Descriptive report of use case areas
D 3.1

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Project Abstract

Biodiversity protection and restoration are critical for maintaining ecological balance and ensuring the planet's sustainability. In the absence of sustainable management and protection of natural resources, the negative impacts of climate change and other environmental issues will only increase.

Private investment can be a critical tool with the potential to play a transformative role in financing conservation and restoration efforts, as public financing alone may be insufficient to address the scale of these challenges.

By activating innovative sustainable finance solutions and incorporating technological advances within the field of geospatial analytics, private investment can be leveraged in a way that benefits the environment and secures investors' confidence.

BIO-CAPITAL is going to implement an interdisciplinary research and innovation endeavour by combining actions in the three fields of (i) biodiversity protection and restoration, (ii) biodiversity-friendly financing mechanisms and (iii) advanced space technology. Implementation will involve three key steps to leverage innovation:

- BIO-CAPITAL will analyse, understand and learn from use cases.
- BIO-CAPITAL will elaborate, monitor, and demonstrate through use cases.
- BIO-CAPITAL will co-develop, implement and amplify back to the use cases.
- BIO-CAPITAL will engage stakeholders, in order to reach shared views on these three steps and how they can be effectively combined to increase financial flows for biodiversity protection, restoration and sustainability.

Foreword

Across Europe and around the world, the urgent need to protect and restore biodiversity has never been more apparent. From forests and grasslands to rivers and wetlands, natural ecosystems are under increasing pressure from climate change, land use change, and unsustainable practices. These challenges threaten not only the health of our environment, but also the well-being of communities and the resilience of economies.

This report, "D3.1 Descriptive report of use case areas," is part of the broader BIO-CAPITAL initiative, which seeks to address these challenges by exploring new ways to monitor, finance, and support biodiversity conservation and restoration. The project is aligned with the European Union's ambitious goals for biodiversity, including the European Green Deal and the EU Biodiversity Strategy for 2030. These strategies call for protecting 30% of EU land and sea, restoring degraded ecosystems, and mobilizing innovative financial solutions to unlock investment in nature.

At the heart of this report is a practical question: How can we identify and track the most meaningful indicators of biodiversity change, and how can these indicators support effective conservation and restoration efforts? To answer this, the BIO-CAPITAL team has brought together experts in ecology, finance, remote sensing, and stakeholder engagement. The result is a comprehensive mapping of observable parameters—grounded in EU policy and financial mechanisms—and a detailed characterization of pilot sites across diverse agroclimatic regions.
What sets this work apart is its commitment to bridging the gap between science, policy, and practice. Rather than relying solely on traditional approaches, the project leverages cutting-edge satellite data and remote sensing technologies to provide transparent, scalable, and repeatable assessments of biodiversity. At the same time, it recognizes the importance of local context, stakeholder input, and practical feasibility.

The recommendations outlined in this report reflect a forward-looking vision. They emphasize the need to refine and validate indicators through collaboration, develop user-friendly monitoring systems, combine different sources of information for a fuller picture, support flexible management that can adapt to changing conditions, and share knowledge widely to inspire further action.

This report does not claim to have all the answers. Instead, it offers a robust foundation for the next steps in the BIO-CAPITAL project, inviting readers to engage with the process of building better tools, stronger partnerships, and more effective solutions for biodiversity. Whether you are a policymaker, land manager, scientist, investor, or concerned citizen, the insights and approaches presented here are intended to inform, inspire, and empower.
As you read on, you will find a thoughtful synthesis of current challenges, strategic opportunities, and practical pathways for advancing biodiversity monitoring and finance. The journey ahead will require ongoing collaboration, innovation, and commitment—but with shared effort and vision, meaningful progress is within reach.

List of participating organisations

Participant No.	Participant Organisation Name	Country
1 (Coordinator)	CESKA ZEMEDELSKA UNIVERZITA V PRAZE	CZ
2	GEOSYS	FR
3	AGROSOLUTIONS	FR
4	PRATENSIS	SI
5	INSTITUTUL DE CERCETARE PENTRU ECONOMIA AGRICULTURII SI DEZVOLTARE RURALA BUCURESTI	RO
6	AGCURATE BV	NL
6.1	AGCURATE BILGI TEKNOLOJILERI ANONIM SIRKETI	TR
7	GND TECHNOLOGY	LT
7.1	GND ADVISORY	LT
8	ON YEDI SURDURULEBILIRLIK HIZMETLERI DANISMANLIK AS	TR
9	UNIVERSITE CATHOLIQUE DE LOUVAIN	BE
10	FORUM PER LA FINANZA SOSTENIBILE ENTE DEL TERZO SETTORE	IT
11	JSC ONE S.R.L.	IT
12	Carbone 4	FR
13	AGRI SUD OUEST INNOVATION	FR
14	AARHUS UNIVERSITET	DK
15	OIKOPLUS GMBH	AT
16	COLLABORATING CENTRE ON SUSTAINABLE CONSUMPTION AND PRODUCTION GGMBH	DE
17	WESTCOUNTRY RIVERS TRUST LBG	UK

Change Log

Version	Date	Description
v0.1	31.07.2025	**Initial draft**: Established chapter structure, outlined objectives, scope, and methodology.
V0.2	26.09.2025	**Core report content**: Description of policy alignment and regulatory compliance, pilot sites, list of indicators and associated methodology, integration with financial mechanisms, and identification of next steps.
V0.3	01.10.2025	**EDAgro Internal validation and project release**: finalization of document formatting and internal validation before release to project partners
V1	31.10.2025	**Partners' validation and feedback integration** **Public release**
V1.1	10.06.2026	**Integration of comments from RP1 reviews**: Review of document structure, improvement on UCs description with respect to remote sensing and ground truth acquisitions, improvement of explanations on document status and indicators selection

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Definitions and Abbreviations

Abbreviation	Meaning
Project-Specific Terms	
CA	Consortium Agreement
CMS	Content Management System
D.	Deliverable
DPM	Data Management Plan
DoA	Description of Action
GDPR	General Data Protection Regulation
KPI	Key Performance Indicator
PS	Pilot Site
PU	Public
UC	Use Case
WP	Work Package
European Initiatives	
BNG	Biodiversity Net Gain
CAP	Common Agricultural Policy
CMS	Content Management System
EC	European Commission
EGD	European Green Deal
ERDF	European Regional Development Fund
ESG	Environmental, Social, Governance reporting
EU	European Union
GES	Good Environmental Status
Financial Mechanisms	
BC	Biodiversity Certificates

CSRD	Corporate Sustainability Reporting Directive
CTFs	Conservation Trust Funds
CSR	Corporate Social Responsibility
NACs	Natural Asset Companies
NbS	Natural base Solutions
PES	Payments for Ecosystem Services
PPPs	Public-Private Partnerships
SFDR	Sustainable Finance Disclosure Regulation
TCA	Triple Capital Accounting
Ecosystem Services Terms	
AEI	Agro Ecological Infrastructures
CICES	Common International Classification of Ecosystem Services
ESS	Ecosystem Services
IPBES	International Panel on Biodiversity and Ecosystem Services
SEEA	System of Environmental-Economic Accounting
Technical Terms	
CSS	Cascading Style Sheets
EVI	Enhanced Vegetation Index
EO	Earth Observation
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GIS	Geographic Information Service
HTML	HyperText Markup Language
MRV	Monitoring, Reporting, Verification
NDVI	Normalized Difference Vegetation Index
SEO	Search Engine Optimization
SFM	Sustainable Forest Management
VHR	Very High Resolution

1 Introduction

Biodiversity loss is one of the most pressing challenges of our time, with far-reaching consequences for ecosystems, economies, and societies. Recent studies show that Europe's natural habitats continue to decline, threatening not only wildlife but also the essential services that healthy ecosystems provide to people and communities. In response, there is a growing demand for practical, actionable solutions that can help track, protect, and restore biodiversity in ways that are both effective and measurable.

This report was developed as part of the BIO-CAPITAL project, an initiative aligned with the European Union's ambitious biodiversity goals. Its main purpose is to propose a clear and practical set of observable parameters—measurable indicators—that can be used to track biodiversity changes and support conservation and restoration efforts. By focusing on the context of the use cases (UCs) studied within the BIO-CAPITAL project, and the selected pilot sites across different regions and agroclimatic conditions, the report ensures that these indicators are not just theoretical but grounded in the realities faced by land managers, policymakers, and stakeholders.

A key strength of this report is its hands-on methodology. The team gathered data from a variety of sources, including European policy targets, local site managers, open geographic databases, and existing financial mechanisms. Using mapping tools and satellite imagery, the project analyzed each pilot site's landscape and environmental context. The findings and proposed indicators were then reviewed and refined in close collaboration with project partners and local experts, ensuring that the final recommendations are both practical and relevant.

This report is organized to guide the reader from the broader context of EU biodiversity policy and finance, through the methodological foundations of the indicator framework, the description of the pilot sites, the integration with financial mechanisms, and the roadmap for the remainder of WP3. The main sections are:

- Introduction (section 1) presents the background, objectives and scope of the report.
- EU Biodiversity-Related Targets (section 4) reviews relevant EU policies, targets and key performance indicators.
- Existing Financial Mechanisms (section 5) describes public and private financial instruments, including innovative solutions, that support biodiversity conservation and restoration.
- Proposed Spatio-Temporal Observable Parameters (section 6) describes the methodology for indicator identification and selection, and lists the portfolio of 54 observable parameters retained for the project.
- Use Case Area Description (section 7) provides detailed profiles of the pilot sites, including their geographic, ecological and agroclimatic contexts, and the indicators retained a priori for each Use Case together with their remote-sensing requirements.
- Integration with Financial Mechanisms (section 8) describes the feedback and validation process, the living-deliverable approach, and the initial mapping of indicators against financial mechanisms.

- Roadmap for the remainder of WP3 (section 9) articulates how the present deliverable feeds into the activities planned under Task 3.2 and Task 3.3, and reports on the status of WP3 tasks at the end of RP1.
- Conclusion (section 10) highlights key findings, lessons learned, and recommendations for future work.
- References and Annexes provides supporting materials, technical details, and supplementary information.

Whether you are a technical expert, policymaker, or stakeholder, this report is designed to offer a strategic perspective and a hands-on roadmap for advancing effective biodiversity monitoring and finance.

4 EU Biodiversity-Related Targets (WP2.1): overview of relevant EU policies, targets, and KPI

4.1 Strategic Roles of the European Green Deal and EU Biodiversity Strategy for 2030

4.1.1 European Green Deal (EGD)

The EGD is the EU's overarching policy framework aiming to make Europe the first climate-neutral continent by 2050. It integrates biodiversity protection as a core pillar alongside climate action, circular economy, and sustainable agriculture [1].

- **Role**: Serves as the umbrella strategy under which biodiversity-related initiatives are nested.
- **Influence**: It drives legally binding targets through instruments like the Nature Restoration Law, Farm to Fork Strategy, and the EU Forest Strategy [1].
- **Integration**: Biodiversity is treated as essential for climate resilience, economic stability, and social equity.

4.1.2 EU Biodiversity Strategy for 2030

This strategy operationalizes the EGD's biodiversity goals with specific, measurable targets [1].

- **Role**: Provides the roadmap for halting biodiversity loss and restoring ecosystems.
- **Key EU Biodiversity Targets**
  - Protect **30% of EU land and sea**, with **10% under strict protection**
  - Restore **20% of degraded ecosystems**
  - Reduce **pesticide use by 50%**
  - Plant **3 billion trees by 2030**
  - Reverse **pollinators decline by 2030**
  - Achieve **no net biodiversity loss by 2030**, and **net gain from 2030 onwards**
- These targets are supported by binding several key legislative Instruments:
  - **Nature Restoration Law**: Establishes binding restoration targets for ecosystems and species [1].
  - **Habitats and Birds Directives**: Provide legal protection for species and habitats, forming the basis of the Natura 2000 network [1].
  - **Environmental Impact Assessment Directive**: Ensures biodiversity considerations are integrated into project planning [1].
  - **Common Agricultural Policy (CAP)**: Aligns agricultural subsidies and eco-schemes with biodiversity goals [1].

- **Financial Mobilization and Governance**

The strategy emphasizes the need to unlock €20 billion annually for biodiversity, combining EU budget allocations, national funding, and private investment. It is linked to:
  - **EU Taxonomy Regulation**: Defines what constitutes environmentally sustainable activities, including biodiversity [1].
  - **Sustainable Finance Disclosure Regulation (SFDR)**: Requires financial entities to disclose biodiversity-related risks and impacts [1].
  - **Corporate Sustainability Reporting Directive (CSRD)**: Mandates biodiversity-related disclosures for large companies [1].

These financial instruments are designed to **align capital flows** with the strategy's biodiversity objectives.

- **Monitoring and Evaluation Backbone**

The strategy introduces a robust monitoring framework:
  - Biodiversity indicators to track ecosystem health.
  - Reporting obligations for Member States.
  - Integration with tools like the Knowledge Centre for Biodiversity and the EU Biodiversity Dashboard [1].

This ensures that legislative instruments are **accountable and adaptive**, with progress tracked against strategic targets.

- **Interoperability and Coherence**

The strategy fosters coherence across EU and international frameworks:
  - It aligns with the **Kunming-Montreal Global Biodiversity Framework** and **UN SDGs**.
  - It integrates with sectoral strategies like the **Farm to Fork Strategy**, **EU Forest Strategy**, and **Soil Strategy for 2030** [1].

This interoperability ensures that biodiversity goals are embedded across policy domains and scales.

Together, the **EGD** and **EU Biodiversity Strategy for 2030** form a **strategic and legal backbone** for biodiversity protection, influencing all subsequent legislative instruments. They provide:

- **Direction** for legislative instruments.
- **Integration** across sectors and scales.
- **Financial alignment** through sustainable finance tools.
- **Monitoring mechanisms** for accountability.
- **Global coherence** with international biodiversity frameworks.

The EU legislative instruments align with five strategic categories: [1].

- **Protection:** Legal safeguards for species, habitats, and ecosystems.
- **Restoration:** Measures to rehabilitate degraded ecosystems
- **Monitoring:** Tools for tracking biodiversity status and progress**.**
- **Funding:** Financial instruments and incentives for biodiversity**.**
- **Governance**: Policy frameworks, reporting, and enforcement mechanisms

Table 1: Alignment of EU Legislative Instruments with the Strategic Goals

Legislative Instrument	Protection	Restoration	Monitoring	Funding	Governance
EU Biodiversity Strategy for 2030	✔ Sets targets for protected areas	✔ Restoration roadmap & targets	✔ Introduces indicators & reporting	✔ Mobilizes €20B/year, aligns finance	✔ Policy backbone, coherence, reporting
Nature Restoration Law	✔ Strict protection for habitats	✔ Legally binding restoration	✔ Monitoring obligations		✔ Enforcement mechanisms
Habitats Directive / Birds Directive	✔ Legal protection for species/habitats	✔ Restoration via Natura 2000	✔ Conservation status reports		✔ Reporting, compliance
Common Agricultural Policy (CAP)	✔ Eco-schemes for biodiversity	✔ Restoration via subsidies	✔ Monitoring eco-scheme uptake	✔ Funding for biodiversity-friendly farming	✔ Policy framework
EU Forest Strategy	✔ Forest protection targets	✔ Restoration of forest ecosystems	✔ Tree planting progress	✔ Funding for forest restoration	✔ Integration with other policies
Pollinators Initiative	✔ Protect pollinators	✔ Restore pollinator habitats	✔ Abundance & connectivity indicators		✔ Initiative & reporting
Water Framework Directive	✔ Aquatic ecosystem protection	✔ Restoration of water bodies	✔ Water quality & river basin plans		✔ Reporting, compliance
Marine Strategy	✔ Marine biodiversity protection	✔ Restoration	✔ GES indicators		✔ Reporting, compliance

Framework Directive		of marine habitats			
EU Taxonomy Regulation			✔ Defines sustainable activities	✔ Aligns capital flows	✔ Reporting, compliance
SFDR (Sustainable Finance Disclosure)			✔ Biodiversity risk disclosure	✔ Aligns finance with biodiversity	✔ Reporting, compliance
CSRD (Corporate Sustainability Reporting Directive)			✔ Biodiversity reporting		

- **EU Biodiversity Strategy for 2030** is shown as a central, cross-cutting instrument supporting all five strategic categories.

4.2 Key EU biodiversity targets and KPI

Based on the analysis of *D2.1 – Policy and financial framework for biodiversity protection investments* [1], here is a structured table mapping the **Key EU Biodiversity Targets** to the **Legislative Instruments** that support or enforce them.

Table 2: Key Biodiversity Targets and Supporting Instruments

Target	Supporting Instrument	Type	Why Critical	KPIs / Monitoring Indicators	Implementation Timeline
Protect 30% of EU land and sea	EU Biodiversity Strategy for 2030	Strategy	Sets overarching conservation goals	% of protected areas; Natura 2000 coverage	By 2030
Restore 20% of degraded ecosystems	Nature Restoration Law	Regulation	Legally binding restoration targets	Area restored; habitat condition reports	30% by 2030, 60% by 2040, 90% by 2050
Reverse pollinator decline	Pollinators Initiative	Initiative	Addresses critical species decline	Pollinator abundance; habitat connectivity	By 2030

Reduce pesticide use by 50%	Farm to Fork Strategy; Pesticide Directive	Strategy + Directive	Reduces biodiversity loss from chemicals	Pesticide usage and risk indicators	By 2030
Plant 3 billion trees	EU Forest Strategy	Strategy	Enhances carbon sinks and biodiversity	Tree planting progress; MapMyTree data	By 2030
Achieve "Good Environmental Status" in marine waters	Marine Strategy Framework Directive	Directive	Protects marine biodiversity	GES indicators (Annex I)	Reviewed every 6 years
Achieve "Good Status" for water bodies	Water Framework Directive	Directive	Ensures aquatic ecosystem health	River Basin Management Plans; water quality	Reviewed every 6 years
Protect habitats and species	Habitats Directive; Birds Directive	Directive	Core legal protection for biodiversity	Conservation status reports; SPA/SAC coverage	Ongoing; reports every 6 years
Prevent biodiversity loss from invasive species	Regulation on Invasive Alien Species	Regulation	Controls species threatening ecosystems	Union List updates; eradication measures	Reports every 6 years
Ensure biodiversity-friendly agriculture	Common Agricultural Policy (CAP)	Policy Framework	Aligns farming with biodiversity goals	% organic farming; eco-scheme uptake	2023–2027 CAP cycle
Ensure biodiversity in urban areas	Nature Restoration Law	Regulation	Targets urban green space and tree cover	Urban biodiversity indicators	No net loss by 2030; increase thereafter

5 Existing Financial Mechanisms for Biodiversity Conservation and Restoration (WP2.2)

The conservation and restoration of biodiversity increasingly depend on financial mechanisms that mobilize, allocate, or incentivize financial resources toward nature-positive outcomes. These mechanisms can be broadly grouped into conventional, mainstream, and innovative approaches, each playing a unique role in addressing the biodiversity financing gap. Key instruments discussed in the *Milestone 1 – Initial identification of innovative biodiversity financing mechanisms* [2] *and* Draft *D2.2 – Mapping opportunities, barriers, bottlenecks, and enablers to the implementation of financial mechanisms* [3] are:

5.1 Public Financing Instruments.

Public financing instruments are essential for funding biodiversity projects that may not attract private investment but have significant societal and environmental benefits. Examples include:

- **Common Agricultural Policy (CAP)**: Provides financial support for agricultural practices that benefit biodiversity, including agri-environmental measures and eco-schemes [2], [3].
- **LIFE Programme**: Funds large-scale restoration projects and capacity-building initiatives for Natura 2000 sites [2], [3].
- **European Regional Development Fund (ERDF)**: Supports projects targeting Natura 2000 species and habitat types [2], [3].

5.2 Private Financing Instruments.

The document emphasizes the role of private investment in financing conservation and restoration efforts. *"Private financial instruments offer greater flexibility compared to public sector funding. Private funds can often be mobilized more quickly than public funds, enabling faster responses to investment opportunities and market changes.* The report highlights the importance of leveraging private capital through mechanisms such as:

- **Green Bonds & Sustainability Bonds:**Bonds issued to fund projects with positive environmental impacts [2], [3].
- **Impact Investing & Funds:** Investments made into companies and funds to generate social and environmental impact alongside financial returns [2], [3].
- **Private Equity & Venture Capital:** Support biodiversity-focused startups and SMEs.
- **Corporate Social Responsibility (CSR) Initiatives**: Business strategies that include biodiversity conservation to demonstrate social responsibility [2], [3].
- **Natural Asset Companies (NACs):** Monetize ecosystem services through sustainable management.

5.3 Blended Finance and Hybrid Instruments

Blended finance combines public and private funding to reduce investment risks and attract private capital. This approach supports projects that may not be commercially viable on their own but have significant environmental benefits [2], [3].

- **Public-Private Partnerships (PPPs)**
  - PPPs leverage the strengths of both the public and private sectors to achieve conservation outcomes that neither could accomplish alone. These partnerships are commonly used in infrastructure projects but are also applicable to biodiversity conservation [2], [3].
- **Debt for Nature Swaps**
  - Debt for nature swaps involve agreements where a portion of a country's external debt is forgiven in exchange for commitments to invest in biodiversity conservation. This mechanism provides financial relief to the country while promoting environmental sustainability [2], [3].
- **Conservation Trust Funds (CTFs):** Long-term financing via endowments and matching contributions.
- **Payments for Ecosystem Services (PES):** Incentivize landowners to maintain ecosystem services.
- **Water Funds & Trading:** Finance watershed protection and pollution reduction.

5.4 Insurance Instruments

Designed to mitigate risks and provide rapid financing for biodiversity recovery.

- **Parametric Insurance:** Triggers payouts based on environmental indices (e.g., rainfall, wind) [2], [3].
- **Green Insurance:** Covers restoration costs post-disaster (e.g., coral reef or mangrove damage) [2], [3].
- **Climate-Resilient Portfolios:** Incentivize adaptation and risk reduction [2], [3].

5.5 Innovative Financial Solutions

Innovative financial solutions attract investment by offering financial returns linked to environmental performance. Examples include:

- **Biodiversity Certificates (BC)**: Market-based mechanisms where forest owners are rewarded for maintaining or improving biodiversity levels [2], [3].
- **Payments for Ecosystem Services (PES)**: Financial incentives provided to landowners for managing their land in ways that provide environmental benefits [2], [3].
- **Digital and Blockchain Technologies:** Innovative tools that enhance transparency, traceability, and efficiency.

- **Smart Contracts & Tokenized Assets:** Automate and secure biodiversity-linked transactions. It helps to automate funding disbursement for verified conservation efforts [2], [3].
- **Blockchain-Based Biodiversity Credits:** Digital credits for conservation efforts managed through blockchain technology to ensure secure and traceable trading of biodiversity outcomes [2], [3].
- **Digital MRV Platforms:** Enable scalable monitoring and verification of ecological outcomes [2], [3].

5.6 Instrument-Specific Highlights

- **Bonds:** Suitable for large-scale, long-term projects; risk of biodiversity-washing if not properly monitored [2], [3].
- **Banking Instruments**: Include sustainability-linked loans and guarantees; accessible to SMEs and municipalities [2], [3].
- **Equity Instruments**: High-risk, high-impact tools for innovative biodiversity ventures [2], [3].
- **Certificates, Credits, and Offsets**: Create tradable units of biodiversity gain; EU is developing a nature credit framework [2], [3].

5.7 Regulatory Frameworks

Regulatory frameworks support biodiversity investments by providing guidelines and standards for aligning financial flows with biodiversity goals. Key frameworks include:

- **EU Taxonomy for Sustainable Finance**: Defines what constitutes environmentally sustainable activities, including biodiversity [2], [3].
- **Sustainable Finance Disclosure Regulation (SFDR)**: Requires financial entities to disclose biodiversity-related risks and impacts [2], [3].
- **Corporate Sustainability Reporting Directive (CSRD)**: Mandates biodiversity-related disclosures for large companies [2], [3].

The integration of these financial mechanisms is crucial for mobilizing resources and addressing funding gaps in biodiversity conservation and restoration. By leveraging public and private investments, innovative solutions, and supportive regulatory frameworks, we can enhance biodiversity outcomes and ensure the sustainability of our natural ecosystems.

5.8 Applicability of financial mechanisms to the Use Case.

Based on the deliverable *D 1.3 Use Cases Description* [4], the report *D2.1 Policy and financial framework for biodiversity protection investments* [1], and *D2.2 Mapping opportunities, barriers,* *bottlenecks and enablers to the implementation of financial mechanisms* [3] the following table provides a comprehensive overview of the key EU targets, the instruments, and financial mechanisms aimed at enhancing biodiversity protection and sustainable investments in each use case.

Use case	Objective	Relevant Targets	Policy Instruments	Financial mechanisms:
UC1: Alpine Forests (Austria & Italy)	Focuses on sustainable forest management practices to preserve and restore biodiversity in Alpine forests	• Restoration of degraded forest ecosystems • Protection of old-growth forests • Sustainable forest management aligned with biodiversity goals	• EU Forest Strategy 2030 • Guidelines on closer-to-nature forest management • Proposed regulation on forest reproductive material	• Biodiversity Certificates (BC), • Payments for Ecosystem Services (PES) • parametric insurance.
UC2: Agricultural Land (France)	Promotes agroecological practices across agricultural lands to enhance biodiversity and improve soil health	• Reduction of pesticide use by 50% • Expansion of organic farming to 25% of EU farmland • Integration of agroecological infrastructure	• Farm to Fork Strategy • Common Agricultural Policy (CAP) • EU Pollinators Initiative	• Mutual insurance funds, • Payments for Ecosystem Services (PES) • CAP funds • Green bonds • biodiversity credits.
UC3: Agricultural Land (Romania)	Implement regenerative agriculture to improve soil health and increase resilience to climate change	• Restoration of carbon-rich ecosystems (e.g., hedgerows, agroforestry) • Soil health improvement and monitoring • Biodiversity-friendly farming practices	• EU Soil Strategy for 2030 • CAP eco-schemes • Nature Restoration Law (agricultural ecosystems)	• CAP funds, • eco-schemes, • Payments for Ecosystem Services (PES) • Green bonds • biodiversity credits.
UC4: Species-Rich	Studies and preserves biodiversity in semi-natural grasslands,	• Restoration of semi-natural grasslands	• Natura 2000 framework • EU Pollinators Initiative	• CAP, • LIFE Programme, • ERDF,

Grasslands (Slovenia)	focusing on ecosystem services	• Pollinator conservation • Integration of biodiversity into rural development	• CAP agri-environmental measures	• National funds. • Result-based payments
UC5: River Corridors & Wetlands (UK)	Enhances and restores biodiversity within river corridors and wetland buffers	• Restoration of 25,000 km of free-flowing rivers • Protection of aquatic biodiversity • Improvement of water quality and hydrological conditions	• Water Framework Directive • Marine Strategy Framework Directive • Nature Restoration Law (wetland and river ecosystems)	• Water company payment schemes, (conservation covenants) • Local authority initiatives (Reverse auctions) • biodiversity net gain frameworks.

5.8.1 Strategic Alignment

These mechanisms align with EU biodiversity targets and policy instruments such as:

- EU Biodiversity Strategy for 2030
- Nature Restoration Law
- Farm to Fork Strategy
- EU Forest and Soil Strategies

They also support the financial mobilization goal of unlocking €20 billion annually for biodiversity, as outlined in the EU Biodiversity Strategy [1]

5.9 Key Challenges Across Mechanisms

The **challenges** associated with implementing innovative financial mechanisms for biodiversity, based on the analysis in *D2.2 – Mapping opportunities, barriers, bottlenecks and enablers to the implementation of financial mechanisms* [3]

Key Challenges Across Mechanisms
1. Data Availability and Quality

- **Problem**: Many instruments rely on robust biodiversity metrics, which are often lacking or inconsistent.
- **Impact**: Difficulties in measuring ecological outcomes hinder credibility, pricing, and investor confidence.
- **Example**: Bonds and sustainability-linked loans require KPIs that are scientifically sound and verifiable, yet biodiversity KPIs remain underdeveloped [3]

2. Regulatory Complexity and Fragmentation

- **Problem**: Diverse national regulations and lack of harmonized EU-wide frameworks.
- **Impact**: Limits scalability and cross-border investment.
- **Example**: Equity and banking instruments face fragmented biodiversity criteria across member states, complicating standardization [3]

3. Market Underdevelopment

- **Problem**: Biodiversity finance is still nascent compared to climate finance.
- **Impact**: Limited investor familiarity and cautious engagement.
- **Example**: Equity markets for biodiversity ventures are small and perceived as high-risk [3]

4. Short-Termism vs. Long-Term Investment Horizon

- **Problem**: Biodiversity outcomes often take decades to materialize.
- **Impact**: Misalignment with investor expectations for short-term returns.
- **Example**: Bonds and insurance instruments may not sustain conservation outcomes beyond their maturity [3]

5. High Transaction Costs

- **Problem**: Small-scale projects face disproportionate administrative burdens.
- **Impact**: Excludes smallholders, cooperatives, and municipalities.
- **Example**: Use-of-proceeds loans and biodiversity bonds are often inaccessible without aggregation mechanisms [3]

6. Greenwashing and Biodiversity-Washing Risks

- **Problem**: Superficial reporting or vague impact claims.
- **Impact**: Undermines trust and effectiveness.
- **Example**: Sustainability-linked bonds and loans may be misused if KPIs are poorly defined or unverifiable [3]

7. Equity and Inclusion Concerns

- **Problem**: Financial mechanisms may favor large actors with technical capacity.
- **Impact**: Marginalizes smallholders, Indigenous communities, and grassroots initiatives.
- **Example**: Insurance payouts and bond-financed projects may bypass local stakeholders without inclusive planning [3]

8. Limited Aggregation Models

- **Problem**: Many biodiversity projects are small and fragmented.
- **Impact**: Difficult to package them into investable portfolios.
- **Example**: Bonds and equity instruments struggle to reach landscapes most in need without aggregation platforms [3]

9. Uncertain Return on Investment (ROI)

- **Problem**: Biodiversity benefits are often intangible or delayed.
- **Impact**: Reduces attractiveness to private investors.
- **Example**: Impact investing and blended finance require strong business models to demonstrate viability [3]

10. Technological and Monitoring Gaps

- **Problem**: MRV (Monitoring, Reporting, Verification) systems are still evolving.
- **Impact**: Limits transparency and accountability.
- **Example**: Digital and blockchain-based instruments risk misuse without rigorous verification protocols [3]

Here is a comparative table summarizing the **key challenges** associated with different types of innovative financial mechanisms for biodiversity, based on D2.2 - Mapping opportunities, barriers, bottlenecks and enablers to the implementation of financial mechanisms [3]

Comparative Table: Challenges by Mechanism Type

Mechanism Type	Key Challenges
Bonds (Green, Blue, Biodiversity)	- Complex ecological outcomes hard to measure - Risk of biodiversity-washing - Favor large-scale projects, excluding smallholders - Limited access for municipalities without aggregation models
Banking Instruments	- High transaction costs for small projects - Fragmented biodiversity criteria across banks and countries - Limited experience with biodiversity KPIs - Equity concerns for small actors
Equity Instruments	- High financial risk and uncertain returns - Difficult biodiversity impact measurement - Cultural resistance to external ownership in SMEs/cooperatives - Nascent market and cautious investors
Insurance Instruments	- Premiums may be unaffordable without subsidies - Trigger-based payouts may miss broader ecological damage - Risk of privileging iconic ecosystems over less visible ones - Equity and legitimacy issues
Digital & Blockchain Tools	- Regulatory gaps and fraud risks - Lack of verification protocols - Decentralized systems hard to monitor - Potential misuse of funds without oversight
Biodiversity Credits & Certificates	- Difficult to quantify biodiversity gains - Need for standardized MRV systems - Risk of greenwashing in voluntary markets - Local nature of biodiversity complicates fungibility
Blended Finance	- Requires strong public-private coordination - High structuring complexity

	- Limited investor familiarity with biodiversity - Uncertain ROI for high-impact, low-commercial projects
Crowdfunding & Micro-Investment	- Limited scalability - Trust and transparency challenges - Difficult to vet and monitor small projects - Risk of low impact without proper governance

5.9.1 Analysis of Financial Tools for Private Investment in Biodiversity Conservation and Restoration

Here is a deep dive analysis by integrating insights from the presentations done by the BIO-Capital partners in WP4 through the "*Deep Dive Presentation*", which are complementary to the work provided by WP2, and also the progress made in WP5 concerning biodiversity certificates.

- Innovative Insurance Mechanisms: Parametric insurance [5].
- Innovative financial solutions:
  - Triple Capital Accounting [6]
  - Payments for ecosystem services (PES) [7]
  - Biodiversity certificates [8]
- Private Financing Instruments: Green Bonds [9]

5.9.1.1 Innovative Insurance Mechanisms: **Parametric Insurance [5]:**

- **Purpose**: Parametric insurance provides rapid financial protection against specific environmental risks (such as storms, droughts, or floods) by triggering payouts based on predefined measurable parameters, rather than actual loss assessments.
- **How it Works:**
  - A specific index or parameter is defined (e.g., rainfall below a certain threshold, wind speed above a set value).
  - When the parameter is met or exceeded (the "trigger event"), the insurance automatically pays out a predetermined amount to the policyholder.
  - There is no need for lengthy claims assessment or on-site loss verification.
  - **Example:**
    A farmer purchases parametric drought insurance. The policy states that if rainfall drops below 50 mm during the growing season (measured by a trusted weather station), the farmer will automatically receive a payout, regardless of the actual crop loss. This allows the farmer to quickly access funds to recover or adapt, without waiting for damage assessments.
- **Benefits**:
  - **Speed:** Fast payouts, often within days of the trigger event.
    - Example: After a cyclone, coral reef insurance in Fiji pays out immediately to fund restoration efforts.
  - **Transparency**: Clear, objective triggers reduce disputes.
    - Example: If wind speed exceeds 120 km/h, forest owners receive compensation without negotiation.
  - **Simplicity:** Lower administrative costs and less paperwork.
    - Example: Farmers receive drought payouts based on satellite rainfall data, avoiding complex claims processes.

    - **Risk Management:** incentivizes stakeholders to adopt biodiversity-positive practices by reducing financial risks and providing timely payouts.
        - Example: Wetland managers invest in restoration, knowing insurance will cover losses from extreme floods.
    - This mechanism can be paired with Payments for Ecosystem Services (PES) to boost participation
- **Limitations:**
    - **Basis Risk:** The payout may not always match the actual loss experienced (if the trigger is met but losses are low, or vice versa).
    - **Data Dependence:** Requires reliable, high-quality data for accurate triggers.
    - **Limited Scope:** Best suited for risks that can be objectively measured by a single parameter
- **Integration with Use Cases**

Alpine Forests (Austria and Italy)	Parametric insurance can cover windstorm risks, providing funds for rapid debris clearing and protecting carbon credit streams.
Regenerative Agriculture (France):	Insurance can protect against drought or excessive rainfall, ensuring farmers can continue regenerative practices.
Agroecological Systems (Romania):	Insurance can safeguard yields from spring frosts or early-season droughts, supporting diverse crop rotations
Species-Rich Grasslands (Slovenia):	Insurance can cover restoration costs or lost biodiversity bonuses due to flooding
River Corridors and Wetlands (UK)	Insurance can fund the replanting of vegetation buffers and maintain the pollutant filtering functions of wetlands.

5.9.1.2 Innovative financial solutions: **Triple Capital Accounting (TCA)** [6]

- **Purpose**: Triple Capital Accounting (TCA) is designed to expand traditional financial accounting by including natural and social capital alongside financial capital. Its goal is to provide organizations with a comprehensive view of their true impacts and dependencies on the environment and society, supporting more robust ESG (Environmental, Social, Governance) reporting and sustainable decision-making.
- **How It Works**:
    - **Identify:** TCA maps all organizational impacts and dependencies on natural (e.g., biodiversity, ecosystem services) and social (e.g., community well-being) capital.
    - **Measure:** These impacts are quantified using scientific and economic methods (e.g., tons of CO_2 absorbed, Soil Organic Carbon (%), hectares of habitat restored, Employment Records, Income from PES/credits).
    - **Value:** TAC translates these impacts into monetary terms using standardized valuation methods (e.g., the cost of restoring a wetland, the value of pollination services, the economic benefit of social programs).
    - **Integrate & Reporting:** The results are incorporated into financial reports and ESG disclosures, allowing organizations to reflect environmental and social costs/benefits in their net value.

    - For example, if a company's activities degrade a forest, TCA calculates the cost of lost ecosystem services and subtracts it from the company's financial profit.
    - If the company restores a wetland, the value of the restored ecosystem is added as an asset.
- **Benefits: It supports Sustainable Finance and Compliance**
  - TCA provides the data needed for ESG disclosures, sustainable finance (e.g., green bonds, biodiversity credits), and compliance with regulations like the EU CSRD and EU Taxonomy.
  - It supports traditional insurance and banking loans, and also Payments for Ecosystem Services (PES) or Climate Resilience Funds (CRF) by translating environmental and social impacts into credible, auditable financial terms
  - It provides investors and regulators a holistic and transparent view of the "real" performance of an organization, not just its financial profit.
  - IT also provides better risk management and enhances the credibility and scalability of biodiversity-linked investments.
- **Limitations:**
  - Assigning accurate monetary values to natural and social capital can be complex and sometimes subjective.
  - Requires robust data and standardized methodologies, which may not be available for all impact types.
  - Implementation can be resource-intensive, especially for organizations new to non-financial accounting.

