
| 3 Benelux-Rhine corridor and northern Italy – strong urban expansion. | 6 Balkans / southeastern Europe – forest gain and agricultural change. |

Highlighted zones indicate broad change hotspots for presentation purposes.

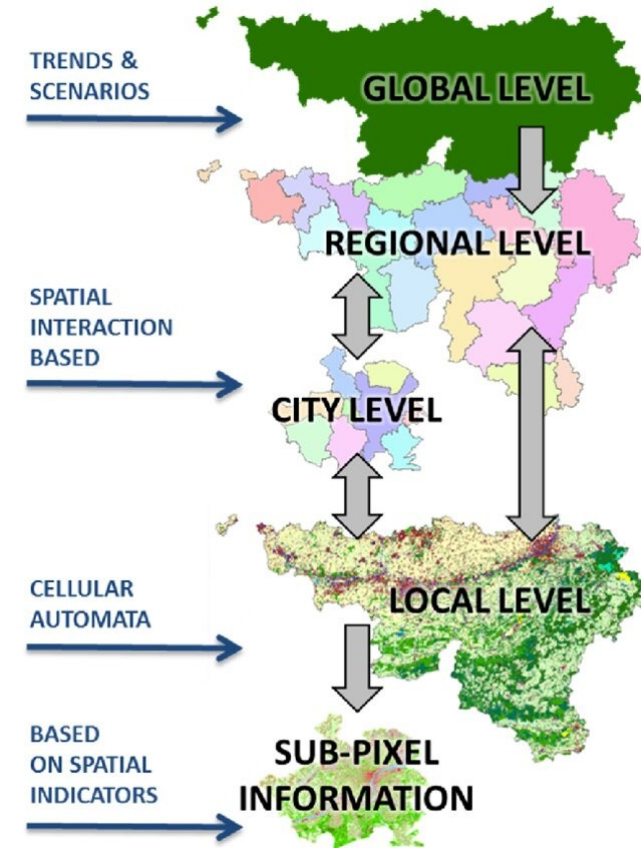


Land use/Land cover changes are critical for nature conservation

To foresee future changes it is critical to simulate LU/LC change scenarios

How to Select a Scenario?

- Future LULC modeling is always **speculative**.
- LULC **changes** are driven by **local** policies, climate, economic development, and cultural factors, making a **universal** scenario **unrealistic** to apply everywhere.
- The **interaction** of demographic changes, technological progress, and climate policies **varies** across regions.
- Global scenarios do not capture **fine-scale** dynamics of land change.
- Scenarios should be **customized** for regional/local studies.
- A **downscale** of generalized global frameworks to local context.

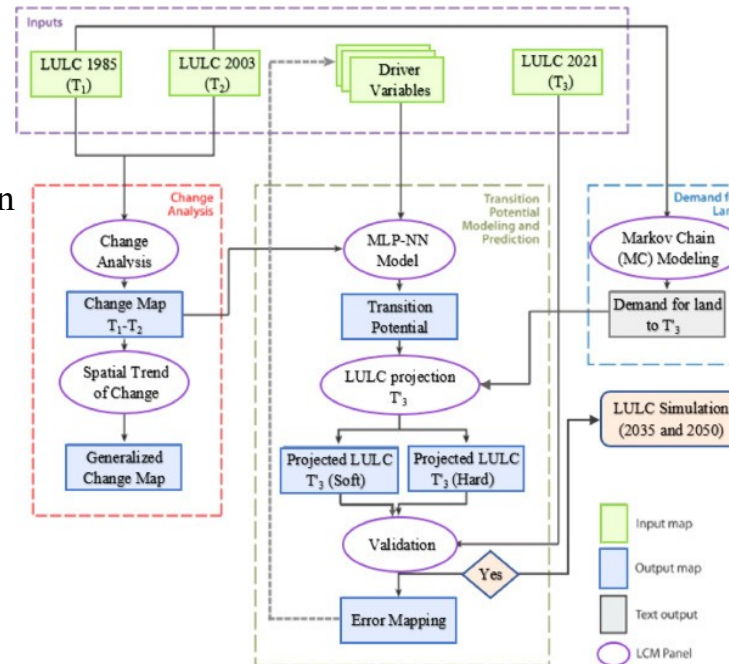


Scale of LULC modeling (Stephenne et al., 2016).

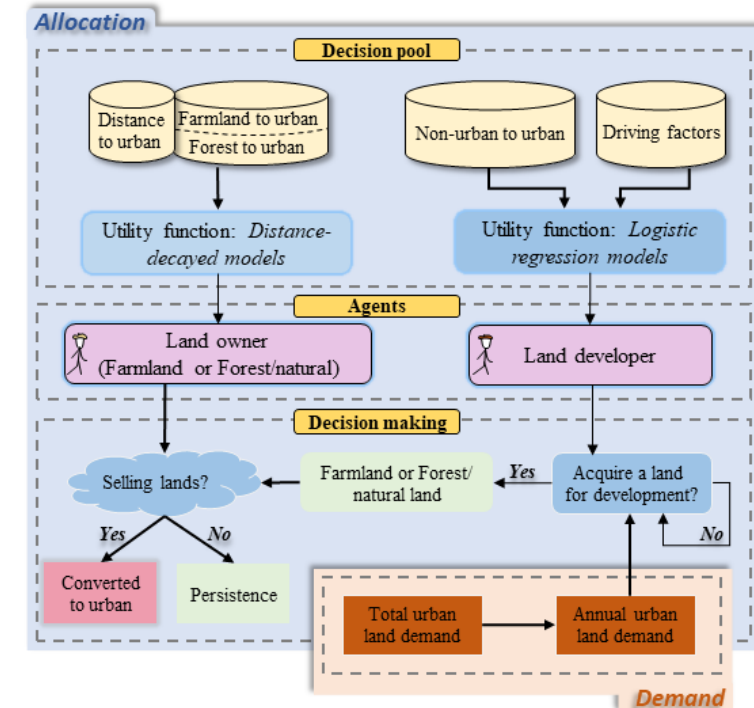
How to Select a Scenario?



