European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

Invasive Species Detection in Croatia

Client:	ESA
Client Representative:	Alessandra Tassa
Date of Delivery:	January 2024
Version:	Final Report
Author(s):	Daire Boyle (EARSC)
Reviewer	Alessandra Tassa (ESA)

Version	Date	Comment
1st Issue	10/01/2024	

or more information contact:

- **EARSC: info@earsc.org**
- **ESA: Alessandra.Tassa@esa.int**

Funded by the EU and ESA – ESA Contract Number: 4000119743/17/I-SBo.

Table of Contents

List of Figures

List of Tables

Setting the Scene

Niko, a farmer who spent his whole life living in Lonjsko Polje nature park once again noticed a new type of plant overgrowing several fields near his house. Niko had spent his entire life working the same plot of land, looking after his native cattle, and growing a variety of crops that sustained both his family and the small community that relied on his produce.

Niko was known throughout the area for his impeccable work ethic and his connection to the land. He had inherited his farm from his ancestors and felt a deep responsibility to care for it. But there was one relentless adversary that had plagued him for years: an invasive plant species called "Amorpha fruticosa" or “False Indigo Bush”. This tenacious plant had taken root on the outskirts of his farm, and no matter how hard he tried to eradicate it, it continued to spread.

One sunny morning, as Niko stood at the edge of his fields, he looked out at the lush, green landscape, marred by the ever-encroaching Amorpha fruticosa. It choked native vegetation, making it nearly impossible for anything else to grow. It was a stubborn, relentless enemy.

Determined to reclaim his land, Niko decided it was time to wage a full-scale war on the Amorpha fruticosa. He began by researching various methods of removal and consulting with local experts. Armed with newfound knowledge and a determination that ran as deep as his roots, he set forth on his mission. He started by clearing a small section at the very edge of his farm. He painstakingly cut away the Amorpha fruticosa, one plant at a time. It was gruelling work, but he was fuelled by a desire to protect the land that meant so much to him. Day after day, he laboured under the hot sun, refusing to let the invasive plant hold dominion over his farm.

Word of Niko's dedication began to spread throughout the community, and soon, neighbours and friends offered their help. Together, they formed a small, dedicated team to battle the plant. They brought tractors and every type of tool they could. As the months passed, the Amorpha fruticosa began to retreat a little. Niko's land, once overrun with the invasive plant, started to show signs of recovery. Native flowers, grasses, and shrubs slowly returned, as if thanking Niko and his team for their relentless efforts. Niko couldn't help but smile as he saw his land healing, becoming the thriving oasis it had once been. However, there was still much work to do. This was only one, relatively small patch of land within the park. Niko brought the problem to the attention of the park management, who told him that more efforts were going to be made to eradicate the Amorpha fruticosa, but at a much wider scale, and this time, satellites were going to help.

Whilst the character in this story is entirely fictional, the situation is inspired by real events based on our knowledge gained through the case interviews.

Executive Summary

This case looks at how Sentinel data is being used to detect and monitor invasive alien species in a nature park in Croatia.

The EU Biodiversity Strategy for 2030, is a comprehensive and ambitious plan aimed at addressing the biodiversity and ecosystem challenges in Europe. The strategy outlines a series of targets and actions to halt and reverse the decline of biodiversity in the EU by the year 2030. The strategy reflects the EU's commitment to protecting and restoring biodiversity, recognising the crucial role biodiversity plays in sustaining life, supporting agriculture, and providing ecosystem services. An important part of the plan involves the management and where possible, the eradication of invasive alien species. Invasive alien species (IAS) refer to non-native organisms introduced to new areas through human actions like trade, travel, or intentional transplantation. These have the potential to damage local ecosystems, compete with native species for resources, change habitats, and upset the ecological equilibrium, resulting in a decline in biodiversity and potential extinctions.

In this case, Oikon, a Croatian research institute and remote sensing company utilise Sentinel-2 data to develop detection methods of Amorpha fruticosa, an invasive species in Lonjsko Polje, a large nature park in Eastern Croatia. Lonjsko Polje have taken several steps in the past to eradicate invasive species due to the various ecosystem-related issues these species cause. Lonjsko Polje are also responsible for helping in the reclamation and conversion of overgrown areas back to agriculturally productive land.

The socio-economic benefits quantified in this case range from **€3.9 – 4.1 million** (all figures explained in Chapter 5) and are derived from data costs saved by Oikon, the reclamation of land by farmers and the protection of Natura 2000 sites for society as a whole.

Possibly the greatest benefits manifested in this case are to do with environmental sustainability. The detection and eradication of invasive species is paramount to the maintenance of biodiversity in an area. The identification of the invasive species Amorpha fruticosa in this case was vital to the redevelopment of the park. Amorpha fruticosa had taken over many areas, particularly grassland areas which otherwise could have supported native livestock. Moreover, through the identification and registration of various different types of ecosystems across Lonjsko Polje, crucially including the registration of Natura 2000 sites, natural habitats are being protected. Having a comprehensive overview of the types of ecosystems present in the park allows park management to monitor changes moving forward, meaning should certain habitats come under threat by natural or human-induced factors, mitigation measures can be taken in time to protect the fragile ecosystems in question.

The benefits within each tier of the value chain are shown in the graphic below.

1 Introduction & Scope

1.1 The Context of this study

The analysis of the case study *'Invasive Species Detection in Croatia"* is carried out in the context of the 'The Sentinel Economic Benefits Study' (SeBS). This study is looking to develop cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The Sentinel satellites form a crucial part of EU's Copernicus Programme, providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – is used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the Globe.

1.2 What is the case all about?

Invasive alien species, or IAS, are non-native organisms introduced to new areas by human activities, such as trade, travel, or intentional transplantation. These species can harm local ecosystems, compete with native species for resources, alter habitats, and disrupt ecological balance, leading to biodiversity loss and potential extinctions. As part of the EU Biodiversity Strategy for 2030, addressing the threat of invasive alien species to native biodiversity through measures such as early detection and control is a major priority.

This case studies how Copernicus Sentinel data is being used to help Lonjsko Polje, a nature park in Croatia, ensure that invasive alien species are kept at bay. Oikon, a remote sensing company and research institute, helped Lonjsko Polje by utilising Sentinel imagery to understand where and how invasive species are overrunning areas within the park and how to best eradicate them.

In this report, you will discover both the story and the rigorous analysis around the benefits experienced by different value chain actors in this case. The analysis relies on clear and openly presented assumptions which have been shaped with the help of the stakeholders we interviewed (see 1.5 below). However, we encourage any reader to contact us if they think the assumptions are unreasonable for any reason through emails to Daire Boyle (daire@evenflow.eu).

1.3 How does this case relate to others?

This case is one of the portfolio cases being developed and analysed within the frame of the SeBS project. It is the second case that deals with biodiversity and natural habitat monitoring, with the earlier case looking at Deforestation Monitoring Worldwide, however, this is the first which looks at the detection and monitoring of invasive alien species specifically.

In terms of the satellite data, Sentinel-2 has featured in many previous reports, especially linked to the likes of agriculture, food production and environmental monitoring.

1.4 More About the Study

Each case study analysed in SEBS, focuses on products and services which use data coming from Sentinel satellites, measuring the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally friendly operations, economic gains and improved quality of life, among others. The evaluated and demonstrated benefits can be used by:

- **Decision makers**: Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision makers not only to justify future investments but also to direct them towards areas that most matter in their country or organisation.
- **Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. In this regard, it is both numbers and stories that can resonate with users and attract them to explore further or deeper uses of EO in their operational activities.
- **Service providers:** Solid argumentation around the economic and environmental benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective marketing tool for service providers seeking to promote their solutions and for EARSC to promote the sector.

In the framework of this project, 20 case studies will be developed with reports to be published on each one.

1.5 Acknowledgements

We wish to thank the following persons for their time spent talking with us. In particular;

Branimir Radun - Oikon

Dalibor Hatić - Oikon

Vlado Kušan - Oikon

Ivan Tomljenovic – Oikon

Maja Sabjlak - Lonjsko Polje

2 Biodiversity and habitat protection in Europe

The heart of this story revolves around the detection and management of invasive alien species and the protection of natural habitats. The following sections give an overview of efforts at European and regional levels to protect natural habitats and preserve biodiversity.

2.1 Efforts to protect biodiversity and natural habitats

Across Europe, there is a plethora of beautiful natural habitats which are home to a multitude of plant and animal species. Some of these creatures and plants can't be found anywhere else on our planet. Yet, the passage of time has not been kind to Europe's natural capital. Climate change, the march of urban expansion, the unyielding grip of intensive agriculture, the relentless pursuit of more forestry and fisheries resources, the insidious spread of pollution, and various other human endeavours have exacted a toll. These relentless pressures have caused the disappearance and degradation of numerous habitats and the unique species that call them home. Today, a chilling reality looms - more than a quarter of Europe's animal species stand on the precipice of extinction.[1]

But there's some hope. The European Union, which is a group of countries in Europe, knows that it's important to protect and restore the amazing nature in Europe. They've made it one of their top goals, as explained in their Biodiversity Strategy for 2030[2]. Moreover, the Birds[3] and Habitats[4] directives are also of major importance to the protection of habits in Europe. Together, these laws have created a large network of protected areas called the Natura 2000 network[5], which is now the largest in the world.

2.1.1 Biodiversity Strategy for 2030

The EU Biodiversity Strategy for 2030 is a comprehensive plan developed by the European Union to address the ongoing biodiversity crisis and set ambitious targets for the conservation and restoration of biodiversity over the current decade. It was adopted by the European Commission in May 2020 as part of the European Green Deal, which aims to make the EU climate-neutral by 2050. The key elements and objectives of the EU Biodiversity Strategy for 2030 include:

- **Halting Biodiversity Loss**: The strategy aims to halt the loss of biodiversity in the European Union by 2030. This means stopping the decline in species populations and ecosystems and restoring them where possible.
- **Protecting and Restoring Ecosystems:** The strategy calls for the protection and restoration of ecosystems across the EU, focusing on natural habitats and their services. This includes dedicating a significant portion of land and seas to protected areas.

[1] https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en
[2] https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
[3] https://environment.ec.europa.eu/topics/nature-and-biodiversity/birds-directive_en
[4] https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en
[5] https://ec.europa.eu/environment/nature/natura2000/index_en.htm

- **Transition to Sustainable Agriculture and Fisheries:** The strategy promotes a transition towards more sustainable agricultural and fisheries practices, with a focus on reducing the use of pesticides and antibiotics, as well as promoting organic farming and sustainable fishing.
- **Promoting Green Infrastructure:** Encouraging the development of green infrastructure, such as urban green spaces, to enhance biodiversity in cities and human-dominated landscapes.
- **Eliminating Pollution:** The strategy aims to reduce pollution, including from pesticides, fertilizers, and plastic waste, to protect both terrestrial and marine ecosystems.
- **Combatting Invasive Alien Species:** Addressing the threat of invasive alien species to native biodiversity through measures such as early detection and control.
- **Climate Change Adaptation:** Recognising the interconnectedness of biodiversity and climate change, the strategy seeks to integrate biodiversity considerations into climate adaptation and mitigation efforts.
- **Global Leadership:** The EU intends to be a global leader in biodiversity conservation by advocating for ambitious international agreements and providing financial support to developing countries.
- **Engaging Society:** The strategy emphasises the importance of engaging citizens, stakeholders, and local communities in biodiversity conservation efforts.
- **Measuring Progress**: The EU Biodiversity Strategy includes a commitment to monitoring progress using a set of indicators and regularly reporting on the state of biodiversity.

The EU Biodiversity Strategy for 2030 is seen as a crucial component of the broader efforts to combat climate change and environmental degradation while promoting sustainable development. It aligns with global initiatives such as the United Nations' Convention on Biological Diversity and contributes to the EU's goals of creating a more sustainable and resilient future for its citizens.

2.1.2 Habitats Directive

A key part of the Biodiversity Strategy, the Habitats Directive is of particular importance to this case. The primary goal of this directive is to safeguard more than a thousand species, encompassing mammals, reptiles, amphibians, fish, invertebrates, and plants, along with 230 distinct habitat types. Its overarching aim is to guarantee the preservation of the habitats these species call home within the EU. Beyond merely preventing their continued deterioration or extinction, the Habitats Directive strives to facilitate their resurgence and enduring prosperity.

The Habitats Directive mandates Member States to enact two primary categories of measures. The first pertains to preserving both habitat types and species habitats, which includes the identification of protected areas within the EU network known as Natura 2000. The second category of measures is centred on safeguarding species and applies to their entire natural range within Member States, encompassing both Natura 2000 sites and areas outside them. It tackles direct threats to these species by prohibiting intentional actions such as capturing, killing, or disturbing them, as well as intentionally harming or taking their eggs, or causing damage or destruction to their breeding sites or resting spots. This comprehensive approach covers a diverse array of animal species, ranging from large, wide-ranging ones like wolves and bears to species with limited territorial ranges, such as butterflies, beetles, or amphibians. Article 16 of the Habitats Directive allows for the possibility of exceptions from the stringent protective provisions mentioned above, but only under specific circumstances when justified and when all conditions outlined in Article 16 are met.

In 2008, the Commission has actively endorsed the formulation of numerous Species Action Plans dedicated to specific species enlisted in the Habitats Directive. These plans serve as comprehensive repositories, encompassing the status, ecological characteristics, identified threats, and ongoing conservation initiatives pertinent to each of the individual species. Additionally, these plans outline pivotal strategies and actions aimed at enhancing the conservation status of these species within the European context. The development of each Species Action Plan involves an extensive consultation process that engages subject matter experts from across Europe. Several action plans are currently detailed, for example, for the Common Midwife Toad[6], the Danube Clouded Yellow Butterfly[7] and the European Ground Squirrel[8].

2.1.3 Reporting the conservation status under the Habitats Directive

Every six years, Member States are required to provide the Commission with comprehensive reports concerning the conservation status of species and habitat types safeguarded under the Habitats Directive within their respective territories. These assessments employ a range of scientific parameters to evaluate the condition of these species and habitats across their natural distribution within the European Union, extending beyond just designated protected areas. The findings of these assessments are made publicly available and are combined with reports on avian species governed by the Birds Directive in the "State of Nature in the European Union"[9] report. The most recent report, issued in 2020, presents the outcomes from the third reporting cycle spanning from 2013 to 2018.

As per the latest report, only 27% of species exhibit a “good” conservation status at the EU level. This marks an improvement from the 23% figure observed in 2015. The majority of species (63%) still exhibit “poor” or “bad” statuses. The situation is even direr for habitat types, with a mere 15% demonstrating a “good” conservation status. The overwhelming majority (81%) of these habitat types are in a “poor” or “bad” condition. The forthcoming report, scheduled for release in 2025, will encompass the period spanning from 2019 to 2024.