- **Integration with Use Cases**

Alpine Forests (Austria and Italy)	TCA can quantify natural capital loss from wind damage and fire, monitor social capital via protection of livelihoods, tourism, and secure carbon credit revenues
Regenerative Agriculture (France):	TCA can track soil health, water retention, pollination, and food quality, linking financial capital to carbon farming schemes, making farmers eligible for Eco-payments or green loans
Agroecological Systems (Romania):	TCA can quantify ecosystem service flows from diverse cropping and highlight financial risks to rural economies, helping farmers obtain subsidies
Species-Rich Grasslands (Slovenia):	TCA can measure species biodiversity metrics, soil quality, and support financial streams via conservation payments
River Corridors and Wetlands (UK)	TCA can value natural capital like nutrient retention to protect water quality and flood mitigation, connecting financial capital via water company investments

5.9.1.3 Innovative financial solutions: **Payments for Ecosystem Services (PES)** [7]

- **Purpose**: PES is a financial tool where providers of environmental services are paid to implement practices that maintain or enhance these services. The goal is to incentivize landowners and managers to protect or restore ecosystems.

- **Types**: PES can be public, private, or hybrid schemes, and payments can be action-based or result-based
- **How it Works:**
    - A contract is established between a service provider (e.g., a farmer or forest owner) and a beneficiary (e.g., government, NGO, water utility, or private company).
    - The provider agrees to carry out specific actions that deliver ecosystem services (such as maintaining wetlands, planting hedgerows, or reducing fertilizer use).
    - The beneficiary pays the provider based on the delivery or maintenance of these services.
    - **Example:**
      A group of farmers is paid by a water utility company to maintain vegetated buffer strips along rivers. These strips filter runoff, improving water quality for downstream users. Payments are made annually as long as the buffer strips are maintained.
- **Advantages**
    - **Direct Incentives:** Encourages sustainable practices by rewarding positive actions.
      Example: Farmers receive payments for planting cover crops that improve soil health and sequester carbon.
    - **Flexibility:** Can be tailored to local ecological and social contexts.
      Example: Payments can be based on either actions taken (planting trees) or results achieved (measured increase in pollinator species).
    - **Co-benefits:** Supports biodiversity, climate mitigation, and rural livelihoods.
      Example: PES schemes for wetland restoration also enhance flood protection and wildlife habitat.
- **Limitations:**
    - **Monitoring and Verification:** Requires robust systems to ensure services are delivered.
    - **Sustainability:** Payments may need to be ongoing to maintain benefits.
    - **Equity:** May favor larger landowners or those with more resources to participate.
    - **Complexity:** Designing effective, fair, and transparent PES schemes can be challenging.
- **Integration with Use Cases**

Alpine Forests (Austria and Italy)	PES can support sustainable forest management practices, ensuring long-term ecosystem service provision
Regenerative Agriculture (France):	PES can fund soil conservation practices and enhance biodiversity
Agroecological Systems (Romania):	PES can support agroforestry and organic farming, improving soil health and water management
Species-Rich Grasslands (Slovenia):	PES can incentivize the preservation and restoration of grasslands
River Corridors and Wetlands (UK)	PES can support effective wetland buffers and riparian management strategies

5.9.1.4 Innovative financial solutions: **Biodiversity certificates** [8]

- **Purpose:** The purpose of the biodiversity certificates mechanism is to create a robust market-based framework for recognizing and rewarding biodiversity-friendly practices. This mechanism aims to enhance biodiversity conservation efforts by providing measurable and certifiable biodiversity gains
- **How it Works:**
  - Quantitative Parameters are established to measure the potential biodiversity uplift. (e.g., habitat restoration, species diversity).
  - Project owners or land managers implement biodiversity-friendly practices.
  - Independent verification confirms the biodiversity uplift.
  - Certificates are issued to certify the achieved biodiversity gains. These certificates can be used to demonstrate compliance with sustainability goals or attract investment, but they are not meant to be traded or offset like carbon credits.
  - **Example:** A forest owner implements mixed-species planting and deadwood retention to enhance habitat quality. After independent verification, they receive a biodiversity certificate confirming the ecological improvement, which can be presented to investors or regulators as proof of real biodiversity action.
  - **Key Principles**
    1. The Quantitative Parameters selected are linked to the status of biodiversity in relation to each cluster of ecosystems and the local importance of the site for the structural connectivity of its neighborhood
    2. **Design and Implementation**: The mechanism involves designing a system for biodiversity certificates and implementing it across various use cases (UCs). This includes harmonizing methodological innovations benchmarked in previous work packages (WP3 and WP4) to describe major clusters and create guidelines for the clusters represented by any UC
    3. **Stakeholder Engagement**: The mechanism involves various stakeholders, including project owners, practitioners, scientific experts, and institutional actors, ensuring a collaborative approach
- **Advantages:**
  - **Financial Incentives:** Provides direct rewards for biodiversity-positive actions. *Example: Farmers receive certificates for planting hedgerows, which can be monetized.*
  - **Credibility:** Certifies that real, measurable biodiversity improvements have occurred. Example: A company can show regulators a certificate as proof of actual habitat restoration, not just a financial transaction.
  - **Prevents Greenwashing:** Ensures that only verified actions receive recognition, reducing the risk of false sustainability claims.
    Example: Investors can trust that their funds are supporting genuine biodiversity outcomes, not just paper credits.
    Supports Policy Compliance: Helps organizations meet regulatory or voluntary biodiversity targets.

Example: Certificates help demonstrate alignment with the EU Biodiversity Strategy for 2030.

- **Limitations:**
  - **Measurement Complexity:** Quantifying biodiversity gains can be challenging and may require robust monitoring systems.
  - **Verification Costs:** Independent validation and certification can be resource-intensive.
  - **Market Maturity:** Biodiversity certificate markets are still emerging and may lack liquidity or standardization.
  - **Limited Fungibility:** Certificates are not interchangeable or tradable like carbon credits; their value is tied to specific, verified actions.

- **Integration with Use Cases**

Alpine Forests (Austria and Italy)	The biodiversity certificate can be awarded to forest owners who implement sustainable forest management practices, such as maintaining mixed-species forests, deadwood retention, and respectful harvesting. These practices enhance biodiversity and contribute to the overall health of the forest ecosystem.
Regenerative Agriculture (France):	Farmers who adopt agroecological practices, such as cover cropping, crop diversification, agroforestry, and no-till farming, can receive biodiversity certificates. These practices improve soil health, reduce chemical inputs, and enhance biodiversity on agricultural lands.
Agroecological Systems (Romania):	Biodiversity certificates can be granted to farmers who integrate hedgerows, agroforestry belts, and organic farming into their agricultural practices. These interventions improve soil health, water retention, and biodiversity, making the farming system more resilient to climate change.
Species-Rich Grasslands (Slovenia):	Farmers and land managers who maintain and restore semi-natural grasslands, promote pollinator conservation, and integrate biodiversity into rural development can receive biodiversity certificates. These practices help preserve the rich biodiversity of grasslands and support ecosystem services.
River Corridors and Wetlands (UK)	Biodiversity certificates can be awarded to landowners and managers who implement nature-based solutions for riparian and wetland restoration, such as creating buffer zones, reducing pollution, and enhancing habitat connectivity. These practices improve water quality, protect aquatic biodiversity, and contribute to the overall health of the river and wetland ecosystems.

5.9.1.5 Private Financing Instruments: **Green Bonds** [9]

- **Purpose:** Green Bonds are fixed-income financial instruments designed to raise capital specifically for projects with positive environmental impacts, including biodiversity restoration, climate mitigation, and sustainable land use. They help bridge the biodiversity finance gap by mobilizing public and private investment.

- A **green bond** is a type of bond (loan) issued by governments, companies, or organizations to raise funds specifically for projects that have positive environmental impacts—such as renewable energy, biodiversity restoration, clean transport, or sustainable land use.
- **How it Works:**
    - **Issuance:** The issuer (Governments, corporations, or financial institutions.) sells the bond to investors.
    - **Use of Proceeds:** The money raised is earmarked for environmentally beneficial projects, as defined in the Green Bond Framework aligned with standards such as the ICMA Green Bond Principles (GBP) or the EU Green Bond Standard (EuGBS)..
    - **Interest Payments:** The issuer pays regular interest (coupon) to investors.
    - **Repayment:** At maturity, the issuer repays the principal to investors.
    - **Verification & Reporting:** The issuer provides regular updates and third-party verification or certifications to ensure the funds are used as promised and the environmental impact is measured and reducing greenwashing risk
    - **Use of Proceeds:** Funds are ring-fenced for nature-positive activities, such as forest restoration, wetland rehabilitation, regenerative agriculture, or pollinator-friendly farming.
- **Example:**
  In 2025, A2A SpA (Italy) issued a €500 million EuGB bond to finance renewable energy and biodiversity restoration. The bond's proceeds are strictly allocated to these nature-positive activities, and the company reports on the environmental outcomes (e.g., hectares restored, CO_2 emissions avoided) to investors and regulators.
- **Advantages**
    - **Mobilizes Large-Scale Capital**: Attracts institutional and retail investors to nature-positive projects.
      Example: European Investment Bank's €3 billion EuGB bond for climate and environmental projects.
    - **Portfolio Diversification:** Offers fixed-income returns and risk diversification for investors.
      Example: EU households can channel savings into green bonds for ecosystem restoration.
    - **Transparency and Credibility:** Regular impact reporting and third-party verification build investor trust.
      Example: Issuers report hectares restored or CO_2 avoided, aligned with EU Taxonomy and SDG goals.
    - **Policy Alignment:** Supports compliance with EU Green Deal, Kunming-Montreal GBF, and SDGs.
- **Limitations:**
    - **Verification Costs:** External reviews and impact reporting can be resource intensive.
    - **Greenwashing Risk:** Requires robust frameworks and independent validation to ensure genuine environmental impact.

- **Market Maturity:** Biodiversity-focused bonds are still emerging and may lack liquidity or standardization.
- **Complexity:** Structuring, monitoring, and aggregating diverse nature-positive projects can be challenging.

The integration of innovative insurance mechanisms, triple capital accounting, payments for ecosystem services, and biodiversity certificates and Green bonds can effectively attract private investment for biodiversity conservation and restoration. These financial tools not only provide financial returns to investors but also contribute to the long-term sustainability of biodiversity and ecosystem services. By leveraging these mechanisms, projects can drive impactful changes and incentivize sustainable business practices that promote conservation and restoration of biodiversity.

6 Proposed Spatio-Temporal Observable Parameters (WP3.2)

The identification and selection of biodiversity indicators for the BIO-CAPITAL project followed a systematic, multi-stage approach specifically designed to ensure scientific robustness, technical feasibility, and alignment with EU policy requirements, as well as to support innovative financial mechanisms through quantitative and objective monitoring capabilities. This methodology prioritized operational feasibility and financial mechanism integration over theoretical comprehensiveness, ensuring that selected indicators could effectively bridge the gap between biodiversity science and sustainable finance applications.

The first part of this section describes how the initial portfolio of indicators was selected (section 6.1) and a synthetic analysis of the selection (section 6.2). The full portfolio is then provided in section 6.3, as well as a description on the methodology envisaged for next steps (refinement of the selected indicators over each specific Use Case). In the following part (section 7), indicators identified as relevant for each Use Case will be described in terms of remote sensing specifications.

6.1 Methodology for indicator identification and selection

6.1.1 Initial Indicator Portfolio Development

The foundation of our indicator framework was established through leveraging proven remote sensing capabilities and operational expertise. Drawing from Earthdaily Agro's existing product portfolio and methodological advances from the ESA AgroBiomes project [10], we developed an initial catalogue of technically validated biodiversity indicators. The initial selection identified indicators with various Technical Readiness Levels (TRL), some of them being available within existing operational frameworks, enabling rapid deployment across diverse European landscapes while maintaining cost-effectiveness essential for the commercial viability of associated financial products. Others have lower TRLs, implying additional development efforts to reach full measurement capacity and scalability. This baseline approach ensured that the first set of indicators proposed to stakeholders is aligned with the idea that financial mechanisms require reliable and scalable monitoring solutions.

6.1.2 List improvement through stakeholders' consultations

Stakeholder engagement was conducted through structured consultations with specialists from two categories: Use Case managers (1 or 2 specialists for each one of the 4 pilot sites considered in WP3) and research partners from the University of Louvain (2 researchers).

In a first step, UC's managers participated in structured workshops (during the Prague consortium meeting and subsequent technical workshops) based on initial Earthdaily indicator proposals. This iterative consultation process enabled: i) validation of indicator relevance across diverse ecological contexts, ii) identification of monitoring gaps not addressed by the initial portfolio, and iii) specification of technical requirements tailored to each use case's biodiversity objectives.

Additional indicators were consequently proposed, ensuring comprehensive coverage of biodiversity monitoring requirements across all pilot sites.
In a second step, the indicator list and framework were further enhanced through integration of complementary expertise from UCL and Earthdaily Agro (Geosys), incorporating specialized knowledge in biodiversity science, agricultural systems monitoring, and geospatial analytics. This expert consultation enabled the identification of novel indicators and refinement of measurement protocols to maximize biodiversity information content while maintaining scientific and technical feasibility.

6.1.3 List improvement through scientific literature analysis

In addition to stakeholders' interactions, we employed targeted scientific validation through strategic literature analysis. This approach involved: i) keyword-based searches using Google Scholar and Web of Science focusing on BIO-CAPITAL thematic areas, ii) citation tracking from identified relevant studies, and iii) expert-recommended publications from project partners. Selection criteria emphasized complementarity with existing indicators, technical feasibility using Earthdaily constellation and public satellite data, and scientific validation for biodiversity assessment applications. This pragmatic approach prioritized operational validation over comprehensive academic coverage, recognizing that financial mechanisms require proven methodologies rather than cutting-edge research approaches with uncertain operational viability.

6.1.4 List improvement through site-specific ground-truthing

Field validation and site-specific adaptation were conducted through direct engagement with the UK UC manager. One field visit to the UK pilot sites (river corridors and wetland buffers) in May 2025 provided critical insights into landscape-specific biodiversity monitoring requirements and the practical application of indicators in wetland ecosystem restoration contexts (see also section 7.5.1). These field assessments enabled refinement of indicator specifications and identification of site-specific measurement protocols essential for accurate biodiversity quantification. Additional site visits are still considered (but not planned) for other UCs' pilot sites.

6.1.5 List improvement through policy alignment and regulatory compliance

Indicator identification was systematically aligned with Key Performance Indicators (KPIs) derived from EU biodiversity policy frameworks analyzed in WP2.1 by ITASIF [1]. Rather than applying quantitative scoring systems, this process employed expert assessment to evaluate: i) direct mapping of indicators to regulatory requirements, ii) identification of suitable proxies for policy-relevant metrics not directly measurable through remote sensing, and iii) validation of indicator potential to support compliance monitoring and reporting under major EU instruments including the Nature Restoration Law, Common Agricultural Policy, and EU Biodiversity Strategy 2030. This alignment process specifically emphasized indicators capable of supporting automated compliance monitoring and objective performance verification - critical requirements for financial mechanism credibility and investor confidence.

6.1.6 List harmonization, feasibility assessment, and cleaning

The final harmonization process involved consolidation of indicators from all sources into a coherent framework, eliminating redundancies and grouping complementary measures. Technical specifications were also standardized across indicators, and technical feasibility was evaluated through a two-dimensional analysis framework specifically adapted for financial mechanism requirements:

Measurability Assessment: Each indicator was evaluated for theoretical measurement capacity considering: i) spatial, spectral, and temporal resolution requirements relative to available satellite constellation capabilities (including Earthdaily's upcoming constellation specifications), ii) spatial extent compatibility with target landscape features, iii) physical process dynamics and spectral response characteristics, and iv) signal-to-noise ratios required for reliable detection.

Scalability Analysis: Computational complexity was qualitatively assessed relative to geographic coverage requirements, considering cloud-based processing limitations, data volume constraints, and cost implications for large-scale implementation. This analysis drew extensively on Earthdaily's operational experience in large-scale data processing and existing sustainability product development pipelines.

6.1.7 Prioritization methodology

The final cleaning process deliberately avoided indicator elimination, recognizing that all scientifically valid indicators contribute to comprehensive biodiversity understanding. It was nevertheless obviously out of reach in the Bio-Capital project to address all 54 identified indicators in terms of development, testing, validation, and industrialization. Therefore, a first set of priorities was established based on policy relevance, technical maturity (existing TRL and development synergies within Earthdaily's product portfolio), scientific priorities identified through UCL partnership and Use Case manager validation of site-specific relevance. Consultation with Earthdaily product managers (3 specialists) was used to emphasize market readiness and commercial viability considerations. Notably, no fundamental conflicts emerged regarding the indicator's scientific validity or biodiversity relevance. Disagreements centered on prioritization tensions between market maturity constraints (limiting investment in complex indicators) and comprehensive scientific monitoring requirements.

This approach resulted in 54 indicators organized across four priority tiers: immediate implementation candidates, medium-term development targets, longer-term research objectives, and conceptual frameworks for future consideration. This tiered approach enables systematic capability building while maintaining comprehensive biodiversity coverage over the project timeline.

6.2 Summary of key elements

The framework's innovation lies not in developing novel biodiversity indicators, but in operationalizing existing scientific knowledge for financial mechanism support. This approach addresses a critical market gap: while comprehensive biodiversity frameworks like Essential Biodiversity Variables (EBVs) exist, they often lack the operational specificity required for investor confidence and automated monitoring systems. Our indicator framework decomposes complex habitat assessment into measurable, site-specific components that enable: i) standardized monitoring across diverse European landscapes, ii) automated data processing and reporting, iii) transparent verification for financial stakeholders, and iv) cost-effective scaling across large geographic areas.

The listed indicators are distributed across the four ecosystems representative of the different UCs (15 indicators could be used for any UC, 21 are related to agricultural areas, 12 focus on wetlands, and 6 are related only to grasslands) and three spatial analysis levels (regional, field, or object). Most indicators operate at the field scale (57% of total), enabling precise monitoring of sustainable practices, favourable to biodiversity.

"Universal" indicators (28% of total) have cross-ecosystem applicability validated across all four monitored use cases, and focus on vegetation health and productivity (through biophysical variables or vegetation indices time series analysis), habitat connectivity features (e.g., hedgerows detection and characterization or woods and agroforestry detection), and floral resources assessment (quantity and diversity, as well as detection of native/invasive species). They often support region-level indicators (17% of total), focusing on landscape-scale connectivity and ecosystem status.

Agricultural indicators (39% of total) target mostly crop management practices (e.g., crop rotation diversity, fertilization detection), biodiversity enhancement features (e.g., grass or flower stripes detection), and soil health and conservation (eg, SOC or soil erosion estimation). Grassland indicators also focus on management practices (e.g., mowing and grazing) while wetland indicators are more related to human activities (through restoration actions or human disturbances) or extreme weather impact.

All those indicators support the main European policies and regulations (EU Common Agricultural Policy, Biodiversity Strategy 2030, Water Framework Directive, Pollinators' Initiative) through monitoring of ecosystem restoration (agricultural, wetlands, and rivers) or sustainable practices. They allow for standardized metrics, enabling consistent reporting across Europe and over a long-term period, and automated monitoring (which reduces compliance costs). Independent satellite-based verification reduces fraud risk in subsidy systems, and real-time monitoring enables adaptive management with early warning capabilities. Finally, standardized protocols ensure an audit trail for regulatory compliance and legal enforcement

6.3 List and description of indicators.

The table below (Table 3) reports all the indicators that have been identified as of interest for biodiversity monitoring in the context of the Bio-Capital project. Previous section explains in more detail the methodology used for indicators identification and selection, as well as the expected outcomes in terms of biodiversity monitoring and restoration effort.

The table is structured in different parts, with colors highlighting for each of them the relevant land use/use case:

- Red: general indicators that could be used for any site
- Green: focus on agricultural areas
- Yellow: focus on grasslands
- Blue: focus on wetlands

Columns can be interpreted as:

- Indicator: identification/naming of indicators
- Level analysis: scale of application, ranging from object (small scale, associated with a particular feature in the landscape) to region (large scale, possibly aggregating information from different fields or objects)
- Measure: elements to be practically monitored (could also be relying on several sub-indicators that would be aggregated to provide the relevant measure)
- Interpretation / Usage explains how the metrics relate to biodiversity, directly or indirectly
- Related policy / KPI: identify regulation for which the indicator would support KPI (direct measurement or as a proxy)
- Target UC: identify more specifically for which use cases the indicators could be evaluated during the project

Table 3 - List of indicators relevant to biodiversity monitoring identified

Indicator	Level analysis	Measure	Interpretation / Usage	Related policy / KPI	2 FR	3 RO	4 SI	5 UK
Habitat type ratio	Region	% of natural (grassland, wetland, forest) vs agricultural lands vs urban areas in buffer	Naturality of areas, link with connectivity Basis for derived indicators (evolution monitoring)	EU Green deal / Biodiversity Strategy 2030 / EU Forest strategy (trees planting) Soil Strategy for 2030 (LULC change, urban sprawl) Nature Restoration Law	X	X	X	X
Land Use change	Region	Evolution of % between 2 dates	Identification of areas with changes over a given threshold	Soil Strategy for 2030 / Nature Restoration Law	X	X	X	X
Vegetation health and Productivity	Region, Field, Object	Evolution of NDVI / EVI Evolution of LAI / fAPAR / FCover / Cab Evolution of LST	General indicator on habitat status, healthy vegetation provides more resources. Identification of N deficiencies	Nature Restoration Law	X	X	X	X
Vegetation water content	Region, Field, Object	Evolution of NDWI Evolution of Cw	Leaf / canopy water content		X	X	X	X
Tree canopy surface monitoring	Region	Calculate tree surface and comparison between 2 dates Presence / Absence in specific areas	Forest monitoring and restoration tracking Protection from drought and flood, increase of ripparian buffer	EU Green Deal / EU Forest strategy	X	X	X	X
Deforestation / cut event detection	Region, Object	Sudden change in canopy surface	Human disturbance, loss of habitat		X	X	X	X
Tree canopy height	Region, Object	Height of canopy	Tree species diversity, age of trees	EU Green Deal	X	X	X	X
Agroforestry belts / woods detection	Field	Presence / Evolution of tree areas around geometry	Connectivity between lands and habitat for wildlife, crop protection from drough and flood	EU Green Deal / Nature Restoration Law	X	X	X	
Hedgerows detection	Field	Presence of small woody features around fields Area proportion, gap length with forest	Connectivity between lands and habitat for wildlife, carbon storage, erosion reduction	EU CAP / Pollinators' Initiative Nature Restoration Law	X	X	X	
Hedgerows characterization	Field	Areas covered by canopy Identification of hedge diversity	Connectivity between lands and habitat for wildlife	Pollinators' Initiative Nature Restoration Law	X	X	X	

Crop detection / Crop mask	Field	Crop identification	Basis for crop rotation and crop diversity Crop type (perennial or seasonnal)	Nature Restoration Law	X	X	X
Mixed crop detection	Field	Crop identification (mixed crop)	Basis for crop rotation and crop diversity Crop type (perennial or seasonnal)		X	X	X
Crop rotation (seasonal crop) / Crop diversity	Field	Type / lenght of rotation Shannon index	Phenological cycle, diversity of crop grown, fallow Agricultural diversity	EU CAP / Soil Strategy for 2030 Nature Restoration Law	X	X	
Identification of leguminous in crop rotation	Field	Presence / absence	Sustainable agricultural practices	EU CAP	X	X	
Crop health (perennial crop)	Field	Evolution of NDVI / LAI based on historical mean?	Healthy vegetation provides more resources		X		
Baresoil detection	Field	Baresoil period duration	Sustainable agricultural practices (link with soil health)	Soil Strategy for 2030 / Pollinators' Initiative	X	X	
Tillage detection	Field	Detection of tillage events / no-till practices	Sustainable agricultural practices (link with soil health, soil disturbance assessment, carbon release)	EU CAP / Soil Strategy for 2030 / Pollinators' Initiative	X	X	
Soil cover type	Field	Type of soil cover (cover crop, crop residues, permanent) Duration of soil cover	Sustainable agricultural practices (link with soil health)	EU CAP / Soil Strategy for 2030 / Pollinators' Initiative	X	X	
Cover crop detection (seasonnal crop)	Field	Length of period with soil cover (seasonal crop)	Sustainable agricultural practices (link with soil health)	Soil Strategy for 2030 / Pollinators' Initiative	X	X	
Cover crop biomass estimation	Field	Biomass quantity	Amount of biomass produced through cover crops		X		
Inter-rows cover crop detection (perenial crops)	Field	Detection of inter-rows (based on greenness / phenological analysis)	Sustainable agricultural practices	Soil Strategy for 2030 / Pollinators' Initiative	X		
Grass strips detection	Field	Presence / absence Identification within field	Biodiversity corridor assessmen / connectivity between lands, pollinator support, pest control, carbon storage, erosion reduction	EU CAP / Biodiversity Strategy 2030 / Farm to fork	X	X	
Flower strips detection	Field	Presence / absence Identification within field	Connectivity between lands, pollinator support, pest control	Biodiversity Strategy 2030 / Farm to fork	X	X	
Irrigation event detection	Field	Event detection	Water management		X	X	
Mulching detection	Field	Event detection	Sustainable agricultural practices	Pollinators' Initiative		X	

Quantity of floral ressources	Field, Object	Colorfulness variation in space	Quantity of flower species over grass Spatial component of nutrients availability Support pollinator populations	Pollinators' Initiative / Nature Restoration Law	X	X	X	X
Diversity of floral ressources	Field, Object	Colorfulness variation in time	Diversity in flower species Temporal component of nutrients availability Support pollinator populations	Pollinators' Initiative / Nature Restoration Law	X	X	X	X
Invasive species detection	Field, Object	Presence / absence	Invasive species management	Water Framework Directive			X	X
Native species detection	Field, Object	Presence / absence	Biodiversity restoration, species abundance monitoring, invasive species management	Water Framework Directive			X	
Soil moisture	Field	Soil moisture content at pixel/time level	Water management, Water availability for vegetation, drought identification		X	X	X	X
Soil Organic Content (SOC)	Field	SOC modeling / Carbon accrual modeling	Carbon sequestration and soil health	Soil Strategy for 2030 / EU Green Deal Nature Restoration Law	X			
Soil Organic Matter (SOM)	Field	SOM modeling	Carbon sequestration and soil health	Soil Strategy for 2030 / EU Green Deal Nature Restoration Law	X			
Soil erosion	Field	RUSLE approach	Soil health	Soil Strategy for 2030	X	X		
Ditch detection / No drainage or ditch clearing	Region, Object	Length of drainage system	Maintaining stable water levels / Reduces carbon emissions by maintaining wetland carbon storage functions.	Habitat directive / EU CAP	X	X		
Fertilization detection (seasonnal crop)	Field	Identification of fertilization events, decrease in number of events	Identification of organic fields	EU CAP / Biodiversity Strategy 2030 / Farm to fork	X			
Pest control	Field	?	Organic farming	Biodiversity Strategy 2030 / Farm to fork	X	X		
Grassland type detection (permanent / temporary)	Field	Grassland identification	Intensive vs extensive management				X	
Fertilization detection	Field	Evolution of biomass through time and comparison between fields NNI (nitrogen nutrition index)	Fertilized grasslands show an higher biomass at the beginning of the season	EU CAP			X	
Mowing / cut event detection	Field	Number of events detected Date of events	Sustainable management (high number is less favorable)	EU CAP / Habitat directive / Pollinators' Initiative			X	
Delayed mowing	Field	Delay between mowing event and reference / optimal date	Sustainable management (high number is less favorable)	EU CAP / Habitat directive / Pollinators' Initiative			X	

Identification of refuge (unmown) zones	Field	Areas with no mowing detection	Sustainable management (high number is less favorable)	EU CAP / Habitat directive / Pollinators' Initiative	X
Grazing management	Field	Presence / absence Intensity and timing	Sustainable livestock management	EU CAP / Habitat directive	X
Wetland restoration	Field	Presence / absence Delineation / area covered through time / per meter of river	Wetland ecosystem recovery, Evaluation of restauration impact	Water Framework Directive / Nature Restoration Law	X
Riparian vegetation planting (herbaceous)	Object	Presence / Absence, increase in grass cover	Stabilize banks, provide shade, and create habitats	Water Framework Directive / Nature Restoration Law	X
Riparian vegetation planting (trees)	Object	Presence / Absence, increase in canopy cover	Stabilize banks, provide shade, and create habitats	Water Framework Directive / Nature Restoration Law	X
Water level	Region	Identification of areas covered by water	Water level monitoring, flood detection Hydrological regime management		X
Low flow & drought management	Region	Cumulative precipitation Water level monitoring	Monitor flows	Water Framework Directive	X
Pond detection	Region	Isolated areas covered by water	Connectivity, habitat, pollution buffer	EU CAP / Habitat directive	X
Water Class Transition	Region	WCT lost permanent / new seasonal	Change in surface areas for water		X
River remeandering	Object	Effective length divided by bird fly length	Reintroducing natural meanders, removing concrete channels, creating side arms	Water Framework Directive	X
Human disturbance	Region, Object	Length of roads intersecting geometry relative to geometry size Population density	Amount of human disturbance on ecosystems, linked to human activities		X
Dam/weir removal monitoring	Region	Presence / absence	Restore ecological continuity and fish migration	Water Framework Directive	X
Fish passes monitoring	Region	Presence / absence	Bypass hydraulic obstacles	Water Framework Directive	X
Livestosck access to riverbank / Buffer zone effetiveness	Field, Object	Identification of trampled areas Presence / absence of fences	Prevent degradation of habitat	Water Framework Directive	X

The previous list of indicators (Table 3) references all metrics of interest for each landscape associated with the different Use Cases. Nevertheless, not all of them are necessarily relevant to every financial mechanism: one financial mechanism is expected to leverage a set of specific indicators that would highlight a change in biodiversity for a given situation or problem that affects a stakeholder within a given Use Case.

In this context, building on the initial mapping, the next step consists in refining this association along three levels of granularity: (i) which indicators are most relevant for each combination of financial mechanism and Use Case; (ii) which operational metrics (e.g., thresholds, units, sampling frequency, remote-sensing acquisition methods) will translate each indicator into a measurable signal; and (iii) how these metrics will be delivered to stakeholders (e.g., reporting cadence, format, integration with existing MRV platforms). Synthesis will be provided following the template table below:

Financial mechanism	**Use case**	**Indicators selected**	**Operational metric**	**Delivery mode**
Biodiversity certificates (BC)	UC2 Agricultural lands			
	UC3 Agricultural lands			
	…			
Payment for ecosystem services (PES)	UC2 Agricultural lands			
	UC3 Agricultural lands			
	…			
….				

This work will be carried out during the second reporting period (RP2), through workshops with project partners (UC managers, WP4 and WP5 task leaders) and targeted stakeholder consultations, complemented by field visits in UC2, UC3, UC4 and UC5 (as described in section 8.1). The prioritisation of indicator × mechanism × UC combinations will rely on (i) the Technical Readiness Level of each indicator within Earthdaily's product portfolio, (ii) the suitability and feasibility scores produced under D2.4, (iii) the data layers available in the catalogue compiled under D3.2, and (iv) the demand signal expressed by UC managers and stakeholders.

The resulting refinements will be progressively integrated into subsequent versions of the present deliverable (especially in section 7.5.3 dedicated to the integration with financial mechanisms considered in the project), in line with the living-document approach described in section 8.2.

7 Use Case Area Description (WP3.2)

This section provides a detailed description of each pilot site selected for the BIO-CAPITAL project, including their geographic locations, boundaries, and agroecological context. Each subsection below presents the specific features and landscape characteristics relevant to biodiversity monitoring and restoration in the respective use case areas.

The report and maps were prepared with layers available at the time of writing (Sept. 2025). New layers may be released after report preparation. Depending on the added value to pilot sites' knowledge, reports and maps may be updated during the duration of the Bio-Capital project.

7.1 UC1: Alpine Forests (Austria and Italy)

Objective: Improve sustainable forest management (SFM) to protect and restore biodiversity in Alpine regions. [4]

NB: this UC does not need development of remote sensing biodiversity indicators, and thus UC1 is not included in the work to be done in WP3.

Agroecological Context [4]**:**

- Alpine forests are managed under challenging geophysical conditions, with limited accessibility and vulnerability to climate-induced disturbances (e.g., windthrows, pests).
- Traditional forestry practices often prioritize timber yield over ecological sustainability, leading to biodiversity loss.
- Agroecological principles here involve “Closer-to-Nature” Sustainable Forest Management (SFM), promoting mixed-species forests, deadwood retention, and respectful harvesting.

Need for Biodiversity Indicators [4]**:**

- Indicators are essential to monitor long-term ecological responses to SFM interventions.
- Key indicators include forest species diversity, deadwood volume, soil health, and resilience to pests.
- These indicators support financial tools like Biodiversity Certificates (BC) and Payments for Ecosystem Services (PES), enabling valuation and investment in biodiversity outcomes.

7.2 UC2: Agricultural Land (Arable Crops, Pastures, Vineyards), France, Regenerative agriculture

7.2.1 Context

Objective: Promote agroecological practices to enhance biodiversity and soil health [4].

Agroecological Context:
The use case supports agroecological transition in three regions: Occitanie (Mediterranean climate), Grand Est (northeastern France, temperate continental climate), and Bourgogne-Franche-Comté (north-central France, temperate continental climate).

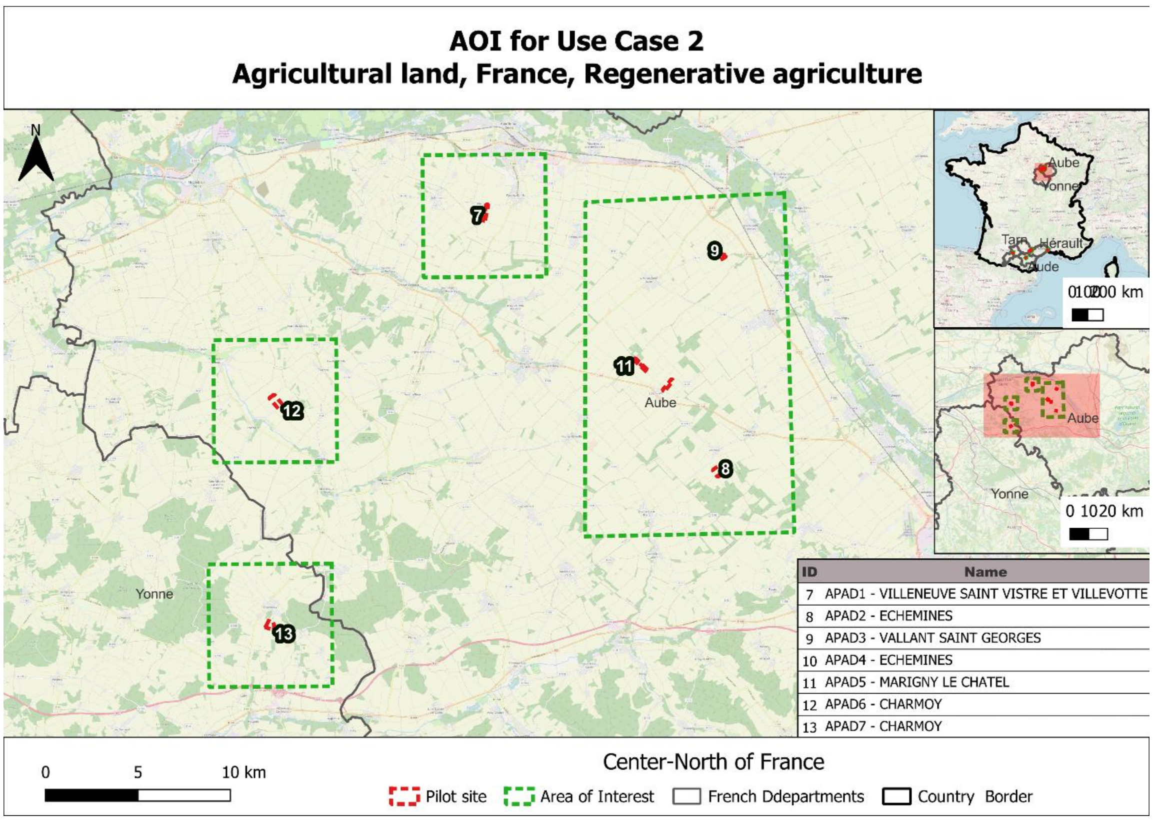


Figure 1 - AOIs map for UC2 (North of France fields)

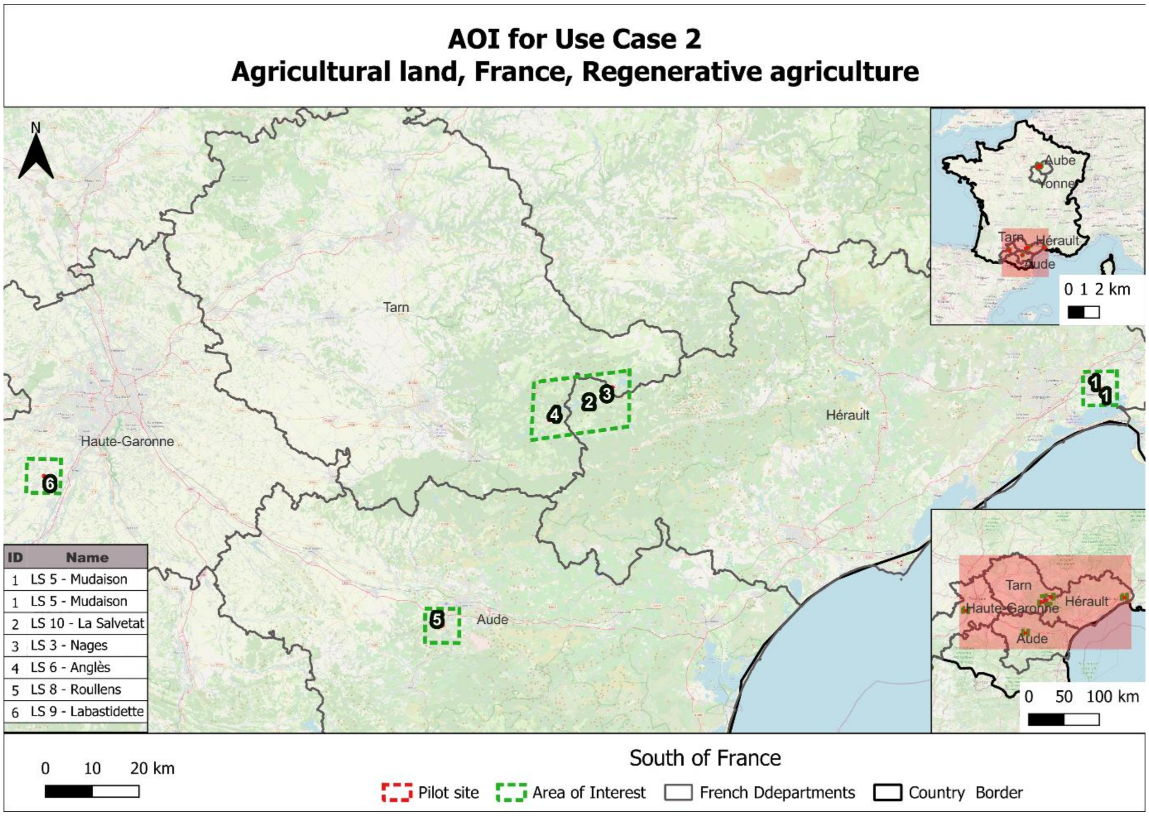


Figure 2 - AOIs map for UC2 (South of France fields)

- **Ecosystem Types:** Arable crops, vineyards; includes semi-natural elements like hedgerows, flower strips, and wetlands [4]
- **Farming Systems:** Farmers already practicing regenerative agriculture are engaged voluntarily, aiming to reduce chemical inputs, improve soil health, and enhance biodiversity [4]
- **Practices include** cover cropping, crop diversification, agroforestry, hedgerow planting, and no-till farming [4]
- **Climate Challenges:** Occitanie faces droughts, wildfires, and extreme weather; Aube deals with frosts and hailstorms. These pressures drive the adoption of climate-resilient agroecological practices [4]
- **Policy Alignment:** Strong alignment with France's Agroecology Law (2014), CAP eco-schemes, and the Low-Carbon Label. Local and national policies support agroecological infrastructure (e.g., 4% UAA requirement) [4].
- **Strategic Frameworks:** Includes GIEE collectives, CAP 2023–2027, Label Bas Carbone, and the international "4 per 1000" initiative for soil carbon [4].