- **Scenario** selection and implementation **differs** whether it is **spatial-temporal** modeling or **agent-based** modeling.
- The two modeling approaches interpret and apply **the same scenario** in fundamentally different ways, hence can **produce different results** in spatial-temporal modeling and agent-based modeling.
- Which model to trust?
 - **Both!** We can use agent-based models to validate the spatial-temporal LULC projections.
 - Yet, agent-based models require **more careful validation** compared to spatial-temporal models (because they are based on **theoretical assumptions** rather than directly observable data).
 - Agent-based model can work as a **driving variable** for spatial-temporal model.



Framework of the spatial-temporal land change model. (Girma et al., 2022)

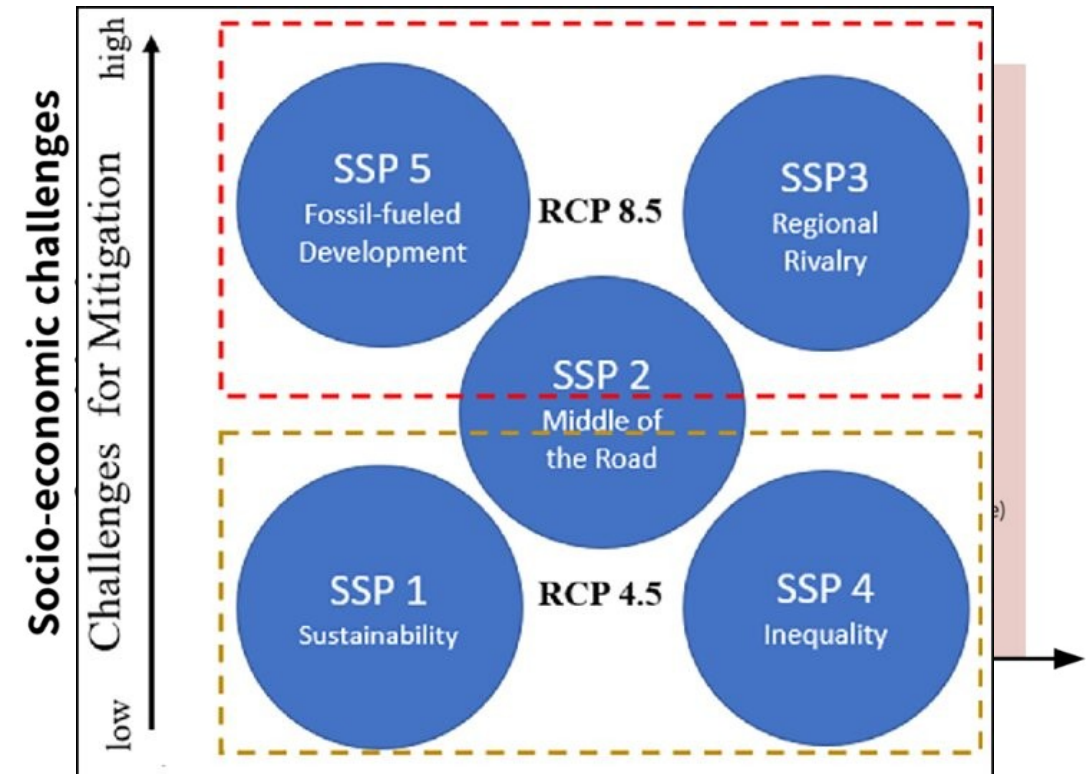


Framework of the agent-based land change model. (Tang and Yang, 2020)

Options for Scenario Selection: Shared Socioeconomic Pathways (SSPs)



- **Human-driven factors.**
- **SSP1** – conservation-oriented: “**best**” case scenario (most conservation-oriented compared to other SSPs).
- **SSP3** – high land use pressure: **worst** case scenario.
- **SSP5** – economic growth first: wealth-driven adaptation strategies.
- Regionally/locally **adapted** adjustments:
 - Enable/disable **driving variables**.
 - Modify **weights** of driving variables.
 - Introduce **constraints**.
 - Determine transition **rules**.

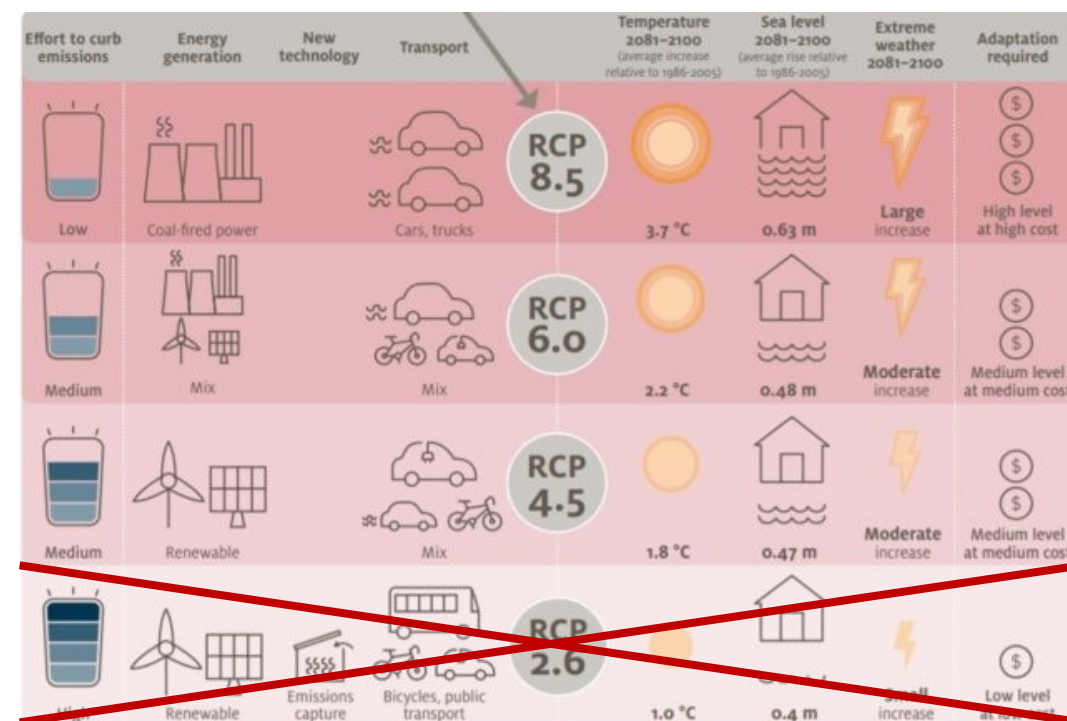


Shared Socio-Economic Pathway (SSP) scenarios (figure from (Van Vuuren et al., 2017))