---

[6] https://circabc.europa.eu/ui/group/3f466d71-92a7-49eb-9c63-6cb0fadf29dc/library/b52a2a5b-6233-456d-97ae-8350d35aa8ac/details
[7] https://circabc.europa.eu/ui/group/3f466d71-92a7-49eb-9c63-6cb0fadf29dc/library/920e2a49-22e2-4dde-8137-858e1ead64de/details
[8] https://circabc.europa.eu/ui/group/3f466d71-92a7-49eb-9c63-6cb0fadf29dc/library/2ba14cf0-7ca1-4db2-9ed9-e01d21b45742/details
[9] https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020

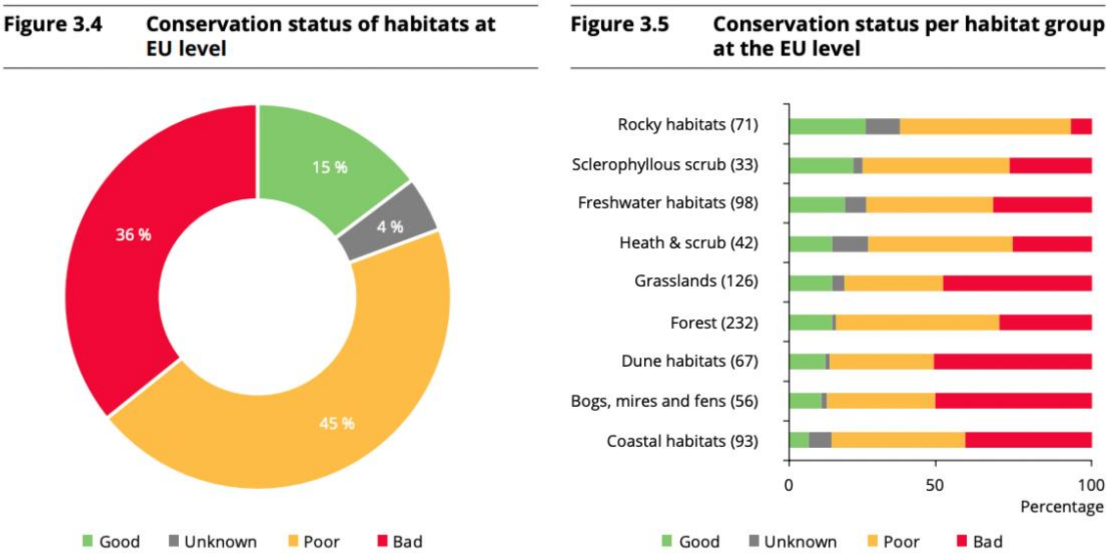


Figure 2-1: Conservation status of habitats at EU level[9]

2.1.4 Natura 2000

Covering more than 18% of the European Union's land area and spanning over 8% of its marine territory, Natura 2000 stands as the world's most extensive coordinated system of protected areas. Natura 2000 consists of a collection of essential breeding and resting sites for rare and endangered species, as well as a plethora of natural habitats. Encompassing all 27 EU member countries, its primary objective is to ensure the enduring survival of Europe's most cherished and imperilled species and habitats, as outlined in both the Birds Directive and the Habitats Directive. Natura 2000 is a key component of the EU's biodiversity conservation strategy. The Natura 2000 network includes both terrestrial and marine areas and comprises two main types of protected areas:

- **Special Protection Areas (SPAs):** These areas are designated to protect bird species and their habitats. SPAs are established under the Birds Directive.
- **Special Areas of Conservation (SACs):** SACs are designated to protect a wide range of habitats and species other than birds. They are established under the Habitats Directive.

Member states of the European Union are responsible for designating and managing these protected areas within their territories. They are required to take measures to maintain or restore the conservation status of the species and habitats listed in the directives. Natura 2000 is a significant conservation initiative in Europe, helping to safeguard the continent's rich biodiversity while also promoting sustainable land use and development practices. It contributes to the EU's broader environmental and biodiversity conservation goals and ensures that Europe's natural heritage is protected for future generations.

The Natura 2000 Viewer is an online tool that showcases all Natura 2000 sites, offering essential details on designated species and habitats, including data on population sizes and conservation status.

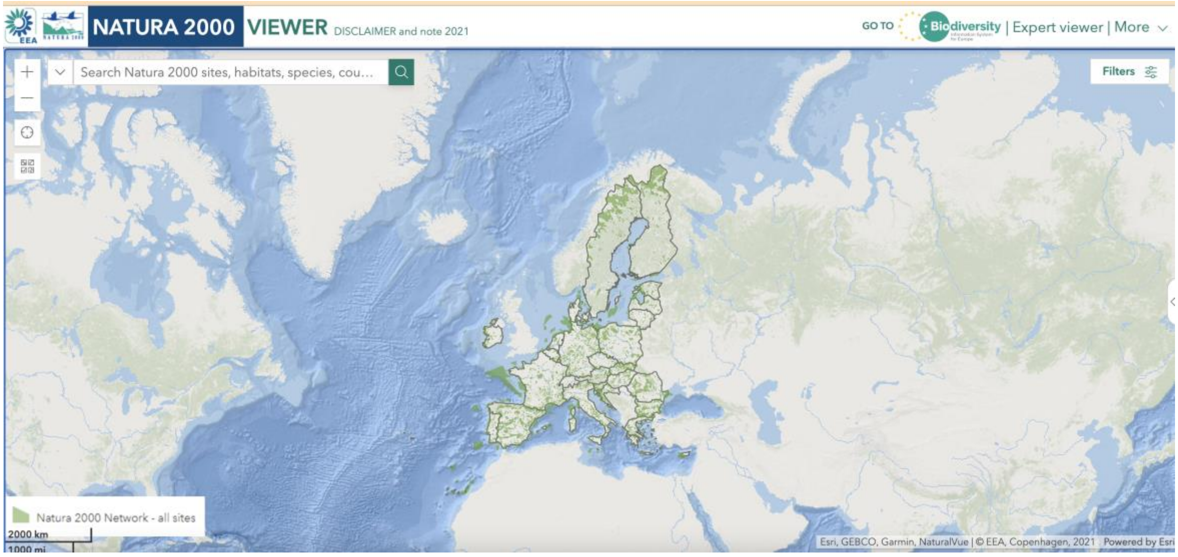


Figure 2-2: The Natura 2000 viewer

2.2 Invasive Alien Species

Invasive alien species (IAS), often referred to simply as invasive species, are organisms (plants, animals, or microorganisms) that have been introduced into a new environment, ecosystem, or region where they are not native. These species can cause significant harm to the local ecosystems, biodiversity, and even human activities. Invasive species are typically introduced to new areas either accidentally or intentionally by human activities. These introductions can occur through various means, such as trade, travel, or deliberate transplantation for agricultural, ornamental, or recreational purposes. Invasive species are called "alien" because they originate from a different region or country and are not native to the area they invade. Native species are those that naturally occur in a particular ecosystem and have evolved there over a long period, forming ecological relationships with other native species. Invasive species can have detrimental effects on the ecosystems they invade. They often outcompete native species for resources such as food, water, and habitat, leading to a decline in native biodiversity. This competition can result in the displacement or even extinction of native species. They can alter the physical and biological characteristics of their new habitat. For example, invasive plants may change the soil composition, invasive animals can disrupt food chains, and invasive microorganisms can introduce new diseases to native species.

Invasive species can also have economic and social consequences. They can damage crops, forests, fisheries, and infrastructure, leading to substantial financial costs. Additionally, the loss of native species and ecosystems can affect cultural practices and recreational activities that rely on healthy natural environments. In fact, the economic impact of IAS in the EU has been estimated at around €12 billion per year[10]. As a result, managing invasive species can be a major challenge. Control methods include mechanical removal, chemical treatments, biological control (introducing natural predators or pathogens), and prevention measures to limit further introductions. The issue is so bad in many regions that most countries around the world have enacted laws and regulations to prevent the introduction and spread of invasive species. These measures often involve quarantine procedures for imported goods, restrictions on the release of non-native species, and educational campaigns to raise awareness about the issue. Some well-known examples of invasive species include the zebra mussel in North America, the European rabbit in Australia, the cane toad in various countries, and various types of invasive plants like kudzu and Japanese knotweed.

Currently, 88 invasive alien species are strictly regulated in the EU. The Biodiversity Strategy for 2030 contains the commitment to manage these invasive alien species and decrease the number of endangered Red List species they threaten by 50% by 2030.

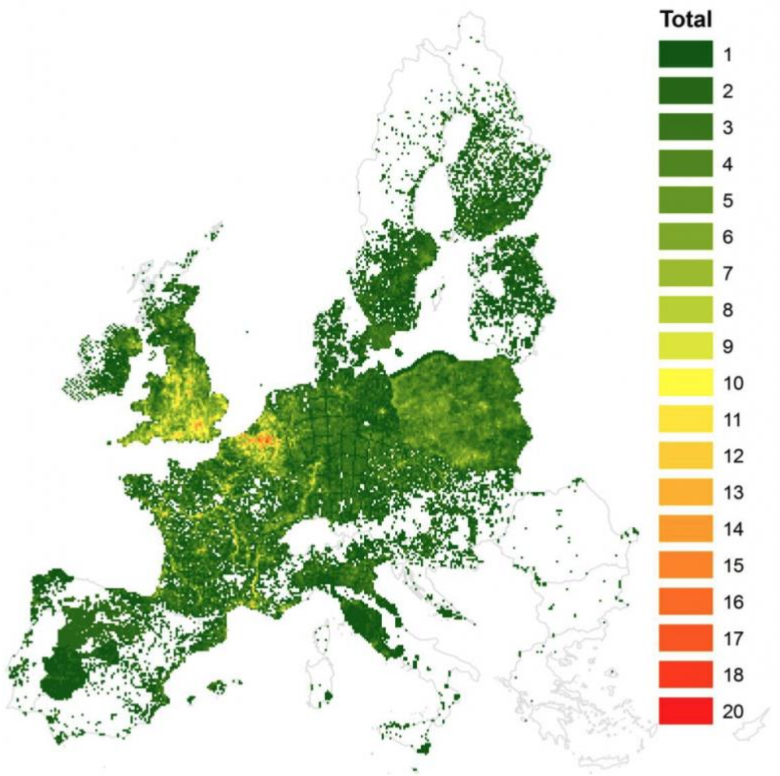


Figure 2-3: Distribution of the 'Union concern' invasive alien species in EU

10 https://environment.ec.europa.eu/topics/nature-and-biodiversity/invasive-alien-species_en#:~:text=Invasive%20alien%20species%20(IAS)%20are,consequences%20for%20their%20new%20environment.

2.2.1 Sava TIES

An initiative of particular relevance to this case is Sava TIES. Sava TIES was regionally significant project implemented in all four countries of the Sava River basin namely Slovenia, Croatia, Bosnia and Herzegovina and Serbia. Its primary aims were to find an effective solution for permanent eradication of IAS in the river basin, reduce habitat fragmentation and improve the connectivity of the transnational ecological corridor. Sava TIES was a regional development project, funded by the Danube Transnational Programme under Interreg. The Danube Transnational Programme (DTP) is dedicated to fostering economic, social, and territorial cohesion in the Danube Region. To attain a greater level of territorial integration in the highly diverse Danube region, this transnational cooperation program serves as a catalyst for addressing shared challenges and requirements within specific policy areas, where transnational cooperation is anticipated to yield concrete outcomes.

The Sava river itself stretches 990km, rising in Slovenia and feeding into the Danube river in Belgrade, it is its longest tributary. The river's basin is home to 8.1 million people and covers approximately 97,200km^2. IAS plants are rapidly expanding without restraint in many parts of the Sava River basin. Their unchecked growth is detrimentally impacting native species, depleting soil fertility, diminishing available agricultural land, exacerbating flood control issues, and contributing to a host of other problems. Sava TIES was the first ever attempt to address this challenging issue at a transnational level within the region. The knowledge gained from this effort was hoped to yield advantages that extend to the broader Danube region and even beyond.

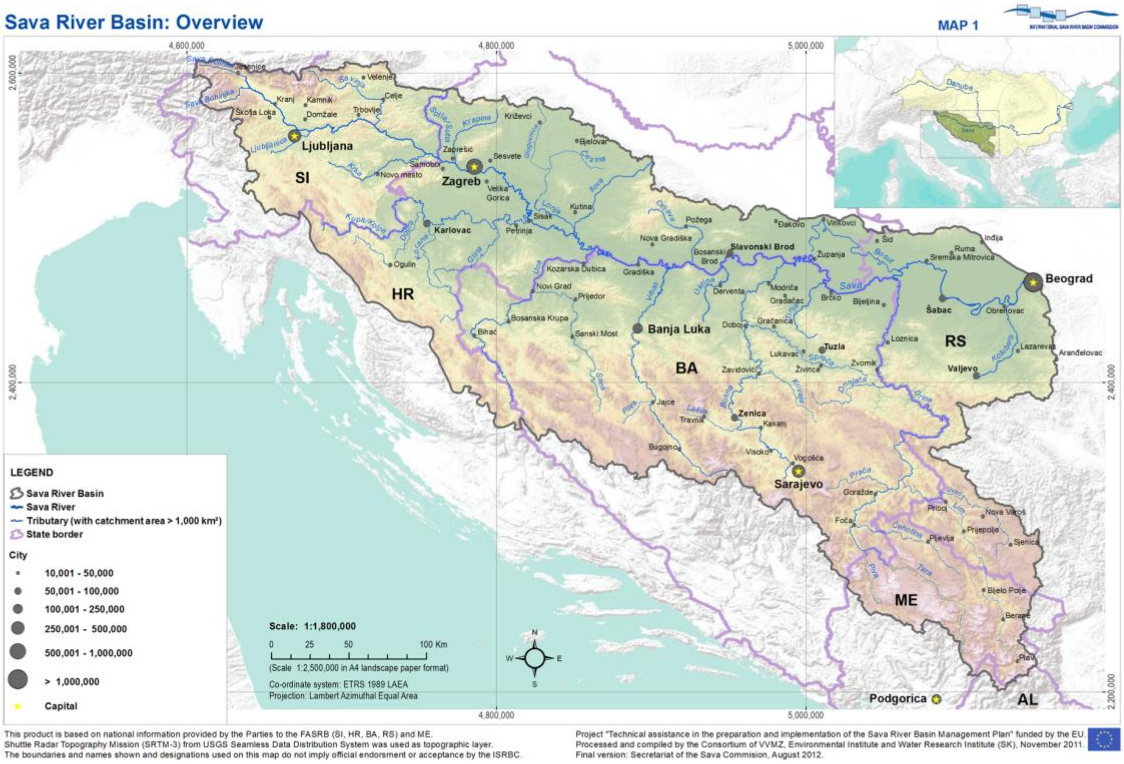


Figure 2-4: Expanse of the Sava river basin

2.2.2 Invasive False Indigo Bush (*Amorpha fruticosa*)

One of the many IAS plants targeted under Sava TIES was False Indigo Bush (*Amorpha fruticosa*). With particular relevance to this case, efforts were made to develop detection, removal and management techniques of False Indigo Bush in the Lonjsko Polje Nature Park in Croatia, who were a participating member of the Sava TIES initiative (see Chapter 4 for further detail on the park). False indigo-bush is a North American native plant that has, either intentionally or unintentionally, expanded its presence across the Northern Hemisphere, often becoming invasive in the process. Particularly, within the watersheds of large rivers where seasonal flooding is common, this plant spreads with ease. Its seeds are buoyant, and when floodwaters recede, new plants sprout, forming dense thickets that stifle the coexistence of other species.[11]

Figure 2-5: False Indigo Bush (Amorpha fruticosa)

To preserve native biodiversity, it is essential to control its spread. However, the current mechanical control and eradication methods are labour-intensive and costly, while herbicide application can be restricted and potentially harmful to surrounding flora and fauna. On the other hand, the plant possesses several advantageous properties and its provision of ecosystem services such as soil stabilization, food for wildlife, and a source of fibre and biomass for certain industries.