Need for Biodiversity Indicators

- **Key Biodiversity Features** [4]**:**
    - Crop and livestock diversity (tracked via technical itineraries).
    - Semi-natural elements (hedgerows, wetlands) enhancing habitat complexity.
    - Soil biodiversity (microbial activity, earthworms—though harder to measure remotely).

- Indicators are required to monitor the impact of practices like hedgerow restoration, crop diversification, and no-till farming.
- **Baseline Status:**
    - Indicators derived from geodata: crop types, cover crops, landscape features.
    - Remote sensing used to assess habitat quality, landscape diversity, and ecosystem services (e.g., pollination, water regulation).
- **Monitoring Tools:**
  - Remote sensing and ground validation are used to track soil carbon, pollination, and water quality.
  - Biodiversity indicators help validate financial tools like Payments for Ecosystem Services (PES), biodiversity certificates, carbon credits and mutual insurance funds, ensuring ecological benefits are measurable and fundable.

Innovative Financial Mechanisms

- **Applicable Instruments:**
    - Biodiversity Certificates & Credits
    - Payments for Ecosystem Services (PES)
    - Green Bonds
    - Result-Based Payments
    - Carbon Credits (with biodiversity co-benefits)
- **Enabling Conditions:**
    - Use of remote sensing for Monitoring, Reporting, and Verification (MRV)
    - Regulatory frameworks (e.g., Label Bas Carbone)
    - Demand from ESG-driven investors
- **Barriers:**
    - Complexity of biodiversity valuation
    - Immature biodiversity credit markets
    - Limitations of remote sensing for microhabitats
- **Risk Mitigation:**
    - Blended finance
    - Insurance products
    - Adaptive management
    - Diversified funding sources

7.2.2 Pilot sites description

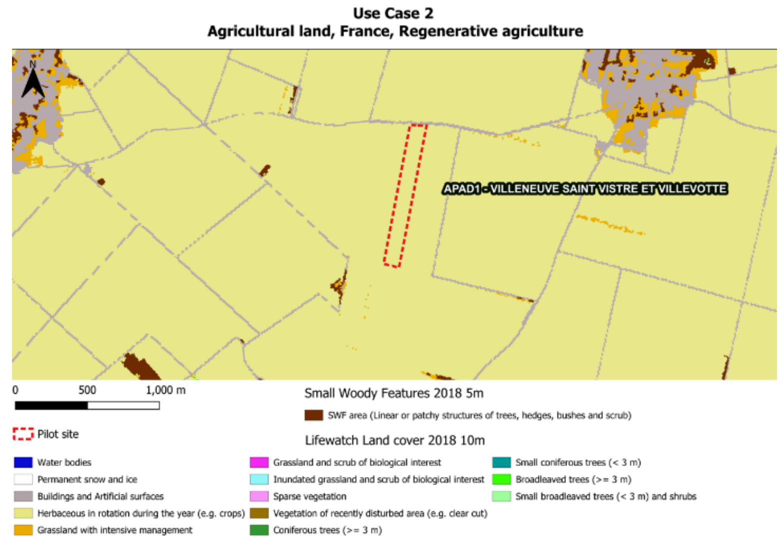
Detailed descriptions of each pilot site, i.e. each field to be monitored in the context of the project, can be found in the next pages. Three maps are included that highlight the specificities of each location:

- one general RGB satellite image to identify site location and context (Google imagery)
- one Land Use / Land Cover map to highlight units around the field (ESA WorldCover v2 2021)
- one map that highlights ecosystem environments, using ecopatch layer (from LifeWatch) and ESA Small Woody features 2018

7.2.2.1 APAD1 – Villeneuve Saint Vistre et Villevotte

Satellite imagery

Ecopatch & Small Woody features



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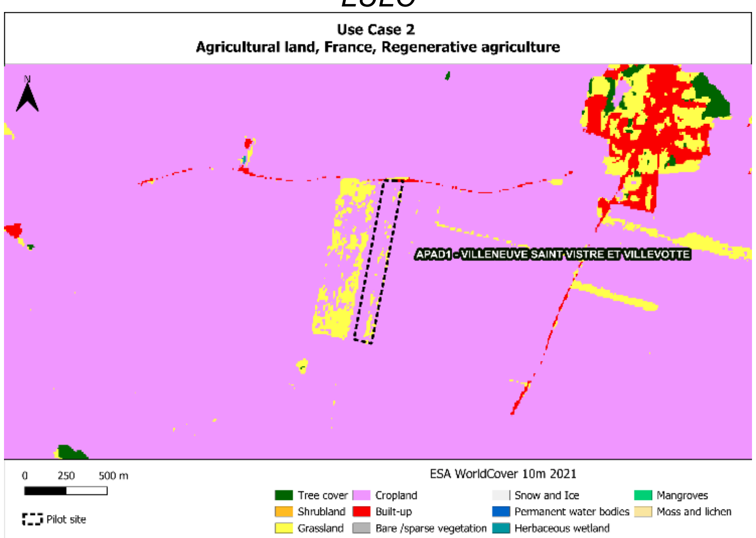
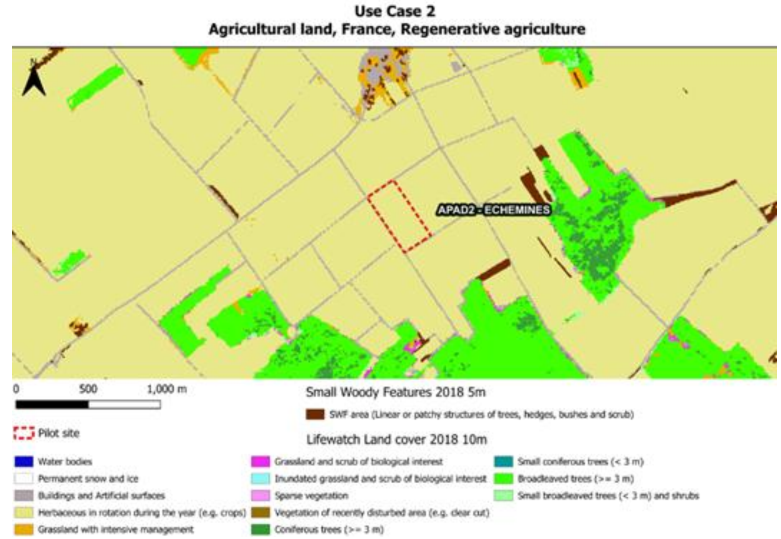


Dense agricultural zone with large expanse of cropland fields (herbaceous in rotation during the year) covering several kilometers around. Roads border the fields and there are no hedges or wooded areas in this zone.

7.2.2.2 APAD2 – Echemines

Satellite imagery

Ecopatch & Small Woody features



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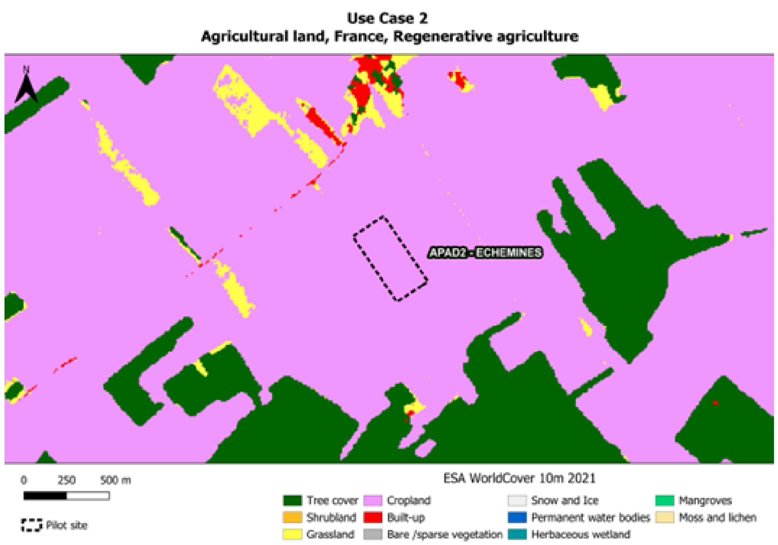
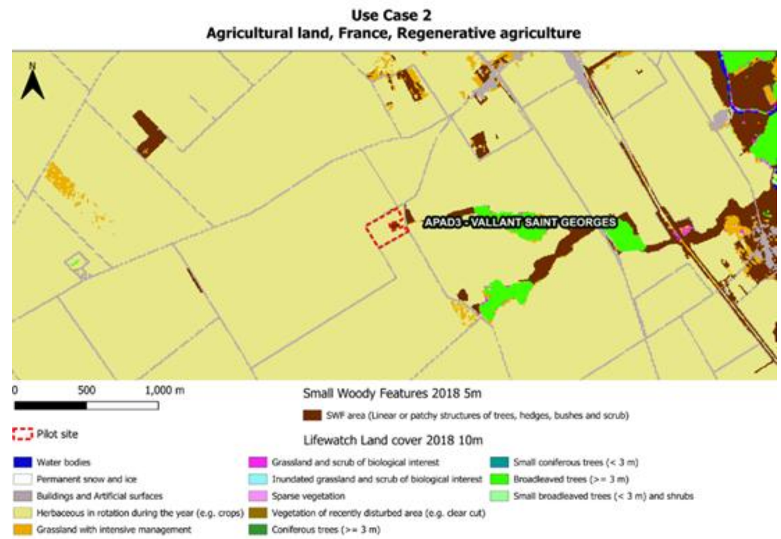


Dense agricultural zone with large expanse of cropland fields (herbaceous in rotation during the year) covering several kilometers around. Areas of broadleaved trees are located less than 1 km to the South, and an urban area is located less than 1 km to the North.

7.2.2.3 APAD3 – Vallant Saint Georges

Satellite imagery

Ecopatch & Small Woody features



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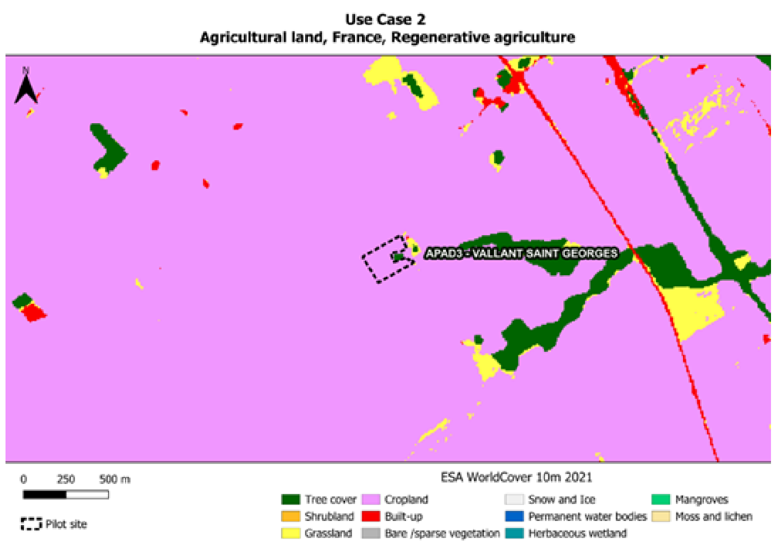
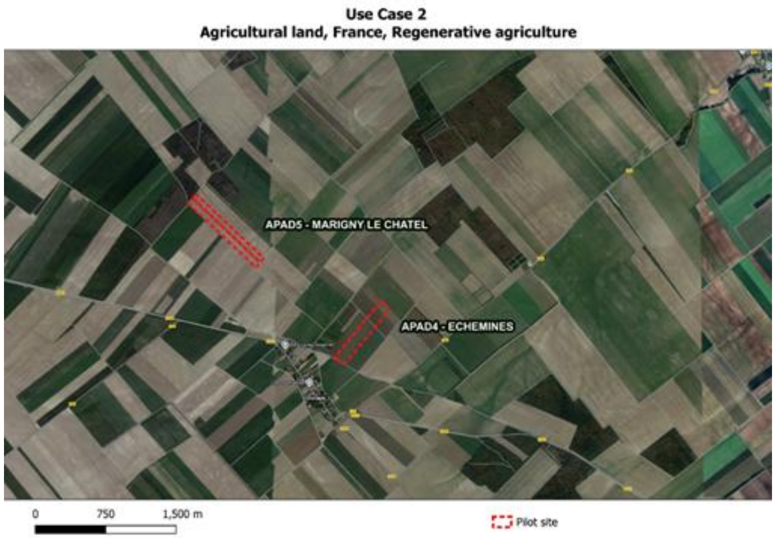


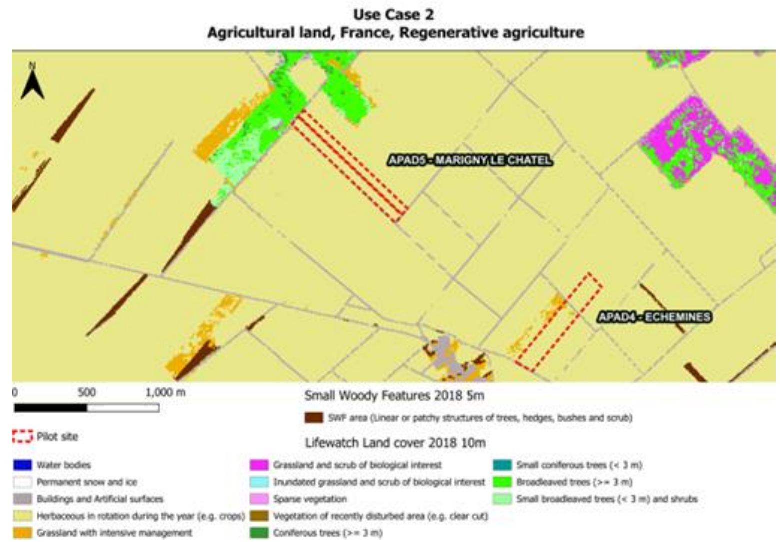
Area consisting mainly of cropland fields (herbaceous in rotation during the year). A small area with small shrubs is identified in the center of the field, and the field itself is close to wooded areas.

7.2.2.4 APAD4 Echemines & APAD5 – Marigny le Chatel

Satellite imagery



Ecopatch & Small Woody features



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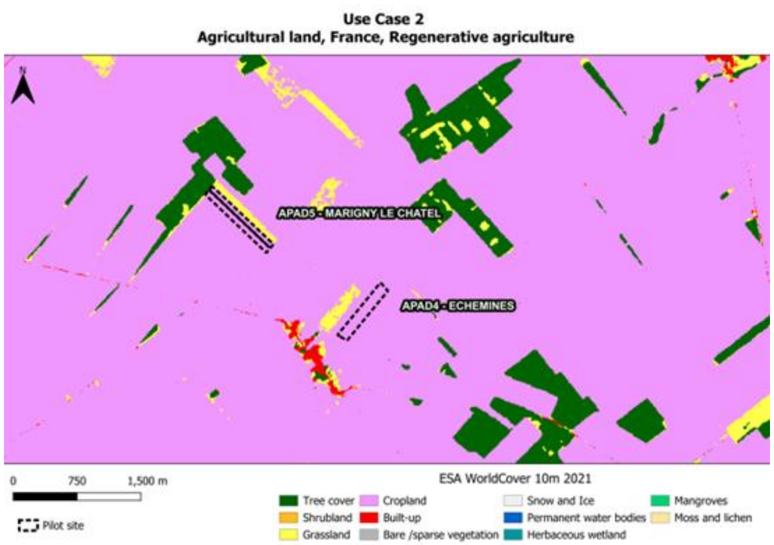
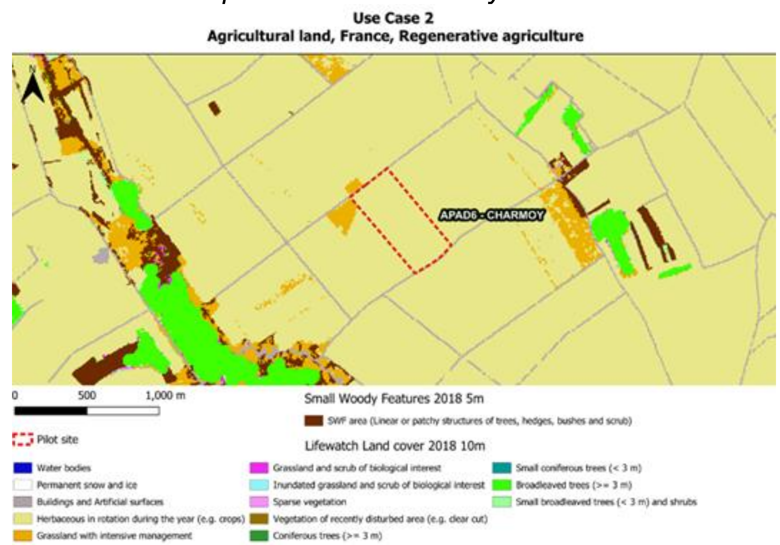


Large expanse of cropland fields (herbaceous in rotation during the year) over several kilometers. There are no hedges, but the most westerly field has a wooded area on its edge. The field further east has an urban area closer to it, located to the South.

7.2.2.5 APAD6 – Charmoy

Satellite imagery

Ecopatch & Small Woody features



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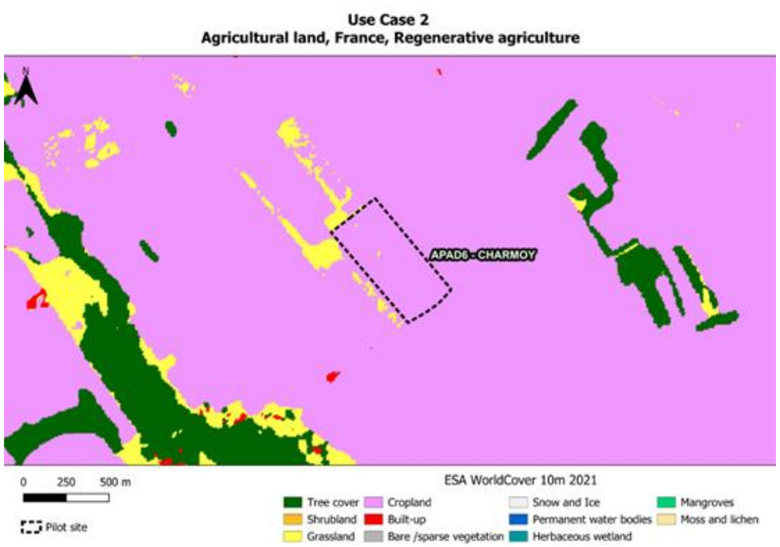
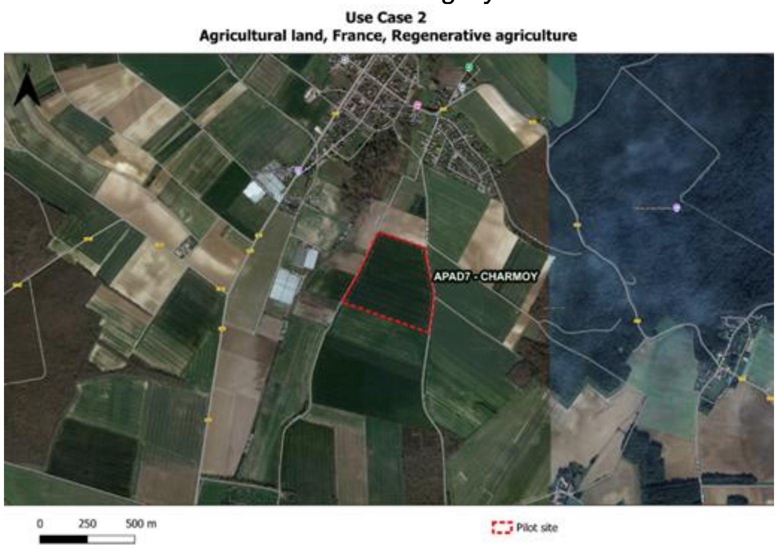


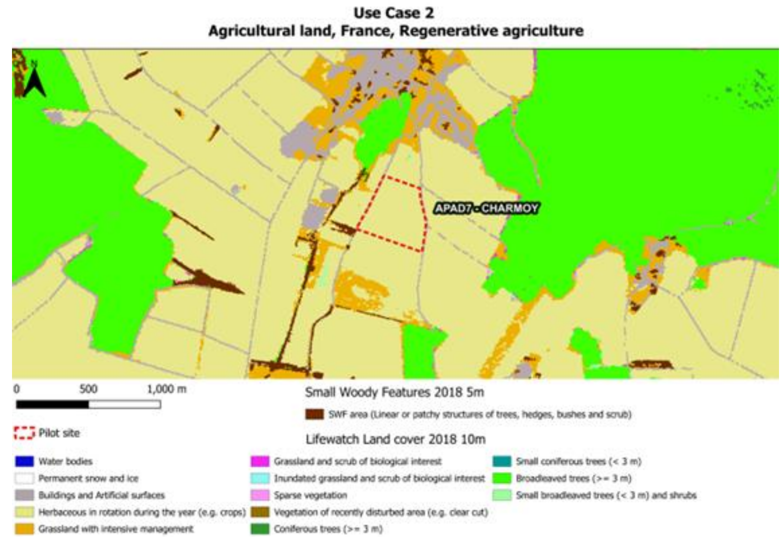
Large expanse of cropland fields (herbaceous in rotation during the year) over several kilometers. There are also a few areas of Broadleaved trees (≥ 3 m), quite far from our field and globally not very present in this area.

7.2.2.6 APAD7 – Charmoy

Satellite imagery



Ecopatch & Small Woody features



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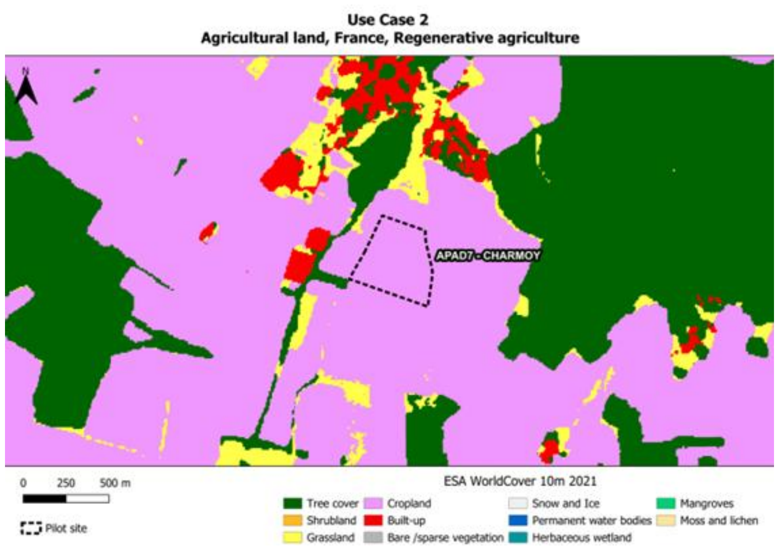
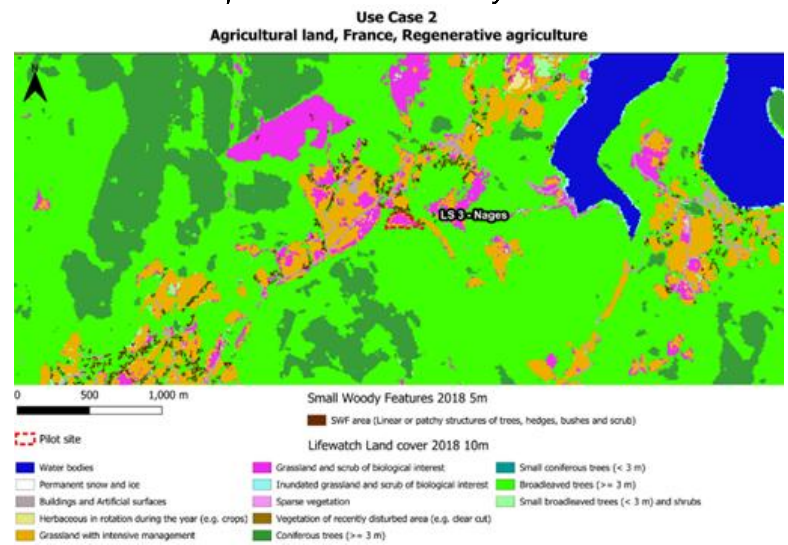


Cropland field (herbaceous in rotation during the year) is surrounded by a road. The area consists of small fields that are quite similar. A forest of Broadleaved trees (≥ 3 m) is located approximately 500m to the East, and we also observe an urban area approximately 500m to the North.

7.2.2.7 LS 3 – Nages

Satellite imagery

Ecopatch & Small Woody features



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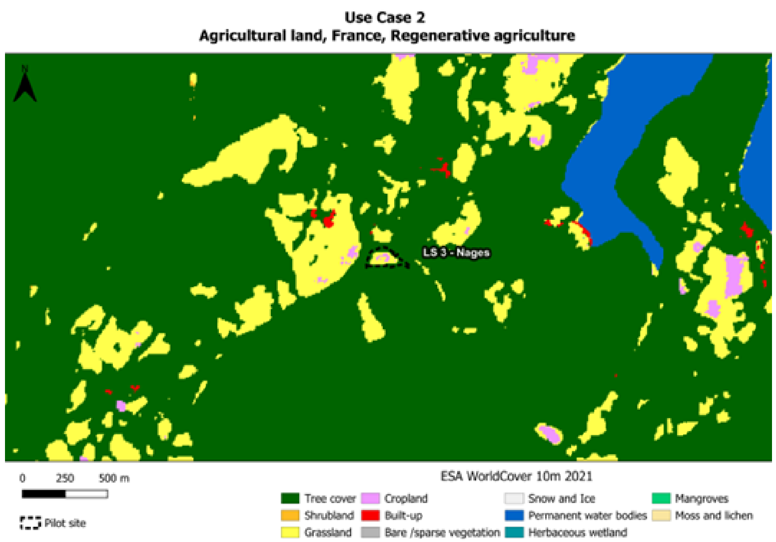


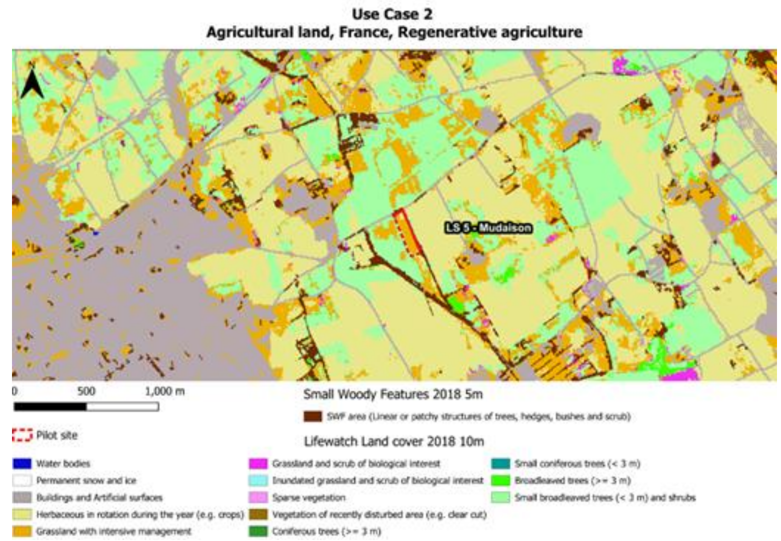
The field is identified as grassland, mostly surrounded by broadleaved trees, with some grassland areas in the northwestern part. The field is also bordered by a river on the north side.

The site is sloped, and the crop type associated is “dairy sheep, meadows, potatoes”.

7.2.2.8 LS 5 – Mudaison

Satellite imagery

Ecopatch & Small Woody features



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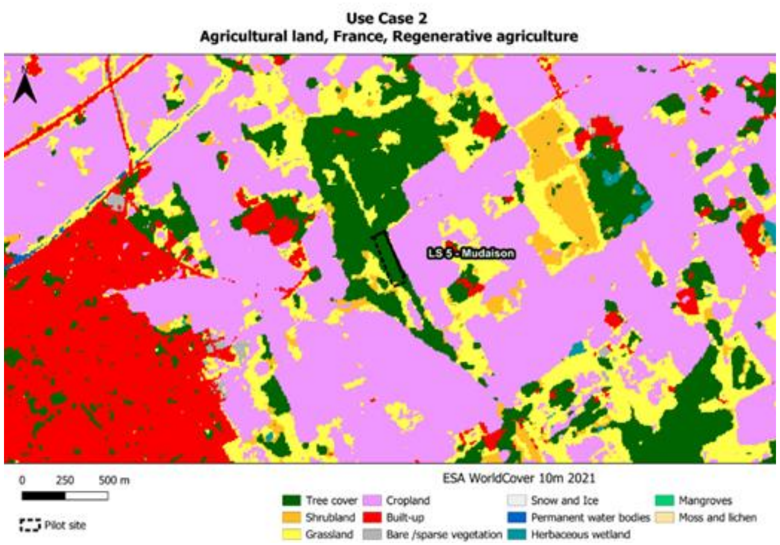
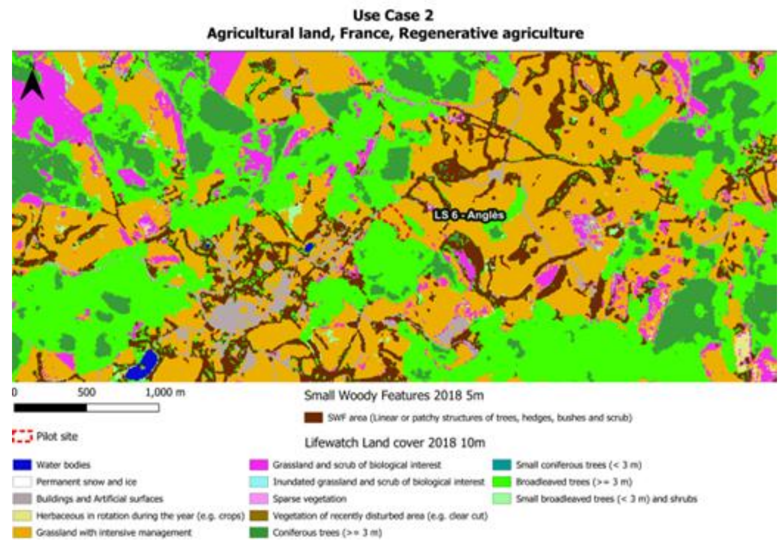


Field with apple crop surrounded by hedges. The area has a very high density of narrow fields.

7.2.2.9 LS 6 – Anglès

Satellite imagery

Ecopatch & Small Woody features



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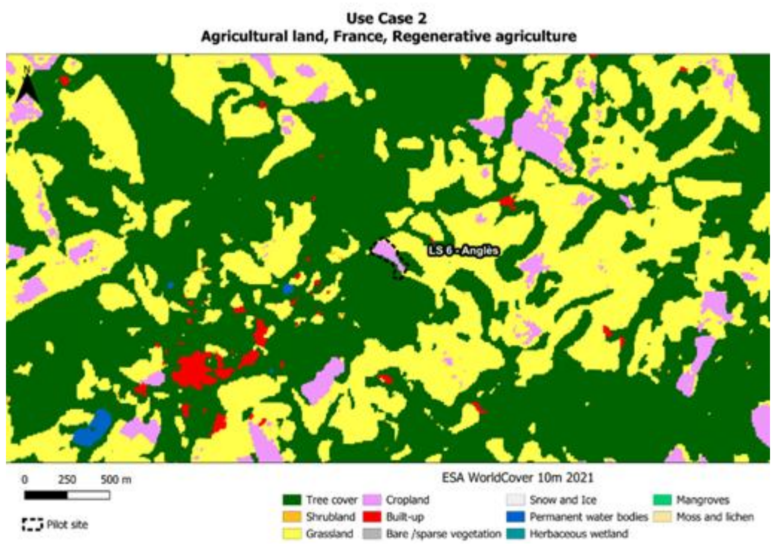
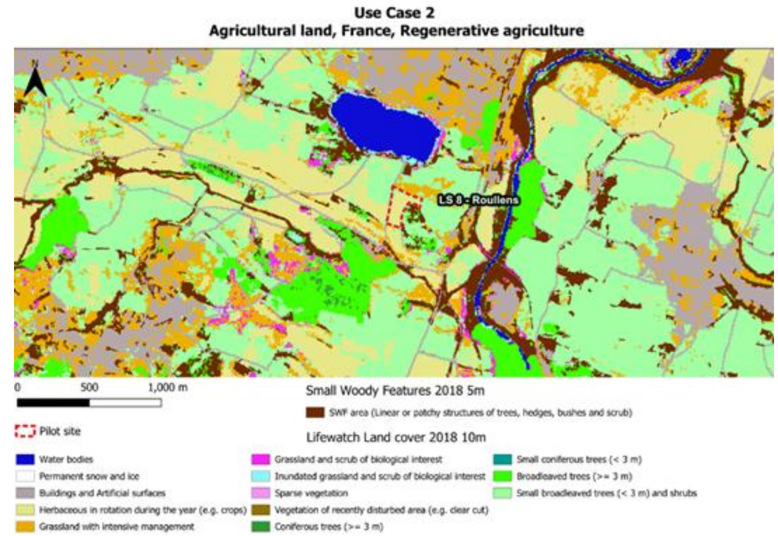


The area is mainly composed of intensively managed grassland located on hills. One can also find broadleaved trees areas, and mosaic herbaceous cover and shrub. A few residential properties are also located to the southwest of the field.
The crop type is identified as “dairy sheep, meadows, cereals, potatoes”. The area is sloped and the soil is quite sandy. We are in an area where rainfall is quite high.