Options for Scenario Selection: Representative Concentration Pathways (RCPs)



- Climate-driven factors.
- **RCP4.5** – lower-emissions scenario (RCP2.6 is unlikely).
- **RCP6.0** – a plausible mid-range scenario (we are closer to RCP7.0).
- **RCP8.5** – high-emission scenario.
- Regionally/locally **adapted** adjustments:
 - Enable/disable **driving variables**.
 - Modify **weights** of driving variables.
 - Introduce **constraints**.
 - Determine transition **rules**.

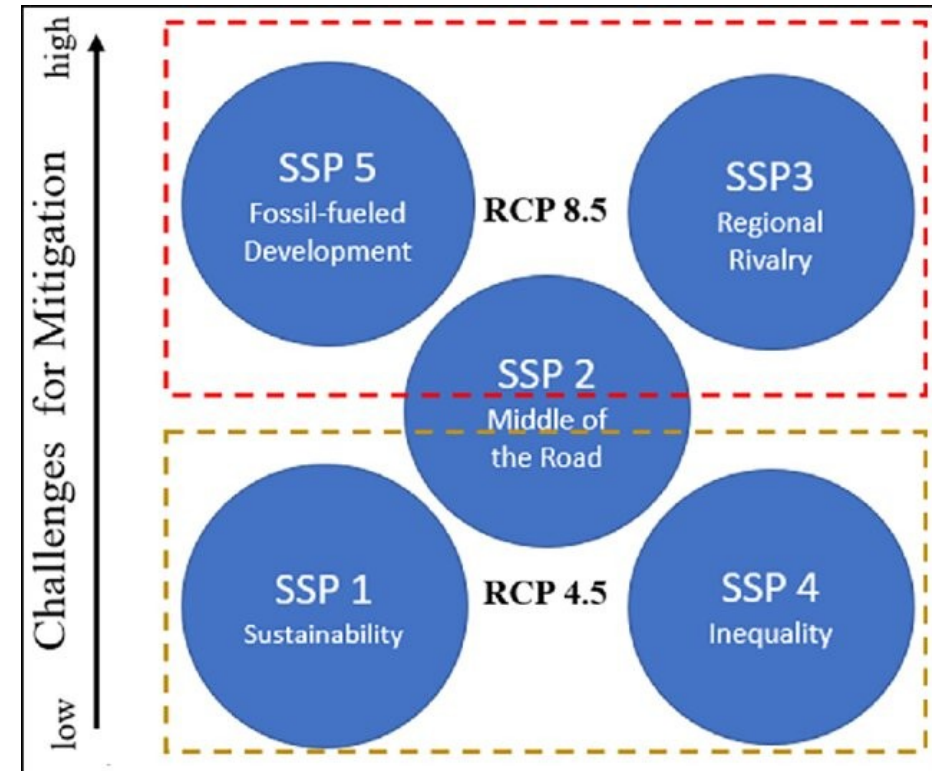


RCP scenarios and their respective impacts on climate (figure from (CoastAdapt, 2014)).

Options for Scenario Selection: Most Practical Option is a Hybrid of SSPs + RCPs



- **Climate** and **human**-driven factors.
- **SSP1-RCP4.5** – a sustainability-oriented scenario with moderate emissions reduction.
- **SSP3-RCP7.0** – regional rivalry with weak climate policies and high land use pressure.
- **SSP4-RCP6.0** – a world with high socio-economic inequality. Wealthy regions adopt cleaner technologies, while poorer regions experience high land-use pressure and slow climate action.
- **SSP5-RCP8.5** – fossil-fueled development with high land use pressure.
- Regionally/locally **adapted** adjustments:
 - Enable/disable **driving variables**.
 - Modify **weights** of driving variables.
 - Introduce **constraints**.
 - Determine transition **rules**.



Scenario combinations between RCP and SSP (adapted from Auer, 2020).



LULC changes in protected areas

Legal protection does not stop LULC change. Protected areas continue to change due to ecological processes, human activities, management decisions, and pressure from surrounding areas!!!



Why LULC Change Matters in Protected Areas?

- Protected areas are established to support the long-term conservation of biodiversity, ecological integrity, and ecosystem functions.
- Studying LULC change in protected areas is essential for evaluating conservation effectiveness, identifying emerging pressures, and understanding whether LULC change supports or undermines biodiversity objectives.
- Effective adaptive management requires continuous monitoring and forward-looking analysis. Remote sensing and GIS show where LULC change is occurring, but spatial modeling, machine learning, and AI help explain its drivers and explore future change trajectories.
- LULC monitoring helps determine whether protected-area status is actually delivering effective conservation.
- Future modeling explores the consequences of insufficient protection or alternative management pathways.





LULC Change Within Protected Areas

- Protected areas remain dynamic despite long-term conservation objectives.
- Legal protection can reduce some pressures, but it does not prevent change driven by natural succession, surrounding land use, external pressures, and management decisions.
- LULC change can occur both within protected areas and along their boundaries.
- Changes in forest, agricultural, wetland, open, and artificial land cover can alter habitat structure, connectivity, and ecological conditions.



Spatial Context of LULC Change

- Spatial context determines whether LULC change is localized, concentrated along boundaries, or distributed across the wider area.
- Internal zoning creates different levels of land-use restriction and can produce different land-use change trajectories within the same protected area.
- Ecological pressures extend beyond administrative boundaries.