[11] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9475134/

Under Sava TIES, efforts to restore grassland vegetation in the Lonjsko Polje Nature Park involved the identification and removal of False Indigo Bush from overgrown areas, covering several hectares across a number of pilot sites in the park. The removal process was carried out using a tractor mulcher. The unchecked growth of False Indigo Bush encroached upon extensive areas of grassland within the park, resulting in challenges for livestock, farmers, the flood defence system, as well as native biodiversity.

2.3 Informed decisions, coordinated actions and effective interventions

Given the well-founded concerns surrounding the prevalence of IAS in the Sava river basin, the mission of the Sava TIES initiative not only helped contribute to the overarching goals of the EU Biodiversity Strategy for 2030 and the EU Habitat Directive, but aimed to develop approaches to improve the wellbeing of local ecosystems and citizens in the Lonjsko Polje Nature Park and throughout the river basin. However, to identify IAS and monitor the effectiveness of Sava TIES, stakeholders needed to be able to develop innovative approaches to overseeing activities.

2.3.1 Collecting the necessary data

To know where IAS are flourishing and how mitigation measures are performing, data must be collected across large areas. For example, one must understand what types of vegetation cover is present across different areas, where vegetation health is degrading, and how mitigation measures perform in terms of eradication and regrowth rates of IAS. Traditionally, this involved gathering different types of in-field data, whereby inspectors would visit given areas to manually inspect vegetation cover, mitigation practices or regrowth patterns of IAS. For practical purposes, only a selected number of “sample” locations would be visited due operational limitations or the fact that some vegetated areas are overgrown or very difficult to reach. By then piecing this data together, park managers could form a representative picture of the health of habitats, the levels of biodiversity and the presence of IAS in a given area.

2.3.2 Limitations of conventional methods

Collecting all the data required for the evaluation of biodiversity and IAS presence using conventional methods had some major drawbacks, in particular the large geographic coverage of nature parks it extremely difficult to monitor all areas. Thick and overgrown areas in rural or difficult to reach areas would often be missed using conventional methods. Practically, manual inspections of areas cannot be done continuously for all areas and can therefore only catch a fraction of the true biodiversity loss given the finite human resources available.

All these limitations can – to a very large extent – be addressed using satellite data. Therefore, a few years ago, Oikon, an Institute of Applied Ecology from Croatia began to develop Earth Observation-enabled monitoring systems which could help to detect and monitor IAS and biodiversity-related issues in the nature park both remotely and continuously.

We will investigate this service in the next chapter, followed by a thorough account of how it was used by the different actors (chapter 4) and the concrete value it brought (chapter 5).

3 The Use of Sentinel Data

3.1 How can satellites help with biodiversity monitoring?

Remote sensing techniques are increasingly harnessed to provide timely and precise data across various aspects related to biodiversity monitoring and management. By merging satellite imagery with meteorological data, biophysical modelling, and statistical analyses, continuous monitoring over natural habitats is made possible, enabling the extraction of valuable insights that aid in the identification and tracking of habitat deterioration and the spread of invasive alien species. In this context, satellites' capability to gather information concerning the well-being of vegetation, grassland, forests and natural habitats over expansive regions with frequent revisits, finds application in a multitude of areas. These applications encompass the likes of biomass monitoring, vegetation health monitoring, species identification, soil monitoring and biodiversity monitoring.

Before delving into the specific biodiversity monitoring services examined in Croatia, it's essential to grasp how satellites can detect changes on the Earth's surface, providing invaluable information to entities involved in overseeing natural habitats.

Broadly speaking there are two main classes of Earth Observation satellites[12]:

- Those carrying **passive sensors** able to detect the sun's energy as it is reflected from the Earth's surface. These "optical" satellites are affected by cloud coverage (at it hinders solar radiation) and can only observe during daytime. Typically used sensors in this category are radiometers (incl. imaging and spectro-radiometers) and spectrometers.
- Those carrying **active sensors** capable of emitting their own energy (in the form of electromagnetic radiation) to illuminate the scene (and objects therein) they observe. Such satellites send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Typically used sensors in this category are radar, scatterometers and lidar. Satellites carrying such sensors – for example Synthetic Aperture Radar (SAR) satellites – are unaffected by cloud coverage.

[12] A nice overview of passive and active instruments on board earth observation satellites is provided in https://earthobservatory.nasa.gov/Features/RemoteSensing/remote_08.php

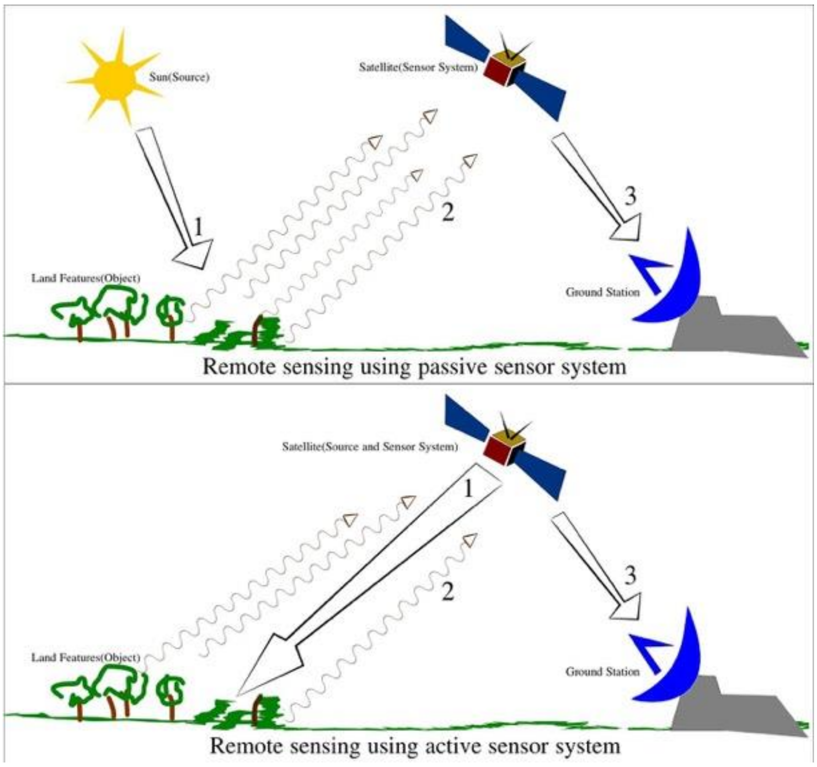


Figure 3-1: Illustration of passive versus active remote sensing[13]

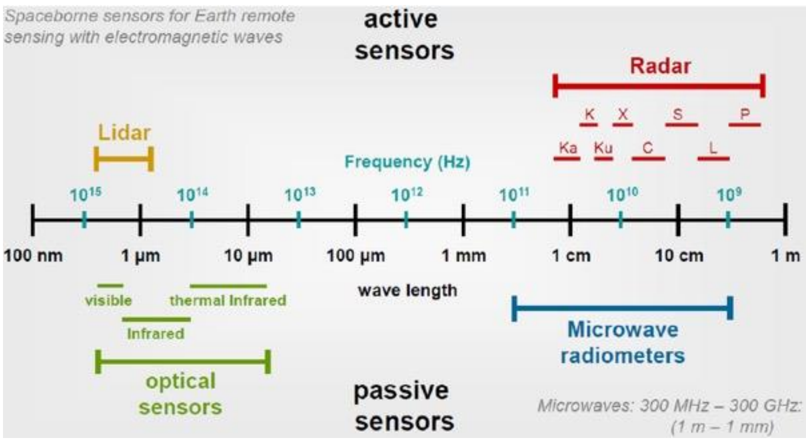


Figure 3-2: Active and passive sensors used for remote sensing[14]

As seen in Figure 3-1, active and passive sensors emit/collect electromagnetic signals of different wavelengths. In practice, different materials on the Earth's surface reflect electromagnetic waves in a different manner. These reflectance differences allow Earth Observation (EO) satellites to distinguish between grasslands, water surfaces, forests, buildings, etc. When more than two wavelengths are used, the separation among objects is even more evident. Thus, satellites

[13] Dall (2017)

[14] Lefeuvre, F & Tanzi, Tullio. (2014)

equipped with multispectral sensors (i.e. utilising different bands of the spectrum) can provide data that allow the quantitative classification of different types of land cover in a given scene.

During the year, vegetation and plants can shed or grow leaves and fruit depending on variables such as temperature, sunlight, and precipitation. Soil characteristics can also further affect vegetation growth. Changes in the health, density, vigour, and productivity of vegetation affect the optical properties of the plant or tree canopy. The use of remote sensing - especially in the red and infrared spectrum - and other proximal sensors enables the mapping of changes (essentially related to vegetation reflectance) across an area and with time, thus enabling the monitoring of vegetation development and growth. Land cover classification can also be achieved using SAR satellites. Contrary to optical satellites – which essentially produce photographs, the SAR imagery is a measure of how much energy is scattered back to the sensor after being reflected on different types of materials.

In all cases, the data collected by EO satellites is transmitted via radio waves to properly equipped ground stations. There they are translated into a digital image that can be displayed on a computer screen. Each satellite image is composed of pixels and each of these pixels represents a square area on the image that is a measure of the sensor's ability to resolve (see) objects of different sizes. The higher the resolution the greater the ability of the sensor to discern smaller objects, but also the narrower the strip of land that can be surveyed by the satellite.

Measuring plant properties

Thanks to this stream of data, a wide range of monitoring and advisory services for biodiversity and habitat protection purposes can be developed. The most common entails the measurement of the Normalised Difference Vegetation Index (NDVI). NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. But it absorbs more red and blue light. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1). By using NDVI and taking advantage of various plant properties, such as the fact that different plants sprout, grow, and shed leaves or flowers at different times of the year can allow researchers to discern invasive species from native species and track how these plants are spreading. This remotely sensed information can also be validated via in-field inspections to ensure detection techniques are accurate. Knowledge of the distribution of this index across a given field and in connection to the applied habitat protection practices, allow stakeholders concerned with protection to make informed decisions on what is needed where and when. To ensure EO data's suitability in various applications, in-situ data can also be used to validate the remotely sensed data.

3.1.1 Advantages

The most important advantages of satellite-based habitat monitoring applications include:

- The **capability to acquire data anywhere in the world** without any limitation by weather conditions (when combining optical and SAR) or the impact of the phenomenon itself.

Satellites offer a **robust source of near-real-time**[15] **information** to aid biodiversity monitoring.

- The ability to generate **consistent, comparable and relatively objective** (i.e. not depending on individual interpretation/observation) information, collected **systematically on multiple scales, from local to regional to nation-wide;**
- The capability to **supply regular, detailed updates on vegetation status** on a local, regional or national basis. By combining different satellites, this can be even done on a **daily basis** offering an invaluable resource to farmers.
- Satellite images offer spatially continuous data coverage of an entire area, with no further interpolation required, in contrast to ground-based discrete sampling. As such, they can serve as a basis for interpolation of information gathered in situ.
- Finally, whilst EO satellite data are a complementary data source to in-situ data (as well as airborne data, socio-economic data, and model outputs) in most countries, they **can be the only reliable source of information in countries lacking the ground infrastructure.**

3.1.2 Limitations

When compared to alternatives such as on-site or aerial surveys, satellite-based forestry mapping presents the following limitations:

- Resolution and active sensor limitations – spatial resolution may not be high enough to detect the required data at small scales or sensors may not be capable/suitable for certain applications.
- Non-daily revisit times for high resolution, non-commercial optical satellites – However, in the application of habitat monitoring, daily revisit times are generally not necessary.
- Possibility of gaps in data availability due to cloud cover.

On-site surveys in particular offer information about soil chemistry and physical properties at different depths below ground which cannot as of yet be fully replicated with either satellite or aerial remote sensing. These soil characteristics tend to be less dynamic by nature than vegetation growth and in consequence, do not have to be reassessed as often. It should be noted that an important upcoming mission, the **Copernicus Hyperspectral Imaging Mission for the Environment (CHIME)**, expected to be launched in 2028, is foreseen to bolster the Copernicus offering even further, particularly when it comes to monitoring of natural habitats. Each CHIME satellite will carry a Hyperspectral Imager (HSI) on board to support the monitoring, implementation, and improvement of a range of policies in the domain of raw material, food security, agriculture, and soil properties. HSI will have secondary applications that relate to biodiversity and ecosystem

[15] "Near real-time" has a different meaning based on the application being studied. In the context of agriculture, near real-time is understood to be a few days. For a comprehensive overview on this we recommend a recent publication by Defourny et al. (2019) https://www.sciencedirect.com/science/article/pii/S0034425718305145

sustainability, forestry management, environmental degradation, lake/coastal ecosystems, water quality, and snow characteristics. [16]

Until a few years ago, another potential limitation was the cost of acquiring satellite data. That has progressively changed, first thanks to Landsat[17], and then with the advent of the Sentinel era – producing vast amounts of data under the Copernicus full, free and open data policy.

3.2 Copernicus and the Sentinels

The service studied is based on the use of both Sentinel-1 and Sentinel-2 data coming from the European Copernicus programme, so we shall start with a simple overview of the programme to place the services into context.

Copernicus is an EU flagship programme[18]. Copernicus started out as GMES (Global Monitoring for Environment and Security) with the goal of meeting European geo-information needs. At its heart is the most complete, operational satellite system in the world; owned by the EU and operated by ESA and Eumetsat and currently comprising six types of satellites, see figure below.

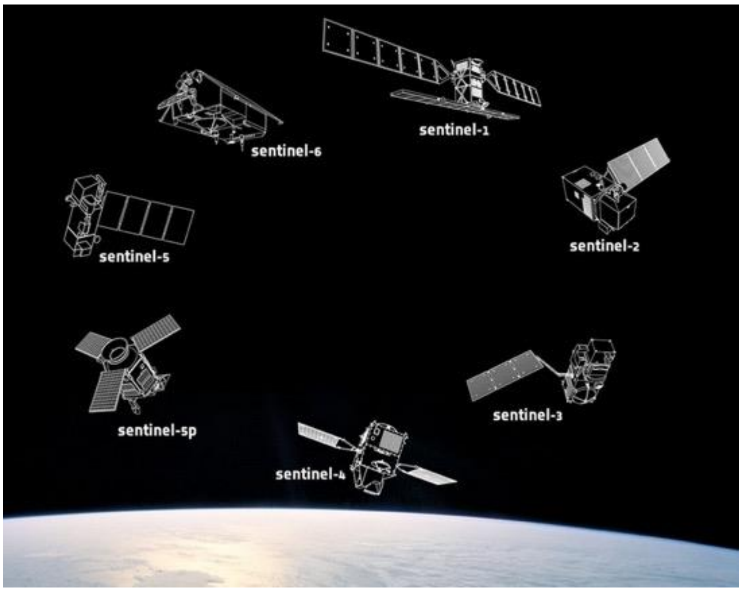


Figure 3-3: Current Sentinel satellites

This case is defined by both Sentinel-1[19] and Sentinel-2[20] (see the info boxes below).