7.2.2.10 LS 8 – Roullens

Satellite imagery

Ecopatch & Small Woody features



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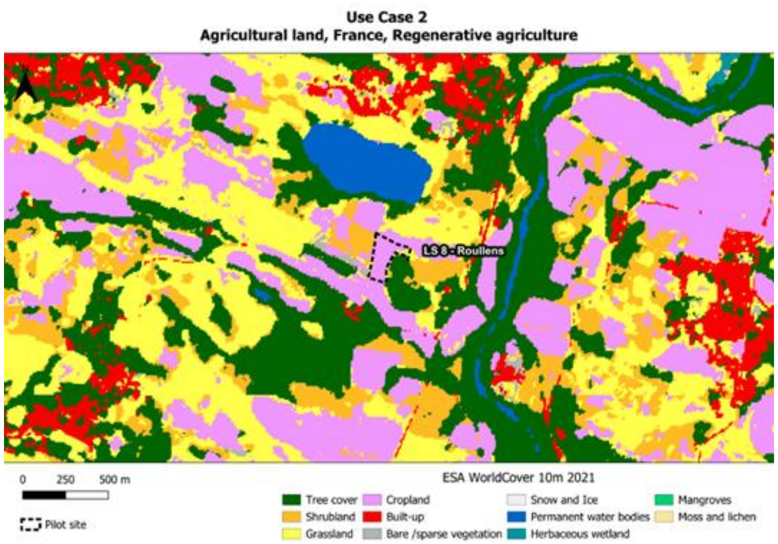
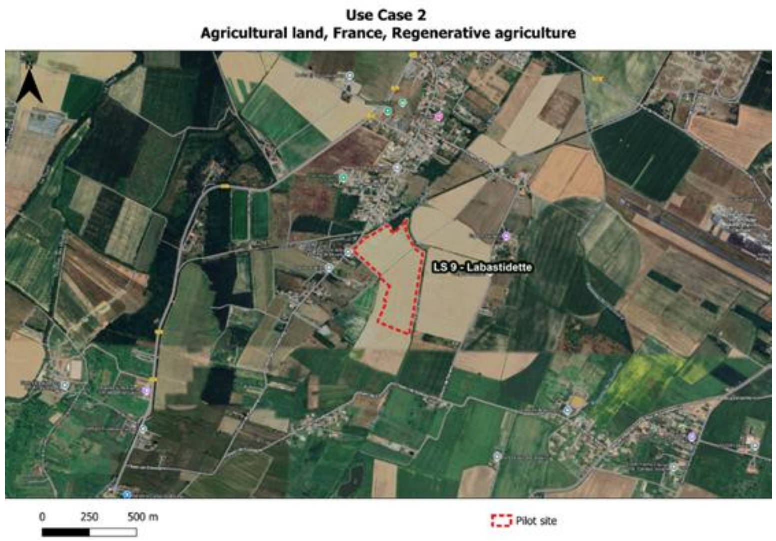


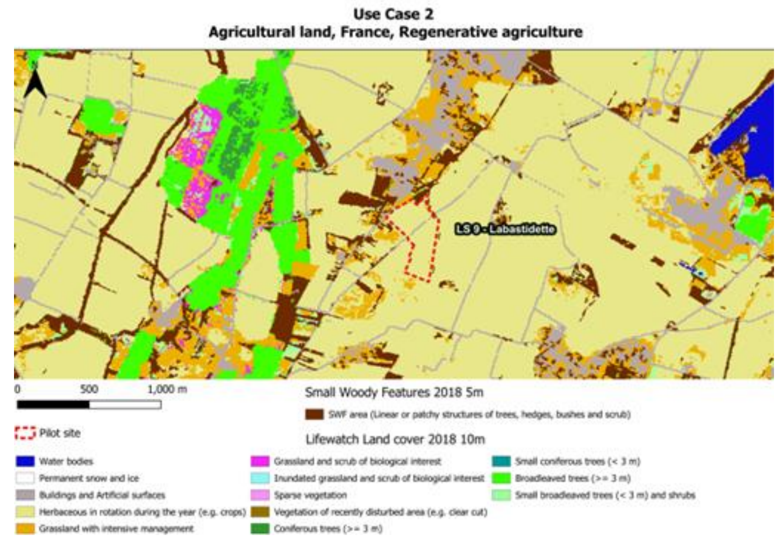
This site is an Olive Oil crop, surrounded by other small and narrow fields. The area surrounding the field includes numerous broadleaved trees (≥ 3 m), small broadleaved trees (< 3 m) and shrubs.
Less than 300 m to the North, there is a lake.

7.2.2.11 LS 9 – Labastidette

Satellite imagery



Ecopatch & Small Woody features



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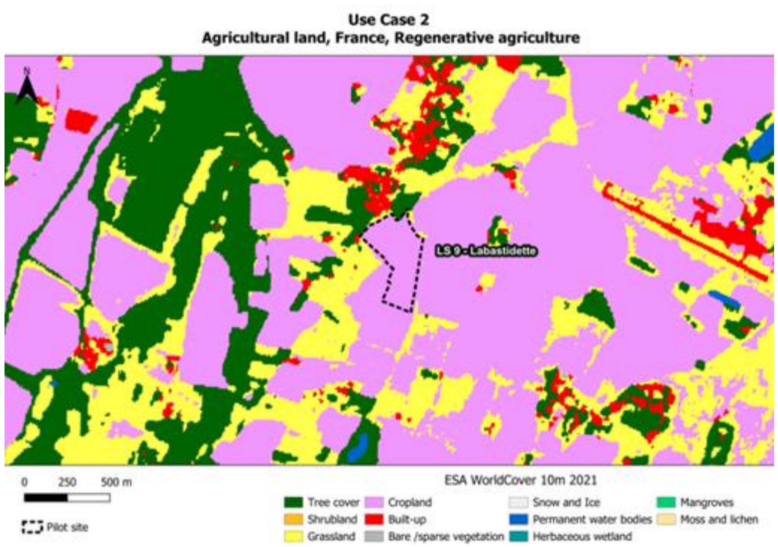
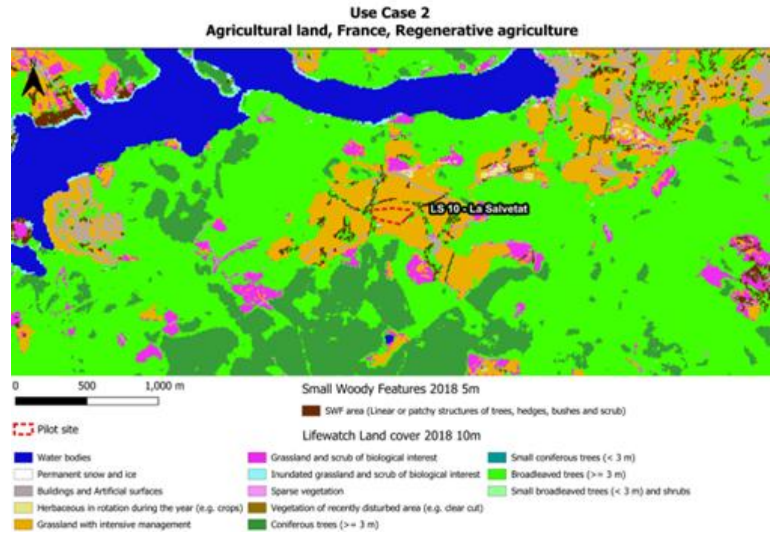


This site is a cropland field located on a plain, surrounded on the South by other similar fields and on the North by residential areas and monospecific grassland. There is a ditch between the road and the field, and grass strip between the field and the ditch. Small woody areas are also present on the edge of the field.
The crop type is almonds trees with rows of crops (alfalfa, cereals), and the soil is stony and with clay.

7.2.2.12 LS 10 – La Salvetat

Satellite imagery

Ecopatch & Small Woody features



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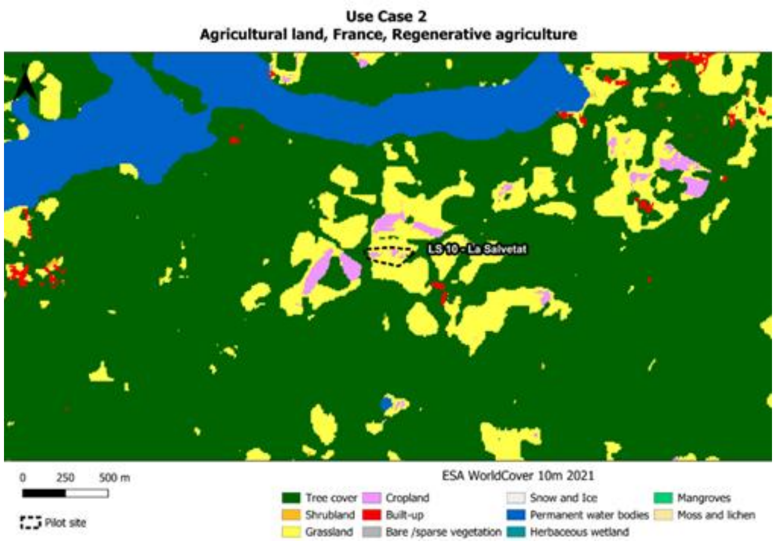


This site is grassland field surrounded by hedges and small shrubs, the field is located lower than the other fields around it and we observe a significative slope. We are on grassland with intensive management. This grassland area is interspersed with hedges and is surrounded by broadleaved trees and coniferous trees. A lake is located 600m to the North.

The crop type is mixed with dairy sheep/crops (cereal, sunflower)/meadows with quite sandy soil.

7.2.3 Indicators retained from portfolio and monitoring requirements

This sub-section identifies, for UC2, the indicators considered a priori relevant from the portfolio of Table 3 and specifies the remote-sensing data sources envisaged for their operational implementation, the monitoring periods to be considered, and the ground-truth requirements expected to support validation. The selection reflects the diversity of pilot sites across two French regions and the target ecosystems addressed by UC2 (arable crops, vineyards, and associated semi-natural features). The retained indicators and acquisition specifications are preliminary at the time of RP1 and will be consolidated, refined or extended during RP2, in line with the living-deliverable approach described in section 8.2.

7.2.3.1 Indicators retained from the portfolio

The most promising indicators marked under column “2 FR” of Table 3 are retained for UC2. They are grouped below by thematic family to support subsequent prioritization and remote-sensing requirement analysis.

- **Landscape structure and habitat composition**: habitat type ratio, land use change, tree canopy surface monitoring;
- **Vegetation status and dynamics**: vegetation health and productivity (through NDVI, EVI, LAI, fAPAR, FCover, Cab, LST), vegetation water content (through NDWI, Cw), crop health for perennial crops (vineyards, orchards);
- **Crop management and rotation**: crop detection / crop mask, crop rotation and crop diversity (Shannon index), cover crop detection, cover crop biomass estimation, baresoil detection, tillage detection;
- **Soil management and condition**: Soil Organic Content (SOC), Soil Organic Matter (SOM), Soil erosion, Soil moisture;
- **Agroecological infrastructure and floral resources**: hedgerows detection, hedgerows characterization, grass strips detection, flower strips detection, quantity of floral resources, diversity of floral resources;
- **Water management**: irrigation event detection;
- **Inputs management**: fertilization event detection, pest control activity detection.

The actual subset of indicators to be operationalised during RP2 will further depend on the financial-mechanism perspective (section 8.3), as not all indicators are equally relevant to every mechanism: PES schemes, biodiversity certificates, green bonds and carbon credits each leverage a distinct subset of the portfolio. The mapping between mechanisms, the UC and the retained indicators will be progressively consolidated in section 8.3.

7.2.3.2 Remote-sensing data sources envisaged

The optimal remote-sensing configuration is described below per indicator family. Sentinel data (Copernicus, ESA) constitute the primary backbone of monitoring. Earthdaily Constellation (EDA) is mobilized where high revisit frequency or fine spatial detail is required. Very-high-resolution imagery (Pléiades) is acquired on demand for small-object characterization and reference validation. Landsat (USGS / NASA) can be used in complement for historical baselines. Additional remote-sensing sources (e.g., hyperspectral missions, LiDAR acquisitions, other commercial constellations) may be considered during RP2 if specific indicators justify it.

Throughout this section, “Sentinel-2” refers to the MSI sensor (10–20 m, 13 spectral bands, 5-day revisit), "Sentinel-1" refers to the C-band SAR (5 m × 20 m IW mode, 12-day revisit currently with a single satellite, 6-day when two are operational), and "Earthdaily" refers to the operational capacity progressively activated during the project (up to 5 m multispectral, 22-band hyperspectral-like capability from visible to SWIR + thermal / Land Surface Temperature (LST), daily revisit).

- **Landscape structure and habitat composition:** Sentinel-2 is the optimal sensor for this family. Its 10 m spatial resolution and 5-day revisit are well suited to land-use-change detection, habitat ratio computation at the buffer / landscape level, and tree canopy surface monitoring on agricultural mosaics.
- **Vegetation status and dynamics:** Sentinel-2 is the optimal sensor for the core vegetation indices (NDVI, EVI, NDWI) and for the red-edge biophysical variables (LAI, fAPAR, FCover, Cab) that rely on its dedicated red-edge bands at 20 m. For LST, Sentinel-3 SLSTR (1 km thermal, 2-day revisit) could be used for global context while Landsat-8/9 (100 m thermal, 8-day revisit) provides higher spatial detail for field-scale observations. It is to be noted that with daily thermal at 120 m / pixel, with joint VIS / TIR observations, Earthdaily constellation will unlock new capabilities in fine monitoring of water stress. For perennial crops where intra-canopy variability matters (e.g., vineyards, orchards with row structure), Earthdaily's 5 m daily acquisitions improve both the spatial detail and the phenological tracking.
- **Crop management and rotation:** Sentinel-2 supports crop type detection through multi-temporal classification, cover crop detection through NDVI/NDWI signatures, baresoil detection through SWIR bands, and cover crop biomass estimation through vegetation indices. Sentinel-1 provides cloud-independent tillage detection (surface roughness signal on the C-band SAR) and complements baresoil detection during cloudy periods. Earthdaily's daily revisit becomes valuable for detecting subtle phenological patterns (helping on phenology characterization) and short cover-crop windows or transient management events (e.g., quick tillage followed by sowing) that may fall between two Sentinel-2 acquisitions. Crop rotation and diversity (Shannon index) are computed from multi-year Sentinel-2 classifications. Earthdaily temporal revisit could also help highlight subtle phenological shifts that would be meaningful for biodiversity uplift.
- **Soil management and condition:** Sentinel-2 contributes through baresoil composites and SWIR-based indices used as inputs to SOC and SOM modelling. Sentinel-1 is the primary sensor for soil moisture estimation (C-band SAR sensitive to surface moisture in the first few centimetres). Earthdaily can refine soil moisture and bare-soil characterization where the daily revisit is critical (post-rainfall recovery, irrigation cycles).

- **Agroecological infrastructure and floral resources:** Hedgerow detection and grass / flower strip mapping can be initialized from Sentinel-2 (10 m) for elements wider than approximately 10 m, but most agroecological infrastructure on UC2 pilot sites is below this threshold. Earthdaily's 5 m daily acquisitions improve both detection and seasonal tracking, particularly for the temporal signature of floral resources (colorfulness variation in space and time, central to the *quantity* and *diversity* of floral resources indicators). VHR imagery (Pléiades at 0.3–0.5 m) is required for hedgerow characterization (width, gap structure, species diversity proxy) and for the detection of narrow strips below the Earthdaily resolution. ESA Small Woody Features 2018 provides a baseline reference.
- **Water management:** Sentinel-1 detects soil moisture variations following irrigation events through its C-band SAR sensitivity, independently of cloud cover. Sentinel-2 complements through vegetation water content (NDWI) and crop status response to irrigation. Earthdaily's daily revisit and thermal bands improve the temporal resolution of irrigation event detection.
- **Inputs management:** Fertilisation event detection is approached indirectly through Sentinel-2 biomass and Nitrogen Nutrition Index (NNI), based on red-edge bands, and through comparison with expected biomass trajectories on similar parcels. Pest control activity is the most difficult family to capture by remote sensing alone: detection relies on phenological anomalies observed on Sentinel-2 vegetation indices, combined with field reports from the farmer partners. Earthdaily's daily revisit improves the sensitivity to short-term biomass changes that may indicate intervention timing.

7.2.3.3 Monitoring periods per indicator family

The monitoring calendar is constructed to match the agroclimatic cycles of the two regions covered by UC2 and the dominant crop types (cereals, sunflower, rapeseed, vineyards, orchards). The cadences indicated below are envisaged for the operational monitoring phase (the precise revisit frequency per indicator and per pilot site will be consolidated during RP2 through the workshops and field visits described in section 8.1).

- **Landscape structure and habitat composition**: a multi-annual baseline of at least five years is required, with annual snapshots for change detection. The full Sentinel-2 archive (since 2015) and the Landsat archive (since 1984) provide the historical context for land-use-change interpretation.
- **Vegetation status and dynamics**: monitoring is concentrated on the growing season (March to October for cereals, approximately April to October for vineyards and orchards) with decadal composites during the growing season and monthly composites outside it. Higher temporal resolution (sub-decadal) is of interest for period of rapid changes (vegetation growth, flowering) or water-stress windows. In those cases, Earthdaily's daily thermal and visible / red-edge revisit becomes most valuable.
- **Crop management and rotation**: monitoring follows the agricultural calendar (sowing windows from March to May, harvest from July to September, and inter-crop / cover-crop period from August to November). Tillage detection is event-triggered around post-harvest (July to November) and pre-sowing (February to April) windows. Crop rotation and

diversity (Shannon index) are assessed seasonally or annually but interpreted over sliding window to capture rotation patterns.

- **Soil management and condition**: the bare-soil season runs from October to March, with high revisit required to capture short cover-crop windows and soil exposure events. SOC and SOM modelling rely on annual aggregations interpreted on multi-annual time series. Soil moisture monitoring is continuous, with sub-weekly Sentinel-1 acquisitions sufficient outside dry spells and daily Earthdaily revisit valuable during irrigation cycles or post-rainfall recovery periods.
- **Agroecological infrastructure and floral resources**: static structural mapping of hedgerows, agroforestry belts and strips is performed annually. Flowering monitoring is concentrated between April and September, with sub-monthly observations during the peak flowering windows. Daily Earthdaily revisit is particularly relevant here for the temporal component of the *diversity of floral resources* indicator (colorfulness variation in time).
- **Water management**: irrigation monitoring is concentrated during the May–September period, with sub-weekly observations required to detect individual irrigation events. The combination of Sentinel-1 (cloud-independent, every 6–12 days) and Sentinel-2 (every 5 days when cloud-free) provides the baseline. Earthdaily daily revisit refines the detection where short irrigation cycles fall between Sentinel acquisitions.
- **Inputs management**: fertilisation events typically occur from February to June and pest treatments from May to August. Detection is event-based during these application windows, with weekly or sub-weekly observations required to disambiguate biomass response from background phenology.

7.2.3.4 Ground-truth requirements

The validation of UC2 indicators requires four categories of ground-truth data, to be collected through the partnerships established with Agri Sud-Ouest Innovation (ASOI), AgroSolutions (AS), and the farmer networks engaged in the project. Where applicable, existing national reference datasets (e.g., RPG, CAP declarations) will be reused to reduce the in situ collection effort and anchor the indicator calibration to validated reference data.

Information of interest includes:

- **Technical itineraries**: crop type per parcel and per year, sowing and harvest dates, cover crop species and dates, rotation history over multi-year periods, fertilization events (date, type, dose), pest control interventions, tillage operations (date, depth), and irrigation events.
- **Agroecological infrastructure surveys**: hedgerow inventory (length, width, height, species composition), grass and flower strip inventory (location, width, sowing year, species), agroforestry belt inventory, and ditch network mapping.
- **Soil measurements**: soil samples for SOC and SOM laboratory analysis on a sub-sample of pilot fields, and surface erosion observations on slopes representative of each region.
- **Phenological observations**: sowing, emergence, flowering and harvest dates for the main crops, and flowering periods for grass and flower strips and for hedgerows.

Not all the observations will be made available within the context of the project, and final validation of selected indicators may be limited to the ground-truth dataset ultimately available. Additional public datasets may also be used.

7.3 UC3: Agricultural Land (Romania – Agroecological Practices)

7.3.1 Context

Objective: Implement regenerative agriculture to improve resilience and biodiversity [4].

Agroecological Context [4]:

- **Region:** South-Muntenia, (Ialomita and Calarasi counties), in Romania
- **Ecosystem Type:** Arable land with agroecological interventions integrating hedgerows, agroforestry belts, and organic farming.
    - **Case 1: Intensive Arable Farm**
        - Crops: Maize, wheat, sunflower, cover crops
        - Practices: Irrigation, conventional inputs
    - **Case 2: Organic Farm**
        - Crops: Vegetables and arable crops
        - Practices: Organic inputs, irrigation, biodiversity-friendly management

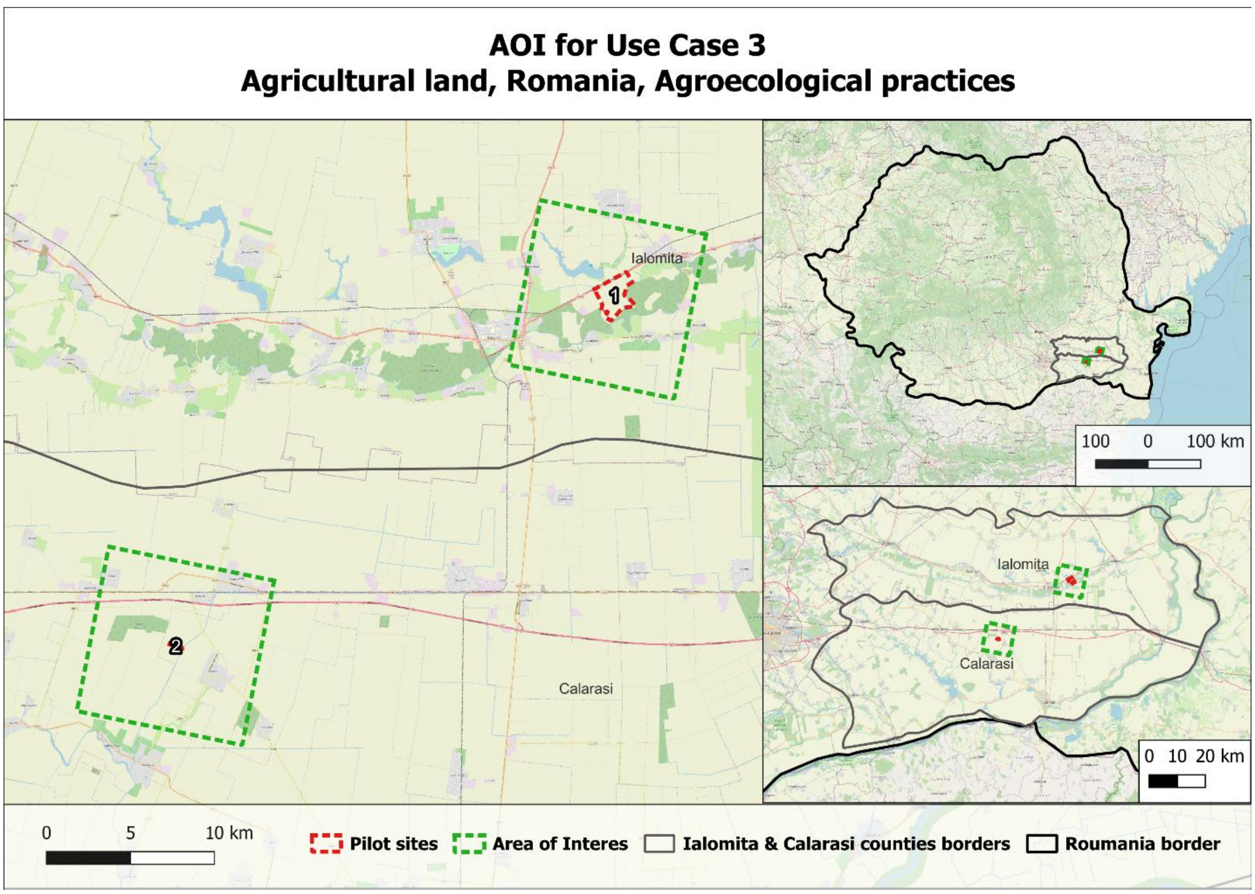


Figure 3 - AOIs map for UC3

Agroecological Goals [4]:

    - Improve soil health and water retention
    - Reduce chemical inputs
    - reduce carbon emissions.
    - Enhance biodiversity and ecosystem services
- **Landscape Features:** Hedgerows, agroforestry belts, and semi-natural habitats integrated into farming systems
- The region is transitioning from conventional to sustainable farming systems, supported by CAP eco-schemes.

Need for Biodiversity Indicators [4]:

- **Key Indicators:**
    - Crop diversity and rotation patterns
    - Presence of hedgerows and buffer zones
    - Soil health metrics (organic matter, erosion control)
    - Pollinator activity and natural pest control
- **Monitoring Tools:**
    - Remote sensing for land use and vegetation cover
    - Ground-level data for validating ecological changes
- **Baseline Status:**
    - Conventional farming dominates, with biodiversity pressures from monocultures and chemical use
    - Transitioning farms offer measurable improvements in biodiversity and resilience
    - Indicators support CAP funding and help meet EU Biodiversity Strategy targets (e.g., 10% cropland conversion to high-diversity features).

Financial Mechanisms

- **Support Structures:**
    - Indicators support CAP eco-schemes and compensatory payments for organic agriculture and help meet EU Biodiversity Strategy targets (e.g., 10% cropland conversion to high-diversity features).
    - National Strategic Plan (2021–2027) for sustainable farming
- **Potential Instruments:**
    - Payments for Ecosystem Services (PES)
    - Biodiversity credits linked to hedgerow and agroforestry establishment
    - Carbon credits with biodiversity co-benefits

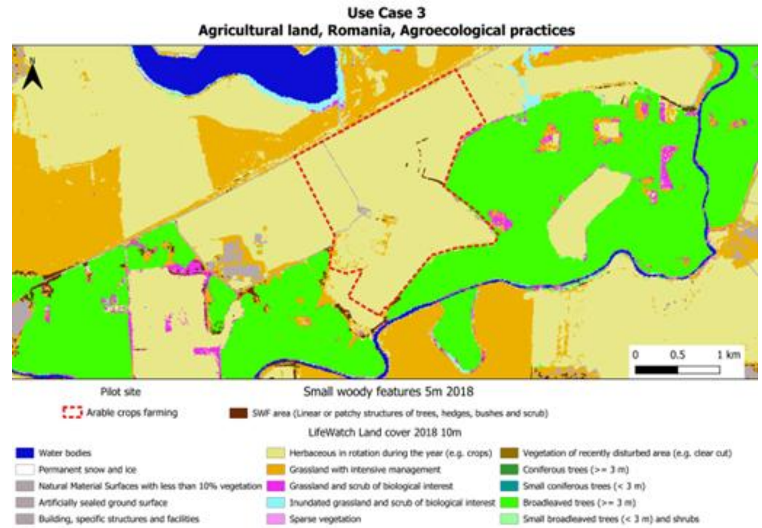
7.3.2 Pilot sites description

As for UC2, detailed descriptions of each pilot site, i.e. each field to be monitored in the context of the project, can be found in the next pages. Three maps are included that highlight the specificities of each location (see section 7.2.2 for details on map sources).

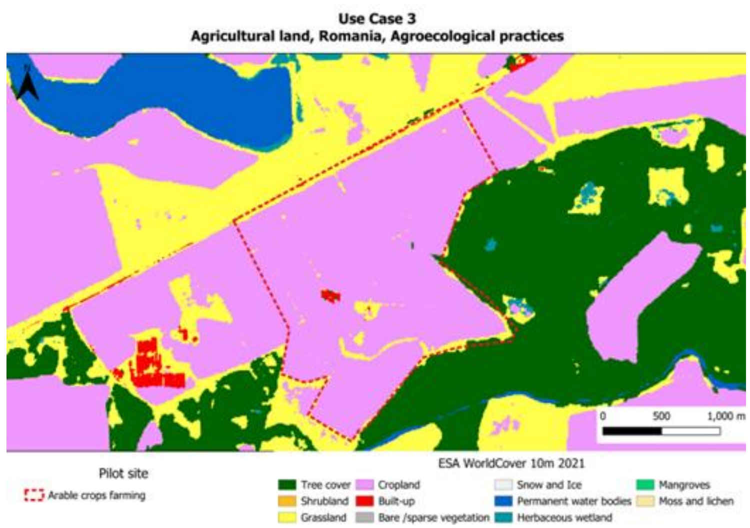
7.3.2.1 Site 1

Satellite imagery

Ecopatch & Small Woody features



LULC

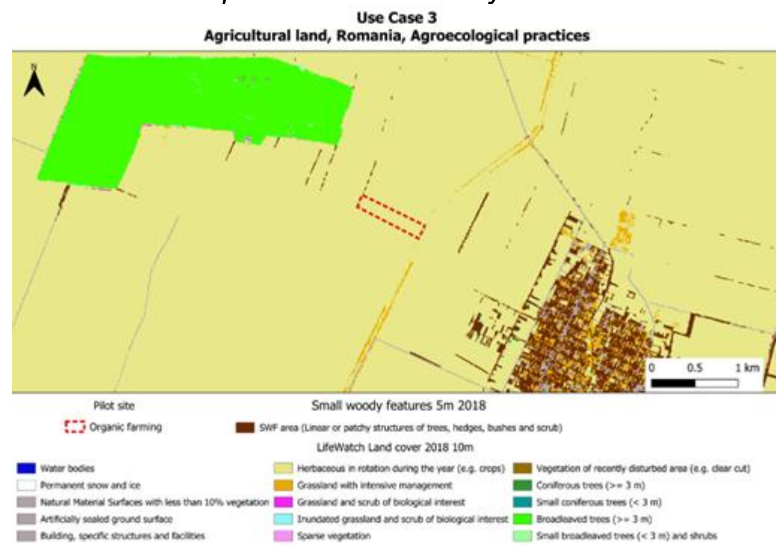


We observe a group of cropland fields (herbaceous in rotation during the year). Those fields include a few sparse hedges.
More than half (southern side) of this use case is bordered by a forest of broadleaved trees (≥ 3m) and on the other part (North side) of similar fields or grassland intensive management.
A river flows less than 500m to the South and a large lake is located less than 1km to the North.

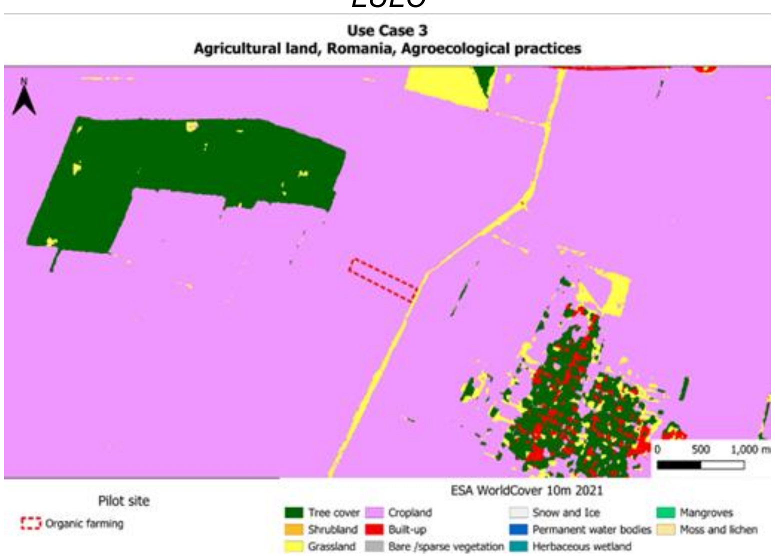
7.3.2.2 Site 2

Satellite imagery

Ecopatch & Small Woody features



LULC



Cropland fields (herbaceous in rotation during the year) are surrounded by other fields over several kilometers. It is a high-density agricultural area including quite small and narrow fields. An area of broadleaved trees is located less than 1 km to the northwest. Some fields located next to this use case have hedges along the edge.

7.3.3 Indicators retained from portfolio and monitoring requirements

This sub-section identifies, for UC3, the indicators considered a priori relevant from the portfolio of Table 3 and specifies the remote-sensing data sources envisaged for their operational implementation, the monitoring periods to be considered, and the ground-truth requirements expected to support validation. The selection reflects the agroecological context of the South-Muntenia region (Ialomița and Călărași counties) and the contrasted farming systems represented in UC3 (an intensive arable farm and an organic farm). The retained indicators and acquisition specifications are preliminary at the time of RP1 and will be consolidated, refined or extended during RP2, in line with the living-deliverable approach described in section 8.2. The actual subset of indicators to be operationalized will further depend on the financial-mechanism perspective consolidated in section 8.3.

7.3.3.1 Indicators retained from the portfolio

The most promising indicators marked under column “3 RO” of Table 3 are retained for UC3. They are grouped below by thematic family to support subsequent prioritization and remote-sensing requirement analysis.

- **Landscape structure and habitat composition**: habitat type ratio, land use change, tree canopy surface monitoring;
- **Vegetation status and dynamics**: vegetation health and productivity (through NDVI, EVI, LAI, fAPAR, FCover, Cab, LST), vegetation water content (through NDWI, Cw);
- **Crop management and rotation**: crop detection / crop mask, mixed crop detection, crop rotation and crop diversity (Shannon index), identification of leguminous crops in rotation, cover crop detection, baresoil detection, tillage detection, soil cover type;
- **Soil management and condition**: soil erosion, soil moisture;
- **Agroecological infrastructure and floral resources**: hedgerows detection, hedgerows characterization, grass strips detection, flower strips detection, quantity of floral resources, diversity of floral resources;
- **Water management**: irrigation event detection, ditch detection / no drainage or ditch clearing;
- **Inputs management**: mulching detection, pest control activity detection.

7.3.3.2 Remote-sensing data sources envisaged

The optimal remote-sensing configuration is described below per indicator family. Sentinel data (Copernicus, ESA) constitute the primary backbone of monitoring. Earthdaily Constellation (EDA) is mobilised where high revisit frequency or fine spatial detail is required. Very-high-resolution imagery (Pléiades) is acquired on demand for small-object characterisation and reference validation. Landsat (USGS / NASA) can be used in complement for historical baselines. Additional remote-sensing sources (e.g., hyperspectral missions, LiDAR acquisitions, other commercial constellations) may be considered during RP2 if specific indicators justify it.

Throughout this section, “Sentinel-2” refers to the MSI sensor (10–20 m, 13 spectral bands, 5-day revisit), "Sentinel-1" refers to the C-band SAR (5 m × 20 m IW mode, 12-day revisit currently with a single satellite, 6-day when two are operational), and "Earthdaily" refers to the operational capacity progressively activated during the project (up to 5 m multispectral, 22-band hyperspectral-like capability from visible to SWIR + thermal / Land Surface Temperature (LST), daily revisit).

- **Landscape structure and habitat composition**: Sentinel-2 is the optimal sensor for this family. Its 10 m spatial resolution and 5-day revisit are well suited to land-use-change detection on the Pannonian arable mosaic, habitat ratio computation at the buffer / landscape level (where landscape simplification is a documented pressure in UC3), and tree canopy surface monitoring on patches of forest, agroforestry or remnant woody features. The Landsat archive is used in complement to extend the historical baseline since 1984, which is particularly relevant for documenting the post-1990 evolution of land tenure and parcel structure in the region.
- **Vegetation status and dynamics**: Sentinel-2 is the optimal sensor for the core vegetation indices (NDVI, EVI, NDWI) and for the red-edge biophysical variables (LAI, fAPAR, FCover, Cab) that rely on its dedicated red-edge bands at 20 m. For LST, Sentinel-3 SLSTR (1 km thermal, 2-day revisit) could be used for landscape-scale drought monitoring, while Landsat-8/9 (100 m thermal, 8-day revisit) provides higher spatial detail for field-scale observations. Earthdaily's daily thermal at 120 m resolution and joint VIS / TIR observations will unlock finer monitoring of water stress, particularly relevant in the drought-prone Pannonian context.
- **Crop management and rotation**: Sentinel-2 supports crop type detection through multi-temporal classification, cover crop detection through NDVI / NDWI signatures, baresoil detection through SWIR bands, and identification of leguminous crops via their distinctive phenological signature. Sentinel-1 provides cloud-independent tillage detection (surface roughness signal on the C-band SAR) and complements baresoil detection during cloudy periods. Earthdaily's daily revisit becomes valuable for detecting short cover-crop windows or transient management events that may fall between two Sentinel-2 acquisitions, and for capturing subtle phenological shifts that would be meaningful for biodiversity uplift. Crop rotation and diversity (Shannon index) are computed from multi-year Sentinel-2 classifications.
- **Soil management and condition**: Sentinel-1 is the primary sensor for soil moisture estimation (C-band SAR sensitive to surface moisture in the first few centimetres). Soil erosion (RUSLE approach) relies on auxiliary geospatial layers (digital elevation model, soil texture maps) combined with Sentinel-2-derived land cover and management factors. Earthdaily can refine soil moisture and bare-soil characterisation where the daily revisit is critical (post-rainfall recovery, irrigation cycles).
- **Agroecological infrastructure and floral resources**: Hedgerow detection and grass / flower strip mapping can be initialised from Sentinel-2 (10 m) for elements wider than

approximately 10 m. Earthdaily's 5 m daily acquisitions improve both detection and seasonal tracking, particularly for the temporal signature of floral resources (colorfulness variation in space and time, central to the quantity and diversity of floral resources indicators). VHR imagery (Pléiades at 0.3–0.5 m) is required for hedgerow characterisation (width, gap structure, species diversity proxy) and for the detection of narrow strips below the Earthdaily resolution. ESA Small Woody Features 2018 provides a baseline reference, particularly relevant in a region where agricultural intensification has historically reduced woody features.