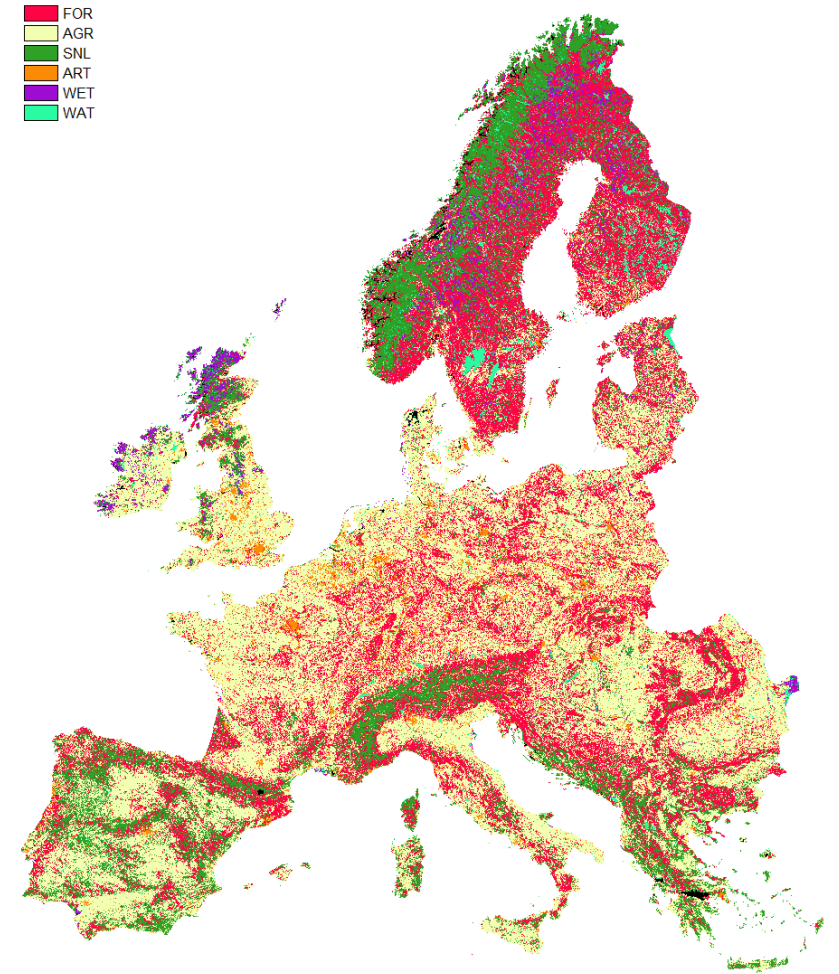
Within protected areas: land-cover transitions and ecological succession.

Boundary zones: edge effects and concentrated land-use pressures.

Surrounding area: connectivity, disturbance, and ecological isolation.

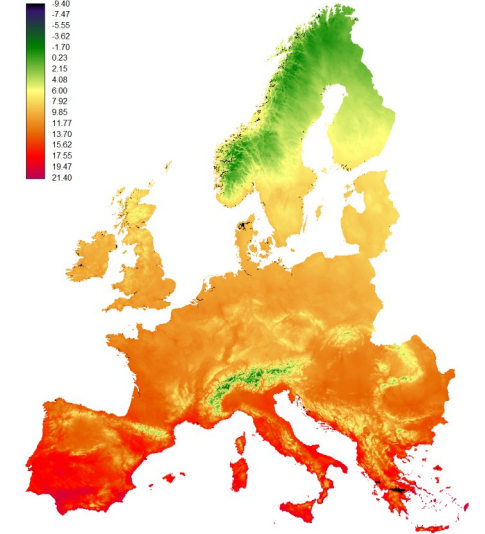
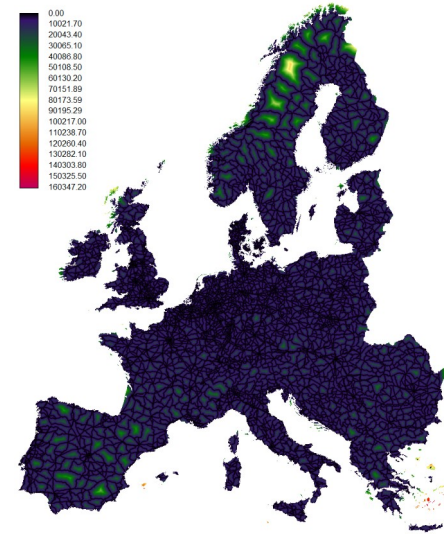
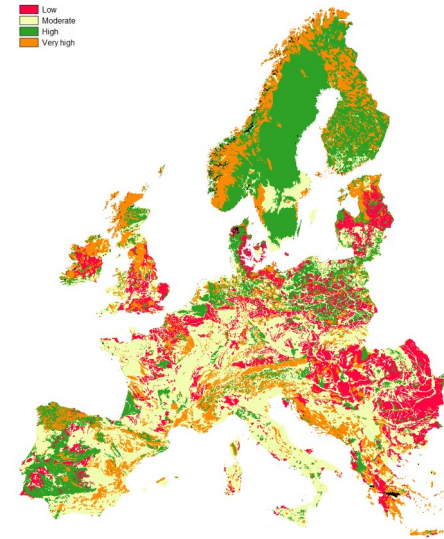
Ecological Meaning of LULC Transitions

- Not all LULC transitions have the same ecological significance. Their effects depend on which habitat is lost, what replaces it, and how the surrounding landscape is reorganized.
- Forest → agriculture: habitat loss, fragmentation, and increased edge effects.
- Agriculture → forest: succession, afforestation, or land abandonment, with effects depending on the ecological value of the former agricultural habitat.
- Open habitats → shrub/forest: potential loss of grassland and other open-habitat biodiversity.
- Natural/semi-natural land → built-up land: long-term habitat conversion, fragmentation, and disturbance.
- Wetland → other land uses: potential alteration of hydrology, habitat structure, and ecosystem functions.