[16] https://www.eoportal.org/satellite-missions/chime-copernicus#eop-quick-facts-section

[17] https://www.usgs.gov/core-science-systems/nli/landsat

[18] https://www.copernicus.eu/en

[19] https://sentinel.esa.int/web/sentinel/missions/sentinel-1

[20] https://sentinel.esa.int/web/sentinel/missions/sentinel-2

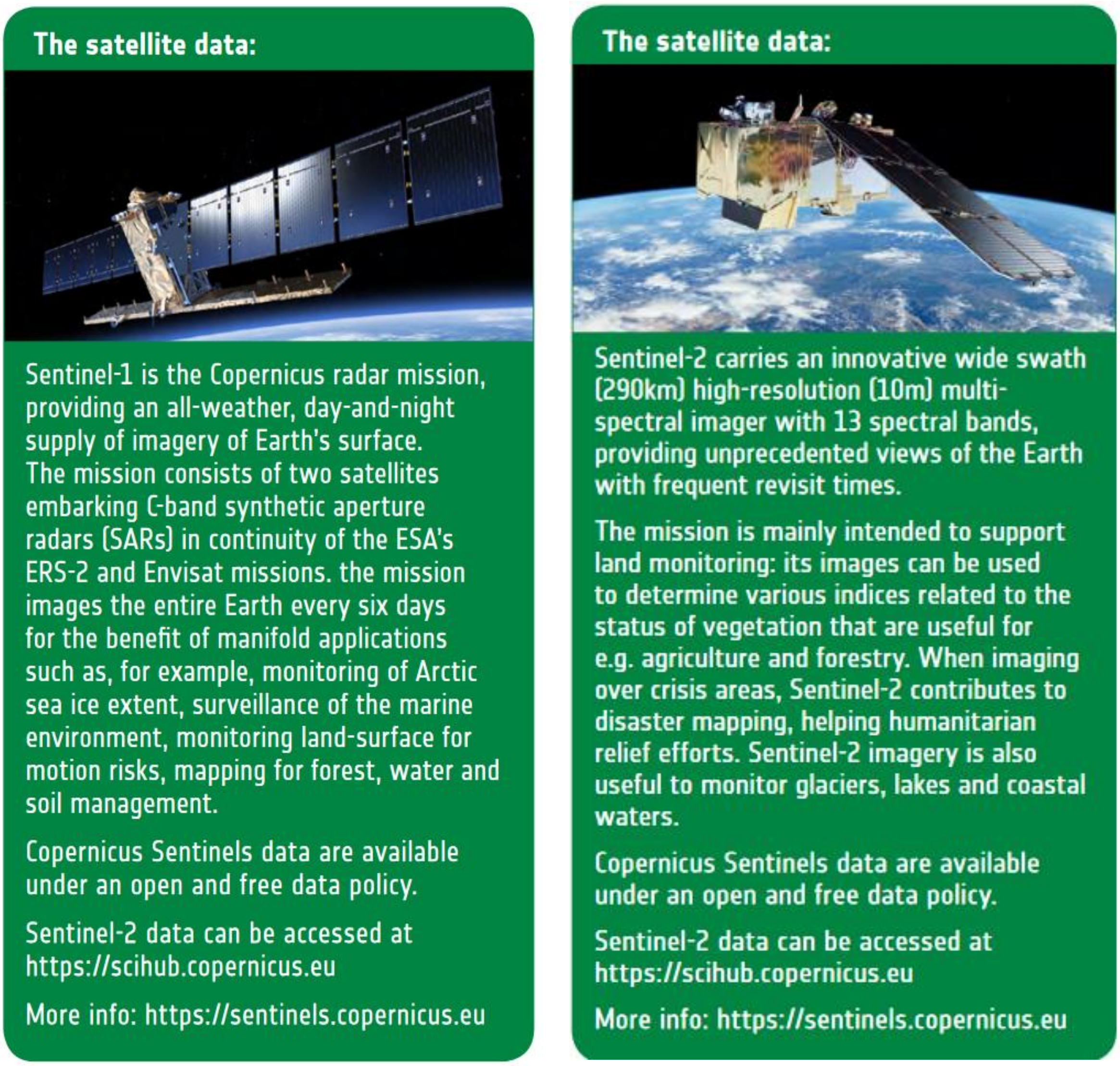


Figure 3-4: Sentinel-1 and Sentinel-2 satellites

Sentinel-1 carries a Synthetic Aperture Radar (SAR) operating in C-band. The two-satellites Sentinel-1A and 1B provide high-reliability data with a short revisit time, global coverage and rapid data dissemination to support operational applications. As already discussed, SAR is an effective and important technique in monitoring habitats and vegetation because its quality does not depend on weather conditions, cloud cover or day/night light coverage. Sentinel-1 SAR can be used to complement optical and NDVI data which is derived from Sentinel-2 (this will be further discussed in the following paragraph).

Sentinel-2 is a wide-swath, high-resolution, multi-spectral imaging mission. Sentinel-2 carries an optical instrument payload that samples 13 spectral bands: four bands at 10m, six bands at 20m and three bands at 60m spatial resolution. Normalized difference vegetation index (NDVI) is a simple graphical indicator that can be derived from Sentinel-2 data which helps to assess vegetation health based on how the vegetation reflects light at certain frequencies. Sentinel-2 helps in monitoring soil properties as well as vegetation conditions. It helps park managers to monitor seasonal changes, assess land use and assist in implementing policies for sustainable development.

3.3 The Oikon Service

Oikon provide a plethora of applied ecology services (both consulting and research) which utilise, among other sources, optical and radar data from Sentinel-1, Sentinel-2 and Landsat. As part of the Sava TIES initiative, Lonjsko Polje contracted Oikon to help them understand what types of habitats were present in the park. **With particular relevance to this case, Sentinel-2 was primarily used to develop a number of habitat mapping and IAS detection/biomass estimation methods across several regions of Lonjsko Polje.** The aim of the service was to:

- Map and classify all aquatic and grassland habitats within the park to the National Habitat Classification and the European Natura 2000 Ecological Network standards.
- Determine the percentage of mapped habitats either partially or fully taken over by invasive Amorpha fruticosa.
- Define habitats that are priority for revitalisation with regard to the value of the site and potential use.

Through a combination of satellite monitoring and in-field visits, Oikon mapped a total area of 8471ha within the park, including aquatic and grassland ecosystems, enabling Lonjsko Polje to better understand the types of habitats present along with a solid classification of each. It also allowed for the identification and registration of 10 Natura 2000 habitats.

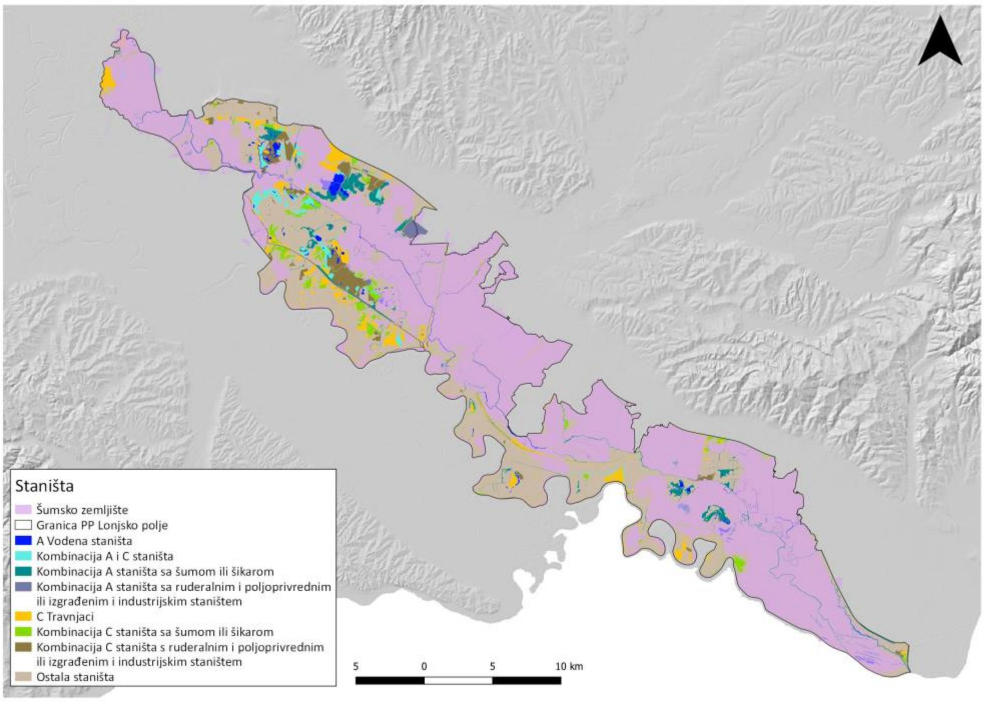


Figure 3-5: Habitat map of Lonjsko Polje made according to the National Habitat Classification

To calculate the presence and biomass of Amorpha fruticosa, several approaches were taken, including in-field inspections, LiDAR and through Sentinel-2 images. Among the three methods, it was found that the most accurate results were obtained using Sentinel-2 images. In fact, the processed data on vegetation height and intensity from the images obtained by the LiDAR system did not meet the minimum requirements for accuracy. Throughout the analysis, different regions of electromagnetic spectrum sensed by Sentinel-2 were analysed and good separability of Amorpha fruticosa from other land cover classes was identified in red edge and near-infrared regions. These regions react to chlorophyll content in plant leaves and distinction was evident particularly with young Amorpha fruticosa. As a result, Oikon could conclude that of the 6645ha analysed, 2250ha (34%) were overgrown with by IAS. Throughout the process several in-field inspections were undertaken to help bolster and validate findings from remotely sensed detection methods. Randomly selected plots, 4x4 metres in size were visited, with a total of 42 plots inspected.

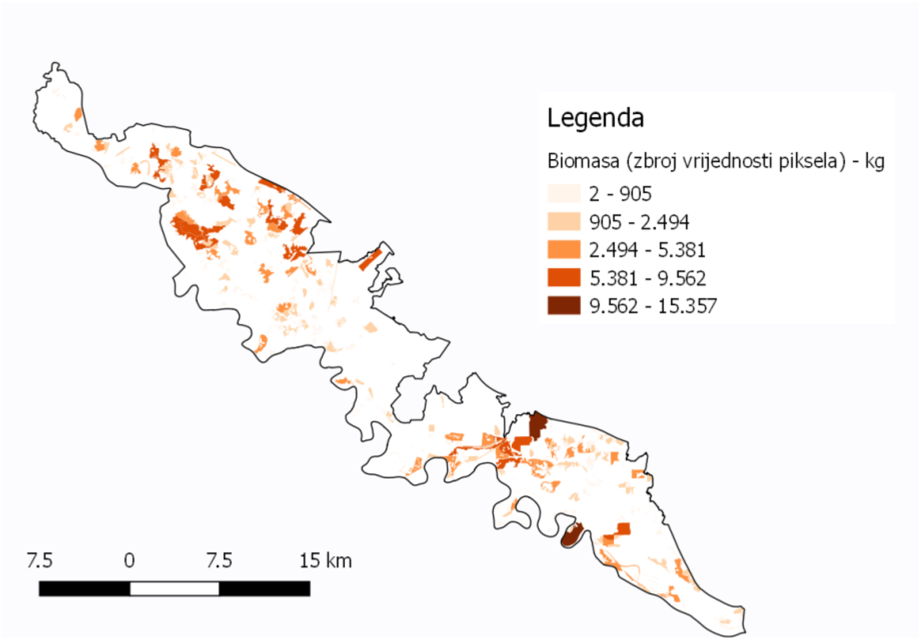


Figure 6: Sentinel-2 derived map of Amorpha fruticosa

3.3.1 Future Evolution of the Service

After the work done for Lonjsko Polje under the Sava TIES initiative, Oikon went on to further develop their detection methods for IAS across several types of habitats using Sentinel data. For example, in a subsequent ESA project (contract no. 4000136101/21/NL/SC), Oikon were contracted to develop Sentinel-based detection models that would achieve the detection of selected plant IAS with an accuracy of at least 70%. This is in line with the EU's special Regulation no. 1143/2014 which requires the Member States, among other, to take measures for the early detection and eradication of these species. Moreover, in Croatia, the Law on Prevention of Introduction and Spread of Alien and Invasive Alien Species and their management (OG 15/18, 14/19) anticipates establishment, standardisation and coordination of inventory, mapping, and monitoring of IAS.

Under this project, Oikon managed to achieve detection accuracies of more than 85% for both young and grown Amorpha classes. In fact, dense Amorpha fruticosa monocultures that invade large forest clearings were easily distinguished, with the model developed managing to separate amorpha even in more complex environments where mixing with grass and young oak and ash trees occurs. In the future they plan to further test the model to explore the possibility of detecting Amorpha fruticosa in more mixed scenarios and especially the inclusion of the flowering phase in early June.

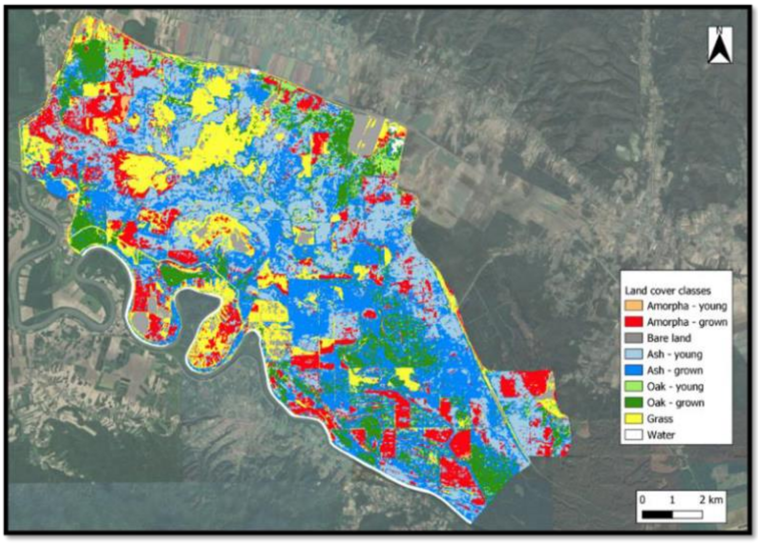


Figure 3-7: Amorpha fruticosa distribution near Novska based on developed detection model

Moreover, under this project, detection models were also developed for Ambrosia artemisiifolia (common ragweed). Ambrosia artemisiifolia is the number one cause of allergic rhinitis in Croatia. It is well adapted to poor environmental conditions, does not tolerate shade, and grows in relatively large colonies that can mix with other species. The detection methods were tested in agricultural areas where the species invades harvested plots or fallow land. The most problematic aspect of Ambrosia artemisiifolia detection is the fact that it grows in agriculturally active areas so it does not cover large swaths of area. Additionally, its coverage is often not uniform and mixes heavily with crops such as corn and sunflower. Beside fields, it tends to grow linearly along field and road edges which escapes Sentinel-2’s peak resolution of 10 m.