- **Water management**: Sentinel-1 detects soil moisture variations following irrigation events through its C-band SAR sensitivity, independently of cloud cover. Sentinel-2 complements through vegetation water content (NDWI) and crop status response to irrigation. Ditch detection and identification of drainage clearing operations rely on Sentinel-2 (linear feature detection) and Sentinel-1 (for water presence in drainage channels). Earthdaily's daily revisit and thermal bands improve the temporal resolution of irrigation event detection, valuable in a region where short irrigation cycles may occur during summer drought episodes.
- **Inputs management**: Mulching detection is approached through Sentinel-2 SWIR bands (sensitive to dry plant matter on soil surface) combined with Sentinel-1 for surface roughness change, with Earthdaily refining detection where the mulching event is short or partial. Pest control activity is the most difficult family to capture by remote sensing alone: detection relies on phenological anomalies observed on Sentinel-2 vegetation indices, combined with field reports from the farmer partners. Earthdaily's daily revisit improves the sensitivity to short-term biomass changes that may indicate intervention timing.

7.3.3.3 Monitoring periods per indicator family

The monitoring calendar is constructed to match the agroclimatic cycles of the South-Muntenia region (temperate continental climate, Pannonian plain, increasing drought risk) and the dominant crop types of UC3 (maize, wheat, sunflower, vegetables, cover crops). The cadences indicated below are envisaged for the operational monitoring phase (the precise revisit frequency per indicator and per pilot site will be consolidated during RP2 through the workshops and field visits described in section 8.1).

- **Landscape structure and habitat composition**: a multi-annual baseline of at least five years is required, with annual snapshots for change detection. The full Sentinel-2 archive (since 2015) and the Landsat archive (since 1984) provide the historical context for land-use-change interpretation.
- **Vegetation status and dynamics**: monitoring is concentrated on the growing season (approximately April to September for cereals and summer crops, with vegetables potentially extending into October) with decadal composites during the growing season and monthly composites outside it. Higher temporal resolution (sub-decadal) is of interest for periods of rapid changes (vegetation growth, flowering) or water-stress windows. In those cases, Earthdaily's daily thermal and visible / red-edge revisit becomes most valuable.

- **Crop management and rotation**: monitoring follows the agricultural calendar (sowing windows from March to May, harvest from July to September, and inter-crop / cover-crop period from August to November). Tillage detection is event-triggered around post-harvest (July to November) and pre-sowing (February to April) windows. Crop rotation and diversity (Shannon index) are assessed seasonally or annually but interpreted over a sliding window to capture rotation patterns, including the contrast between the conventional and organic management of the two pilot sites.
- **Soil management and condition**: the bare-soil season runs from October to March, with high revisit required to capture short cover-crop windows and soil exposure events. Soil moisture monitoring is continuous, with sub-weekly Sentinel-1 acquisitions sufficient outside dry spells and daily Earthdaily revisit valuable during irrigation cycles or post-rainfall recovery periods. Soil erosion assessment relies on annual or seasonal aggregations, interpreted at storm-event scale where high-intensity rainfall occurs.
- **Agroecological infrastructure and floral resources**: static structural mapping of hedgerows and strips is performed annually. Flowering monitoring is concentrated between April and September, with sub-monthly observations during the peak flowering windows. Daily Earthdaily revisit is particularly relevant here for the temporal component of the diversity of floral resources indicator (colorfulness variation in time).
- **Water management**: irrigation monitoring is concentrated during the May–September period, with sub-weekly observations required to detect individual irrigation events. The combination of Sentinel-1 (cloud-independent, every 6–12 days) and Sentinel-2 (every 5 days when cloud-free) provides the baseline. Earthdaily daily revisit refines the detection where short irrigation cycles fall between Sentinel acquisitions. Ditch and drainage mapping is conducted annually, with event-based monitoring of clearing operations.
- **Inputs management**: mulching events typically occur in spring (March to May) and after harvest (July to October); pest treatments are concentrated from May to August. Detection is event-based during these application windows, with weekly or sub-weekly observations required to disambiguate management responses from background phenology.

7.3.3.4 Ground-truth requirements

The validation of UC3 indicators requires four categories of ground-truth data, to be collected through the partnerships established with the Institute of Research for Agricultural Economy and Rural Development (ICEADR) as UC3 lead, Agcurate as geospatial partner, and the two farms engaged as pilot sites in Ialomița and Călărași counties. Where applicable, existing national reference datasets (e.g., the Romanian Land Parcel Identification System managed by APIA, CAP declarations) will be reused to reduce the in situ collection effort and anchor the indicator calibration to validated reference data.

Information of interest includes:

- **Technical itineraries**: crop type per parcel and per year, sowing and harvest dates, cover crop species and dates, rotation history over multi-year periods, fertilisation events (date, type, dose), pest control interventions, tillage operations (date, depth), irrigation events, and mulching practices. The contrast between the intensive arable farm (Case 1) and the organic farm (Case 2) is of particular interest to calibrate indicators across the practice spectrum.

- **Agroecological infrastructure surveys**: hedgerow inventory (length, width, height, species composition), grass and flower strip inventory (location, width, sowing year, species), agroforestry belt inventory, and ditch network mapping.
- **Soil measurements**: soil samples and surface erosion observations on slopes representative of the region. Where existing soil monitoring data are available at the regional level, they will be mobilised in priority to limit the field campaign effort.
- **Phenological observations**: sowing, emergence, flowering and harvest dates for the main crops, and flowering periods for grass and flower strips and for hedgerows.

Not all the observations will be made available within the context of the project, and final validation of selected indicators may be limited to the ground-truth dataset ultimately available. Additional public datasets may also be used.

7.4 UC4: Species-Rich Grasslands (Slovenia)

7.4.1 Context

Objective: Nature-based solutions for pollinators and biodiversity-rich grasslands [4]
Key Sites:
Agroecological Context [4]:

- **Grassland Importance:** Slovenia's semi-natural grasslands are biodiversity hotspots, shaped by centuries of traditional mowing and grazing. Grasslands are among the most species-rich ecosystems in Europe, covering:
  - 34% of EU agricultural area
  - 58% of Slovenia's agricultural area
- **Natura 2000 sites:** Slovenia has 355 Natura 2000 sites, covering 37.5% of its territory.
- **Threats:** Decline due to intensification, abandonment, and poor socio-economic conditions.
- **Pollination Focus:** Pollinators are keystone species; 78% of wildflowers and 84% of European crops depend on insect pollination.
- **Pollinator Decline Drivers:** Habitat loss, pesticides, diseases, and climate change.
- **Slovenia's Biodiversity:** Hosts 571 wild bee species, but 14% are threatened.
- **Agroecological management**: involves maintaining extensive use, delayed mowing, reduced fertilization, and promoting habitat heterogeneity.

In agreement with the case manager, 2 sites were selected to focus on (at least to start) the project. For each site, several fields will be monitored.

- **Site 1: Goričko Landscape Park** Protected area, high biodiversity, socio-economic challenges
  - **Location & Size**: It is a protected nature park in **northeastern Slovenia**, covering about **462 km²** (46,200 hectares). It is the **second-largest nature park in Slovenia**.
  - **Established**: The park was officially declared on **9 October 2003**.
  - **Significance**: It is part of the **Goričko–Őrség–Raab trilateral park**, which spans Slovenia, Austria, and Hungary.
  - **Landscape & Biodiversity**: The area is characterized by rolling hills formed by the ancient Pannonian Sea, oak forests, wetlands, and meadows. It hosts rare species like the **European otter**, **stag beetle**, and **hazel dormouse**, and it preserves Slovenia's only native red deer population.
  - **Cultural & Ecological Role**: The park combines **traditional farming landscapes** with high biodiversity, making it a hotspot for conservation and sustainable rural development.

Goričko is a **Natura 2000 site** with a high share of species-rich grasslands, but under pressure from land abandonment and intensification. It's a key site for **nature-based solutions for**

pollinators, involving stakeholders like the **Goričko Nature Park Public Institution**, farmers, and environmental associations [4]

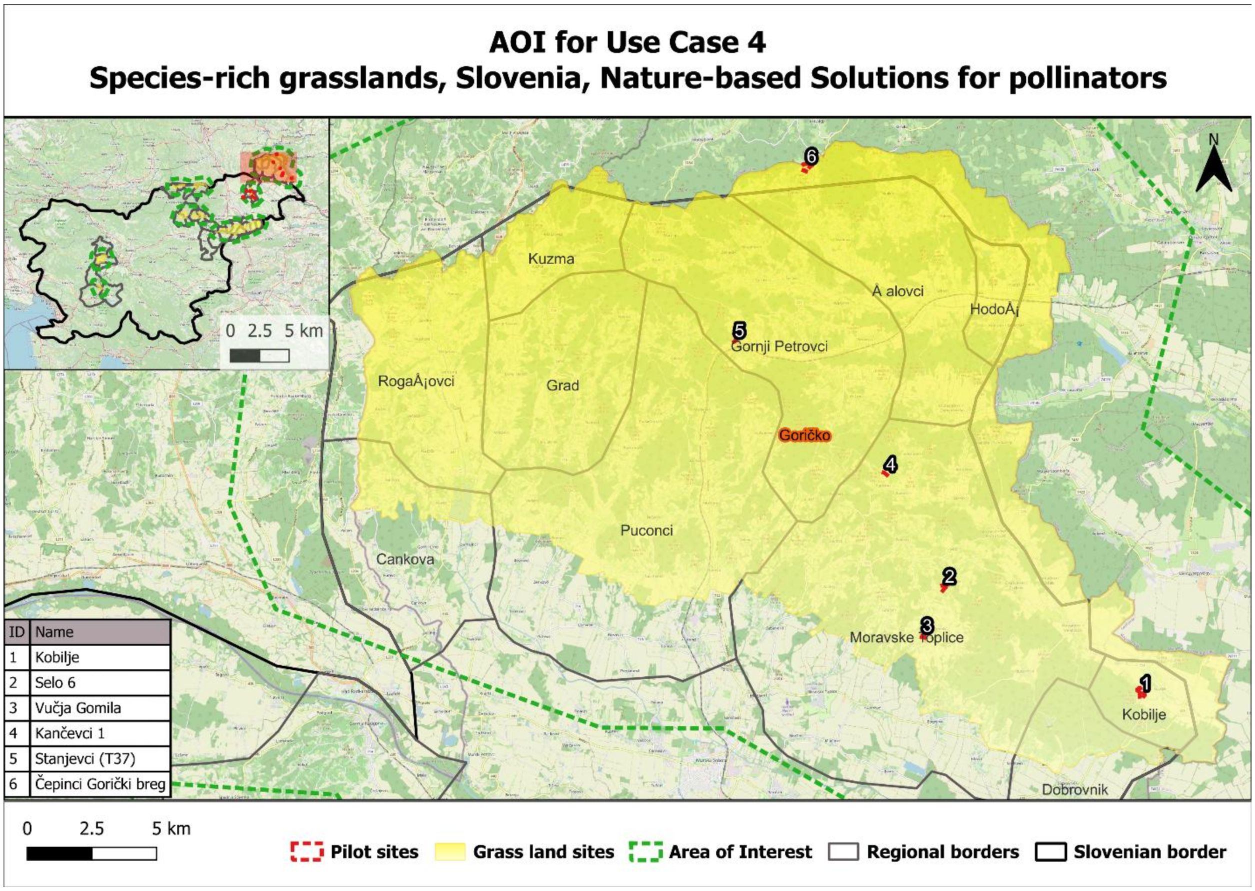


Figure 4 - AOIs map for UC4 (North-East area 1)

- **Site 2: Slovenske gorice** – Forgotten Natura 2000 site, under pressure
- Intensive farms managing the grasslands
    - The **largest hilly region** in Slovenia, covering 1,017 km².
    - Divided into **Western** and **Eastern** Slovenske gorice (Prlekija).
    - Known for **vineyards and wine**, with Lenart as the central town.
    - Part of the **Natura 2000 network**, and the only nesting site of the **European roller** (Coracias garrulus) in Slovenia.
        - Other parts outside of Natura 2000;
    - Characterized by hilly terrain, a moderately continental climate, and pronounced temperature inversions [4].

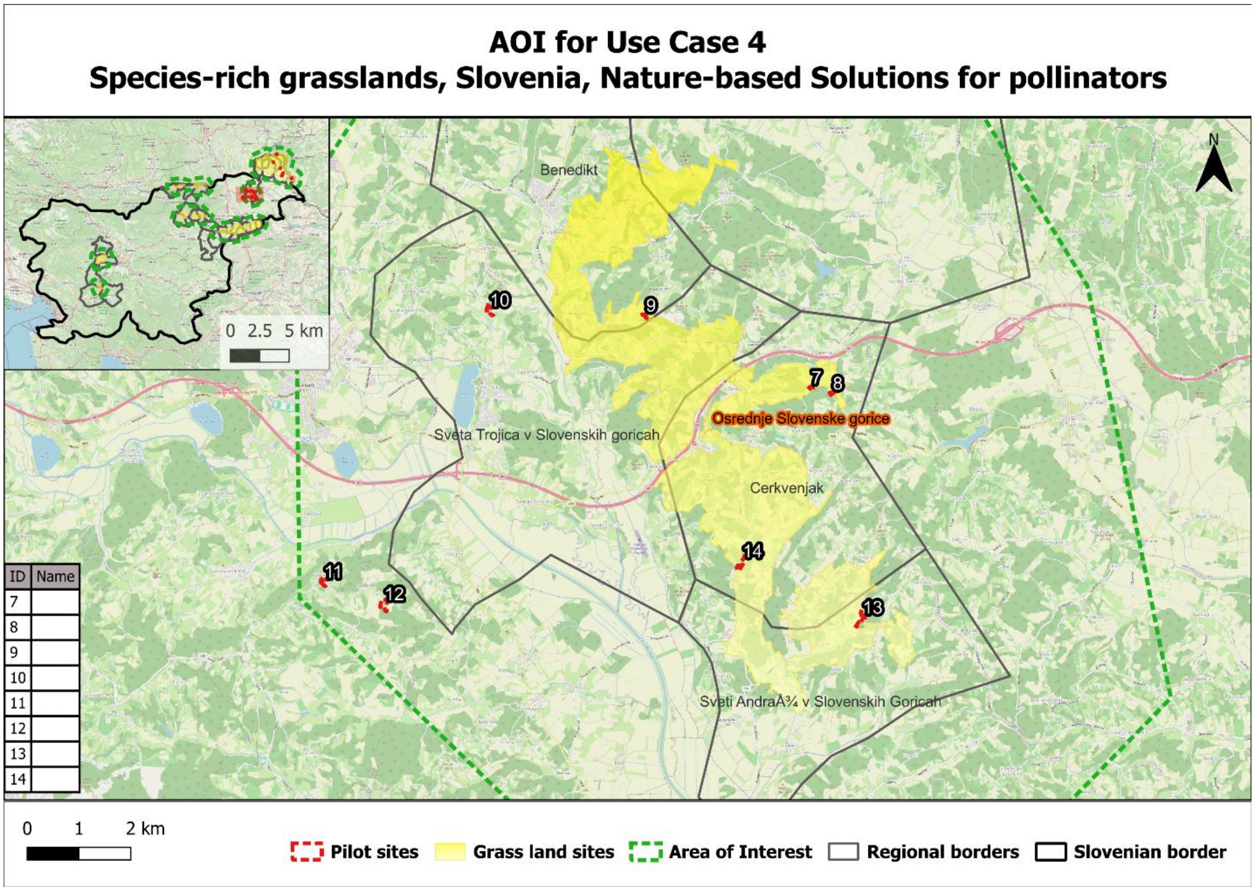


Figure 5 - AOIs map for UC4 (North-East area 2)

Need for Biodiversity Indicators [4]**:**

- **Indicators Needed For:**
  - Pollinator presence and diversity
  - plant species richness
  - Flowering plant diversity ("colourfulness")
  - Habitat quality and conservation status
  - Landscape features (hedgerows, wetlands, meadows)
- **Monitoring Tools:** for grassland health and ecosystem services.
  - Remote sensing for landscape-level biodiversity
  - Ground validation in pilot sites
- Indicators are vital for result-based schemes and financial mechanisms (CAP, LIFE, ERDF), linking payments to ecological outcomes.

Financial Mechanisms

- **Supported By** [4]**:**
  - Common Agricultural Policy (CAP)
  - LIFE Programme
  - European Regional Development Fund (ERDF)
  - European Social Fund (ESF)

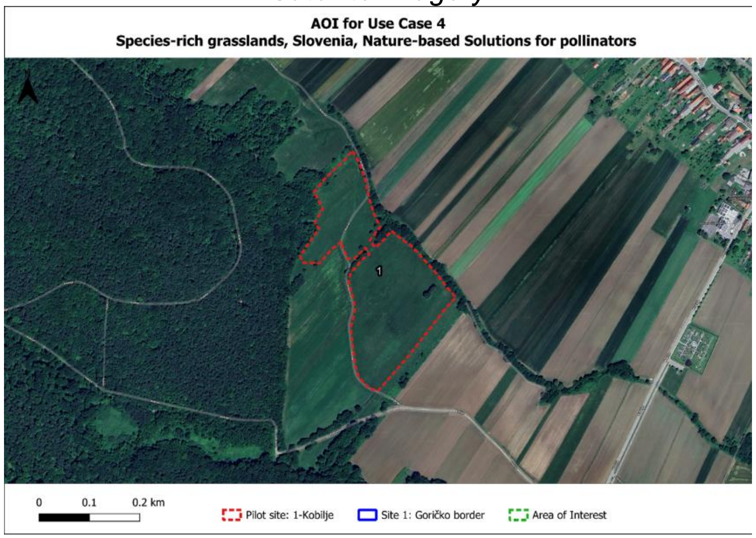
    - EEA and Norway Grants
    - Slovenia's Climate Fund
- **Challenges** [4] **:**
    - CAP payments are often not linked to ecological outcomes
    - Prescriptive schemes discourage farmer participation
- **Opportunities:**
    - Result-based payments
    - Biodiversity credits
    - Nature-based solutions for pollination and soil health

7.4.2 Pilot sites description

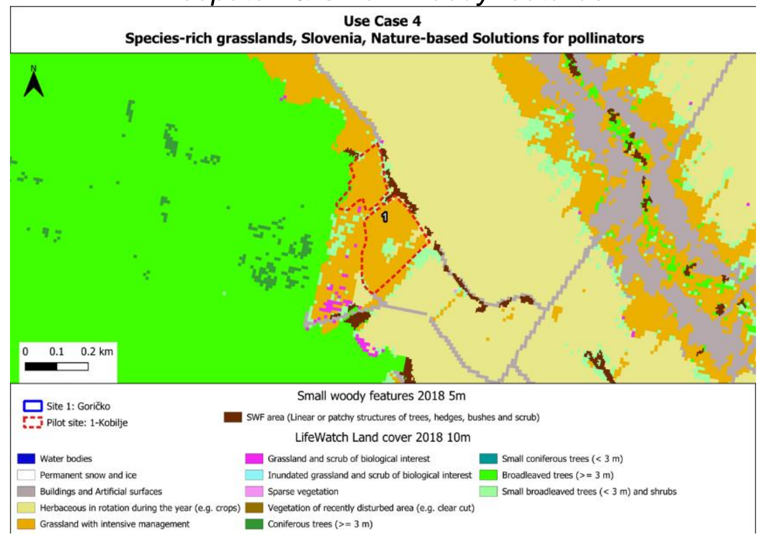
As for UC2, detailed descriptions of each pilot site, i.e. areas to be monitored in the context of the project, can be found in the next pages. Three maps are included that highlight the specificities of each location (see section 7.2.2 for details on map sources).

7.4.2.1 Site 1- Goričko Landscape Park, Field 1

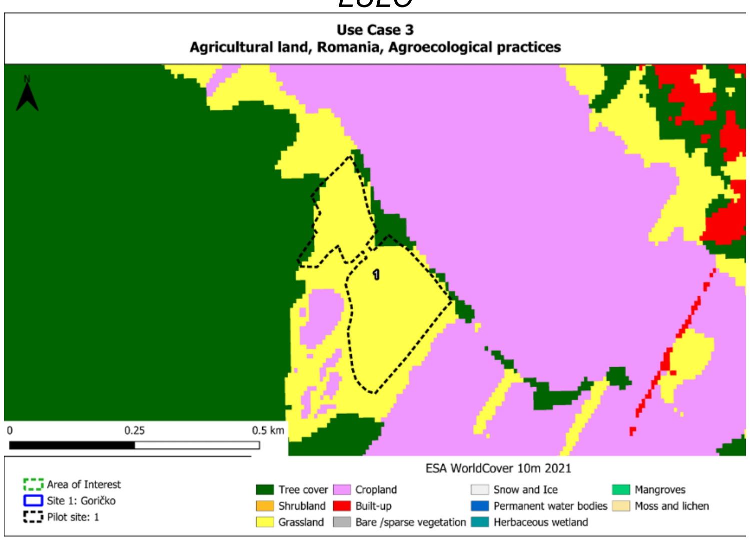
Satellite imagery



Ecopatch & Small Woody features



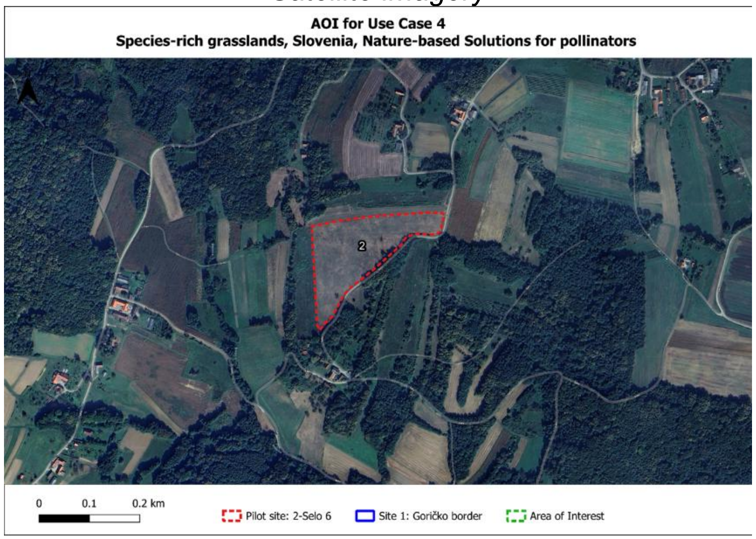
LULC



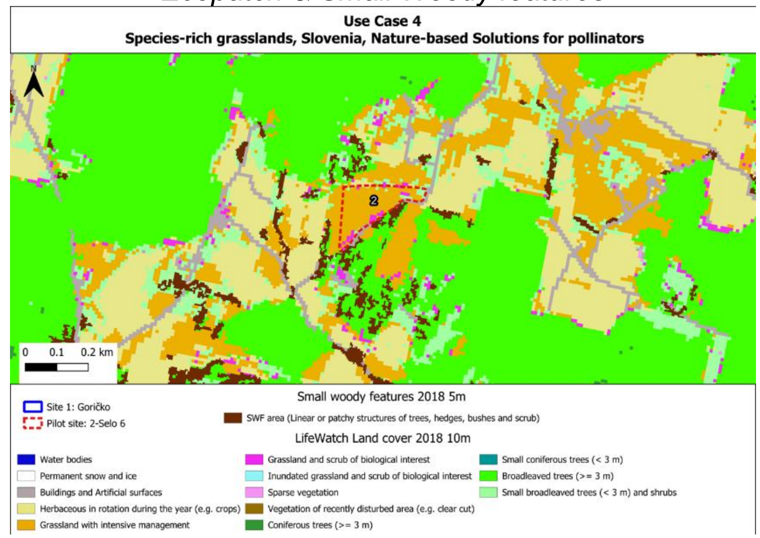
Grassland area with intensive management surrounded on the East by cropland fields (herbaceous in rotation during the year) over approximately 500m. A residential area is observed further East. To the West, the pilot area is surrounded by broadleaved trees (≥ 3m) over several kilometers.

7.4.2.2 Site 1- Goričko Landscape Park, Field 2

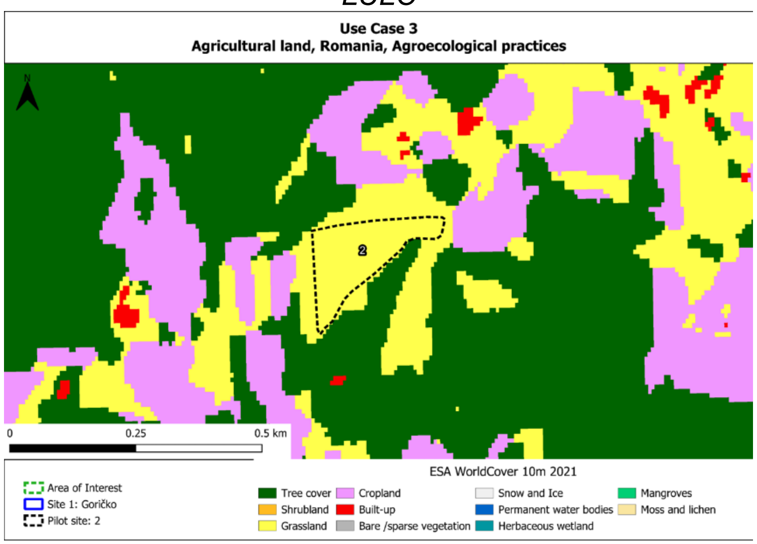
Satellite imagery



Ecopatch & Small Woody features



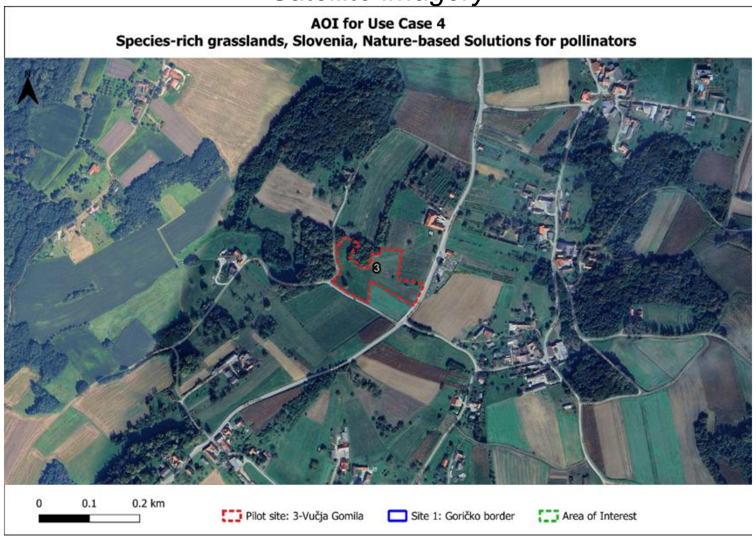
LULC



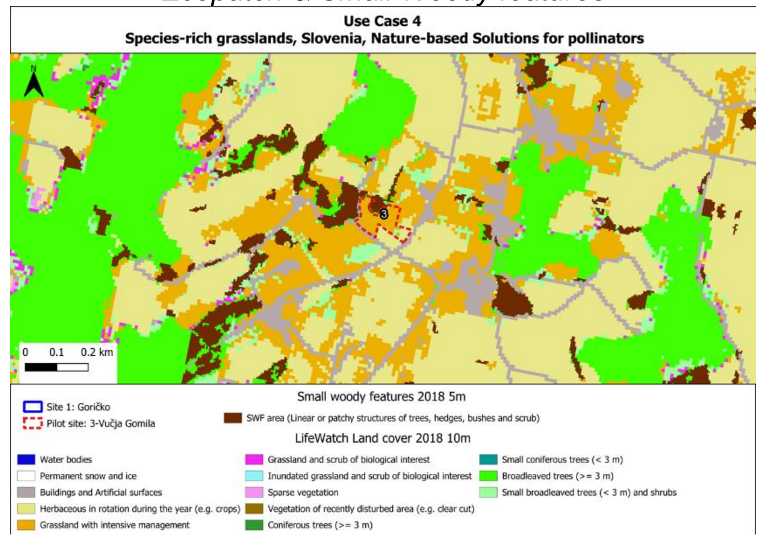
Grassland area under intensive management, with small wooded areas along the edges. This pilot site is surrounded by other grassland areas, by cropland fields (herbaceous in rotation during the year), and by broadleaved trees (≥ 3m).

7.4.2.3 Site 1- Goričko Landscape Park, Field 3

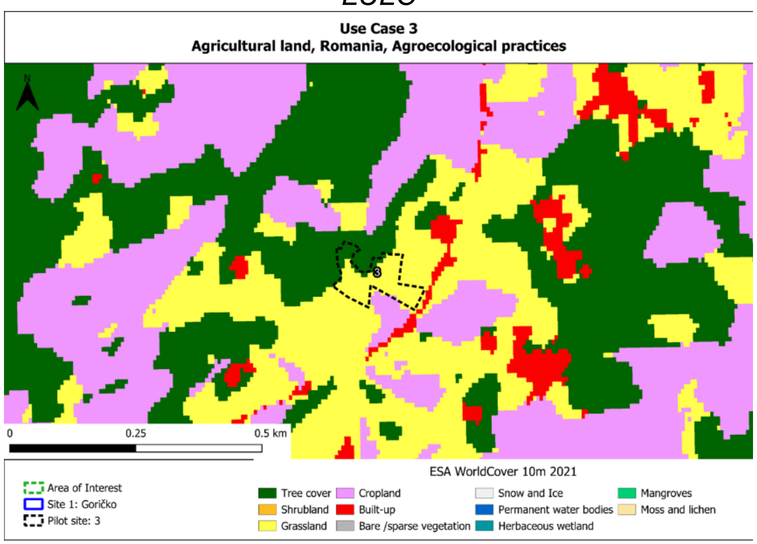
Satellite imagery



Ecopatch & Small Woody features



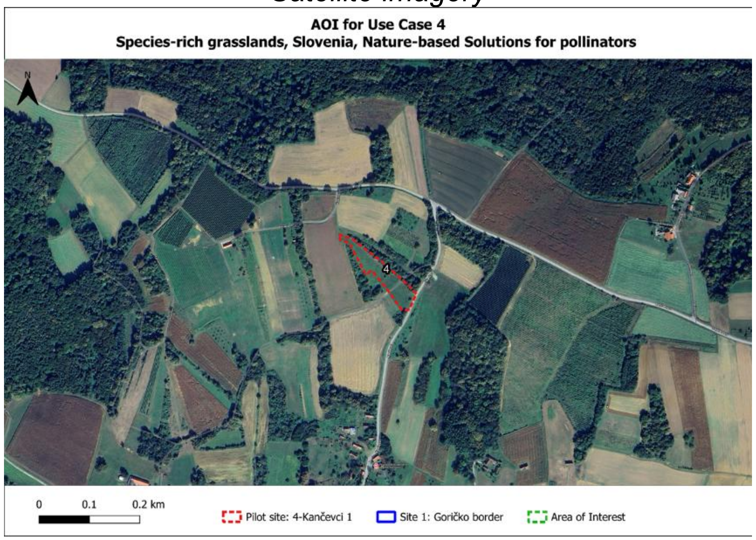
LULC



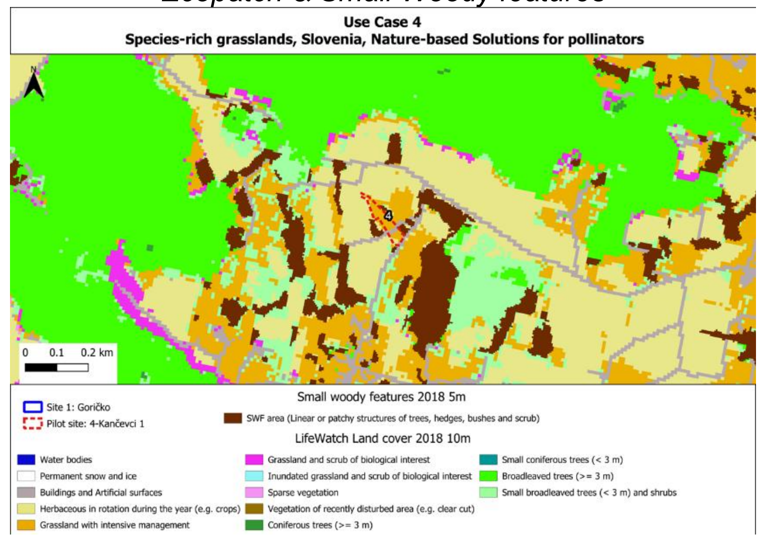
Grassland area with intensive management surrounded on the northwest by small wooded areas and broadleaved trees (≥ 3m). This pilot site is directly surrounded by other grassland area and by cropland fields (herbaceous in rotation during the year) over 2 kilometers. We also have broadleaved trees (≥ 3m) 100 meters North of the site and 400 meters to the East.

7.4.2.4 Site 1- Goričko Landscape Park, Field 4

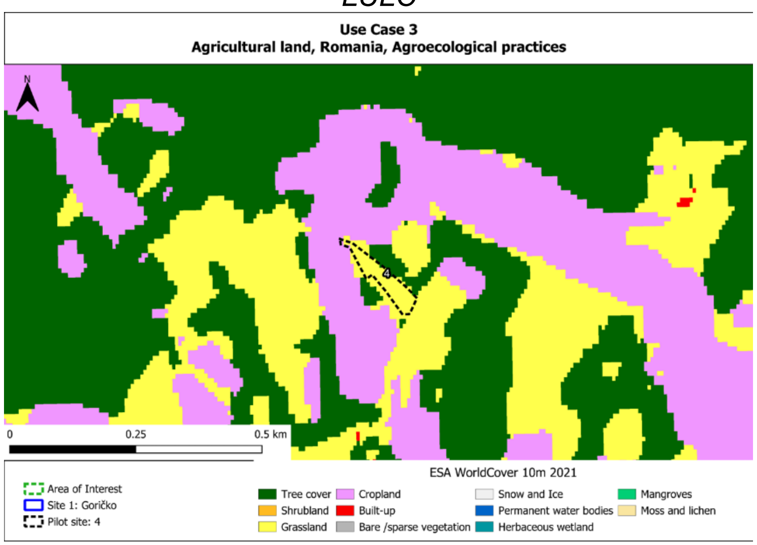
Satellite imagery



Ecopatch & Small Woody features



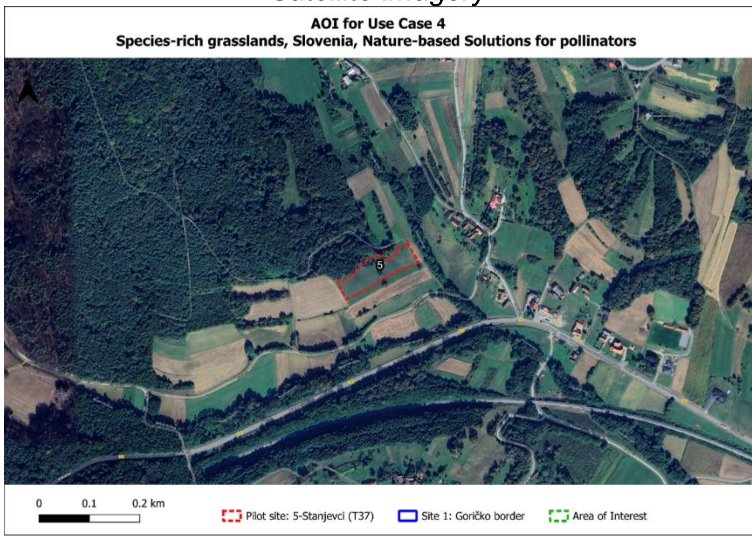
LULC



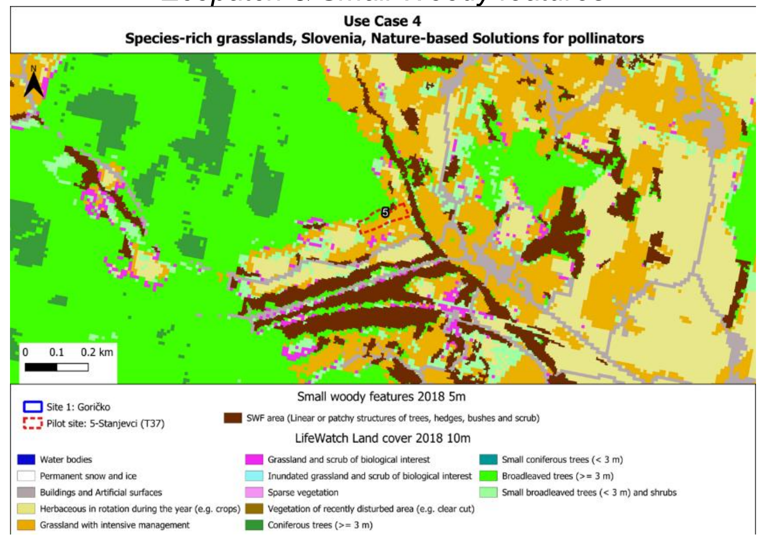
Grassland area with intensive management directly surrounded by other grassland areas and by cropland fields (herbaceous in rotation during the year). The area also includes many small broadleaved trees (< 3m) and shrubs. There are also large areas of broadleaved trees (≥ 3m) less than 300 meters to the North and West and a small area is also located 100 meters to the East.