Drivers of LULC Change in Protected Areas

- LULC change is not driven by a single factor. It emerges from interactions among environmental conditions, accessibility, socioeconomic pressures, and governance.
- Environmental conditions — slope, soils, hydrology, climate, and existing vegetation.
- Accessibility and infrastructure — roads, settlements, market access, and tourism infrastructure.
- Socioeconomic pressures — agricultural profitability, population change, land abandonment, and urbanization.
- Governance and management — protection status, zoning, subsidies, conservation measures, and enforcement.





Ecological Trade-offs in Protected-Area Management

- LULC change creates trade-offs among habitats, ecosystem functions, and conservation priorities.
- Forest expansion can increase forest habitat and carbon storage while reducing open and semi-natural habitats.
- Agricultural abandonment can reduce intensive land-use pressure but accelerate succession and the loss of semi-natural grasslands.
- Strict protection can reduce direct conversion, but some conservation objectives still require active habitat management.
- Effective conservation therefore depends on directing the right type of change to the right place.



From LULC Scenarios to Adaptive Management

- Protected areas are dynamic areas affected by internal management and external pressures.
- Scenario outputs can identify where habitat loss, succession, fragmentation, or restoration may become concentrated.
- These spatial patterns can be used to decide on management priorities for habitat quality, connectivity, zoning, and active intervention.
- Drivers produce observable LULC change; observed change informs future scenarios, and scenario outcomes support management responses.
- Land-use scenarios are most valuable when they make potential conservation consequences visible before they become difficult or irreversible to address.

Case studies in protected areas

North Vidzeme Biosphere Reserve and Teiči Nature Reserve



North Vidzeme Biosphere Reserve

- Protection within the North Vidzeme Biosphere Reserve is spatially differentiated. The reserve includes landscape protection and neutral zones, while separately designated protected areas within it are subject to additional protection regimes.
- Much of the biosphere reserve remains an actively managed landscape where forestry, agriculture, settlements, tourism, ecological succession, and other land-cover processes continue within regulatory constraints.
- Land use is therefore not prohibited across the reserve; its intensity and permitted forms vary spatially according to zoning, protected values, and applicable conservation regulations.



North Vidzeme Biosphere Reserve → large, multifunctional protected area where substantial land use continues under differentiated regulation.

Teiči Nature Reserve

- The Teiči Strict Nature Reserve is established to preserve the Teiči bog and associated wet-forest ecosystems and to maintain their natural development. Protection is spatially differentiated into strict-regime, regulatory-regime, and nature-park zones.
- Human activity is strongly restricted. Economic activity and construction are prohibited in the strict-regime zone, while the regulatory-regime zone permits only limited activities compatible with conservation objectives. The nature-park zone allows some traditional and extensive land management under substantial restrictions.
- Protection also extends beyond the reserve itself through an external protection zone, where activities that could alter hydrology, damage important landscape elements, or negatively affect protected species, habitats, and ecosystem development are restricted.



Teiči Strict Nature Reserve → much stronger restrictions, greater emphasis on natural ecosystem development, but still with internal zoning and external pressures.



Historical LULC Change in North Vidzeme Biosphere Reserve

Overall Landscape Stability

- The NVBR remained relatively stable in its overall LULC composition, despite substantial local transitions.

Cyclical Agricultural Change

- Agricultural land experienced alternating periods of intensification and extensification, including crop expansion and land abandonment.

Minor Net Forest Decline

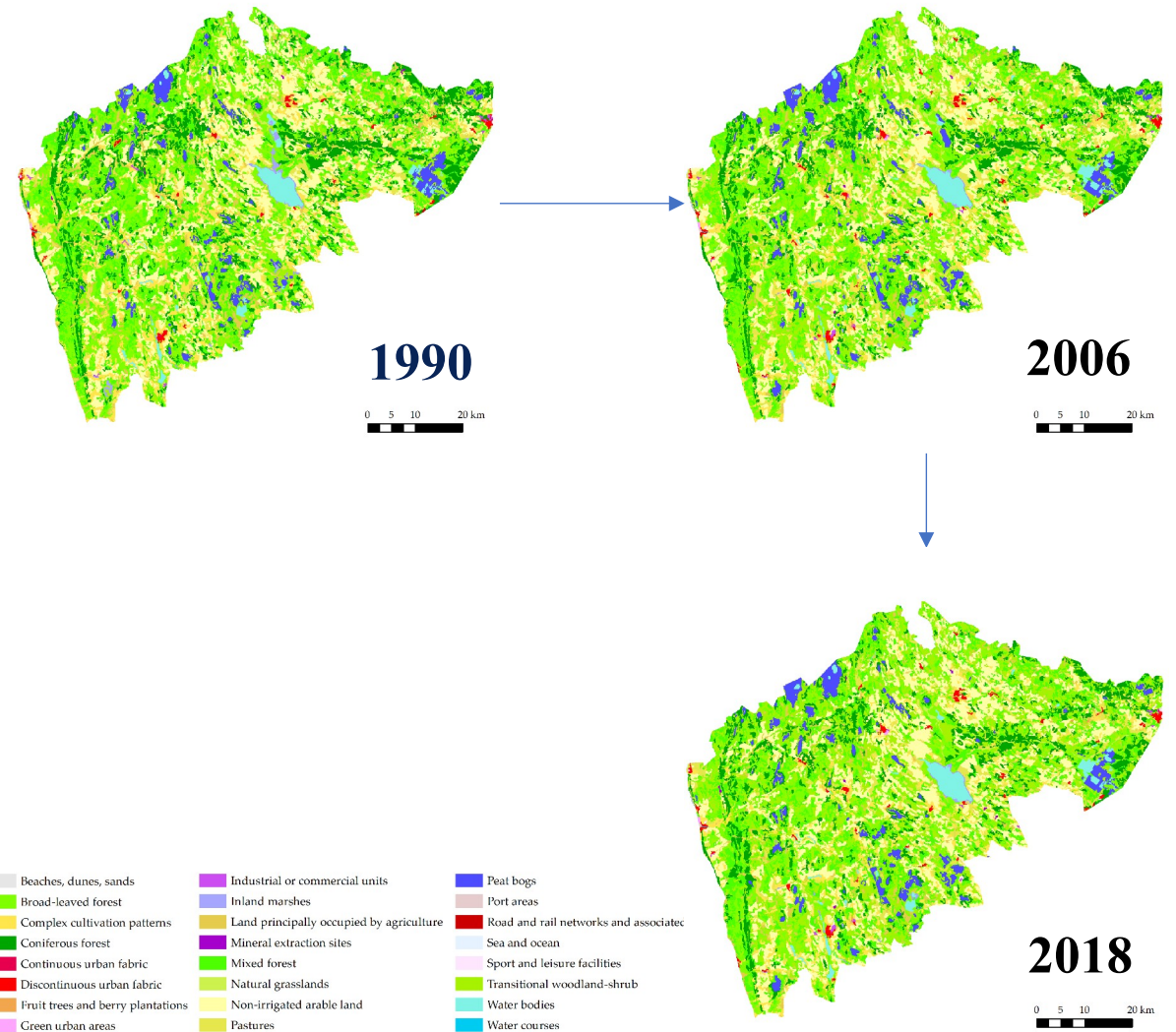
- Forest cover showed a slight net decline, associated mainly with agricultural conversion and infrastructure development.
- Large forest areas remained relatively stable, while fragmentation was more evident in transitional parts of the area.