Figure 3-8: Patch of Ambrosia artemisiifolia growing in a sunflower plot with a width of 10m

Ambrosia artemisiifolia grows from June through summer months, with rapid intensification from mid-July. It is tolerant to drought, so it retains more water in its leaves than surrounding vegetation. In late August it develops flower buds which results in a decrease in its chlorophyll levels. From September the plants start to whither while the stems remain in ground for several months. Therefore, a time series of Sentinel-2 images that cover the period from early August to November was used in the detection model. Three vegetation indices that combine red edge, near-infrared and short-wave infrared regions were combined with selected bands to detect changes in water and chlorophyll content between Ambrosia class and other land cover classes. The model based on time series could distinguish healthy and green Ambrosia artemisiifolia from corn, soybeans, and sunflower in August when the crops reach maturity whereas October and November images differentiate withered stems from surrounding healthy grass and weeds. Overall, the detection model achieved an accuracy of more than 90% when validated in heavily affected areas.

Again, Oikon plan further iterations of the model that could benefit from more quantity of ground truth data and inclusion of June and July in time series so that better detection can be achieved in more mixed environments.

4 Understanding the Value Chain

4.1 Description of the Value-Chain

This case, as mentioned already, revolves around biodiversity, habitat, and IAS monitoring. This ability, enabled by the satellite-based services provided by Oikon, enables supply chain actors to ensure the loss of biodiversity in sensitive areas is kept to a minimum. It is thus precisely this ability that gives rise to the value chain we will be studying. In practice, the use of satellite data at the entry point of the value chain, results in enhanced information or improved operations that bring value for each link further down the chain. Ultimately, the implementation of habitat mapping and IAS detection (both from an economic and an environmental point of view), results in benefits experienced by our society at large at the far end of the value chain. But before we dive into the individual links and attempt to quantify the benefits (this is done in chapter 5) it is instructive to understand how the use of satellite data helps actors along the value chain to address the challenges that shape their own operational reality. Thus, in the following sections we provide details on the interests and responsibilities of the stakeholders in each tier.

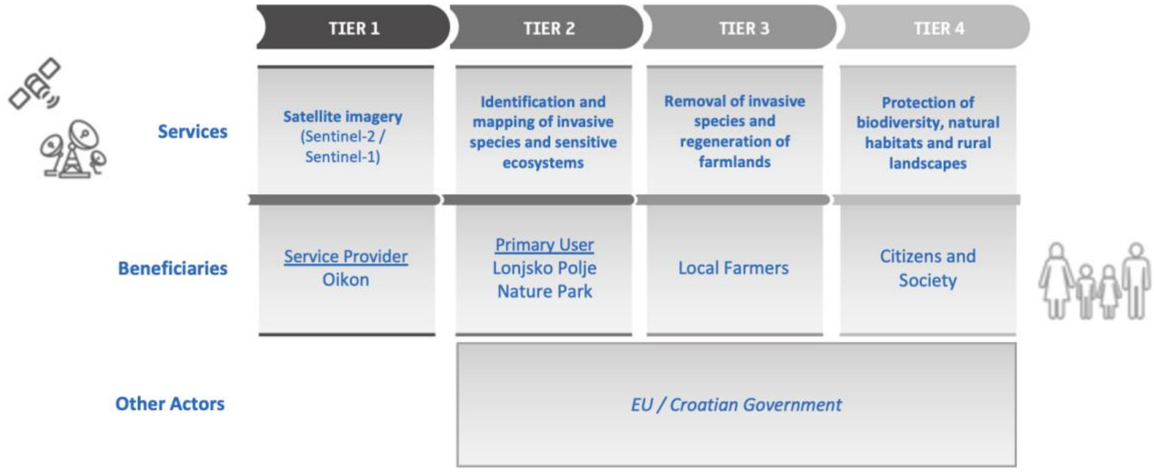


Figure 4-1: The value chain for Invasive Species Detection in Croatia

4.2 The Actors

4.2.1 Tier 1: Service Provider – Oikon

Oikon are a research institute and consulting company based in Zagreb, Croatia who have been in operation for over 25 years. Oikon provide services in the fields of applied ecology, nature and environmental protection, industrial ecology, renewable energy, natural resource management, ecological modelling, landscape analysis and design, geographic information systems (GIS), remote sensing and ICT, environmental law, policy and economics, feasibility studies, as well as program and project management.

The company is organised into 4 main departments, the Department of Environmental Engineering, the Department of Nature Protection and Landscape Architecture, the Department of Natural Resources Management, and the Department of Environmental Law, Policy, and Economics. Oikon also have 5 laboratories: Laboratory for Remote Sensing and GIS – LaDIGIS, Laboratory for Research and Monitoring of Large Carnivores and Ecology of Vertebrates, Laboratory for Fish and Aquatic Ecosystems, Laboratory for Data Science and Laboratory for Biodiversity and Population Genetics.

Since 2019, Oikon have been a UNIGIS Study Centre and a focal point for students from nine Southeast European countries (Albania, Bosnia and Herzegovina, Bulgaria, Montenegro, Croatia, Kosovo, Northern Macedonia, Slovenia and Serbia) enrolled in online academic programs in Geoinformatics with degrees awarded by the University of Salzburg.

Figure 4-2: The Oikon team

Some of Oikon's primary service lines include environmental impact assessments (EIA), environmental management plans (EMP) and assessments regarding Natura 2000 sites in Croatia across both terrestrial and marine environments.

The organisation's primary customers include the likes of development agencies and international financing institutions such as the EU/EuropeAid, WB, EBRD, EIB, KfW, UNDP, WWF, GEF and NATO. Moreover, in the implementation of projects funded by development agencies and international financing institutions they often cooperate closely with leading European environmental consultancies and scientific institutions.

4.2.2 Tier 2: Primary User – Lonjsko Polje Nature Park

Lonjsko Polje Nature Park is a protected area in Croatia, known for its wetlands and rich biodiversity. It is located in the central part of Croatia, primarily in the Sisak-Moslavina county, but it extends into the areas of Zagreb and Vukovar-Syrmia counties as well. The park covers an extensive area and is renowned for its important ecosystems. Lonjsko Polje is characterised by extensive floodplains, meadows, and wetlands. The park is situated along the Sava River, which can cause periodic flooding, creating a dynamic and diverse habitat for various plant and animal species. It is home to numerous plant and animal species, including a variety of birds, fish, and amphibians. It is particularly famous for being a habitat for white storks, with one of the highest recorded stork populations in Europe. The park also showcases traditional architecture in the form of wooden houses and buildings, often raised on stilts to protect them from flooding. These structures are known as "hiže" and provide insight into the cultural heritage of the region. Lonjsko Polje acts as a popular destination for ecotourism and outdoor activities such as bird watching, hiking, and canoeing. There are several visitor centres and educational facilities within the park to help visitors learn about the unique environment.

Figure 4-3: Visitors to the park

The park is dedicated to the conservation of its natural and cultural heritage, and it is part of the Natura 2000 network. Because of its natural and cultural values, Lonjsko Polje is also recognized as an important area at international level. Thus, in 1993, Lonjsko Polje was included in the List of Wetlands of International Importance, the so-called Ramsar List[21], as Ramsar Site 584, under the International Convention on Wetlands (Ramsar Convention).

[21] https://rsis.ramsar.org/

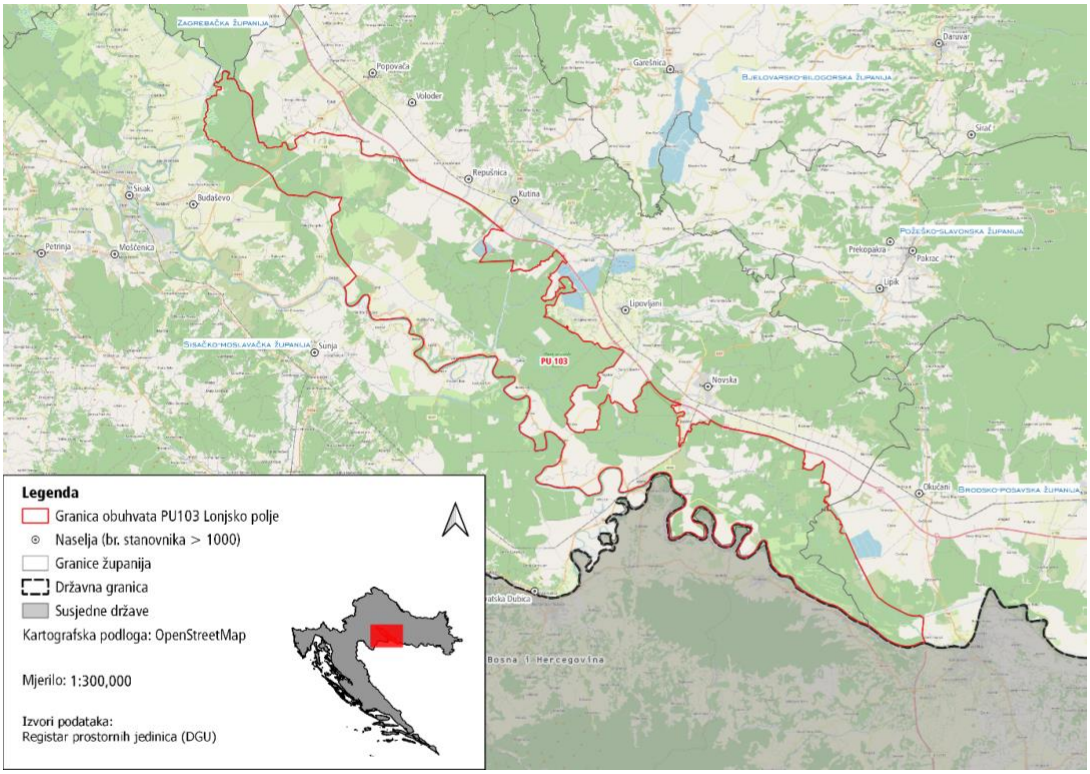


Figure 4-4: Area and position of Lonjsko Polje Nature Park

The Sava River has significant impact on the landscape and culture of the park. The embankments located around the area on the north, south, east, and west sides of Lonjsko Polje can hold up to 600 million m³ of water. The Middle Posavlje Flood Control system is of key importance in flood protection for Zagreb, the Slavonic section of the Sava downstream from Stara Gradiška and in flood protection in the neighboring states of Bosnia and Herzegovina and Serbia.

The park is also home to residents all year round, in fact, there are fourteen rural settlements (Čigoč, Kratečko, Mužilovčica, Suvoj, Lonja, Trebež, Puska, Krapje, Drenov Bok, Jasenovac, Košutarica, Mlaka, Stružec and Osekovo), which are mostly located on the southwestern border, directly next to the left bank of the Sava River. According to data from 2021, a total of 2,927 inhabitants live across the settlements. In the period from 2001 to 2021, all settlements recorded a decrease in the number of inhabitants, by an average of about 30%, and considering the local economic opportunities it is expected that these numbers will continue to decrease in the future.

About 90% is state-owned with the remaining 10% held by private owners. Forested areas are almost entirely state-owned (97%), while cultivated non-forest (arable) and grassland areas are mostly privately owned. Large complexes of state grasslands (pastures) are owned by the Republic of Croatia but managed by local self-government units where the local population uses them jointly as communal pastures for the grazing of cattle and horses.

Figure 4-5: White storks are an important symbol of Lonkso Polje

The main economic activities in Lonjsko Polje are agriculture, forestry, water management, hunting and fishing. However, tourism is becoming more and more important. Currently, agriculture brings the most significant economic value to the park, and as already discussed, 6645ha of land analysed, 2250ha were overgrown by Amorpha fruticosa and/or Xanthium strumarium (Rough Cocklebur).

Lonjsko Polje are continually involved in several conservation and revitalization projects as part of their operational mandate to protect the sensitive ecosystems within the park. The Sava TIES project was one such initiative which aimed reduce the harmful impact IAS was having along the Sava River.

4.2.3 Tier 3: Local farmers

The primary livelihood of the local population in the park revolves around agriculture, particularly traditional extensive animal husbandry practices such as pasturing, foraging, and haymaking. Indigenous species play a vital role within this pasturing system, contributing to the preservation of extensive farming and the maintenance of biological diversity. The large pastures within the park are home to indigenous livestock species found in this region including the Posavina horse, the TuroPolje pig, and slavonian-syrmian grey-cattle. These species are tough, exhibit minimal dietary needs and are also all finely attuned to the challenging conditions presented by seasonal flooding along the Sava River.

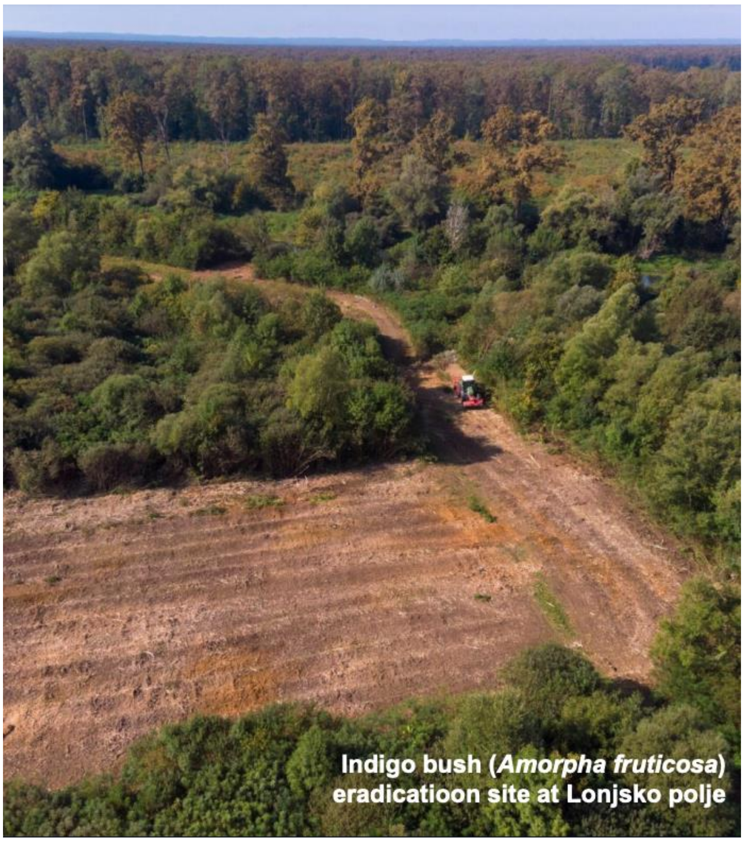


Figure 4-6: Amorpha fruticosa mechanical removal in the park

The revival of livestock rearing as a key economic activity within the park has been both a major priority and a major challenge. Farmers have faced numerous challenges that impede the revitalisation process, chiefly caused by pastures overrun by invasive species such as Amorpha fruticosa, ragweed (Ambrosia artemisifolia) and Rough Cocklebur (Xanthium strumarium).