7.4.2.5 Site 1- Goričko Landscape Park, Field 5

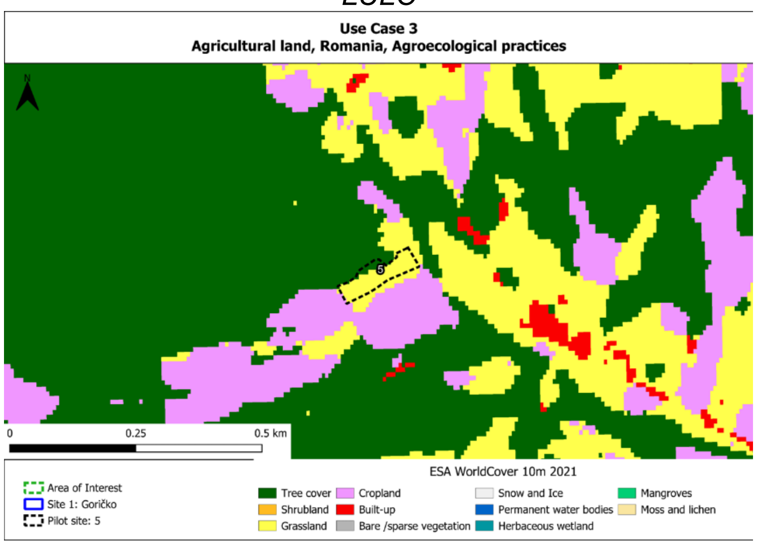
Satellite imagery



Ecopatch & Small Woody features



LULC

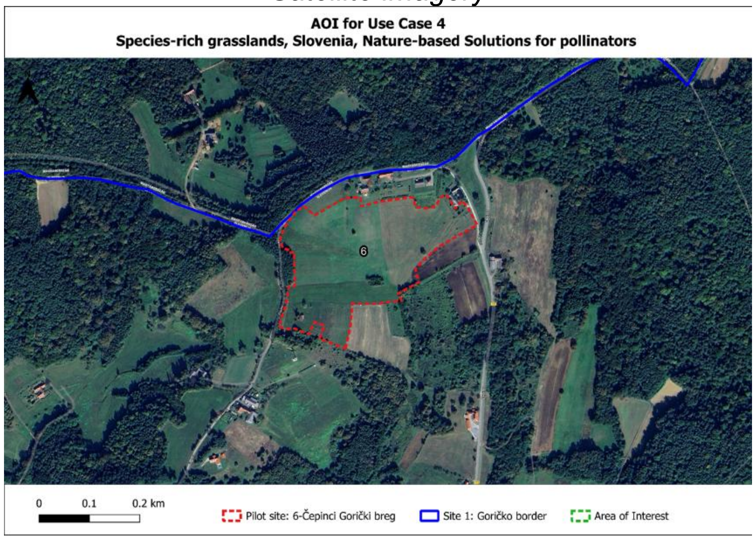


Grassland area with intensive management directly surrounded to the South and West by cropland fields (herbaceous in rotation during the year). It is bordered to the north by a large area of broadleaved trees (≥ 3m).

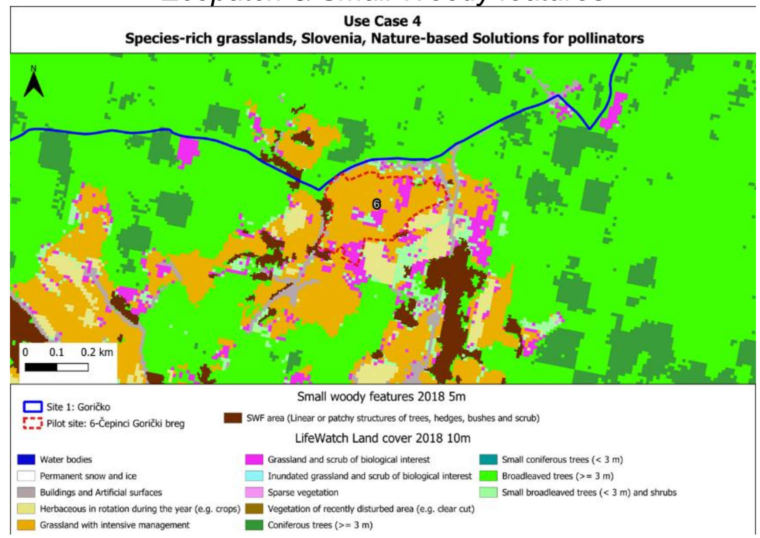
On a larger scale, the southern and eastern areas include mainly grasslands, cropland fields, and small areas of small broadleaf trees (< 3 m) and shrubs, while the northern and western areas include mainly large areas of broadleaf trees (≥ 3 m).

7.4.2.6 Site 1- Goričko Landscape Park, Field 6

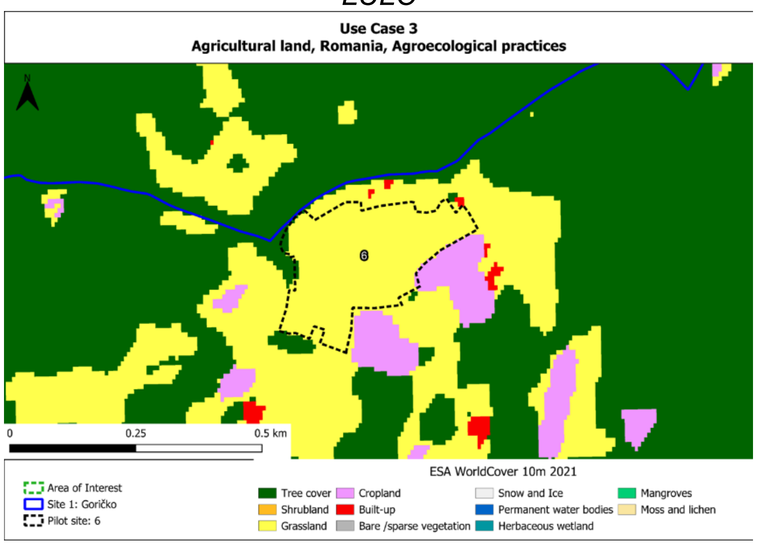
Satellite imagery



Ecopatch & Small Woody features



LULC

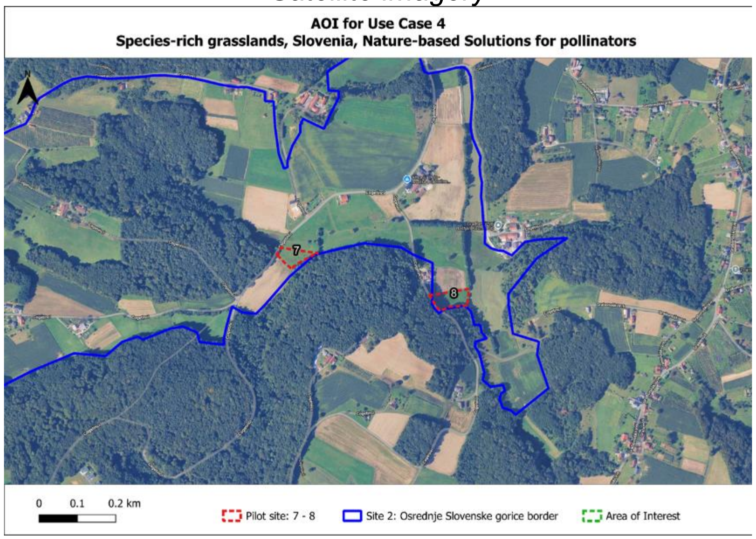


Grassland area with intensive management directly surrounded to the South by other grassland areas and cropland fields (herbaceous in rotation during the year). It is bordered to the North by a large area of broadleaved trees (≥ 3m).

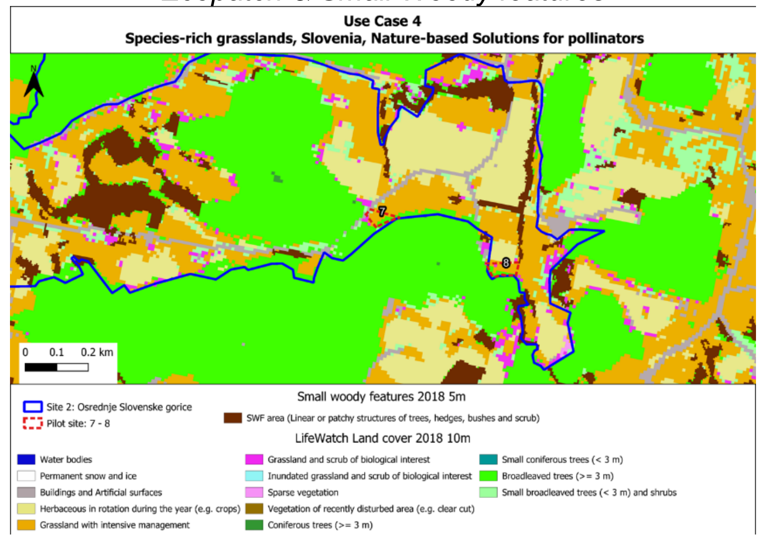
On a slightly larger scale, the South and southwest areas include mainly grasslands, cropland fields, and small areas of broadleaf trees (> 3 m), while the North and southeast areas include mainly large areas of broadleaf trees (≥ 3 m).

7.4.2.7 Site 2: Slovenske gorice, Field 7 & 8

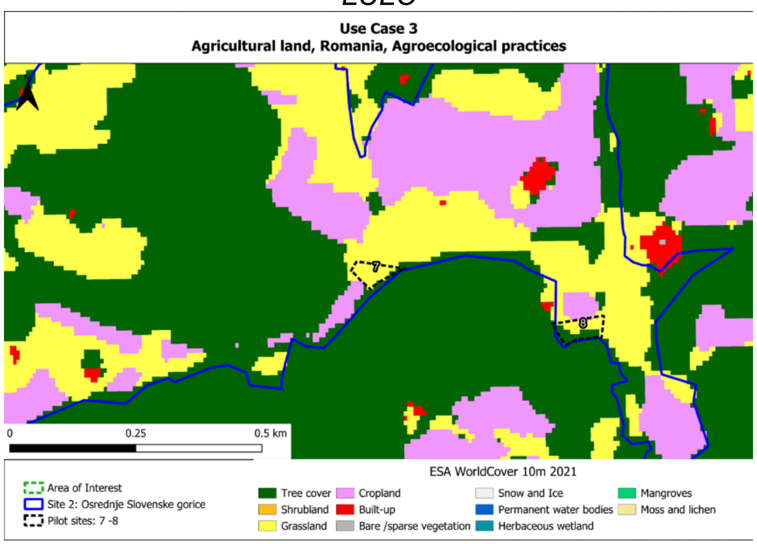
Satellite imagery



Ecopatch & Small Woody features



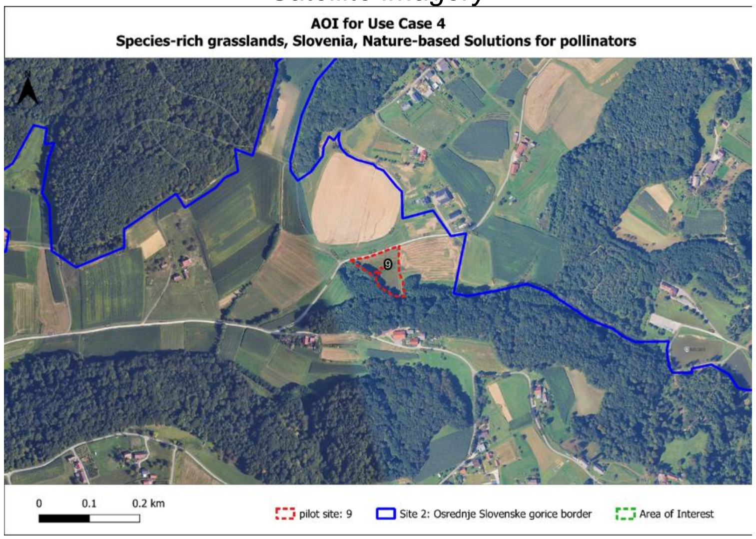
LULC



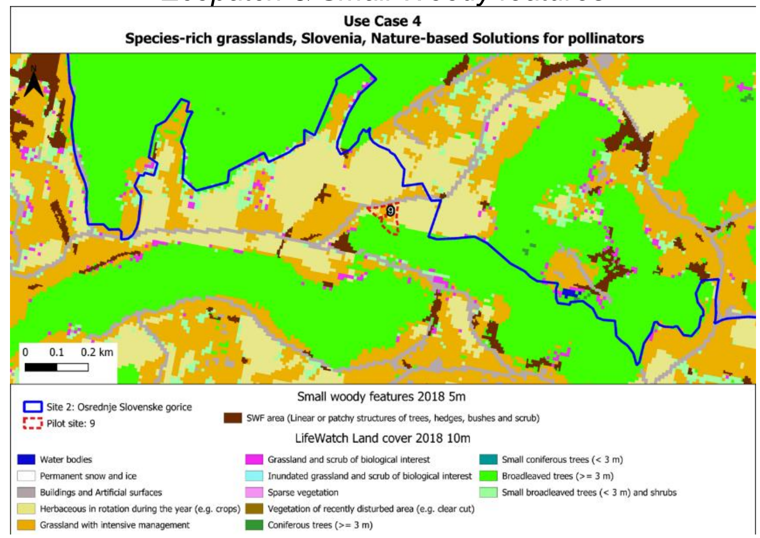
Two grassland areas with intensive management directly surrounded on the South by large areas of broadleaved trees (≥ 3m) and on the northern part by other grassland areas and cropland fields (herbaceous in rotation during the year). On a larger scale, the area includes grassland, cropland (which can be surrounded by small wooded areas) and large areas of broadleaved trees (≥ 3m). We also have on this site few scattered built-up zones.

7.4.2.8 Site 2: Slovenske gorice, Field 9

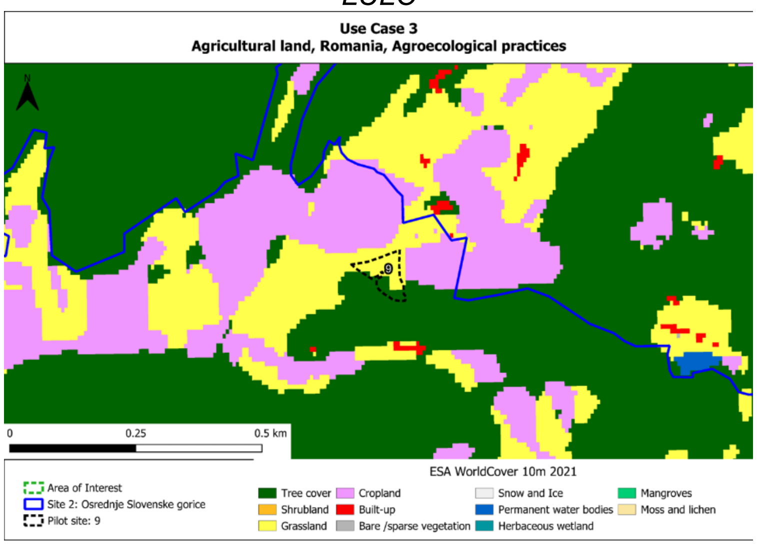
Satellite imagery



Ecopatch & Small Woody features



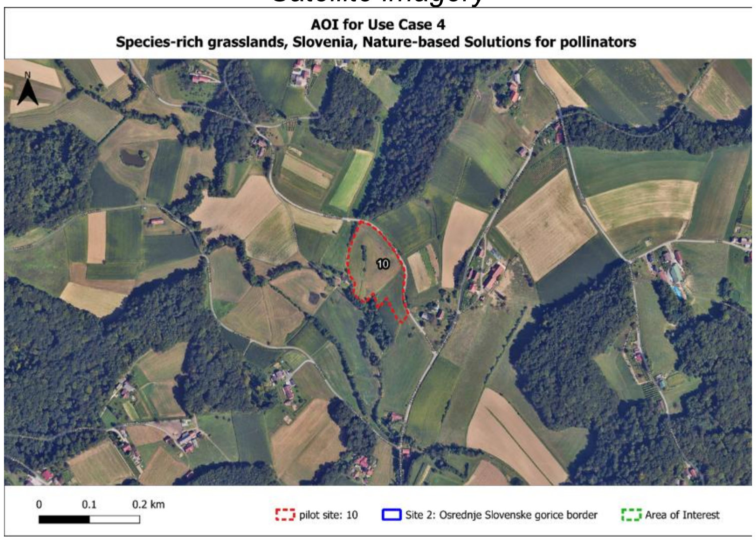
LULC



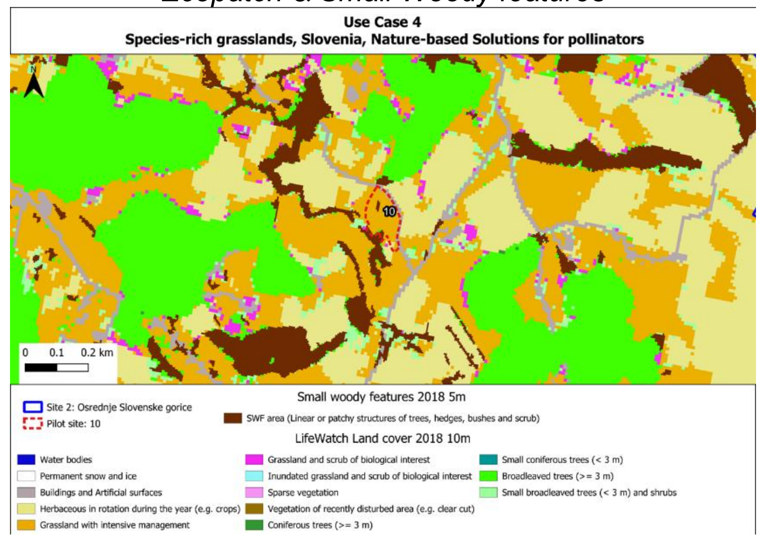
Grassland area with intensive management directly surrounded to the North by other grassland areas and cropland fields (herbaceous in rotation during the year). And to the South by an area of broadleaved trees (≥ 3m).
On a larger scale, the area includes grassland, cropland and large areas of broadleaved trees (≥ 3m). We also have on this site few scattered urban areas.

7.4.2.9 Site 2: Slovenske gorice, Field 10

Satellite imagery



Ecopatch & Small Woody features



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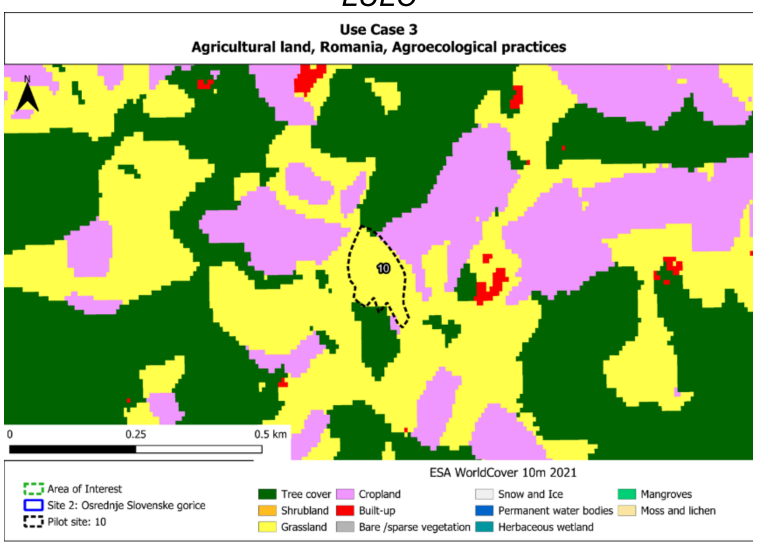
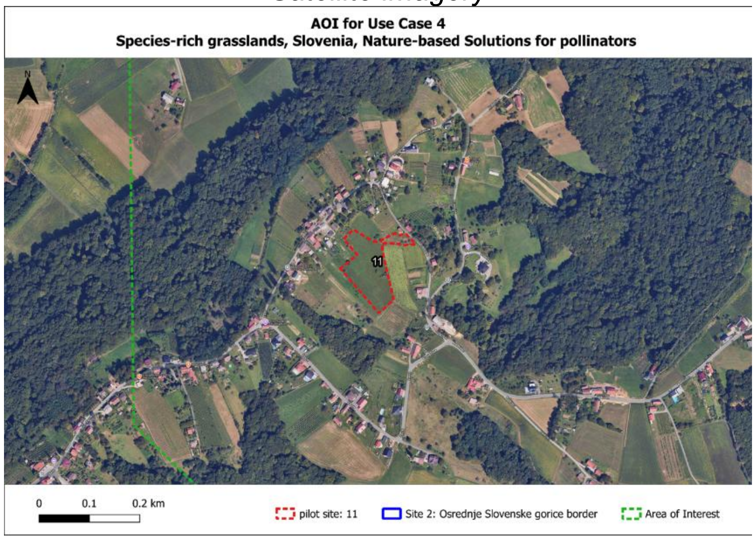


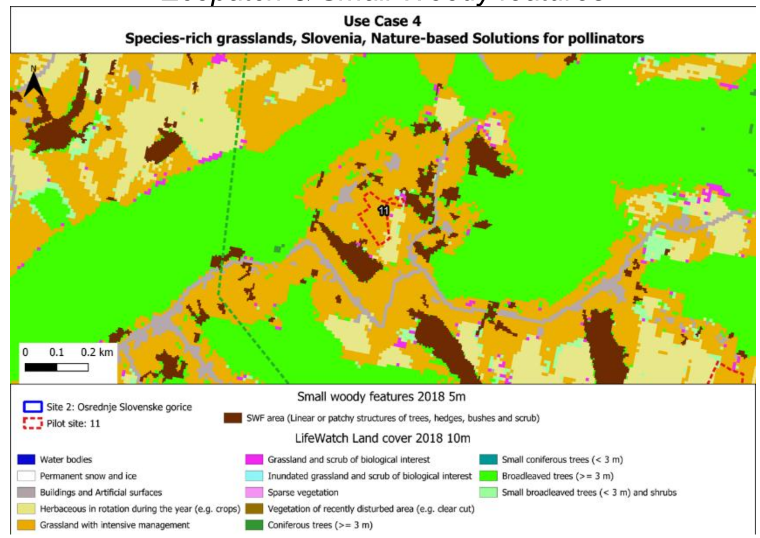
Grassland area with intensive management directly surrounded by other grassland areas and cropland fields (herbaceous in rotation during the year). On the southwestern side, the field includes hedges bordering the adjacent field.
A very small area (less than 40m) in the northern part of the site is connected to a large area of broadleaved trees (≥ 3m).
On a larger scale, the area includes grassland, cropland (which can be surrounded by small wooded areas) and areas of broadleaved trees (≥ 3m). We also have few scattered habitations, and a lake is located less than 1 kilometer from the site.

7.4.2.10 Site 2: Slovenske gorice, Field 11

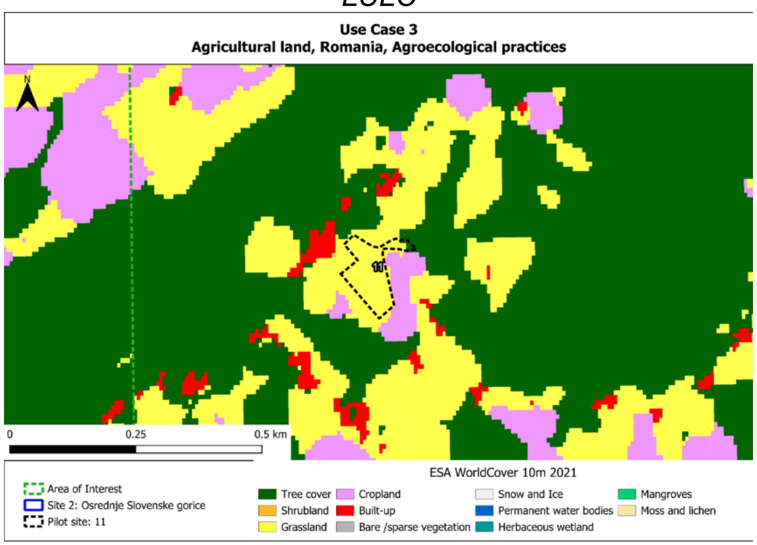
Satellite imagery



Ecopatch & Small Woody features



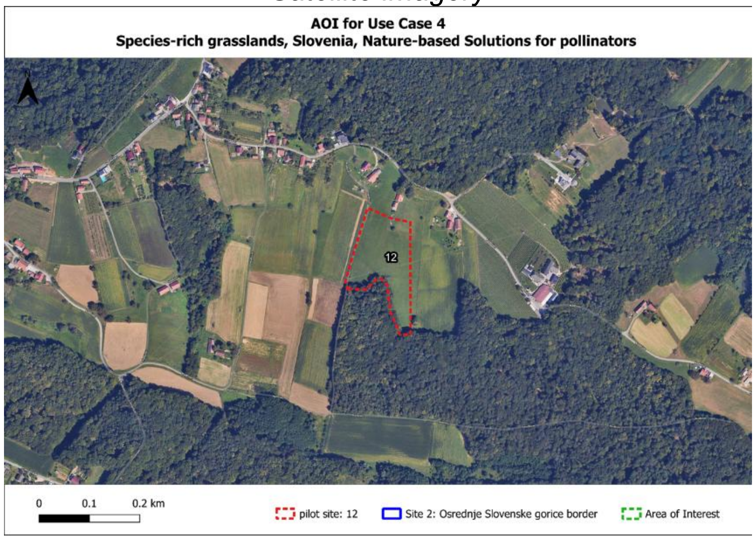
LULC



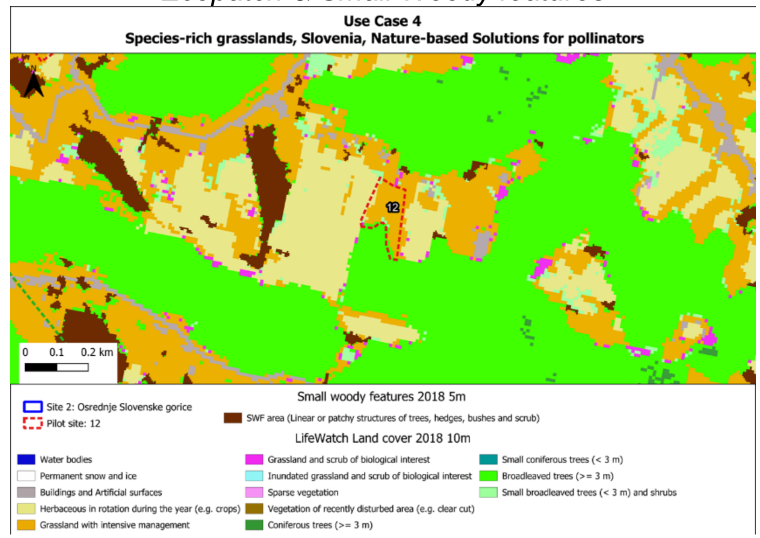
Grassland area with intensive management directly surrounded by other grassland areas and cropland fields (herbaceous in rotation during the year). There are also numerous built-up areas, some of which are located on the edge of the site (to the North and East).
Small area of broadleaved trees (≥ 3m) are located at less than 50m of the site.
On a larger scale, the area includes grassland, cropland, areas of broadleaved trees (≥ 3m), and some residential areas.
This site is located near site 12.

7.4.2.11 Site 2: Slovenske gorice, Field 12

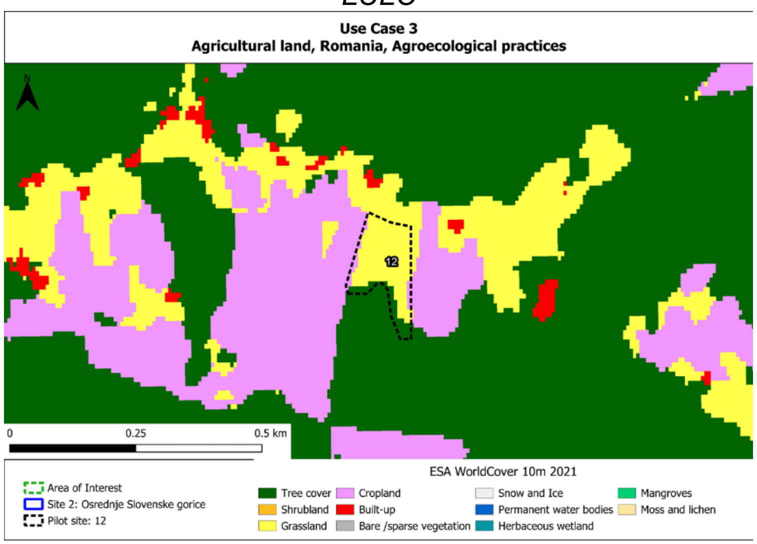
Satellite imagery



Ecopatch & Small Woody features



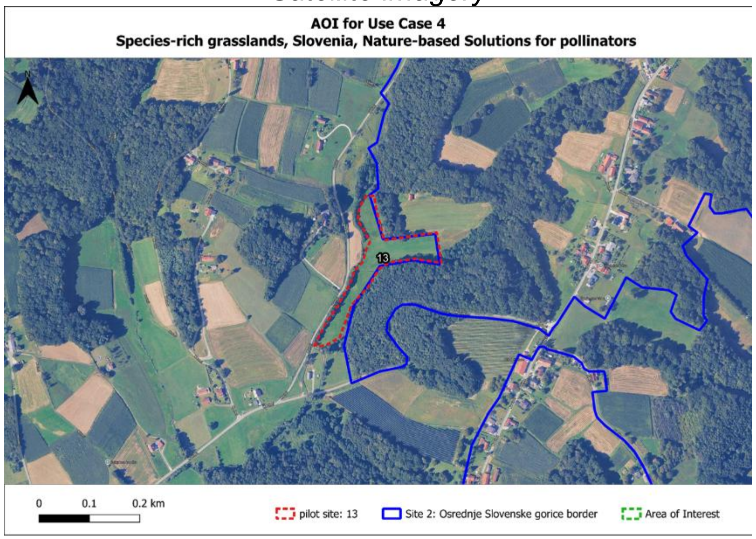
LULC



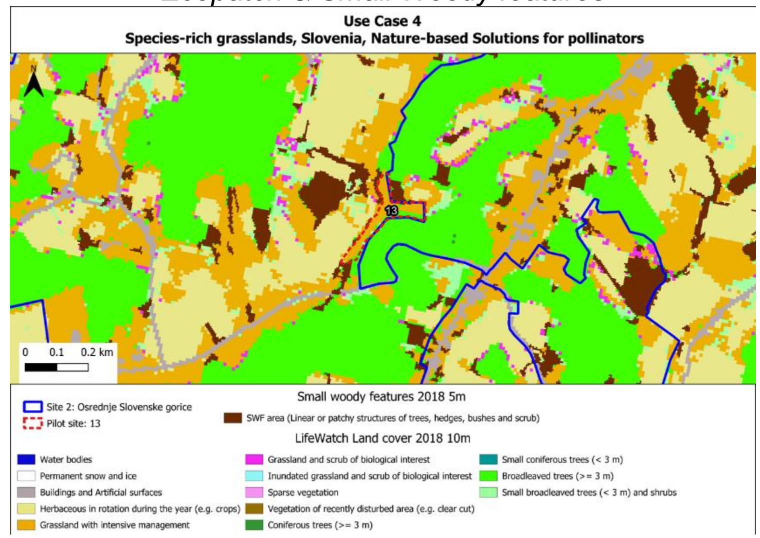
Grassland area with intensive management directly surrounded by cropland fields (herbaceous in rotation during the year) to the East and West, by area of broadleaved trees (≥ 3m) to the South and by residential areas to the North (just a few houses, broadleaved trees are located less than 100 meters North of the site).
On a larger scale, the area includes cropland, grassland, large areas of broadleaved trees (≥ 3m), and some residential areas. This site is located near site 11.

7.4.2.12 Site 2: Slovenske gorice, Field 13

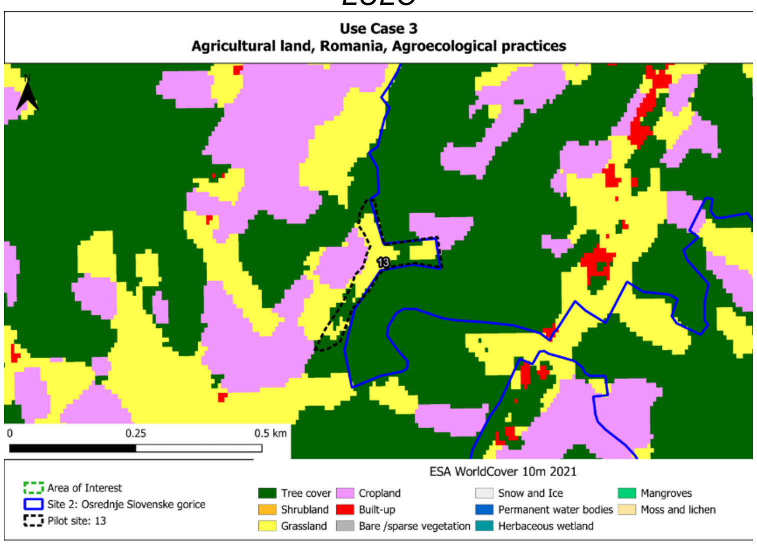
Satellite imagery



Ecopatch & Small Woody features



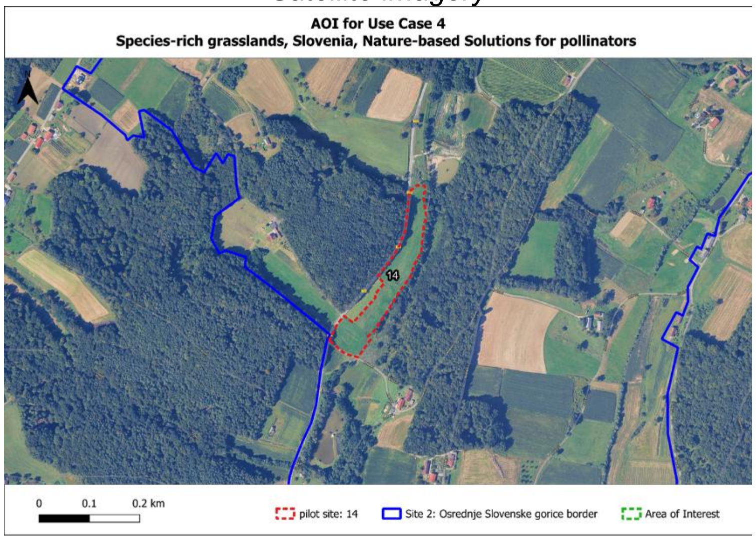
LULC



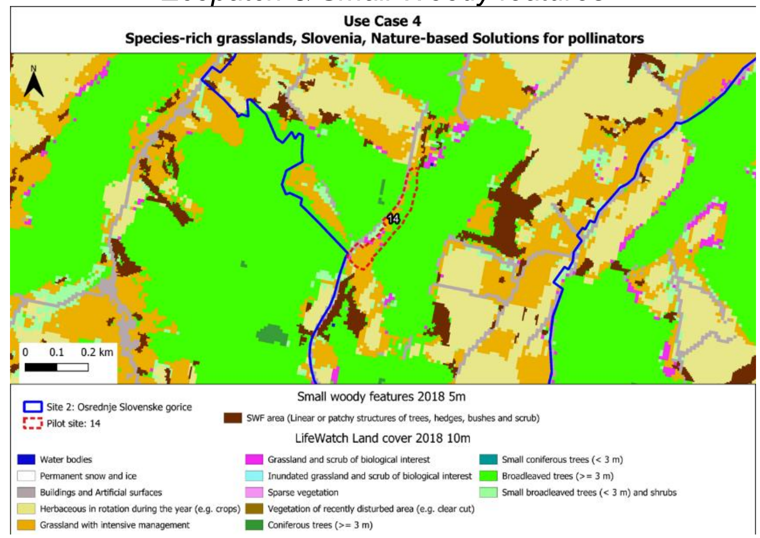
Grassland area with intensive management directly surrounded by hedges and small wooded areas which separate the site along the entire western part of the cropland fields (herbaceous in rotation during the year) and grassland.
The northern and eastern parts are mainly areas of broadleaved trees (≥ 3m).
On a larger scale, the area includes cropland, grassland, large areas of broadleaved trees (≥ 3m), and some residential areas.