Expansion of Transitional Woodland–Shrub

- Transitional woodland and shrub cover increased substantially.
- Expansion was frequently associated with abandoned or regenerating former agricultural land.

Spatial Pattern of Change

- LULC change was concentrated mainly in more intensively used and peripheral parts of the biosphere reserve, while more strictly protected areas remained comparatively stable.



Historical LULC Change in Teiči Strict Nature Reserve

Expansion of Built-Up and Arable Land

- Built-up and arable land increased in parts of the wider area.
- These changes indicate continuing anthropogenic pressure despite the high level of protection.

Landscape and Forest Fragmentation

- Fragmentation increased in parts of the area.
- Forest fragmentation became more pronounced where land-use pressure intensified.

Changes in Peat-Bog Extent

- Mapped peat-bog extent showed both expansion and decline across different parts of the study period and area.
- Long-term peat-bog expansion was most evident within the strict-regime zone.

Increase in Shrub and Regenerating Vegetation

- Shrubland expanded in some areas, showing succession and changing land management.
- **Spatial Pattern of Change**
- Coniferous forest cover increased within the regulatory-regime zone.
- LULC trajectories differed between protection zones, indicating a strong spatial influence of management and protection intensity.

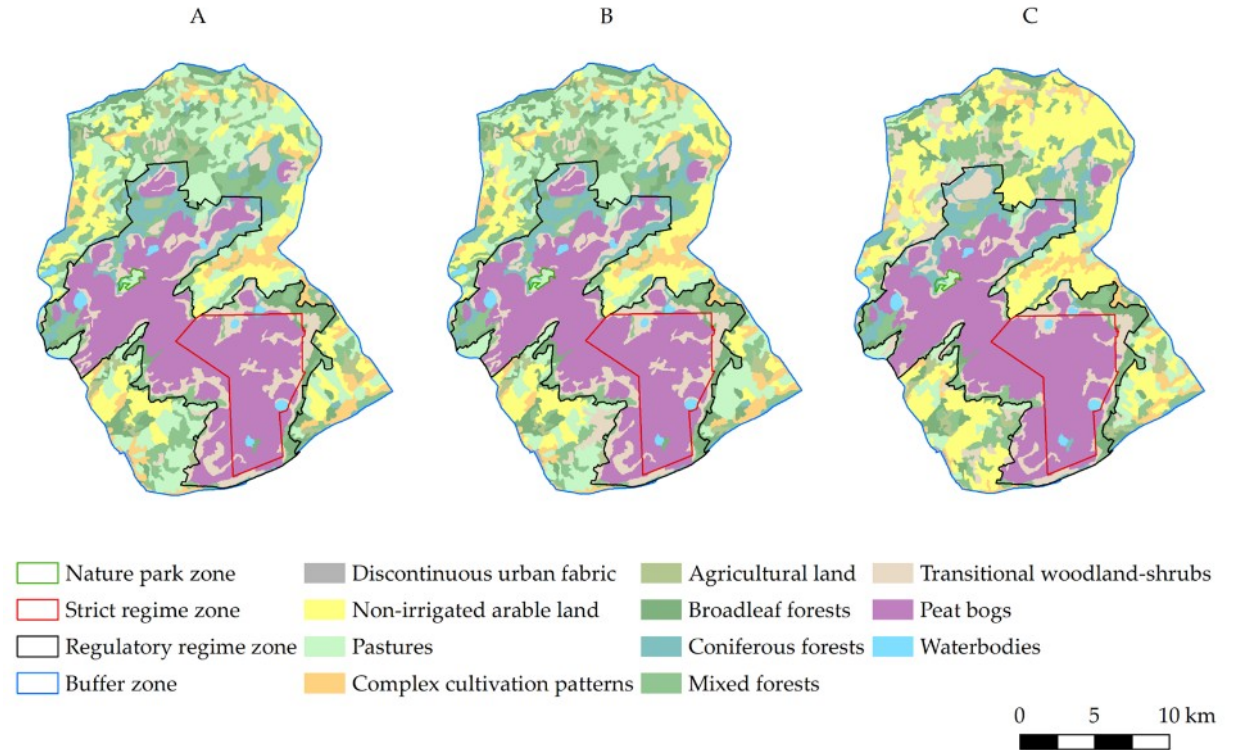
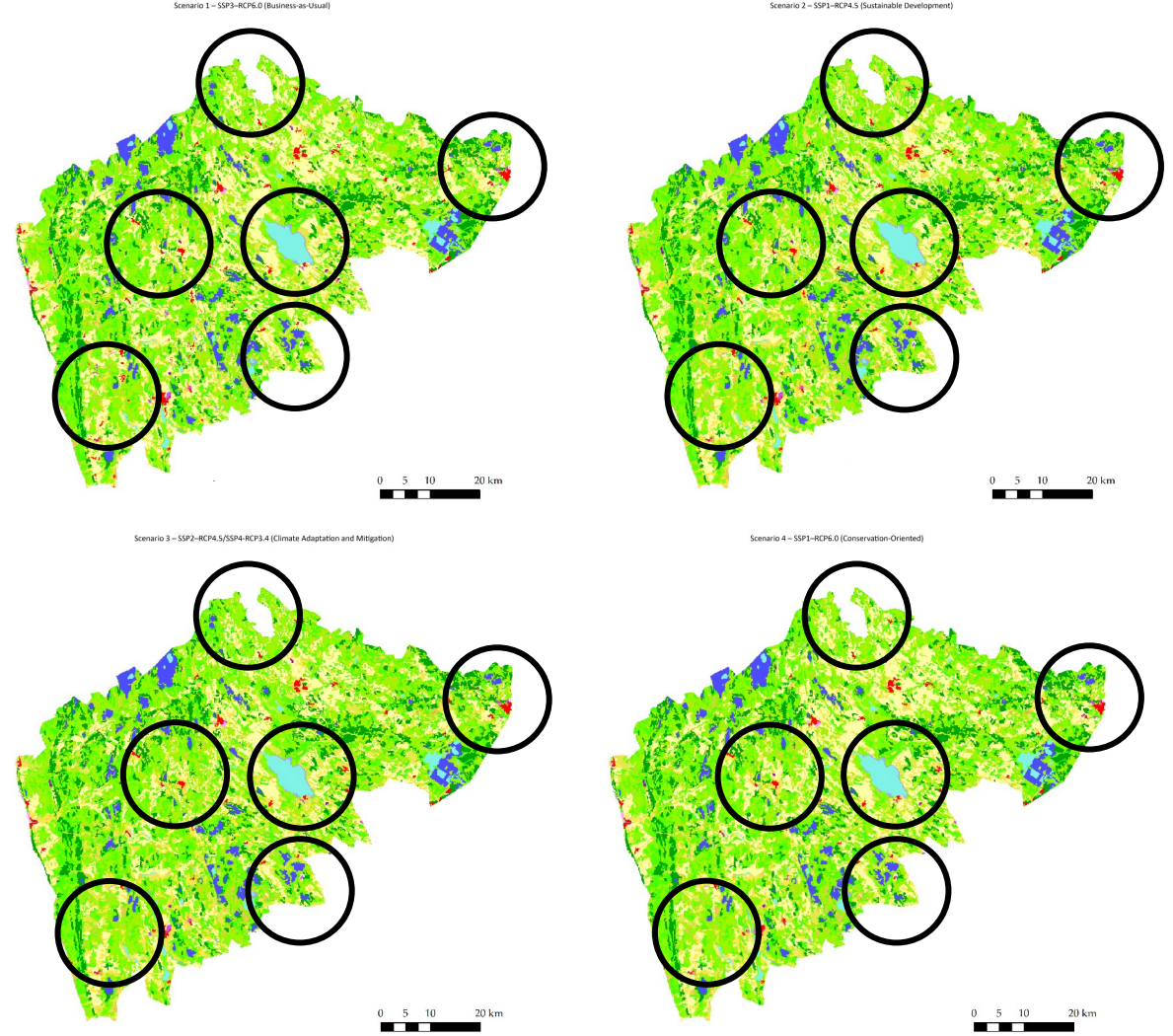


Figure. Digitized land use and land cover maps of the case study area for the years (A) 1982, (B) 1991, and (C) 2023.



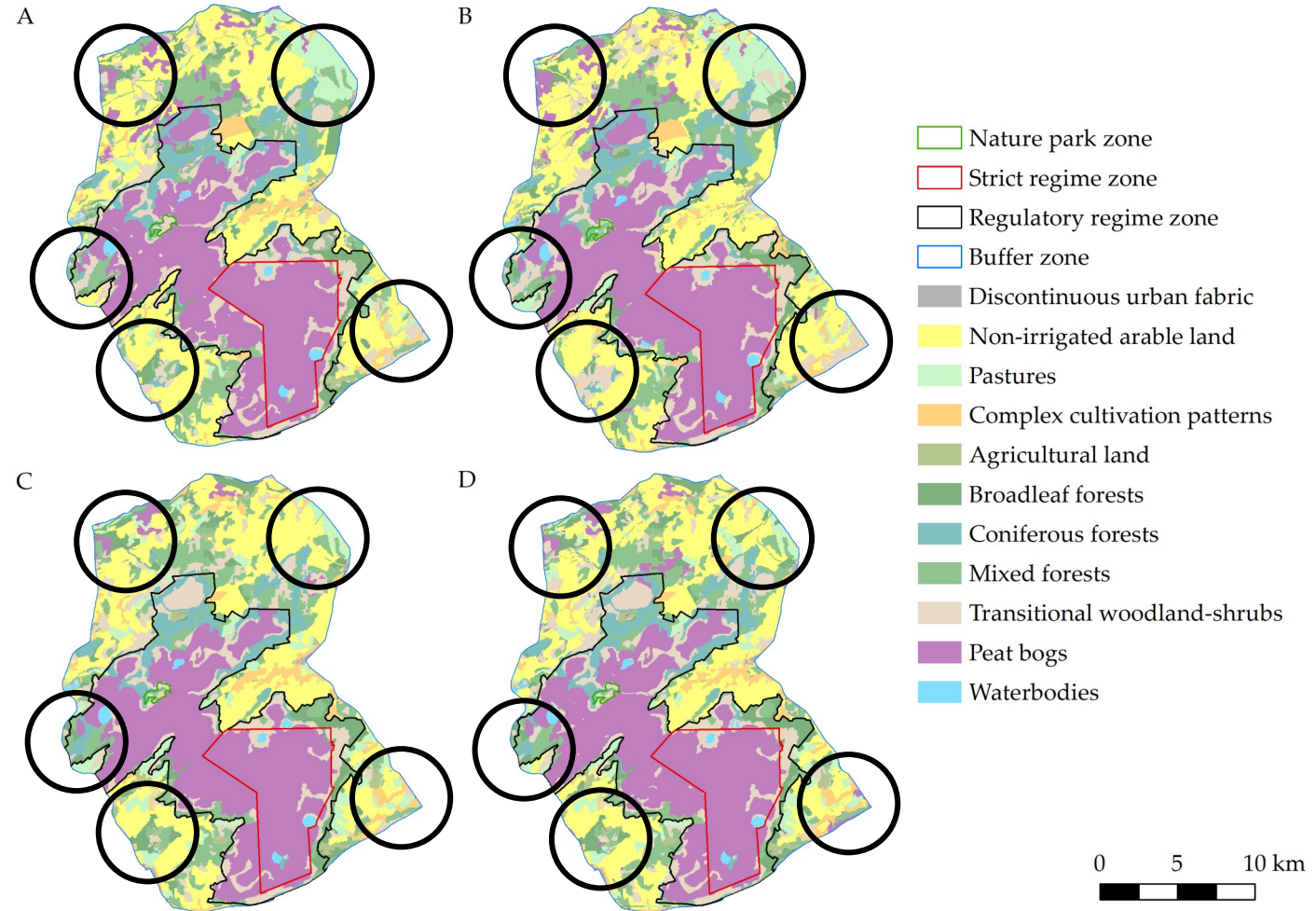
Future LULC Scenarios for North Vidzeme Biosphere Reserve