There is an extensive history of IAS eradication efforts in the park. In fact, the management of IAS commenced in 1999, with its primary focus on eradicating the Amorpha fruticosa. The initial efforts were made possible through donations from the EECONET Action Fund and EuroNATUR, as part of the Sava Wetlands–Spoonbill Colony Krapje Đol project. The first phase of this endeavour involved revitalising 50ha of land and introducing Slavonian-Syrmian Grey cattle for controlled grazing.

Over the following years, Lonjsko Polje, in collaboration with the local community, made significant progress in its conservation efforts during two LIFE projects: "*Towards Wise Use in Lonjsko Polje Nature Park, Croatia*" and "*Central Posavina–Wading Toward Integrated Basin Management*," which were carried out from 2001 to 2008. Approximately 200ha of overgrown pastures in Lonjsko and Mokro Polje were successfully revitalised.

In the subsequent decade, park management, in partnership with the EuroNATUR Foundation and "Croatian Waters" Public Enterprise, continued its work on the eradication of IAS and restored an additional 100ha. The selection of areas for revitalisation was a collaborative effort with local cattle breeders to ensure sustainable grazing practices. The engagement and support of local communities played a pivotal role in the success of these restoration initiatives. In more recent years, these communities, using their own resources, further restored another 300ha. These combined efforts not only facilitated the removal of invasive species but also heightened the interest in preserving traditional grazing practices, leading to a 20% increase in the number of cattle and horses in the area.

Lonjsko Polje, in conjunction with the Ministry of Agriculture, developed a solution for incorporating large state-owned parcels into the subsidy system. However, the revitalisation process remains ongoing. Beginning in 2019, park management conducted the comprehensive mapping of the park. As of now, approximately 1200ha are still densely covered by Indigo bush, with 650ha covered dominantly by Indigo bush.

4.2.4 Tier 4: Citizens & Society

The final beneficiaries in this value chain are citizens and society. The maintenance of biodiversity, natural habitats and rural landscapes is incredibly important for society for a variety of reasons. The protection and preservation of Lonjsko Polje contributes to various industries, including agriculture, fishing, and tourism. The maintenance of nature parks helps keep them beautiful and visually attractive, thereby drawing tourists and outdoor enthusiasts. These visitors contribute to the local economy and local communities through spending on lodging, food, and recreational activities. The people of Croatia also have deep cultural connections to the park, meaning the preservation of its landscapes play an essential role in cultural traditions, art, and the sense of identity and place.

Biodiversity also plays a crucial role in providing ecosystem services such as clean air, clean water, pollination of crops, decomposition of organic matter, and regulation of climate and disease. Well managed natural ecosystems, such as forests and wetlands within the park help regulate the climate by absorbing and storing carbon dioxide. Biodiversity conservation is integral to mitigating climate change and its associated impacts. Protecting these natural resources increases the resilience of ecosystems and their ability to adapt to environmental changes.

Finally, many people and societies believe in the ethical and moral responsibility to protect and preserve other species and the ecosystems they inhabit. The loss of biodiversity is seen as a violation of this responsibility. Therefore, to protection of the nature park is not just a concern for conservationists but is of paramount importance for society. Its preservation and sustainable use are crucial for ensuring the health, prosperity, and cultural richness of the Lonjsko Polje, the people who live in it and visit it and of Croatia as a whole.

In view of that, let us take a brief look on the role of “other beneficiaries” in our value chain.

4.2.5 Other Beneficiaries

EU / National Government

Given the context of the efforts in this case, the EU and Croatian Government can be considered another beneficiary. Not only is the Sava TIES project partially funded by the EU via Interreg, but the continuing efforts of the park in also trying to maintain biodiversity and fight IAS helps feed into the overarching goals of several national and EU-level initiatives, including the EU Biodiversity Strategy for 2030, the Habitats Directive and the Natura 2000 initiative.

5 Assessing the Benefits

Now that we know which effects the Sentinel-enabled habitat monitoring service is causing in the subsequent tiers of the value chain, we can establish the different types of benefits that are generated through its use. Which financial value can we attribute to the availability of the service? Which environmental or regulatory benefits can we identify? Are there social or scientific impacts that we can track? These are the questions we are addressing in this chapter. In this regard, it is useful to recall our value chain picture whilst adding the last two layers to it.

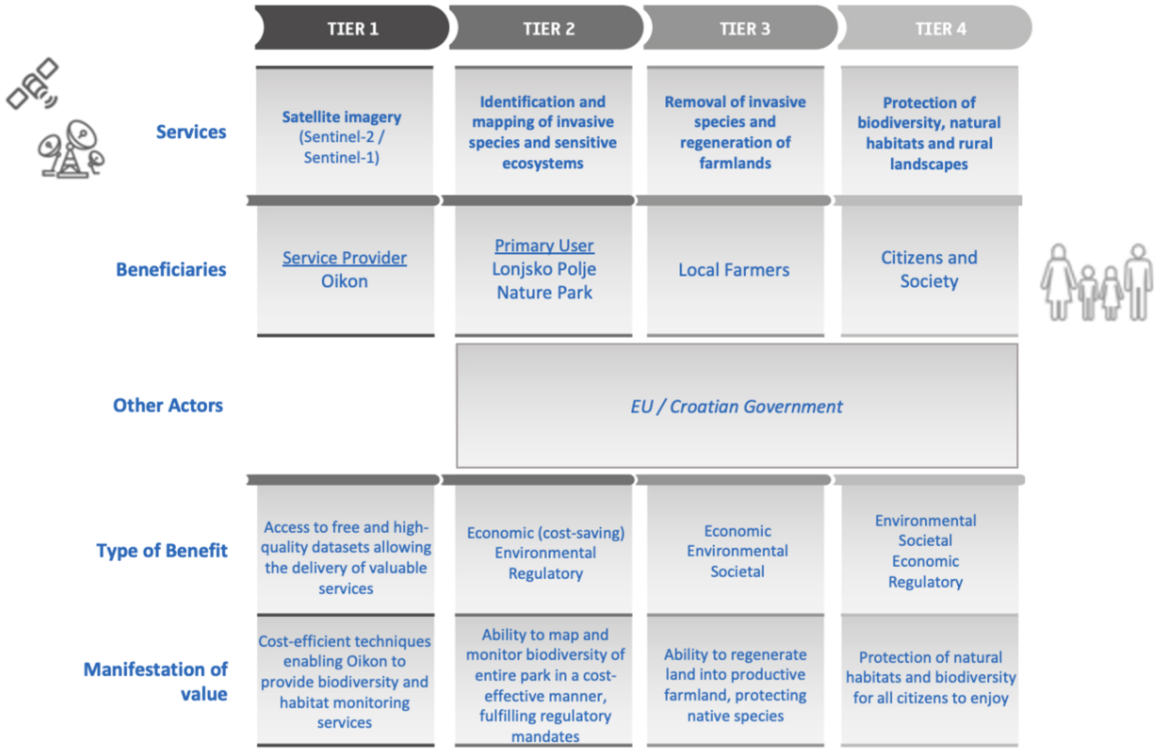


Figure 5-1: Benefits along the value chain

5.1 Overview

In this section we look at the benefits which were and continue to be generated using Sentinel-enabled habitat monitoring and IAS detection services. We will examine the impacts comprehensively, considering more than just economic factors, although these are typically the benefits of most interest to readers. In our prior research, we have discovered that non-monetary benefits often play a significant role in creating substantial value.

Before we dive into the discussion for each of the tiers it is instructive to make some high-level observations:

1. Attribution of value to Sentinel data

In most of the previous cases which have been analysed, we face the issue of attribution, i.e., how much of the economic benefit is due to the use of the data from Sentinel satellites specifically? In this case, the Oikon service developed within the Sava TIES initiative is entirely based on Sentinel-2 data and then complimented by ground-truth verification via on-site visits. As already mentioned, under Sava TIES, the processed data of vegetation height and intensity from the images obtained via a LiDAR system did not meet the minimum accuracy requirements of the biomass prediction model. Therefore, we can attribute 100% of the benefits in this specific instance to Sentinel data.

2. Putting a value on nature

It is often difficult to put a monetary value on the preservation of natural habitats, rural landscapes, or the maintenance of biodiversity. Traditionally in SeBS cases we have made reference to the many intangible or unquantifiable but very real benefits associated with the maintenance of such natural resources, but sometimes refrained from placing economic values on such benefits due to various associated uncertainties. Given that this case involves the eradication of IAS and reclamation of land back to productive farmland and the identification and definition of Natura 2000 sites, both of which can have relatively robust value approximations applied based on land area, we will make estimations of the value of nature here.

5.2 Benefits along the Value-Chain

5.2.1 Tier 1: Service Provider – Oikon

In this case, as with many others, the fact that Oikon's service relies on a completely free primary data source allows them to consistently cut substantial operational costs. If Oikon were to continuously pay for such substantial volumes of data, it would likely necessitate a dramatic overhaul of their business model, ultimately resulting in reduced profits. The ability to use Sentinel data, due to its free and open nature, has been instrumental in helping Oikon maintain a sustainable business model. In fact, this freedom from certain financial constraints is often a major barrier for businesses and can even discourage the launch of new services or innovations altogether.

In order to estimate the economic benefit at this tier, Oikon have actually provided an estimate of cost savings associated with using Sentinel data in lieu of commercial data. Oikon estimate that they save between €100,000 – €125,000 in commercial data costs at a minimum of 6 purchases per year for doing vegetation dynamics analysis similar to what was done for Lonjsko Polje. **This equates to an economic benefit of between €600,000 – €750,000 per year**.

Apart from the economic aspects, it is crucial to highlight Oikon's significant contribution to the innovation and entrepreneurship landscape of the EU and the scientific understanding of how IAS can be managed. This contribution stems from their inventive utilisation of Sentinel data to create algorithms and methods for the detection and monitoring of IAS. Being one of the pioneering fully functional demonstrations of Sentinel data's application in detecting Amorpha fruticosa, the potential impact of this service when extended to other rural settings cannot be understated. It stands out as a pioneering innovation in the realm of IAS detection, and the efforts put into its development and operation are paving the way for the emergence of further innovations. The efforts from Oikon have also contributed to the understanding of how IAS can best be detected and monitored using remote sensing techniques. For a full list of relevant scientific publications see **Annex 1**. For more information on related innovative developments that Oikon is currently pursuing and aims to enhance in the future, please refer to section **3.3.1 – Future Evolution of the Service**.

5.2.2 Tier 2: Primary User – Lonjsko Polje

As the primary user of Oikon's service, Lonjsko Polje have benefited in several ways. First, without the use of Oikon's Sentinel-enabled service, they would have great difficulty in comprehensively understanding where, and to what extent IAS have taken over areas of the park. Prior to mapping efforts undertaken in this case, Lonjsko Polje were not fully aware of the extent of the coverage of IAS in the park. Thanks to the use of Sentinel data, Lonjsko Polje were better able to understand which areas were most overgrown and needed most attention in terms of reclamation efforts. Without utilising space technologies, the traditional way of surveying the park would have involved on-site inspections. Given the size of the park, achieving the same level of coverage with on-site inspections would have been extremely time consuming and costly. As part of the Sava TIES initiative, a "**Mapping and Monitoring Protocol for IAS**"[22] was developed to guide users in manually mapping IAS within their parks. The document describes 4 methods of field inspection that could be used depending on given requirements and considerations. Although these methods were not implemented in Lonjsko Polje to map the full 8471ha that were mapped by Oikon using Sentinel data, "Method 4" within the document would have likely been the most appropriate given its ability to map larger areas at lower costs. The document states that using Method 4, typically 200-400 hectares can be mapped by one person in one day. If we assume an average of 300 hectares can be mapped by one person in one day using this method, it would have taken roughly 28 person days of effort to achieve the same level of coverage. This, however, is a very rough estimate of effort as the document states that "*Selecting (or specifically developing) the most appropriate method is not easy, as is it highly context dependent and depends on e.g., arial extent, staff, money, and time availability*." We will therefore leave these counterfactual avoided costs as noted, but unquantified.

Although not used in this case, drones are also an alternative to field inspections but again can be expensive to operate regularly over large areas. The retrieved images may also need GIS specialists' interpretations, which are also not free.[23] Moreover, whilst satellite data can cover large areas in one pass, a drone's range is limited and could be subject to flying regulations depending on the country or region. We are also seeing commercial satellite data costs falling year on year as satellite launch costs get lower and more data and service providing companies are entering the market.[23] It is undoubtedly cheaper, more efficient, and more effective to do these inspections via remote

[22] https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/45/6d3c13fdda82a5dd31683eb2f326f647a4c0e896.pdf
[23] https://eos.com/blog/drones-vs-satellites/

sensing. Given that the use of drones and/or helicopters was not optioned by Lonjsko Polje in this case, we do not have good counterfactual data on avoided costs, therefore we will leave these avoided costs as noted, but unquantified.

There is also the question of eradication and removal costs of IAS. Invasive plant species can often grow in large volumes or in remote areas and can even have extensive root systems that enable them to spread rapidly. Removing them can require digging up the roots, which can be labour-intensive and incur costs, thereby reducing some positive economic benefits. Under the Sava TIES initiative, pilot sites were set up within Lonjsko Polje to understand and compare IAS eradication and control methods. After initial monitoring of vegetation, a 10ha pilot site of grassland infested by Amorpha was machine mulched. After that, one part of this area (6ha) was subjected to grazing, another part (3ha) was fenced and mowed/mulched and the third, smallest part (1ha) was fenced and the spontaneous progress of Amorpha fruticosa was monitored. Five months after eradication in the smallest area, Amorpha fruticosa had reached a height of 2.5m and completely covered the area. Similarly on the mulched/mown area, Amorpha quickly resprouted and reached a height of 2m, completely covering the area. The pastured area showed the best results in terms of height of amorpha, number of stems, degradation of habitat and distribution of IAS. The average cost of eradication efforts was calculated to be **€1,550 (+ 25% VAT) per ha**. As the total land area reclaimed from IAS was 350ha (see next Tier for details), we can conclude that the total associated incurred cost for reclamation and restoration equates to **€678,125.** We will record this as an economic expense within Tier 2. Despite this, for Lonjsko Polje, the true value materialised here is in the preservation and reclamation of the park's precious natural habitats.

Given that Lonjsko Polje are an important nature park in the region, the environmental benefits are clear. By ensuring IAS is monitored and kept to a minimum, Lonjsko Polje are maintaining biodiversity in the region, protecting natural habitats, and helping the nature flora and fauna flourish.

Moreover, through the work done in protecting natural habitats and removing IAS, Lonjsko Polje are also fulfilling regulatory mandates. As part of their role in the Sava TIES initiative, the park has contributed to eradication of IAS in the Sava River basin and the generation of knowledge on how to do so. The efforts of the park also feed into the goals of various national and EU-level initiatives, in particular, the EU Biodiversity Strategy for 2030, the Habitats Directive and the Natura 2000 initiative.

5.2.3 Tier 3: Local farmers

The third beneficiaries in this value chain are the local farmers within Lonjsko Polje. As a result of the efforts of Oikon and the park management, IAS was identified and removed, thereby making way for arable land which farmers can use to help reintroduce and support native livestock, including the Posavina horse, the TuroPolje pig, and slavonian-syrmian grey-cattle, which in itself is an environmental benefit. Placing an economic value on the increase in farming activity can be difficult as it depends greatly on market prices of livestock and their derived products as well as herd sizes. It is also difficult to quantify fully the economic value this brings to local famers and communities as there can be multiplier effects, meaning when local farmers gain in financial terms from farming activities, they in turn can then support other local business i.e., shops/restaurants. Nevertheless, we can simplify this calculation down by estimating the value generated by the creation of new farmland in terms of land prices.