7.4.2.13 Site 2: Slovenske gorice, Field 14

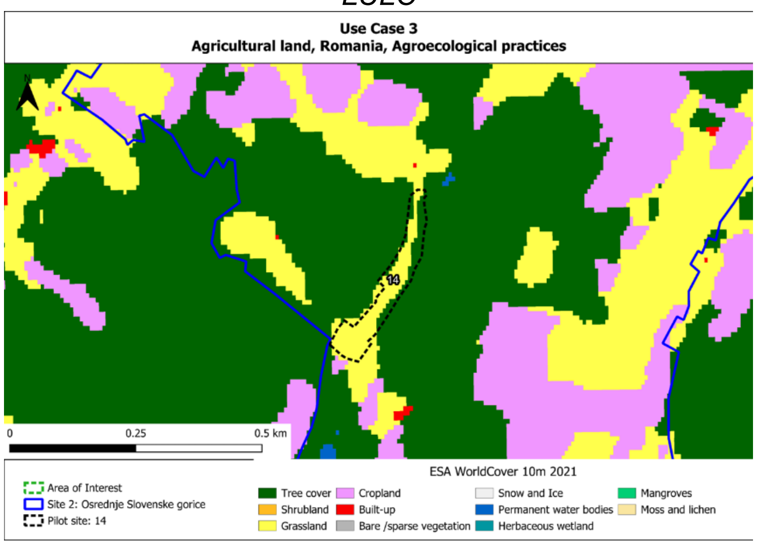
Satellite imagery



Ecopatch & Small Woody features



LULC



Grassland area with intensive management mainly surrounded by areas of broadleaved trees (≥ 3m). Near the site (less than 50m), there are areas of grassland and cropland.
On a larger scale, the area includes large areas of broadleaved trees (≥ 3m) but also cropland and grassland.

7.4.3 Indicators retained from portfolio and monitoring requirements

This sub-section identifies, for UC4, the indicators considered a priori relevant from the portfolio of Table 3 and specifies the remote-sensing data sources envisaged for their operational implementation, the monitoring periods to be considered, and the ground-truth requirements expected to support validation. The selection reflects the specificities of the species-rich semi-natural grasslands targeted in UC4, distributed across the two Natura 2000 sites of the project (Goričko Landscape Park and Slovenske gorice, 14 fields in total) and the Annex I habitat types they host (6210, 6410, 6510 and 6520). The retained indicators and acquisition specifications are preliminary at the time of RP1 and will be consolidated, refined or extended during RP2, in line with the living-deliverable approach described in section 8.2. The actual subset of indicators to be operationalised will further depend on the financial-mechanism perspective consolidated in section 8.3.

7.4.3.1 Indicators retained from the portfolio

The most promising indicators marked under column "4 SI" of Table 3 are retained for UC4. They are grouped below by thematic family to support subsequent prioritization and remote-sensing requirement analysis. The grassland-specific family is the distinctive component of UC4, alongside the universal indicators that anchor the landscape and vegetation context.

- **Landscape structure and habitat composition**: habitat type ratio, land use change, tree canopy surface monitoring, deforestation / cut event detection, tree canopy height, agroforestry belts / woods detection;
- **Vegetation status and dynamics**: vegetation health and productivity (through NDVI, EVI, LAI, fAPAR, FCover, Cab, LST), vegetation water content (through NDWI, Cw);
- **Grassland type and crop identification**: crop detection / crop mask, mixed crop detection, grassland type detection (permanent vs temporary);
- **Grassland management practices**: mowing / cut event detection, delayed mowing, identification of refuge (unmown) zones, grazing management, fertilization detection (grasslands);
- **Agroecological infrastructure and biodiversity features**: hedgerows detection, hedgerows characterization, quantity of floral resources, diversity of floral resources, native / invasive species detection;
- **Soil and water condition**: soil moisture.

7.4.3.2 Remote-sensing data sources envisaged

The optimal remote-sensing configuration is described below per indicator family. Sentinel data (Copernicus, ESA) constitute the primary backbone of monitoring. Earthdaily Constellation (EDA) is mobilized where high revisit frequency or fine spatial detail is required. Very-high-resolution imagery (Pléiades) is acquired on demand for small-object characterization and reference validation. Landsat (USGS / NASA) can be used in complement for historical baselines. Additional remote-sensing sources (e.g., hyperspectral missions, LiDAR acquisitions, other commercial constellations) may be considered during RP2 if specific indicators justify it.

Throughout this section, “Sentinel-2” refers to the MSI sensor (10–20 m, 13 spectral bands, 5-day revisit), "Sentinel-1" refers to the C-band SAR (5 m × 20 m IW mode, 12-day revisit currently with a single satellite, 6-day when two are operational), and "Earthdaily" refers to the operational capacity progressively activated during the project (up to 5 m multispectral, 22-band hyperspectral-like capability from visible to SWIR + thermal / Land Surface Temperature (LST), daily revisit).

- **Landscape structure and habitat composition**: Sentinel-2 is the optimal sensor for this family. Its 10 m spatial resolution and 5-day revisit are well suited to land-use-change detection on the mosaic landscapes of Goričko and Slovenske gorice (meadows, arable fields, traditional high-trunk orchards, hedgerows, woody patches), habitat ratio computation at the buffer / landscape level, and tree canopy surface monitoring. The Landsat archive is used in complement to extend the historical baseline since 1984, which is relevant for documenting the long-term contraction of species-rich grasslands under abandonment or intensification pressures.
- **Vegetation status and dynamics**: Sentinel-2 is the optimal sensor for the core vegetation indices (NDVI, EVI, NDWI) and for the red-edge biophysical variables (LAI, fAPAR, FCover, Cab) that rely on its dedicated red-edge bands at 20 m. For LST, Sentinel-3 SLSTR (1 km thermal, 2-day revisit) could be used for landscape-scale drought monitoring, while Landsat-8/9 (100 m thermal, 8-day revisit) provides higher spatial detail for field-scale observations. Earthdaily’s daily thermal at 120 m resolution and joint VIS / TIR observations will unlock finer monitoring of water stress, particularly relevant in northeastern Slovenia where summer drought episodes have intensified and threaten Molinia and lowland hay meadows.
- **Grassland type and crop identification**: Sentinel-2 is the optimal sensor for discriminating permanent from temporary grasslands through multi-temporal phenological analysis, and for distinguishing grasslands from arable fields and orchards in the surrounding mosaic. Mixed crop detection in adjacent cultivated fields also relies on Sentinel-2 multi-temporal classification. Sentinel-1 contributes during persistently cloudy periods that are frequent in northeastern Slovenia. Earthdaily's finer spatial resolution (5 m) and daily revisit are valuable to resolve intra-field heterogeneity, both in terms of habitat type micro-mosaics (e.g., wet patches of Molinia meadows interspersed within drier grassland) and in terms of within-parcel management patterns (mosaic mowing, uncut refuge strips), which are characteristic of the UC4 sites.
- **Grassland management practices**: this is the distinctive family for UC4. Sentinel-2 supports mowing / cut event detection through abrupt drops in NDVI and biomass-related indices, with the 5-day revisit setting the lower bound on detection accuracy. Sentinel-1 (C-band SAR) detects mowing events through changes in backscatter signature independently of cloud cover, and is essential for resolving short cloud-occluded windows. Earthdaily's daily revisit is particularly valuable for delayed mowing assessment (precise

dating of the first cut against the optimal phenological reference) and for capturing the contrast between cut and unmown refuge zones at field scale. Grazing management is approached through Sentinel-2 biomass dynamics and structural change, with Sentinel-1 contributing for trampling and bare-patch detection. Fertilization on grasslands is approached indirectly through biomass and Nitrogen Nutrition Index (NNI) signatures from Sentinel-2 red-edge bands.

- **Agroecological infrastructure and biodiversity features**: Hedgerow detection can be initialized from Sentinel-2 (10 m) for elements wider than approximately 10 m, but most hedgerow features in the small-scale Slovenian landscape are below this threshold. Earthdaily's 5 m daily acquisitions improve both detection and seasonal tracking, particularly for the temporal signature of floral resources (colorfulness variation in space and time, central to the quantity and diversity of floral resources indicators which are themselves central to pollinator habitat assessment in UC4). VHR imagery (Pléiades at 0.3–0.5 m) is required for hedgerow characterization (width, gap structure, species diversity proxy). Native / invasive species detection is approached through spectral signatures combined with Earthdaily's hyperspectral-like capability, where the spectral discrimination of indicator species (positive and negative, as defined by the Pratensis taxonomy) becomes feasible. ESA Small Woody Features 2018 provides a baseline reference.
- **Soil and water condition**: Sentinel-1 is the primary sensor for soil moisture estimation (C-band SAR sensitive to surface moisture in the first few centimetres). Earthdaily can refine soil moisture characterization where the daily revisit is critical, particularly during the drying spells affecting Molinia meadows that depend on seasonal inundation.

7.4.3.3 Monitoring periods per indicator family

The monitoring calendar is constructed to match the agroclimatic cycles of northeastern Slovenia (continental climate with Pannonian influences, increasing drought risk, more frequent severe convective storms) and the management regimes characteristic of species-rich grasslands (low-intensity mowing and grazing, late first cut, no mineral fertilization, uncut refuge strips). The cadences indicated below are envisaged for the operational monitoring phase (the precise revisit frequency per indicator and per pilot site will be consolidated during RP2 through the workshops and field visits described in section 8.1).

- **Landscape structure and habitat composition**: a multi-annual baseline of at least five years is required, with annual snapshots for change detection. The full Sentinel-2 archive (since 2015) and the Landsat archive (since 1984) provide the historical context for land-use-change interpretation, including the documented decline of species-rich grasslands under intensification and abandonment.
- **Vegetation status and dynamics**: monitoring is concentrated on the growing season (approximately April to October), with decadal composites during the growing season and monthly composites outside it. Higher temporal resolution (sub-decadal) is of interest for periods of rapid changes (spring green-up, flowering peak, mowing events) and water-

stress windows during summer drought episodes. In those cases, Earthdaily's daily thermal and visible / red-edge revisit becomes most valuable.

- **Grassland type and crop identification**: annual classification at the end of the growing season, with multi-year aggregation to consolidate the distinction between permanent and temporary grasslands.
- **Grassland management practices**: this is the family with the most demanding temporal cadence. Mowing detection requires sub-weekly observations from the start of the growing season (April) to the late summer (September), with particular attention to the optimal mowing date thresholds defined by Pratensis (after mid-June for the late-mowing prescription). Delayed mowing assessment requires comparison of the detected first cut against this reference date. Identification of refuge zones is performed at the end of each cutting cycle. Grazing management monitoring is continuous through the grazing season (typically April to October). Fertilization detection is interpreted on the biomass trajectory across the growing season.
- **Agroecological infrastructure and biodiversity features**: static structural mapping of hedgerows and woody features is performed annually. Flowering monitoring is concentrated between April and September, with sub-monthly observations during the peak flowering windows. Daily Earthdaily revisit is particularly relevant here for the temporal component of the diversity of floral resources indicator (colorfulness variation in time), which is central to pollinator habitat assessment in UC4. Native / invasive species detection through spectral signatures requires acquisition during the flowering window of each indicator species.
- **Soil and water condition**: soil moisture monitoring is continuous, with sub-weekly Sentinel-1 acquisitions sufficient outside dry spells and daily Earthdaily revisit valuable during drought episodes and post-rainfall recovery periods, particularly for Molinia meadows whose habitat condition depends on seasonal water availability.

7.4.3.4 Ground-truth requirements

The validation of UC4 indicators requires four categories of ground-truth data, to be collected through the partnerships established with Pratensis as UC4 lead, UCLouvain as scientific partner for ecological clustering and biodiversity uplift assessment, and the protected-area institutions managing the two Natura 2000 sites (Public Institute Goričko Nature Park; Institute of the Republic of Slovenia for Nature Conservation - ZRSVN). Engagement with the farmers managing the 14 pilot fields is mediated through these institutions. Where applicable, existing national reference datasets (e.g., the Slovenian Land Parcel Identification System managed by ARSKTRP, CAP declarations, Natura 2000 monitoring data, butterfly and bird monitoring datasets) will be reused to reduce the in situ collection effort and anchor the indicator calibration to validated reference data.

Information of interest includes:

- **Management itineraries per parcel**: number and dates of cutting events per year, first-cut date relative to the optimal phenological reference, presence and width of uncut refuge strips, mulching practices, grazing periods and stocking rates, fertilization practices (type, dose, timing / absence), and any restoration interventions (overseeding, scrub clearance).

- **Botanical surveys and species inventories**: floristic composition with explicit reference to the positive and negative indicator species lists defined in the Pratensis taxonomy (5.4 prototype context), habitat condition assessment per parcel against the Annex I habitat types (6210, 6410, 6510, 6520), and presence / abundance of invasive species (Solidago canadensis, Erigeron annuus and others).
- **Pollinator and fauna observations**: butterfly transect data for the target species (Phengaris teleius, Phengaris nausithous, Lycaena dispar), bird surveys for grassland and meadow species, where compatible with ongoing monitoring schemes managed by Slovenian Butterfly Research and Conservation Society, DOPPS-BirdLife Slovenia and other partners.
- **Phenological observations**: flowering periods for indicator species and for hedgerow / scrub elements, timing of grassland green-up and senescence, first-cut date per parcel.

Not all the observations will be made available within the context of the project, and final validation of selected indicators may be limited to the ground-truth dataset ultimately available. Additional public datasets may also be used.

7.5 UC5: River Corridors and Wetland Buffers (UK – South Devon)

7.5.1 Context

Objective: Restoration and protection of riparian and wetland ecosystems through conservation covenants and nature-based solutions [4].

Study Area Strategy:
The Thrushell water catchment serves as the primary pilot site for UC5, representing the baseline conditions where restoration actions will be implemented through the Bio-Capital project. However, since biodiversity restoration and riparian corridor management interventions typically require several years to produce measurable ecological outcomes detectable through remote sensing, three additional demonstration sites were strategically selected in the South Devon region. These sites have undergone similar restoration actions at different temporal stages, providing a chronological gradient that enables the assessment of intervention effectiveness and the validation of remote sensing indicators for biodiversity monitoring.
The demonstration sites were visited in May 2025 and represent typical small-scale farming landscapes in Southwest England, characterized by traditional hedge-bank systems and integrated water management practices. Each site exemplifies different aspects of nature-based solutions implementation, from wetland restoration to invasive species management and riparian buffer enhancement.

Figure 6 - View of typical regional landscape (picture taken from Kit Hill)

Agroecological Context [4]:

- **Region:** Southwest England is characterized by fragmented agricultural landscapes with high connectivity through extensive hedgerow networks. Devon and Cornwall host a rich mosaic of agroecological zones.
- **Landscape Features:** Traditional small fields (typically <5 hectares) bounded by ancient hedge-banks (stone walls topped with diverse woody vegetation), natural grasslands

under rotational grazing, and integrated water management systems. Riparian buffers and wetlands are key features in the pilot sites identified by Westcountry Rivers Trust (WRT), particularly within the river catchment. A recent biodiversity enhancement initiative across 11 reservoirs in the region established baselines for Biodiversity Net Gain (BNG), assessed 41 species, and developed habitat management plans [4]. These landscapes are critical for biodiversity restoration, natural flood management, and ecological connectivity, and are among core goals of Bio-Capital.

- **Land Use:** Mixed dairy and beef farming systems with extensive grassland management, minimal intensive crop cultivation. Agricultural landscapes adjacent to rivers and wetlands and riparian zones are often degraded by conventional farming.
- **Ecological Pressures:** Limited intensification compared to other UK regions, but localized issues including invasive species colonization, stream sedimentation, and habitat fragmentation in riparian corridors. Pollution from intensive agriculture (pesticides, nutrients), habitat fragmentation, erosion, and water stress.
- **Climate Context:** Temperate oceanic climate with high rainfall variability; recent drought conditions (2 months without significant rainfall at the time of visit) affecting typical wetland hydrology.
- **Agroecological restoration** includes riparian buffer zones, wetland rehabilitation, and nature-based flood management. Practices aim to reduce pollution, enhance habitat connectivity, and improve water regulation.

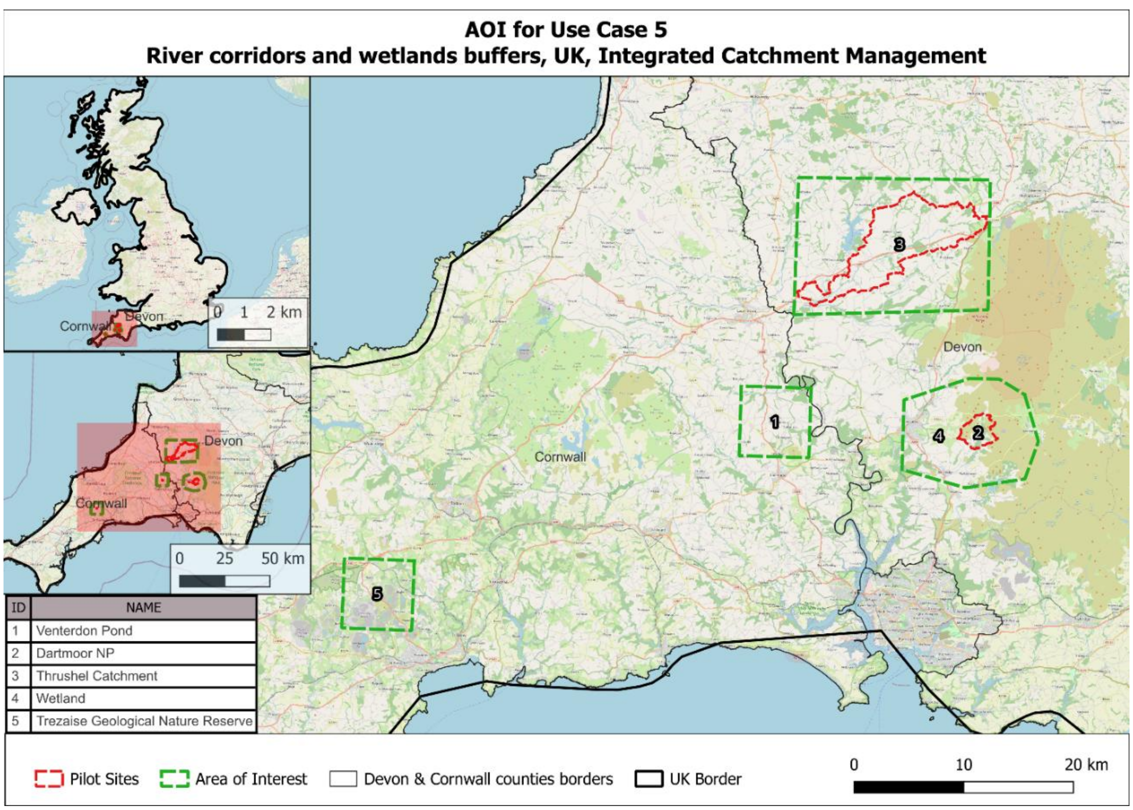


Figure 7 - AOIs map for UC5

Need for Biodiversity Indicators [4]:

- **Key Indicators:**
  - Riparian vegetation establishment and riparian habitat condition and connectivity: Assessment of tree planting success and canopy development over time, quantification of riparian corridor width, and continuity enhancement
  - Vegetation health gradients: Monitoring of habitat transitions from upland grassland to wetland communities
  - Invasive species management: Detection of rhododendron flowering periods and assessment of removal effectiveness
  - Water quality (e.g., nitrogen, phosphates, sediment) and water body dynamics: Detection and temporal monitoring of pond restoration and seasonal water level variations
  - Aquatic biodiversity and pollinator presence (eDNA, species richness)
  - Soil health and erosion control
  - carbon sequestration
- **Monitoring Tools:**
  - Remote sensing for scalable habitat assessment
  - Ground-level data (e.g., soil tests, pesticide modelling)
  - Spatial mapping of riparian zones
  - Indicators support schemes like Upstream Thinking and align with the Water Framework Directive, enabling scalable catchment management.
- **Monitoring Challenges:**
  - Dense canopy cover limits understory monitoring capabilities
  - Small-scale features requiring high spatial resolution imagery
  - Complexity and frequency of assessments, especially for seasonal phenological variations affecting species discrimination
  - Integration of multi-temporal analysis for intervention effectiveness assessment

Innovative Financial Mechanisms:

Conservation Covenant Framework [4]*:*

- **Responsible Body Model:** Westcountry Rivers Trust operates as a legally recognized entity implementing 5-25 year conservation agreements with landowners
- **Payment Structure:** Compensation based on "income foregone" calculations for land removed from conventional agricultural production
- **Asset Protection Contracts:** Differentiated agreements for temporary (5-year) farmed asset protection versus permanent (25-year) built asset conservation

Applicable Instruments:

- **Payments for Ecosystem Services (PES):** Targeted payments for flood mitigation, water quality improvement, and habitat provision. Tailored to riparian and wetland restoration.
- **Biodiversity Net Gain (BNG) frameworks:** Quantified habitat enhancement supporting development of offset requirements
- **Reverse auction mechanisms:** Competitive bidding for cost-effective conservation outcome delivery

- **Insurance-linked products:** Parametric insurance covering restoration investment against extreme weather events

Implementation Challenges:

- Long-term monitoring requirements for outcome verification
- Inflation and cost management in multi-decade contracts
- Legal and operational risks in covenant enforcement
- Integration with existing agricultural support schemes

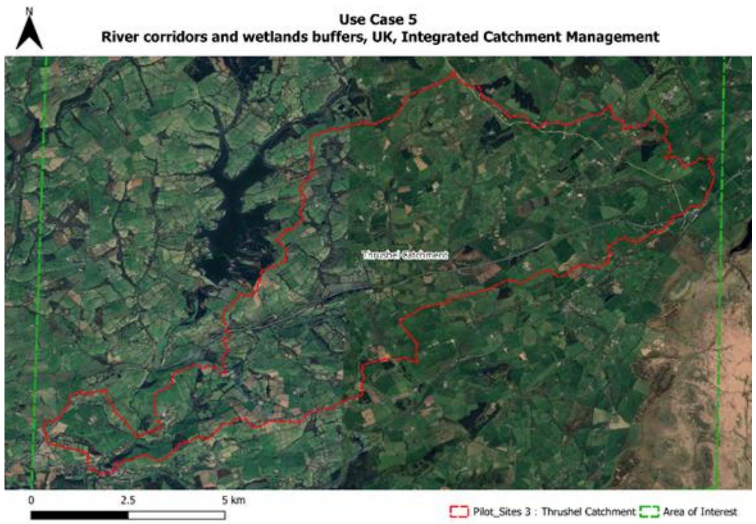
7.5.2 Pilot sites description

Detailed descriptions of baseline site and each pilot site, i.e. each area to be monitored in the context of the project, can be found in the next pages. Four maps are included that highlight the specificities of each location:

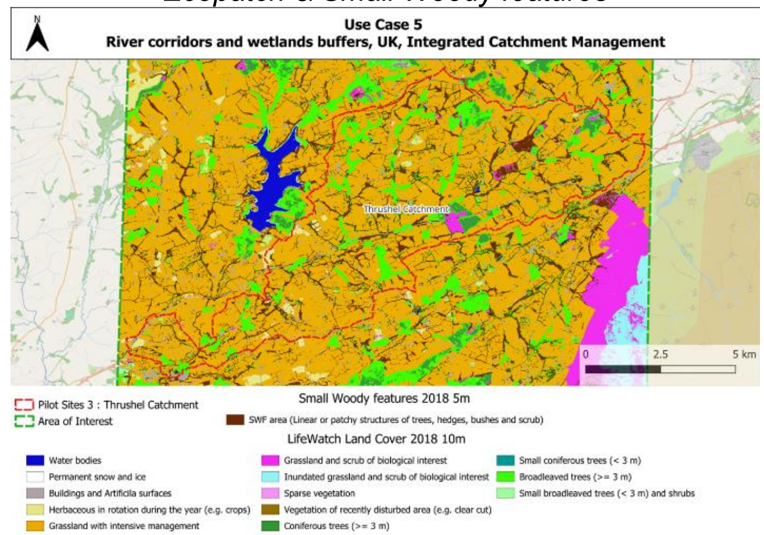
- one general RGB satellite image to identify site location and context (Google imagery)
- Two Land Use / Land Cover maps to highlight units around the field and changes observed at a large scale (ESA WorldCover v2 2021, CLC+ 2023)
- one map that highlights ecosystem environments, using the ecopatch layer (from LifeWatch) and ESA Small Woody features 2018

7.5.2.1 Baseline site: Thrushell water catchment

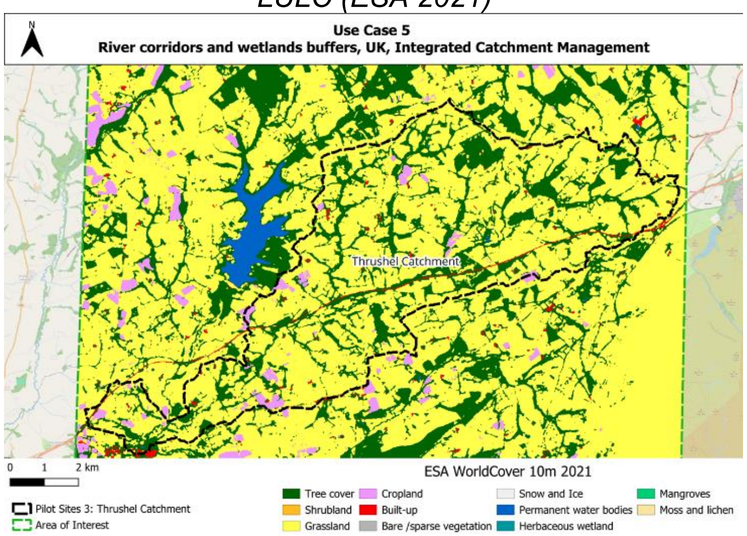
Satellite imagery



Ecopatch & Small Woody features



LULC (ESA 2021)



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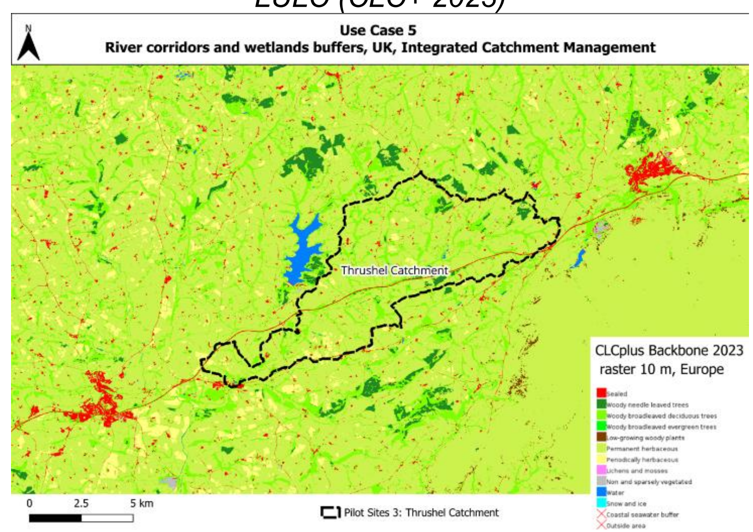


7.5.2.2 Site 1: Small Dairy Farm - Wetland Restoration (1.5 years post-intervention)

Location and Context: Small-scale mixed dairy and beef operation representing traditional South Devon farming systems that avoided post-WWII agricultural intensification. The farm maintains original hedge-bank boundaries and implements rotational grazing on natural grasslands.

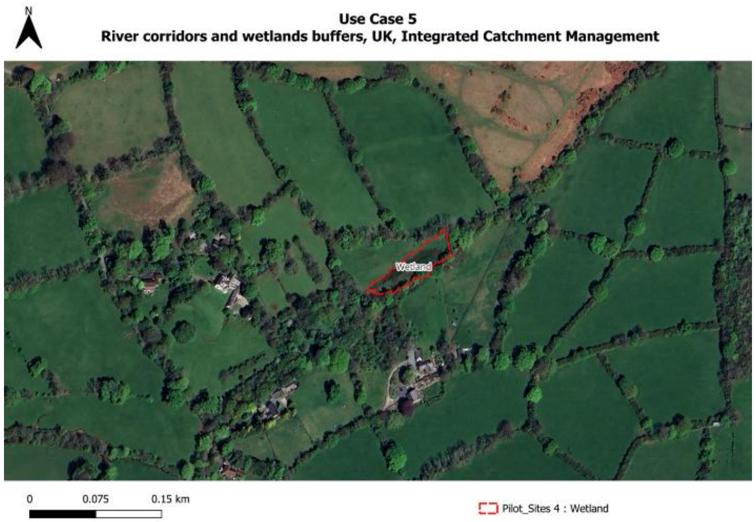
Restoration Intervention: Connected pond system restoration with associated stream corridor enhancement, implemented as part of a regional flood management strategy involving 56 protection basins across the catchment. The intervention specifically targets flash flood mitigation while providing ecosystem co-benefits.

Observed Outcomes: Rapid vegetation regeneration around restored water bodies, with clear habitat differentiation along topographical gradients. Upper slope areas maintain typical grassland communities while lower elevation zones exhibit emergent wetland vegetation characteristics. The restoration demonstrates successful integration of flood management objectives with biodiversity enhancement.

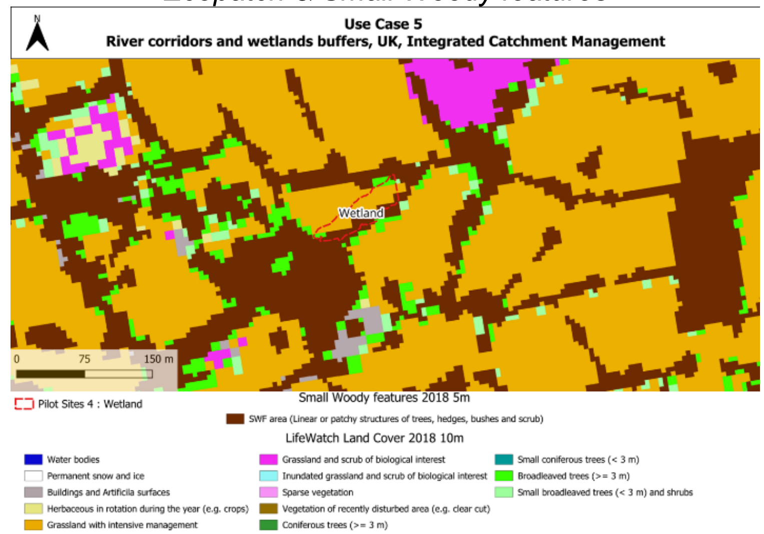
Remote Sensing Implications: Site provides validation opportunities for pond detection algorithms, vegetation health monitoring around water bodies, and habitat transition zone mapping. The 1.5-year timeframe offers insight into early-stage vegetation establishment patterns detectable through multitemporal satellite imagery.

Figure 8 - View of wetland area (back) next to grassland (front)

Satellite imagery



Ecopatch & Small Woody features



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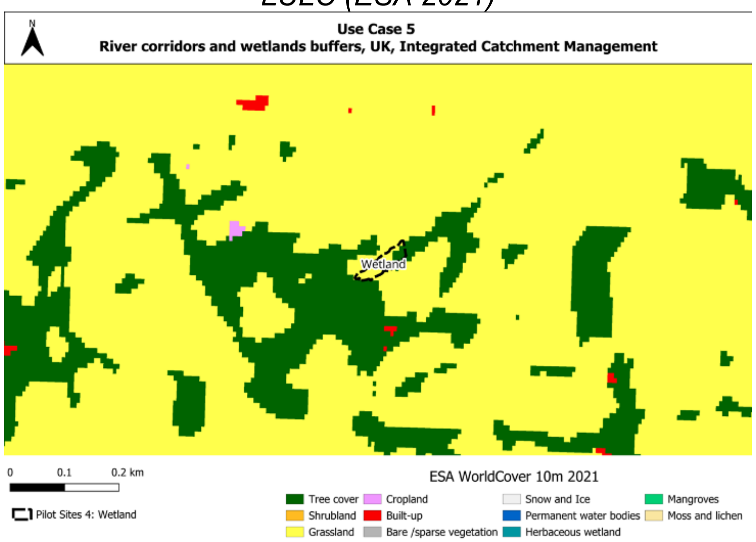

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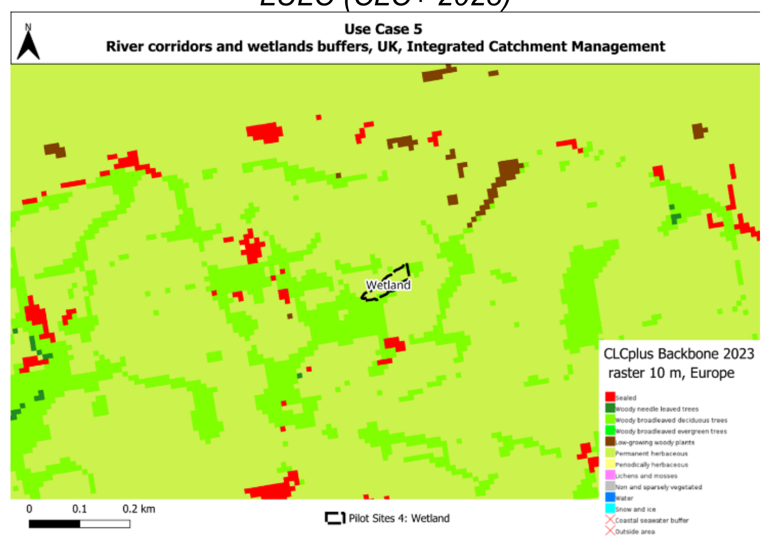


7.5.2.3 Site 2: Wetland Reserve - Invasive Species Management

Location and Context: Established wetland conservation area with dense, diverse vegetation communities and narrow stream systems (<1m width). The site represents high-value biodiversity habitat under active management.

Management Challenge: Active removal of invasive rhododendron (Rhododendron ponticum) with characteristic pink flowering, which forms dense understory thickets that suppress native vegetation and alter habitat structure.

Vegetation Characteristics: Dense canopy cover creating humid understory conditions that prevent effective remote sensing monitoring from above. The site exemplifies the challenges of monitoring forest understory biodiversity and management interventions in closed-canopy environments.

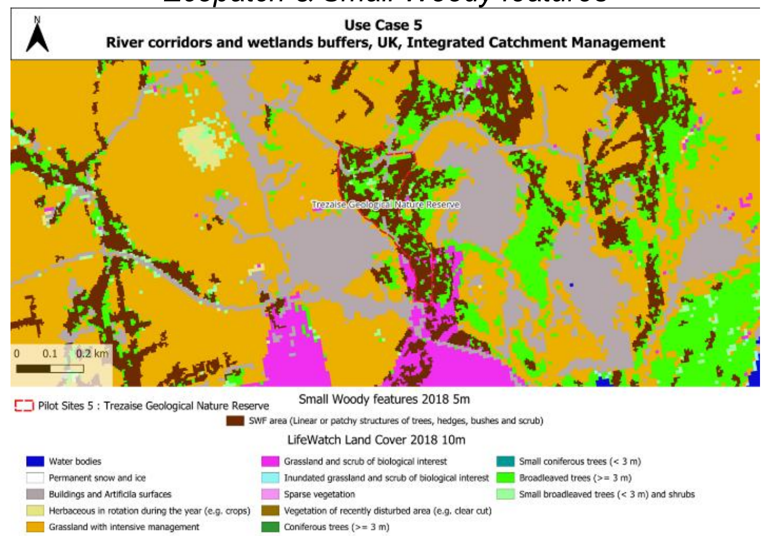
Remote Sensing Applications: Primary monitoring opportunity involves detection of invasive species flowering periods through identification of pink spectral signatures, and monitoring of treatment success through gap analysis and regrowth detection in cleared areas.

Figure 9 - Growth of low vegetation under canopy

Figure 10 - Rhododendron flowers

Satellite imagery

Ecopatch & Small Woody features



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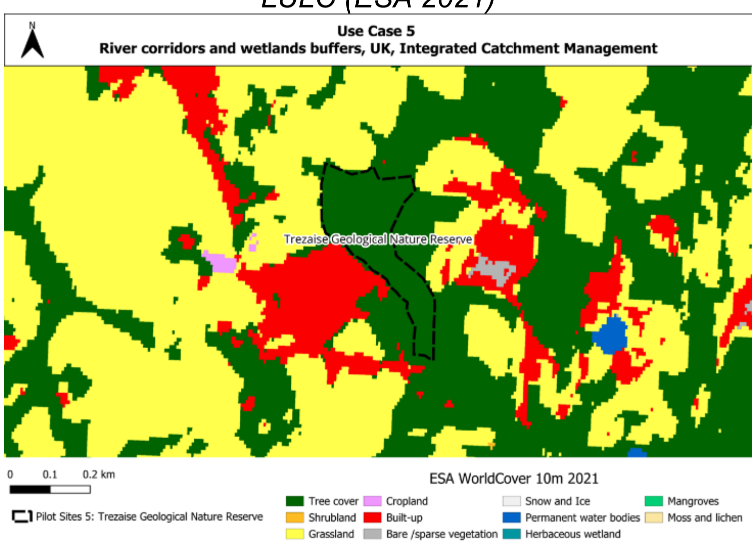

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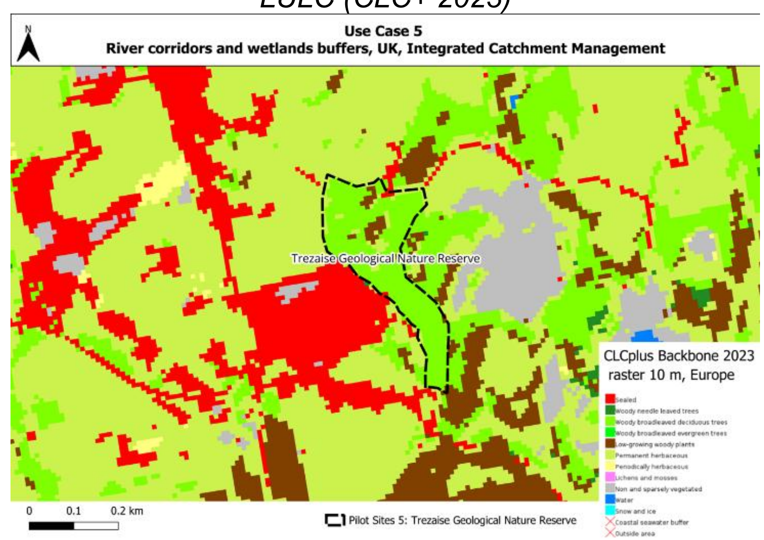


7.5.2.4 Site 3: Duchy College - Riparian Corridor Enhancement (0-12 months post-planting)

Location and Context: Agricultural college demonstration site serving as a model for riparian corridor restoration applicable to typical small farm landscapes across the region. Baseline biodiversity data are available through audio and video monitoring systems.