- **Business-as-Usual Scenario** — continuation of historical LULC trends with limited additional conservation intervention. Urban and agricultural pressures continue, while forest loss and habitat fragmentation may increase where economic and demographic pressures dominate.
- **Sustainable Development Scenario** — balances land use with biodiversity conservation and ecological restoration. Afforestation, wetland protection, and sustainable agriculture support habitat quality, carbon storage, and long-term landscape resilience.
- **Climate Adaptation and Mitigation Scenario** — prioritizes landscape resilience under climate change. Reforestation, wetland restoration, and adaptive land-management measures strengthen carbon storage, ecological connectivity, and resistance to climate-related degradation.
- **Conservation-Oriented Scenario** — prioritizes ecosystem protection and limits intensive human intervention. Conversion of natural land is strongly constrained, while restoration and active landscape modification remain comparatively limited.



Future LULC Scenarios for Teiči Strict Nature Reserve

- **(A) Business-as-Usual Scenario** — continuation of existing landscape trends under the current protection regime. Natural succession dominates within strongly protected areas, while agricultural, infrastructure, and other land-use pressures continue in the external protection zone and surrounding landscape. Increasing external pressure may affect connectivity, edge conditions, and ecosystem integrity.
- **(B) Enhanced Conservation Scenario** — strengthens conservation beyond the reserve core through tighter control of land-use change in the external protection zone, restoration of natural and semi-natural cover, protection of hydrological conditions, and improved landscape connectivity.
- **(C) Agricultural Pressure Scenario** — assumes increasing agricultural demand in the surrounding landscape and permitted parts of the external protection zone. Conversion pressure increases around the reserve rather than within strictly protected zones, potentially increasing fragmentation, isolation, and hydrological disturbance.
- **(D) Balanced Conservation and Development Scenario** — allows continued agricultural and infrastructure development around the reserve while maintaining stronger spatial controls near ecologically sensitive areas. Conservation measures reduce, but do not eliminate, increasing external land-use pressure.





Conclusions: North Vidzeme Biosphere Reserve

Relative LULC Stability with Localized Change

- Overall LULC composition remained relatively stable, while the most dynamic changes occurred in agricultural and transitional areas.
- Landscape stability therefore coexisted with substantial local land-cover turnover.

Future Trajectories Depend on Management Choices

- Scenario projections diverge substantially under different policy and management assumptions.
- Climate-adaptation and conservation-oriented pathways maintain stronger ecological and climate-related outcomes, while the BAU pathway show greater risks to conservation objectives.

Governance Influences Scenario Feasibility

- Effective implementation depends on coordination among conservation, forestry, agriculture, climate, and rural-development interests.
- Stakeholder participation and cross-sectoral governance are important for turning scenario objectives into realistic land-management decisions.

Scenario Modeling Supports Adaptive Planning

- Scenario modeling makes long-term trade-offs and spatial consequences visible before management decisions are implemented.
- It provides a basis for comparing alternative pathways and identifying where conservation, restoration, or land-use intervention may be most necessary.



Conclusions: Teiči Strict Nature Reserve

Historical Change Despite Strong Protection

- Historical LULC change included expansion of built-up and arable land, changes in peat-bog extent, and increasing landscape fragmentation.
- LULC change trajectories differed among protection zones, with peat-bog expansion in the strict-regime zone and increasing coniferous forest cover in the regulatory-regime zone.

Future Trajectories Depend on Management and External Pressure

- Scenario projections indicate continued changes in transitional woodland–shrub and potential reductions in peat-bog and waterbody extent under some pathways.
- Differences among scenarios demonstrate that future change trajectories depend strongly on assumptions about land-use pressure, conservation measures, and management.

Protection Does Not Eliminate Landscape-Level Risk

- Strong internal protection can limit direct conversion, but pressures in external protection zones and surrounding areas may still affect fragmentation, connectivity, hydrology, and habitat conditions.

Scenario Modeling Supports Adaptive Management

- Scenario comparison identifies where future pressure, and ecological changes may become concentrated.
- Adaptive management can use these spatial patterns to prioritize habitat protection, connectivity, hydrological integrity, and intervention where pressures are greatest.

Thank you for attention!