Through the work done in the previous two tiers, it has been estimated that 6645ha of land was identified as overgrown by IAS, with 2250ha overrun by Amorpha fruticosa and/or Xanthium strumarium (Rough Cocklebur). Of this area, approximately 350ha was then specifically targeted and redeveloped into arable land to be used as pastures along with freshwater habitats.

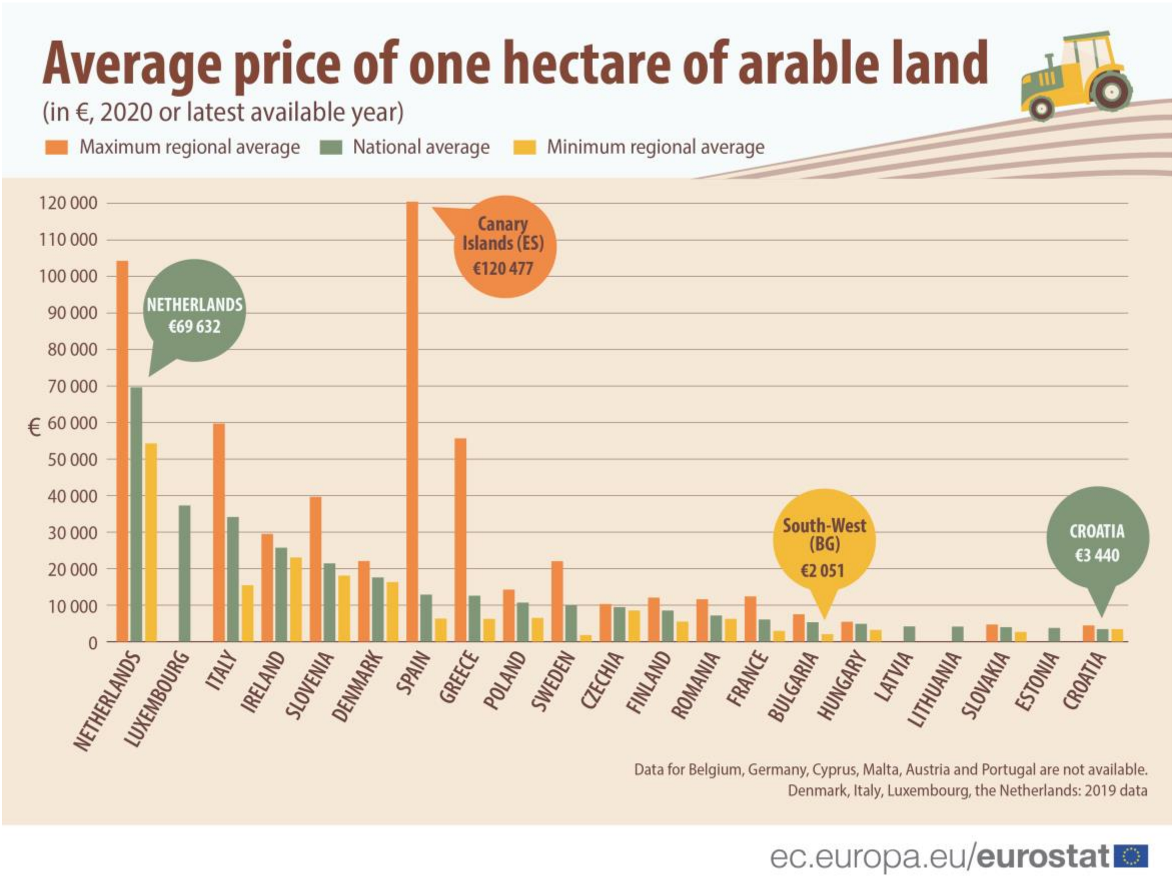


Figure 5-2: Average value of a hectare of land across the EU

By essentially reclaiming and creating new arable land, we can claim that value has also been created. We will use the average price of one hectare of arable land in Croatia as our multiplying factor. Croatia actually has the lowest arable land prices across the EU27, with the national average being **€3,440/ha[24].** This therefore gives us a Tier 3 economic value of **€1,204,000**.

Additionally, societal benefits are manifested in this tier thanks to the supporting of livelihoods of local communities in the park as a result of the improved economic activities.

24 https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20211130-2

5.2.4 Tier 4: Citizens & Society

Citizens and society benefit from the protection of natural landscapes, the maintenance of biodiversity and the eradication of IAS in Lonjsko Polje. This helps ensure these sensitive ecosystems remain protected for the enjoyment of tourists and local economies. Moreover, these efforts can help in contributing to the regulation of climate and natural phenomena such as flooding. But how can we put an economic value on the protection of biodiversity and habitats? As already mentioned at the beginning of this chapter, this is quite a difficult thing to do, however, what we can point to in this case is identification of new Natura 2000 sites within the park as a result of the efforts of Oikon and park management.

There is actually quite some robust analysis done on the economic benefits brought to society through the protection and/or development of Natura 2000 sites. The comprehensive economic analysis titled "***Estimating the Overall Economic Value of the Benefits provided by the Natura 2000 Network***"[25] delves into a lot of detail on how Natura 2000 brings economic benefits. These benefits are manifested via several ways, including through natural hazard mitigation and climate adaptation, the value of tourism and recreation, water provision and purification benefits, food-related provisions, and health, identity, and educational value for society. The graphic below shows the different types of economic benefits studied and how important they are at local, national, and global scales.

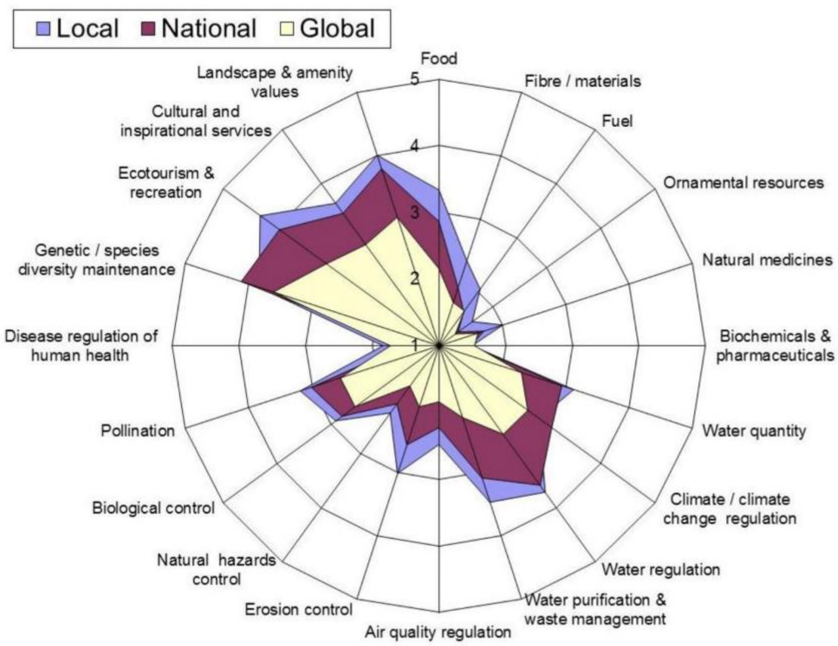


Figure 5-3: Perceived economic benefit types of Natura 2000 sites

The report itself estimates that Natura 2000 sites generate between €200 – 300 billion per year across the EU. The report also revealed that the benefits of Natura 2000 sites range from just less than €50 per hectare per year to almost €20,000 per hectare per year. The range of values identified

[25] https://ieep.eu/wp-content/uploads/2022/12/Economic_Benefits_of_Natura_2000_Network_Main_Report.pdf

underscores that sites are not uniform, while estimates of the value of the services they deliver also vary according to the methods used and data available. Variations in estimated values reflected differences in:

- The location and characteristics of different sites (including their condition, scarcity and substitutability);
- The ecosystem services delivered, which vary by habitat and location relative to people and natural resources;
- The value placed on those services by people and by markets;
- The extent to which studies have been able to estimate ecosystem service delivery and its value;
- The methods used in valuation, and the assumptions used in benefit estimation; and
- The role of non-use values which can form a significant share of the total value.

Nevertheless, the report does provide median estimations of value manifested on a per hectare basis. We will take the lower hectare estimation of value of €2,447/ha/year. As the report was published in 2011, adjusting for inflation[26] we arrive at a median value per hectare of Natura 2000 sites of €3,367/ha/year.

Under the Sava TIES initiative, 822ha of new Natura 2000 sites were mapped by Oikon using Sentinel-2 data and other resources and methodologies. **We can therefore claim an overall economic value for Tier 4 in this analysis of €2,767,674/year.**

There is also a second economic benefit to be considered in this tier. We have already spoken of the benefits brought by Natura 2000, but we have not spoken of the economic cost of invasive species themselves, and the associated benefit in removing them. A comprehensive analysis entitled "***Economic costs of invasive alien species across Europe***"[27] looked into exactly this question.

The report found that the cumulative expenses associated with IAS in Europe amounted to €116 billion over the period of 1960 to 2020. A significant portion (60%) of these costs was attributed to damages spanning multiple sectors. The impact of these costs was widespread across Europe but particularly notable in larger Western and Central European countries such as the UK, Spain, France, and Germany. Factors like human population size, land area, GDP, and tourism played a substantial role in predicting invasion costs, while the expenses for managing IAS were further influenced by the number of introduced species, research efforts, and trade activities. Over time, these invasion costs escalated exponentially, from €19.64 billion in 2013 up to €116.24 billion by 2020. The report also states that despite the substantial financial implications, it's essential to acknowledge that these costs are likely underestimated due to knowledge gaps on various geographical and taxonomic scales. This study used the InvaCost database, a freely available global dataset of costs

[26] https://www.in2013dollars.com/europe/inflation/2011?amount=2447

[27] https://environment.ec.europa.eu/news/expenditure-preventing-biological-invasions-far-below-environmental-damage-costs-2022-10-05_en

associated with invasive alien species. The data it contains were initially gathered through extensive online research and are regularly updated.

Delving into the InvaCost database, unfortunately data specifically on Amorpha fruticosa could not be found, therefore we will not quantify an economic value on the eradication of the species here due to several uncertainties. Nevertheless, it is still important to acknowledge the very real value that undoubtedly materialises for society when IAS is removed.

Again, built into this economic benefit are also societal benefits as a result of the preservation of water sources, the control of natural hazards and the contribution to the fight against climate change.

5.2.5 Other Beneficiaries

EU / Croatian Government

It could be claimed that the economic benefits analysed in Tier 4 could also be claimed by the EU and Croatian Government. However, to avoid double counting we will just reiterate that through the efforts of the actors in tier 1 and 2, the EU and Croatian Governments benefit through both stimulated economies and the fulfilling of regulatory mandates including the EU Biodiversity Strategy for 2030, the Habitats Directive and the Natura 2000 initiative.

5.3 Summary of Benefits

In this section, we draw together the different benefits to the stakeholders identified along the value chain, grouping them by six dimensions of value-chain analysis. A summary of the degree of the benefits as applicable to this case, taking into account previously studied cases, is shown below. The assessment is subjective; the basis for it is given in Annex A2.

Economic	Environmental	Societal	Regulatory	Innovation & Entrepreneurship	Scientific & Technological
★★★	★★★★★	★★★	★★★★	★★	★★

Table 5-1: Benefits Assessment by Category

5.3.1 Economic

The economic benefits are shown in the table below.

Tier	Benefits identified	Annual economic value stemming from the use of Sentinel-enabled services (in €)	
		Present	Forecast
Tier 1 (Oikon)	Savings linked to the use of Sentinel data	**€600,000**	**€750,000**
Tier 2 (Lonjsko Polje)	Expenses incurred to remove IAS	**(€678,125)**	

Tier 3 (Local farmers)	Reclamation and conversion of overgrown land to productive agricultural land	**€1.2 million**	
Tier 4 (Citizens/ Society)	Identification, registration, and maintenance of Natura 2000 sites	**€2.8 million**	
TOTALS		**€3.9 million**	**€4.1 million**

Table 5-2: Summary of economic benefits

As discussed in previous sections, there are undoubtedly many economic benefits manifested in each tier of the value chain that have not been quantified within this report due to the many unknowns and complexity involved in performing this analysis. Therefore, it should be noted that the figures in the table are what could be objectively quantified within this report and are considered quite conservative in terms of the actual total economic value Sentinels are bringing in this case.

It should also be noted that despite seeing a "negative" economic benefit in Tier 2, this expenditure ultimately results in Lonjsko Polje better fulfilling their mandate to protect and maintain the biodiversity of the park. Moreover, the benefits across the entire value chain remain positive overall.

- Cost savings linked to the use of Sentinel data (tier 1)
- Savings in on-site inspection costs (tier 2)
- Reclamation of land to productive agricultural land (tier 3)
- Identification, registration, and maintenance of Natura 2000 sites (tier 4)

5.3.2 Environmental

Through the efforts of the stakeholders in tiers 1 and 2, very significant environmental benefits are realised.

Protecting natural habitats

Through the identification and registration of various different types of ecosystems across Lonjsko Polje, crucially including the registration of Natura 2000 sites, natural habitats are being protected. Having a comprehensive overview of the types of ecosystems present in the park allows park management to monitor changes moving forward, meaning should certain habitats come under threat by natural or human-induced factors, mitigation measures can be taken in time to protect the fragile ecosystems in question.

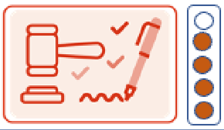
Ensuring biodiversity through the reduction of IAS

Related to the protection of natural habitats, the detection and eradication of invasive species is paramount to the maintenance biodiversity in an area. The identification of Amorpha fruticosa in this case was vital to the redevelopment of the park. Amorpha fruticosa had taken over many areas, particularly grassland areas which otherwise could have supported native livestock.

- Reduction of presence of invasive plant species (tiers 2, 3 and 4)
- Identification and registration of Natura 2000 sites (tiers 2 and 4)

5.3.3 Regulatory

The Sentinel-enabled service here helps Lonjsko Polje management to fulfil its mandate to protect the nationally significant nature park. As already discussed, the efforts under the Sava TIES project feed into several high-level EU initiatives, including the EU Biodiversity Strategy for 2030, the Habitats Directive and the Natura 2000 initiative. More specifically, the efforts also help address EU's special Regulation no. 1143/2014 which requires the Member States, among other, to take measures for the early detection and eradication of these species. In Croatia, the Law on Prevention of Introduction and Spread of Alien and Invasive Alien Species and their management (OG 15/18, 14/19) anticipates establishment, standardisation and coordination of inventory, mapping, and monitoring of IAS.



- Better monitoring and enforcement of biodiversity and habitat protection (tiers 2 and 4)

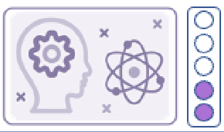
5.3.4 Entrepreneurship & Innovation

Oikon have contributed greatly to the entrepreneurship and innovation landscape with the development of their IAS detection services. They are one of the first service providers to specifically develop services for the detection of Amorpha fruticosa and Ambrosia artemisiifolia based on Sentinel data, in turn positioning themselves as key experts in the management of these IAS.