Restoration Intervention: Systematic riparian buffer widening through native tree planting adjacent to existing hedge-banks. Implementation involves 2-3 rows of native species planted at varying densities, with most recent plantings completed in March 2025.

Hydrological Features: Small stream (2-3m width, shallow) with engineered retention structures creating pond features (3-5m width) partially obscured by existing canopy cover.

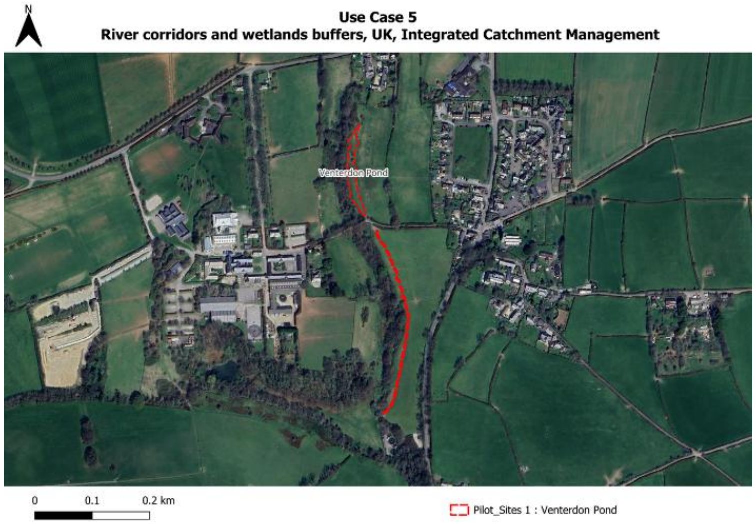
Vegetation Establishment: Recent plantings (March 2025) provide opportunity to monitor early establishment success, while older plantings (12+ months) demonstrate successful canopy closure and habitat development. High planting density strategy anticipates natural mortality and competitive establishment.

Habitat Complexity: Site exhibits patches of wetland-type grassland communities adjacent to riparian zones, providing habitat heterogeneity sufficient for remote sensing detection and validation.

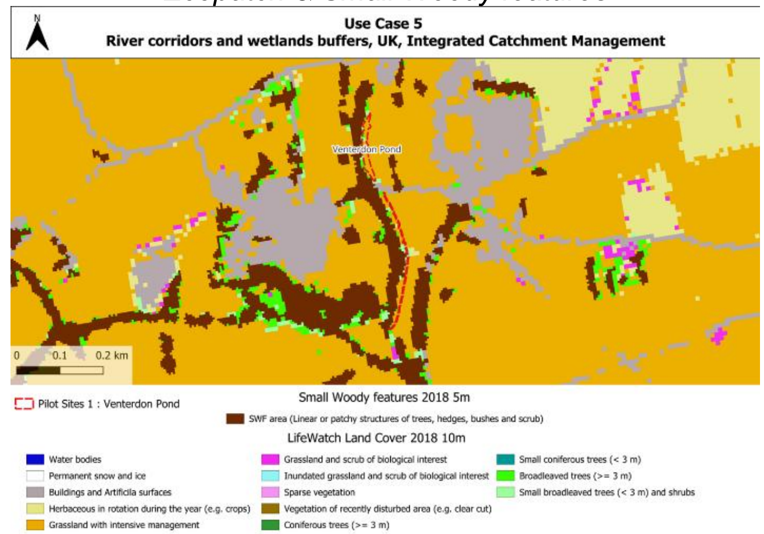
Figure 11 - View of riparian trees planted

Figure 12 - Growth of vegetation in between planted riparian trees

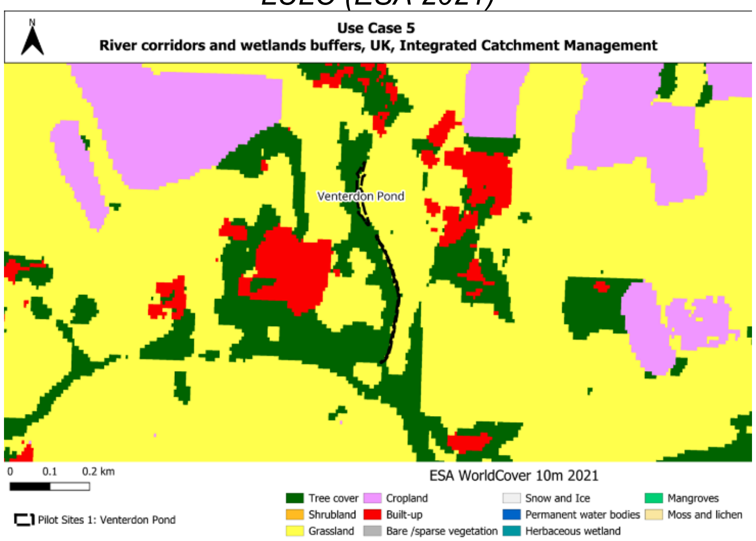
Satellite imagery



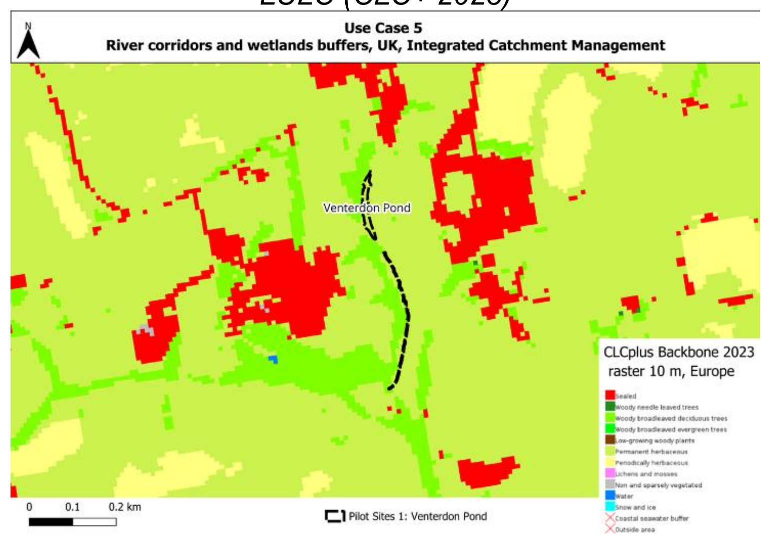
Ecopatch & Small Woody features



LULC (ESA 2021)



LULC (CLC+ 2023)



7.5.3 Indicators retained from portfolio and monitoring requirements

This sub-section identifies, for UC5, the indicators considered a priori relevant from the portfolio of Table 3 and specifies the remote-sensing data sources envisaged for their operational implementation, the monitoring periods to be considered, and the ground-truth requirements expected to support validation. The selection reflects the specificities of river corridors and wetland buffer ecosystems addressed in UC5, distributed across the Thrushell water catchment (baseline site) and the three demonstration sites in South Devon: small dairy farm (wetland restoration, 1.5 years post-intervention), wetland reserve (invasive species management) and Duchy College (riparian corridor enhancement, 0–12 months post-planting). The retained indicators and acquisition specifications are preliminary at the time of RP1 and will be consolidated, refined or extended during RP2, in line with the living-deliverable approach described in section 8.2. The actual subset of indicators to be operationalised will further depend on the financial-mechanism perspective consolidated in section 8.3.

7.5.3.1 Indicators retained from the portfolio

The most promising indicators marked under column “5 UK” of Table 3 are retained for UC5. They are grouped below by thematic family to support subsequent prioritization and remote-sensing requirement analysis. The riparian, wetland and hydrological families are the distinctive components of UC5, alongside the universal indicators that anchor the landscape and vegetation context.

- **Landscape structure and habitat composition**: habitat type ratio, land use change, tree canopy surface monitoring, deforestation / cut event detection, tree canopy height;
- **Vegetation status and dynamics**: vegetation health and productivity (through NDVI, EVI, LAI, fAPAR, FCover, Cab, LST), vegetation water content (through NDWI, Cw);
- **Riparian and wetland restoration**: wetland restoration, riparian vegetation planting (herbaceous), riparian vegetation planting (trees);
- **Hydrological condition and water bodies**: water level, low flow and drought management, pond detection, water class transition, soil moisture;
- **Biodiversity features and pressures**: quantity of floral resources, diversity of floral resources, invasive species detection, human disturbance.

7.5.3.2 Remote-sensing data sources envisaged

The optimal remote-sensing configuration is described below per indicator family. Sentinel data (Copernicus, ESA) constitute the primary backbone of monitoring. Earthdaily Constellation (EDA) is mobilized where high revisit frequency or fine spatial detail is required. Very-high-resolution imagery (Pléiades) is acquired on demand for small-object characterization and reference validation. Landsat (USGS / NASA) can be used in complement for historical baselines. Additional remote-sensing sources (e.g., hyperspectral missions, LiDAR acquisitions, other commercial constellations) may be considered during RP2 if specific indicators justify it (LiDAR is particularly relevant in UC5 for canopy structure characterization in narrow riparian corridors).

Throughout this section, “Sentinel-2” refers to the MSI sensor (10–20 m, 13 spectral bands, 5-day revisit), "Sentinel-1" refers to the C-band SAR (5 m × 20 m IW mode, 12-day revisit currently with a single satellite, 6-day when two are operational), and "Earthdaily" refers to the operational capacity progressively activated during the project (up to 5 m multispectral, 22-band hyperspectral-like capability from visible to SWIR + thermal / Land Surface Temperature (LST), daily revisit).

- **Landscape structure and habitat composition**: Sentinel-2 is the optimal sensor for this family. Its 10 m spatial resolution and 5-day revisit are well suited to land-use-change detection on the mixed farming and woodland mosaic of South Devon, habitat ratio computation at the buffer / landscape level, and tree canopy surface monitoring. The Landsat archive is used in complement to extend the historical baseline since 1984, which is relevant for documenting the long-term modification of river corridors and wetland margins under agricultural intensification.
- **Vegetation status and dynamics**: Sentinel-2 is the optimal sensor for the core vegetation indices (NDVI, EVI, NDWI) and for the red-edge biophysical variables (LAI, fAPAR, FCover, Cab) that rely on its dedicated red-edge bands at 20 m. For LST, Landsat-8/9 (100 m thermal, 8-day revisit) provides field-scale observations, while Sentinel-3 SLSTR (1 km thermal, 2-day revisit) supports catchment-scale monitoring. Earthdaily's daily thermal at 120 m resolution and joint VIS / TIR observations will unlock finer monitoring of riparian vegetation stress and wetland thermal dynamics, particularly during summer low-flow episodes.
- **Riparian and wetland restoration**: this is one of the distinctive families for UC5. Sentinel-2 supports the detection of riparian vegetation extent and the tracking of restoration progress at the buffer / catchment scale, while Sentinel-1 (C-band SAR) provides cloud-independent detection of standing water in wetland areas. Earthdaily's 5 m daily revisit is particularly valuable for the chronological gradient implemented in UC5 (0–12 months post-planting at Duchy College, 1.5 years post-intervention at small dairy farm), where short-term vegetation establishment and canopy closure dynamics need to be tracked. Pléiades imagery (0.3–0.5 m) is required for the characterization of narrow riparian corridors that fall below the Earthdaily resolution threshold. LiDAR acquisitions, if available, would substantially refine canopy height and vertical structure assessment in narrow riparian bands.
- **Hydrological condition and water bodies**: Sentinel-1 is the primary sensor for water extent and surface water dynamics through its C-band SAR sensitivity to water, independently of cloud cover, which is essential in the persistently overcast climate of South Devon. Sentinel-2 complements through water indices (NDWI, MNDWI) and through pond and small water body detection. Sentinel-3 OLCI / SLSTR supports the catchment-scale view of water class transitions. For water level monitoring on small streams and ponds (typically 2–3 m wide on UC5 pilot sites), the spatial resolution of Earthdaily (5 m daily) is more appropriate than Sentinel for fine tracking, and Pléiades may

be used punctually. Soil moisture is derived from Sentinel-1, with Earthdaily refining the daily dynamics in saturated catchment areas.

- **Biodiversity features and pressures**: quantity and diversity of floral resources are addressed through Sentinel-2 multi-temporal vegetation indices and refined with Earthdaily's 5 m daily revisit, with the hyperspectral-like capability of Earthdaily becoming valuable for the spectral discrimination of specific flowering events. Invasive species detection, in particular the documented invasions of Rhododendron and Himalayan balsam on UC5 pilot sites, relies on Sentinel-2 for large patches and on Earthdaily for finer patches and for tracking the distinctive flowering signatures (Rhododendron in May–June, Himalayan balsam in July–October). Pléiades is mobilised on demand for the validation of treatment effectiveness on smaller invasive patches. Human disturbance is approached through Sentinel-1/2 land cover indicators combined with auxiliary geospatial datasets (road network, population density).

7.5.3.3 Monitoring periods per indicator family

The monitoring calendar is constructed to match the agroclimatic cycles of South Devon (maritime temperate climate, mild winters, persistently overcast conditions, summer low-flow episodes, winter flood risk) and the chronological gradient of the four pilot sites (baseline, 1.5 years post-intervention, 0–12 months post-intervention, invasive species management context). The cadences indicated below are envisaged for the operational monitoring phase (the precise revisit frequency per indicator and per pilot site will be consolidated during RP2 through the workshops and field visits described in section 8.1).

- **Landscape structure and habitat composition**: a multi-annual baseline of at least five years is required, with annual snapshots for change detection. The full Sentinel-2 archive (since 2015) and the Landsat archive (since 1984) provide the historical context for land-use-change interpretation, including the long-term modification of river corridors and the more recent restoration interventions.
- **Vegetation status and dynamics**: monitoring is concentrated on the extended growing season (March to November under mild years), with decadal composites during the growing season and monthly composites outside it. Higher temporal resolution (sub-decadal) is of interest for periods of rapid changes (spring green-up, summer water stress) where Earthdaily's daily thermal and visible / red-edge revisit becomes most valuable.
- **Riparian and wetland restoration**: continuous monitoring throughout the year, with particular attention to the post-planting establishment phase (sub-monthly observations during the first 12 months) and to the seasonal dynamics of wetland vegetation. Sentinel-1 provides cloud-independent winter monitoring during persistently overcast periods. Earthdaily's daily revisit is most valuable for short-term establishment tracking on the Duchy College site (0–12 months post-planting).
- **Hydrological condition and water bodies**: continuous monitoring throughout the year, with sub-weekly Sentinel-1 acquisitions for water extent dynamics and event-triggered higher-frequency observations during flood (winter) and low-flow (summer) episodes. Earthdaily daily revisit refines event detection where short flood pulses or rapid drying

spells occur. Soil moisture monitoring is continuous, with daily Earthdaily revisit valuable during recovery from extreme events.

- **Biodiversity features and pressures**: static structural mapping is performed annually. Flowering monitoring is concentrated through the growing season (April to September), with specific attention to invasive species flowering windows (Rhododendron in May–June and Himalayan balsam in July–October) where sub-monthly observations support both detection and treatment effectiveness assessment. Daily Earthdaily revisit is particularly relevant here.

7.5.3.4 Ground-truth requirements

The validation of UC5 indicators requires four categories of ground-truth data, to be collected through the partnerships established with Westcountry Rivers Trust (WRT) as UC5 lead and Responsible Body for the conservation covenants, with engagement of landowners on the four pilot sites and articulation with the UK statutory frameworks that structure ecological monitoring in this context. Where applicable, existing national and regional reference datasets (UK Land Cover Map, Environment Agency data on water quality and hydrology, Biodiversity Net Gain assessments, River Condition Assessments, DEFRA monitoring schemes) will be reused to reduce the in situ collection effort and anchor the indicator calibration to validated reference data.

Information of interest includes:

- **Restoration and management itineraries per pilot site**: dates and nature of restoration interventions (planting, scrub clearance, hydrology modification), species planted (herbaceous and tree species, with planting dates and densities), invasive species treatments (location, method, date), and management practices adjacent to riparian corridors.
- **Habitat and biodiversity assessments**: River Condition Assessments and Biodiversity Net Gain baselines and follow-ups per parcel, habitat condition scores against the UK biodiversity metric, target species lists and observation records (e.g., salmon, trout, otter, water vole, white-clawed crayfish, kingfisher), invasive species mapping and treatment records.
- **Hydrological measurements**: water level records (where gauges exist), turbidity and water quality measurements, flow regime data, flood event records. Existing Environment Agency telemetry networks and Upstream Thinking monitoring data are anticipated as primary sources.
- **Phenological and event observations**: vegetation establishment milestones (canopy closure, flowering onset), invasive species flowering periods, flood and drought event timestamps, treatment effectiveness assessments.

Not all the observations will be made available within the context of the project, and final validation of selected indicators may be limited to the ground-truth dataset ultimately available. Additional public datasets may also be used.

8 Integration with financial mechanisms considered in the project

The framework described in the previous sections and the associated indicators' list align well with EU biodiversity policies, particularly the Nature Restoration Law, the EU CAP, and the Biodiversity Strategy 2030. The various indicators listed provide quantifiable metrics, objectifying the monitoring, which is essential to support innovative financial mechanisms, for instance, through i) baseline establishment for biodiversity certificates and Payment for Ecosystem Services schemes, ii) additionality verification for impact investments and green bonds, iii) performance monitoring for parametric insurance products, and iv) outcome verification for result-based payment systems. Application of remote sensing to support those financial mechanisms differs from academic biodiversity frameworks by prioritizing operational reliability, standardization potential, and investor acceptability alongside scientific rigor. The resulting framework provides the measurement infrastructure necessary for scaling nature-based financial solutions across European markets while maintaining ecological integrity and scientific credibility.

8.1 Description of feedback / validation process

The methodology for integrating indicators with financial mechanisms is structured around three complementary phases aimed at ensuring alignment between remote sensing monitoring capabilities and the needs of the innovative financial instruments identified in the BIO-CAPITAL project.

Phase 1 - Presentation and general validation: A webinar will be organized in early RP2 for all project partners to present in detail the consolidated list of 54 biodiversity indicators. This presentation will address, for each indicator, the remote sensing measurement methods, spatial scales of application, ecological interpretation, and links with European policies. This phase will allow for the collection of initial feedback from partners and the identification of technical or scientific questions requiring clarification.

Phase 2a - Technical specification workshops: Targeted working meetings will be organized with two key stakeholder groups. On one hand, use case managers (UC2-France, UC3-Romania, UC4-Slovenia, UC5-United Kingdom) will participate in dedicated workshops to specify technical requirements and implementation priorities for indicators according to agroecological contexts and restoration objectives specific to each pilot site. On the other hand, working sessions with Work Package leaders 4 (innovative financial mechanisms) and 5 (biodiversity certificates) will identify optimal combinations of indicators meeting the requirements of each financial mechanism: parametric insurance, triple capital accounting, payments for ecosystem services, green bonds, and biodiversity certificates.

Phase 2b - Field visits and on-site validation: Targeted field visits will be organised at the pilot sites of UC2 (France), UC3 (Romania), UC4 (Slovenia) and UC5 (United Kingdom). These visits

aim to (i) ground-truth indicator feasibility and validate remote-sensing acquisition conditions; (ii) consolidate the description of local site conditions, ecological characteristics, and the way ecosystem types and management practices interact in practice (elements that remain partial at the time of RP1); and (iii) gather direct stakeholder input.
UC1 (Alpine Forests) is excluded as the use case does not require the development of remote-sensing biodiversity indicators in WP3.

Phase 3 - Consolidation and update: Following these various consultation phases, this report will be updated to integrate technical specifications, priority adjustments, and, most importantly, to document in detail the specific integration of indicators with each financial mechanism. This consolidated version will constitute the operational framework for the development and implementation phases of indicators in subsequent Work Packages.

Across the three phases, the prioritization of indicator × mechanism × UC combinations relies on four converging criteria: (i) the Technical Readiness Level of each indicator within Earthdaily's operational product portfolio; (ii) the suitability and feasibility scores produced under D2.4; (iii) the data layers available in the geospatial catalogue compiled under D3.2; and (iv) the demand signal expressed by UC managers and stakeholders during workshops and consultations.

This iterative and collaborative approach ensures that technical developments remain aligned with the operational needs of financial mechanisms and the field realities of pilot sites.

8.2 Update of deliverable D3.1 following living-deliverable approach during RP2

D3.1 follows a living-deliverable approach, deliberately chosen to reflect the iterative nature of indicator definition in BIO-CAPITAL. Three axes of evolution are anticipated:

- Operational specifications of indicators. As workshops, stakeholder consultations and field visits progress during RP2, the description of selected indicators may be enriched with thresholds, sampling frequencies, remote-sensing acquisition modes and associated uncertainties.
- UC-specific findings. The current understanding of the pilot sites (i.e., their specific local conditions, ecological characteristics, and the way ecosystem types and management practices interact in practice) remains partial at the time of RP1. New evidence gathered on a pilot site through field visits, workshops or stakeholder consultations may therefore lead to a re-prioritisation of indicators relevant to that UC, or to the addition of indicators that were not anticipated at the start of the project.
- Policy and KPI alignment. Should the EU regulatory landscape evolve, the alignment of the indicator portfolio with policy and KPI references will be updated accordingly.

The methodological framework for indicator selection (section 6.1), the structure of the indicator portfolio (section 6.3), and the descriptive content of the pilot sites (section 5) constitute the stable backbone of the document. Updates affect the operational and contextual layers that connect these stable elements to the project's financial mechanisms. Each substantive update gives rise to a new version, recorded in the Change Log with a description of the scope and rationale of the modifications. Versions submitted to the European Commission (i.e., V1.0 and V1.1) remain identifiable and archived in the project repository to preserve the auditability of the deliverable. Any external reference to D3.1 (in other BIO-CAPITAL deliverables, publications or stakeholder communications) should specify the version number consulted, in line with standard practice for living documents.

8.3 Identification of indicators integration

This section presents an initial draft of the indicator × financial mechanism × Use Case mapping introduced in section 6.3, prepared during RP1 to provide a structuring backbone for further work. It is the principal evolving content of this deliverable and it should be read as preliminary in two respects: (i) the operational specifications of indicators (thresholds, sampling frequencies, RS acquisition modes) have not yet been consolidated through workshops and field visits; and (ii) the description of local site conditions, ecological characteristics, and the way ecosystem types and management practices interact in practice is still partial (particularly at the level of detail required to anchor each indicator to a specific pilot context).

The RP2 process described in section 8.1 will progressively close these gaps, and the corresponding updates will be reflected in subsequent versions of this deliverable according to the living-deliverable approach described in section 8.2. Goal is to provide a synthesis of validated mechanisms × UC × indicators following the template table below:

Financial mechanism	Use case	Indicators selected	Operational metric	Delivery mode
Biodiversity certificates (BC)	UC2 Agricultural lands			
	UC3 Agricultural lands			
	…			
Payment for ecosystem services (PES)	UC2 Agricultural lands			
	UC3 Agricultural lands			
	…			
….				

8.3.1 Payment for Ecosystem Services (PES)

Three categories of ecosystem services are considered for PES quantification, each supported by specific indicators of the portfolio (Table 3):

Carbon Sequestration Services:

- **Cover crop biomass estimation:** Direct carbon storage measurement (2-4 tC/ha/year)
- **Soil Organic Content/Matter:** Long-term carbon sequestration quantification
- **Tree canopy surface monitoring:** Above-ground carbon stock changes (10-50 tC/ha)
- **Agroforestry belt detection:** Additional carbon storage in agricultural systems (5-15 tC/ha)

Financial Application: Enable per-hectare payments based on measured carbon accumulation rates, supporting carbon credit markets valued at €25-50/tCO2

Water Regulation Services:

- **Soil cover type/duration**: Infiltration capacity and erosion prevention (50-80% reduction)
- **Buffer zone effectiveness**: Water quality protection value (€200-500/ha/year)
- **Wetland restoration**: Flood mitigation and water purification services (€1,000-3,000/ha)
- **Riparian vegetation planting**: Stream temperature regulation and habitat provision

Financial Application: Watershed management payments and water utility partnerships based on quantified service delivery, supporting €2-5M annual payments per catchment.

Biodiversity Conservation Services:

- **Hedgerows detection/characterization**: Wildlife corridor value (€100-300/km/year)
- **Flower/grass strips**: Pollinator habitat provision (€150-400/ha/year)
- **Species detection (native/invasive)**: Conservation outcome measurement
- **Habitat type ratio**: Landscape-scale biodiversity value assessment

Financial Application: Biodiversity credits and conservation payments based on habitat quality improvements, supporting an emerging €500M/year market.

8.3.2 Biodiversity Certificates

The biodiversity certificate mechanism rests on four functional layers, each operationalised through indicators of the portfolio (Table 3):

Baseline Establishment: The framework provides comprehensive baseline metrics validated across ecosystem types:

- Pre-intervention habitat condition using 31 field-level indicators
- Species habitat suitability through floral resource and structural metrics
- Connectivity assessment via landscape feature detection and characterization

Additionality Verification: Multi-temporal change detection enables robust additionality assessment:

- **Land use change detection**: Confirms genuine habitat conversion/restoration with 95% accuracy
- **Vegetation health evolution**: Documents ecosystem condition improvements over time
- **Feature enhancement tracking**: Hedgerows, strips, and woodland establishment monitoring

Permanence Monitoring: Long-term tracking capabilities ensure certificate validity:
- Continuous monitoring prevents reversal of improvements with automated alerts
- Early warning systems detect degradation or management changes
- Automated alerts enable rapid response to threats within 48-72 hours

Quantified Impact Measurement:
- Standardized metrics enable comparable impact quantification across regions
- Species proxy indicators provide biodiversity outcome estimates
- Ecosystem service metrics enable co-benefit quantification

8.3.3 Parametric Insurance

The parametric insurance mechanism was the most advanced at the time of RP1 writing, and therefore the structure of components described below reflects the final organization expected for each financial mechanisms considered (i.e., per UC indicators with associated thresholds).

8.3.3.1 Technical implementation (cross-UC)

- Real-time trigger activation through satellite monitoring.
- Automated payout systems within 72 hours of the trigger event.
- Risk premium calculation based on 20-year historical data.

8.3.3.2 Parametric Insurance × UC2 – Regenerative Agriculture (France)

- Drought protection enabling continuation of cover cropping practices (trigger: NDWI < 0.2)
- Excessive rainfall insurance supporting no-till farming systems (trigger: >150mm/week)
- Climate resilience for agroecological transition (€500-1,500/ha coverage)

8.3.3.3 Parametric Insurance × UC3 – Agroecology (Romania)

- Spring frost protection for diverse crop rotations (trigger: <-2°C during flowering)
- Early-season drought insurance for organic farming systems
- Support for hedgerow and agroforestry establishment (€200-800/ha coverage)

8.3.3.4 Parametric Insurance × UC4 – Species-rich Grasslands (Slovenia)

- Flooding damage compensation for grassland restoration (trigger: water level >2m above normal)
- Pollinator habitat protection funding
- Delayed mowing practice continuity insurance

8.3.3.5 Parametric Insurance × UC5 – River Corridors and Wetlands (UK)

- Riparian buffer vegetation restoration funding after flood damage
- Wetland functionality maintenance insurance
- Water quality protection service continuity (trigger: turbidity >100 NTU)

8.3.4 Green Bond and Sustainable Finance

EU Taxonomy Compliance Verification: Multiple indicators directly support Taxonomy activity verification:

- **Forest monitoring indicators**: Support sustainable forestry investments (€2-5B annually)
- **Agricultural biodiversity metrics**: Verify climate adaptation in agriculture
- **Wetland restoration tracking**: Demonstrate ecosystem restoration impacts

Impact Reporting Framework: The indicator framework enables comprehensive impact reporting:

- Quantified environmental outcomes using standardized metrics
- Regular monitoring updates through automated satellite systems
- Transparent methodology enabling third-party verification and audit trails

Risk Assessment Integration: Environmental risk indicators support investment decision-making:

- **Soil erosion monitoring**: Land degradation risk assessment (0-5 risk scale)
- **Water level tracking**: Drought and flood risk evaluation
- **Vegetation health trends**: Climate resilience assessment for portfolio management

8.3.5 Triple Capital Accounting (TCA)

Enhanced Implementation Framework:

Natural Capital Asset Valuation:

- **Habitat area measurement**: Natural asset extent quantification (±5% accuracy)
- **Ecosystem condition assessment**: Asset quality evaluation using vegetation indices
- **Service flow quantification**: Annual ecosystem service production measurement

Social Capital Integration:

- Rural livelihood protection metrics through agricultural biodiversity indicators

- Community resilience assessment via landscape connectivity measures
- Cultural landscape value preservation through traditional management practices

Financial Capital Alignment:

- ESG reporting compliance framework supporting CSRD requirements
- Investment risk assessment through environmental degradation indicators
- Return on investment calculation for nature-based solutions

Depreciation and Appreciation Tracking: Multi-temporal analysis enables natural capital accounting:

- Habitat degradation detection provides depreciation rates (2-5% annually in degraded systems)
- Restoration success measurement shows asset appreciation (10-30% in restored systems)
- Management impact assessment informs maintenance costs and optimal intervention timing

9 Roadmap for the remainder of WP3

The role assigned to Task 3.1 in the Description of Action is to integrate the results of WP2 into the Use Cases and to set up the subsequent tasks of WP3. This section makes that connection explicit: it summarises how the content produced under RP1 (i.e., the portfolio of observable parameters – section 6.3, the agro-environmental description and remote-sensing specifications per Use Case – section 7, and the integration with financial mechanisms – section 8) feeds into the activities planned under Task 3.2 and Task 3.3, and reports on the status of WP3 tasks at the time of RP1 review.

9.1 Inputs from D3.1 to Task 3.2

Task 3.2, "Matching the spatio-temporal observable parameters derived by Task 3.1 thanks to EO data and remote-sensing methods", will derive, for each indicator considered, the technical requirements that allow its operational implementation through remote sensing, run the corresponding image processing, characterise habitats, and produce the geographical layers and habitat connectivity layer that will support biodiversity uplift assessment.

The present deliverable provides the following inputs to T3.2:

- Portfolio of observable parameters: Section 6.3 (Table 3) presents a list of 54 indicators distributed across four ecosystem categories (universal, agricultural, grassland, wetland) and three spatial scales (region, field, object), each with an indication of biodiversity interpretation and policy/KPI relevance. This portfolio constitutes the input set from which T3.2 will retain and operationalise the indicators most adapted to each Pilot Site.
- A priori indicator retention and remote-sensing specifications per Use Case: Section 7 details, for each UC, the indicators considered a priori relevant for the local ecological and management context, together with the type of remote-sensing data envisaged (spatial, spectral and temporal resolutions), the monitoring period to be considered, and the ground-truth requirements identified for validation. These inputs constitute the immediate starting point for the scale, resolution, frequency and spectrum decisions that T3.2 will consolidate.
- Pilot-site agro-environmental description: Section 7 also documents, for each UC, the landscape structure, dominant ecosystem types, land cover mosaics and management practices observed on the Pilot Sites. This descriptive layer anchors each retained indicator to the specific physical context in which it will be acquired and validated, and informs decisions on small-object detection (hedges, flower strips, streams) and on habitat characterisation that T3.2 will undertake.
- Validation pathway: Section 8.1 describes the feedback and validation process planned with WP partners and Use Case managers, including workshops, technical specification meetings and field visits at the pilot sites of UC2, UC3, UC4 and UC5. This process directly supports the ground validation activity foreseen by T3.2.

The combination of these four inputs is intended to enable T3.2 to start its activities with a clearly bounded perimeter, a documented set of candidate indicators per Use Case, and an articulated link to the validation work to be carried out with UC managers.

9.2 Inputs from D3.1 to Task 3.3

Task 3.3, “Improvement of RS-observable parameters created in 3.2 through diachronic analysis“, extends the parameters operationalised in T3.2 through time-series analysis based on Earthdaily data and Sentinel archives, develops a change-detection algorithm, and explores new spectral and resolution capabilities for specific indicators.

Unlike T3.2, T3.3 is largely transversal across Use Cases. The present deliverable provides three categories of inputs:

- Identification of time-dependent indicators: Several indicators of the portfolio (Table 3) carry an intrinsically temporal biodiversity signal, including mowing and cut-event detection, delayed mowing, vegetation health evolution, land use change detection, flowering detection, wetland status, and evapotranspiration in croplands. These indicators are natural candidates for the change-detection algorithm to be developed in T3.3 and for the exploration of new spectral and resolution capabilities mentioned in the Description of Action.
- Baseline reference layers for archive exploitation: The descriptive content of the Pilot Sites (section 7) is anchored on documented reference layers (ESA WorldCover v2 2021, CLC+ 2023, Lifewatch ecopatches v4.03 2018, ESA Small Woody Features 2018). These layers provide the T0 reference against which Sentinel and Earthdaily images can be exploited by T3.3 to construct change-detection time series.
- Diachronic requirements derived from financial-mechanism integration: The integration framework presented in section 8 highlights specific functions of financial mechanisms that depend on temporal change information: additionality verification for biodiversity certificates and green bonds, permanence monitoring for biodiversity certificates, and performance monitoring for parametric insurance. The corresponding indicators inherit, through that mapping, an explicit prioritisation for the change-detection developments to be undertaken under T3.3.

9.3 Status of WP3 tasks at the end of RP1

At the end of RP1, the structure of the present deliverable corresponds to what was foreseen for Task 3.1 in the Description of Action: integrating the results of WP2 into the Use Cases and setting up the subsequent tasks of WP3.

The portfolio of observable parameters (section 6), the agro-environmental description and remote-sensing specifications per Use Case (section 7), and the integration with financial mechanisms (section 8) constitute, together, the foundation on which Task 3.2 (M12–M24, lead UCL) and Task 3.3 (M12–M42, lead EDA) can build during the remainder of the project. Their operational outputs will be reported in their dedicated deliverables, while updates relevant to the indicator framework and its Use Case anchoring will be reflected in subsequent versions of the present document, in line with the living-document approach described in section 8.2.

10 Conclusion

This report proposes a structured list of the most relevant observable parameters for biodiversity monitoring, grounded in EU targets and existing financial mechanisms for conservation and restoration. By providing a detailed description of the pilot sites and their agroclimatic contexts, the report aims to ensure that the selection and development of indicators in WP3 are well-targeted and scientifically robust.

Key Impacts of the Report:

- **Comprehensive parameter mapping:** the report identifies and organizes a wide range of observable parameters, directly linked to EU biodiversity policies and financial instruments, to guide future monitoring and evaluation efforts.
- **Contextualized site descriptions:** detailed agroclimatic and landscape analyses of each pilot site provide a strong foundation for tailoring indicators to local realities and ecological priorities.
- **Alignment with policy and finance:** the proposed indicators are selected to support compliance with EU strategies and to enable integration with innovative financial mechanisms such as biodiversity certificates, PES, and green bonds.
- **Stakeholder engagement:** the process incorporates feedback from project partners and use case managers, ensuring that the selected parameters are relevant, feasible, and aligned with on-the-ground needs.

Outlook:

The connection between the foundations laid in this deliverable and the subsequent activities of WP3 (Task 3.2 on the matching of observable parameters with EO data and remote-sensing methods, and Task 3.3 on the diachronic improvement of these parameters) is articulated in section 9. The validation pathway and the prioritization criteria that will drive the consolidation of indicators per Use Case and per financial mechanism are detailed in section 8.1. The present deliverable thereby fulfils its role under Task 3.1 of integrating the results of WP2 into the Use Cases and setting up the subsequent tasks of WP3, while remaining open to incremental refinement through the living-document approach described in section 8.2.

By establishing a robust foundation for indicator selection and pilot site characterization, this report contributes to the broader goal of advancing effective, transparent, and policy-aligned biodiversity monitoring and finance across Europe.

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11.1 Notes for maps reference:

All the maps produced in this report use a certain number of public layers that are cited here

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4. Copernicus Land Monitoring Service (CLMS), 2018. Small Woody Features 2018 (Raster 5 m), Europe. DOI: 10.2909/a8e683b1-2f96-45c8-827f-580a79413018
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6. Data source: LifeWatch Belgium, Ecopatches v4.03 (2018), UCLouvain – Elie Group Available at: https://maps.elie.ucl.ac.be/lifewatch/ecopatches.html

12 Annexes

- Supplementary maps, tables, and technical details.
- Detailed methodology for GIS and data collection.