- Creation of innovative services (tier 1)

5.3.5 Science and Technology

Oikon contribute to the scientific landscape through their efforts in this case. As a research institute, they have developed novel methods and algorithms which utilise Sentinel data to detect various IAS, including both coverage and biomass analysis. These contributions to the scientific and technological landscape will be further refined in future by Oikon researchers. For a full list of relevant scientific publications see **Annex 1**.

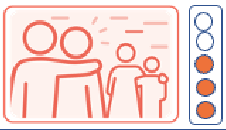


- Contribution to the development of new remote sensing techiques for the detection of IAS (tier 1)

5.3.6 Societal

In this case, both local communities and society as a whole are considered beneficiaries. Firstly, the livelihoods of rural communities living in Lonjsko Polje are supported through redevelopment of overgrown lands into productive farmland. Given the dwindling numbers of people living in the park, the efforts under the Sava TIES project are helping to provide capacity for local farmers to reintroduce native livestock and support local livelihoods.

Secondly, the overall mapping and identification of IAS as well as sensitive ecosystems within Lonjsko Polje ensures that this nationally significant park protects its biodiversity for years to come. As already discussed, the maintenance of such ecosystems brings cultural, historical, and educational benefits to the people of Croatia. Moreover, it helps in attracting tourism, which in turn supports local economies.



- Flourishing of rural communities and stimulation of agricultural activities (tier 3)
- Protection of nationally significant park (tier 2 and 4)

5.4 Synoptic overview

Having looked at the different types of benefits and before proceeding to the conclusions extracted in this study it is instructive to provide a synoptic overview in the table below.

Tier	Benefits identified	Type	Value where **economic** (annual)
Tier 1 (Oikon)	**Cost savings** linked to the use of Sentinel data	Economic	€ 600k – 750k
	Creation of **innovative services**	Entrepreneurship and innovation	
	Development of new remote sensing-based IAS detection techniques	Science and Technology	
Tier 2 (Lonjsko Polje)	**Expenses incurred** to remove IAS	Economic	(€678,125)
	Reduction of presence of **invasive plant species**	Environmental	
	Identification and registration of **Natura 2000 sites**	Environmental	
	Better **monitoring and enforcement** of biodiversity and habitat protection regulations	Regulatory	
	Protection of **nationally significant park**	Societal	
Tier 3 (Local farmers)	**Reclamation and conversion** of overgrown land to productive agricultural land	Economic	€1.2 million
	Reduction of presence of **invasive plant species**	Environmental	

	Flourishing of rural communities and stimulation of agricultural activities	Societal	
Tier 4 (Citizens and Society)	Identification, registration, and maintenance of Natura 2000 sites	Economic	€2.8 million
	Reduction of presence of **invasive plant species**	Environmental	
	Identification and registration of **Natura 2000 sites**	Environmental	
	Better **monitoring and enforcement** of biodiversity and habitat protection regulations	Regulatory	
	Protection of **nationally significant park**	Societal	
TOTALS			**€ 3.9 – 4.1 million**

Table 5-3: Summary of benefits for each Tier

6 Key Findings and Final Thoughts

6.1 Key findings

This case highlights the ongoing efforts all across Europe in fighting biodiversity loss and protecting natural habitats. The Sava TIES project is just one such instance, and within Sava TIES we have only focused on Lonjsko Polje in this case. Several other partners in Sava TIES positively impacted the ecosystems of their regions in the development of innovative ways to detect and eradicate IAS within the Sava River basin. The adoption of Sentinel-enabled services by Lonjsko Polje here shows the efficacy of the data in not only identifying IAS, but also in efficiently detecting and registering Natura 2000 sites and performing a mapping exercise of the various ecosystems across the entirety of the park. **In that regard, the standout benefits in this case relate to the environmental dimension**. Given the strong link between the protection of the environment and governmental initiatives to encourage habitat protection, **regulatory benefits are also strongly present as has been seen in this case**. Finally, given the cultural significance Lonjsko Polje has in Croatia, its protection is considered of national importance, hence the strong societal benefits realised. This is summarised in the graph below.

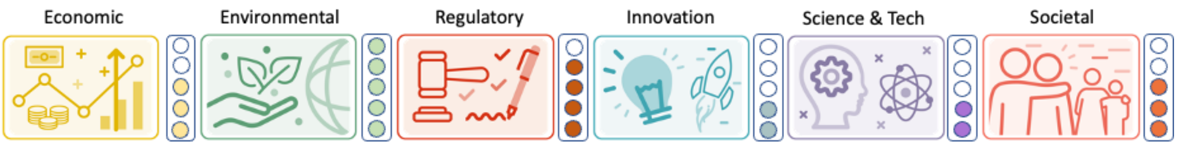


Figure 6-1: Delivering value across the full range of dimensions

As already noted, we see a "negative" economic benefit in Tier 2. However, this expenditure ultimately results in Lonjsko Polje better fulfilling their mandate to protect and maintain the biodiversity of the park. Moreover, the benefits across the entire value chain remain positive overall. Given that this case only focussed on one nature park, the overall economic value of Sentinels in relation to IAS detection and eradication is undoubtedly much larger than the **€3.9 – €4.1 million** reported here, with the same applying to all other dimensions of benefit too. This wider perspective is discussed in greater detail, but before that we provide an account of the impact of Sentinel data and the issue of attributing a value to this impact.

6.2 The Impact of Sentinel Data

In most cases analysed under the *Sentinel Benefits Study* the question of attribution arises, i.e., what part (or percentage for the economic value) of the produced benefit can be attributed to the use of Sentinel data? In this case we can say 100%. The ability of Lonjsko Polje to manage IAS relies heavily on the services of Oikon, which as discussed stemmed almost entirely from Sentinel data plus the addition of some in-field ground truth inspections. Had Sentinel data not been used, a comprehensive analysis of the entire park would have been difficult. In-person inspections can realistically only sample a small number of areas, thereby not providing the high-quality analysis performed. Commercial data could be bought but given the free and open nature of Sentinel data, Oikon could perform the analysis for Lonjsko Polje at a competitive price that was within the scope of the Sava TIES budget.

6.3 Widening the Perspective

The main focus of this case has been the use of optical (and sometime radar) data to detect IAS in Croatia. The application, however, of the technique used is by no means specific to this region. Instead, it has a much wider perspective. This can be studied along three dimensions: (i) geographic extension, (ii) increased market penetration and (iii) improved technological maturity. Below we discuss these dimensions in the context of this case

- **Geographic Extension**

It is obvious that the service discussed in this case lends itself to increased geographic coverage. IAS are not unique to the Sava River basin and occur all over the world. Ignoring the administrative and bureaucratic barriers to providing services in other parts of the world, the technical barriers to entry are relatively low. Given the global coverage of the Sentinels, some "tuning" of the IAS detection algorithms would be required for new terrains and ecosystems as each area on the globe is different Nevertheless, this type of development is something that Oikon are continually working on.

- **Increased Market Penetration**

When speaking of market penetration in this case, it makes more sense to talk about increased ability to detect other types of invasive alien species. Entities concerned with the management of IAS will typically be public institutions or regional/national governments. As discussed in the previous point, geographic extension of such services is relatively easy, meaning Oikon could easily transfer their IAS detection methods to other countries and serve other public actors. To increase "market penetration", it would really mean that a company such as Oikon would expand its service portfolio to the detection of other types of species. We have seen that Oikon have developed detection methods for Amorpha fruticosa and Ambrosia artemisiifolia. Extending the know-how developed in this case to other invasive species is the obvious next step in terms of market penetration. Given the technological capabilities of Oikon, paired with utility of Sentinel data, market penetration across several IAS is absolutely within reach.

- **Improved Technological Maturity**

Improvements are clearly possible for this type of service, such as increased accuracy of detection along with smarter and wider detection capabilities across different types of terrain and species. As already discussed, Oikon are continually working on this exact point.

6.4 Final Thoughts

This case exemplifies how publicly funded initiatives like the Copernicus programme can support other public initiatives, such as the protection of nature parks. It also highlights the deep interconnection between European efforts and investments in space and their positive effects on the ground. The fight against invasive alien species and habitat loss is a daunting idea but focussing on the efforts of just one nature park show just how much can be done. Extrapolating these efforts across all of Europe show that we are certainly making moves in the right direction. The important connection between environmental preservation and government-backed efforts to promote habitat protection is evident in this case. Furthermore, owing to Lonjsko Polje's significant historical and cultural importance in Croatia, the value of the Sentinel-enabled services helping to protect it are profound for the region.

Annex 1: References and Sources

1. Tekić, I., (2023): Invasive alien plant species detection capabilities and outlook – example of Ambrosia artemisiifolia and Amorpha fruticosa, "New capabilities and countries in European Space" Conference 2023, ESA/ESTEC, Noordwijk Netherlands
2. Tekić, I., Jantol, N., Ljubić. I., Neferanović, N., Radun, B., Tomljenović, I., Žiža, I., Kušan, V., (2022): Detection of invasive plant species in Croatia with Sentinel satellite imagery // Europska i regionalna konferencija „Okolišne procjene i Europski zeleni plan '22": Zbornik sažetaka radova. Vodice: Hrvatska udruga stručnjaka zaštite prirode i okoliša (HUSZPO), 190.
3. Tekić, I., Neferanović, A., Jantol, N., Ljubić, I., Žiža, I., Radun, B., Tomljenović, I., Kušan, V., (2022): Problems with detection and monitoring of invasive plant species – a survey of Croatian stakeholders // Europska i regionalna konferencija „Okolišne procjene i Europski zeleni plan '22": Zbornik sažetaka radova. Vodice: Hrvatska udruga stručnjaka zaštite prirode i okoliša (HUSZPO), 189.
4. Jantol, N., Čvrljak, M., Tomljenović, I., Žiža, I., Radun, B., Mesić, Z., (2021): Testing Remote Sensing Methods for Invasive Alien Plants Ailanthus altissima and Amorpha fruticose, Symposium proceedings at the 4th Croatian Symposium on Invasive Species, 29th – 30th September 2021., Zagreb

Annex 2: General Approach and Methodology

This case has been analysed as a part of the Sentinel Benefits Study (SeBS), which looks at the value being created by the use of Sentinel data. It follows a methodology[28], established during a previous study, looking at a value chain for the use of a single EO service.

For each case, a value chain is established with a service provider and a primary user. The value-chain is validated with these two key players. Through a combination of desk and field research, we develop our understanding of all the actors in the value chain, the role that they play and how they may benefit through the use of the satellite-derived products.

The value-chain is divided into a number of tiers where the supplier is Tier 1, and the primary user is Tier 2. The last Tier is always “Citizens and Society”. The number may vary according to the complexity of the value-chain. The benefits are then analysed against each of these tiers.

Once written, the draft report is then shared with all the persons with whom we have spoken, and their comments are incorporated, or a further discussion is held to establish a common understanding. Note that we are not asking these experts to endorse our findings but to indicate any gross errors or sensitivities which may have been introduced. At the end of this process, the report is made public.

As work has proceeded and more cases analysed, some modifications have been made to the methodology described in reference 28. The first of these has been to expand from the two dimensions used earlier, namely economic and environmental benefits, to add those connected to societal, regulatory, innovation and entrepreneurship and scientific and technological. These six dimensions are described in the table A2-1 below.

Dimension	Definition
ECONOMIC	Impacts related to the production of goods or services, or impacts on monetary flow or volume, such as revenue, profit, capital and (indirectly, through turnover generation) employment.
ENVIRONMENTAL	Impacts related to the state and health of the environment, particularly as regards the ecosystem services on which human societies depend.
SOCIETAL	Impacts related to societal aspects such as increased trust in authorities, better public health or secured geostrategic position.
REGULATORY	Impacts linked to the development, enactment or enforcement of regulations, directives and other legal instruments by policymakers.
INNOVATION-ENTREPRENEURSHIP	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market.
SCIENCE-TECHNOLOGY	Impacts linked to academic, scientific or technological research and development, the advancement of the state of knowledge in a particular domain.

Table A2-1: Definitions for the benefit dimensions

[28] SeBS Methodology; June 2017.

For each of these, a ranking has been introduced to give an immediate, visual impression of the scale of the benefits under each dimension. To aid in the quantification of these, a guide has been introduced which is shown in Table A2-2.

Rank	Benefit status	Criteria
0	**Null**	The case presents no perceivable benefits in this dimension, and no potential for such benefits to emerge is anticipated.
1	**Latent**	The value chain described in the case may, in general, present potential benefits in this dimension, but none have been identified or described in this particular instance.
2	**Manifest**:	**Low**
3	At least one benefit in this dimension has been identified through the value chain within the case. Its significance in the context of the case overall is judged to be:	**Moderate**
4		**High**
5		**Exceptional**

Table A2-2: The ranking of the benefits.

In order to introduce further basis for comparison, a systematic approach has been developed for the analysis of the benefits. A series of indicators have been defined for each of the benefit dimensions against which each case can be considered.

The indicators used in the case are listed in chapter 5, and a full list of all indicators considered is provided in Table A2-3.

Dimension	Indicator	What it can mean.
Economic	Avoided costs (AV)	Alternative means to gather data
	Increased Revenues (IR)	Increased production/sales
	Reduced Inputs (RI)	Less time spent or material saved
	Improved Efficiency (IE)	Better use of resources
Environmental	Reduced pollution (RP)	Reduced amounts of pollutants in key resources e.g. water, air
	Reduced impact on natural resources (RR)	Reduced environmental impact e.g erosion, habitats/biodiversity.
Societal	Improved public health (IPH)	Less toxicological risk
	Common Understanding (CU)	Better control and communication of remedial efforts i.e through common maps.
	Increased trust and better transparency (ITT)	Improved preparedness / response
	Strategic Value (SV)	Common societal value to a country or region.
Regulatory	Improved policy / regulation design/drafting	Better information (scale, accuracy) leading to better regulation
	Improved efficiency in policy/regulation monitoring	Better information available to monitor adherence to regulations.
Innovation & Entrepreneurship	Innovative products	Sentinel data leads to creation of new products / services
	New Business models	New ways to generate income.
	New markets	Global nature of sentinel data enables international business development
	New businesses	Creation of new companies; start-ups
Science & technology	Academic output	
	Research exploitation	Applied science to operational services
	Research contribution	New product enabling scientific research

Table A2-3: Complete list of indicators considered within SeBS analyses.

Annex 3: About the Authors

Dáire Boyle, BEng (Electrical Engineering), MSc Business & Economics

Dáire is a consultant with the Brussels-based consultancy Evenflow, who work in collaboration with EARSC on the Sentinel Benefits Study (SeBS). Dáire worked as an engineer for a large upstream oil & gas company in Aberdeen, Scotland for 4 years before moving to Belgium to complete a masters in International Business Economics & Management. Dáire has extensive root cause analysis and statistical analysis skills developed through both his professional and academic career. He currently acts as exploitation manager for the H2020 CYBELE project.

Email: daire@evenflow.eu