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Coláiste na hOllscoile Corcaigh

Utilising Copernicus Sentinel Satellite Data to analyse the unique patterns of agriculture on Inis Oírr.

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Abstract

The project "Utilizing Copernicus Sentinel Satellite Data to Analyse Agriculture on Inis Oírr" provides a novel examination of traditional farming patterns on a landscape shaped by centuries of sustainable farming practice. By harnessing the high-resolution, multispectral capabilities of Sentinel-2 satellite imagery, the study investigates the island's distinct 'wintering' farming system characterized by low-intensity grazing and its impact on local biodiversity.

This research project analyses farming practices on Inis Oírr using Copernicus Sentinel satellite data to explore the evolving landscape of high nature value farmland areas. The research project spans from January 2018 to March 2024, tracking seasonal fluctuations in Inis Oírr's agricultural methods. Using indices such as the Normalised Difference Vegetation Index (NDVI) and the Normalised Difference Water Index (NDWI), the research evaluates vegetation vitality and soil moisture, two key markers for measuring the health of agricultural systems. These indexes give useful information about the fluctuating pattern of farming activity, demonstrating how traditional techniques coexist with the island's fragile nature.

This research aims to showcase the story of Inis Oírr's agricultural heritage through a functional website (AranIslandsAgriculture.com), recognising its reliance on traditional farming practices and the utilisation of its distinctive terrain. This website will curate critical information, presenting a narrative that delves deep into the island's history, endangered species conservation, and the preservation of traditional farming practices on which the island and its endangered fauna and flora are dependent.

Temporal and spatial analytical approaches indicate a synchronised agricultural cycle, which is essential to soil preservation and flora growth. The findings highlight how Inis Oírr's farming not only sustains but enhances biodiversity, highlighting the ecological benefits provided by traditional techniques in the face of growing industrial agricultural practices. Thus, analysing and illustrating the unique patterns of agriculture on Inis Oirr.

Ultimately, This project serves as a case study on the importance of remote sensing in environmental conservation, demonstrating that combining traditional farming knowledge with modern satellite technology provides a significant tool for preserving and maintaining agricultural tradition. The implications extend beyond local traditions, flowing into global discussions on agricultural sustainability and accountability to the environment.

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Introduction

Understanding the relationship between traditional farming and the sustainability of the environment is becoming increasingly important in our changing world. This project, "Utilising Copernicus Sentinel Satellite Data to Analyse Agriculture on Inis Oírr," examines how traditional agricultural methods affect the land and nature of this island. The research uses Sentinel-2 satellite imagery to provide an in-depth understanding of land usage and sustainability on Inis Oírr. The heritage-rich landscape of Inis Oírr demonstrates 'winterage', a traditional and sustainable agricultural practice. The conventional method practices, rotational grazing and enhances biodiversity. Sentinel-2's high-resolution imagery from the Copernicus program enables a close study of these practices by providing consistent data on vegetation health and soil moisture through NDVI and NDWI indices.

The project takes advantage of Sentinel-2's ability to revisit areas frequently, gathering data that reveals the patterns of Inis Oírr’s farming cycles. The research attempts to provide a full picture of Inis Oírr's unique farming system by combining up-to-date satellite analysis with traditional agricultural practices and knowledge.

This research goes beyond just mapping the current situation of Inis Oírr's agriculture. It is about highlighting the long-term importance of traditional farming for sustainability while also providing insights that may be used to enhance global sustainable farming methods.

Literature Review

Satellite Remote Sensing in Agriculture

Satellite remote sensing has transformed agricultural monitoring, providing data critical for informed decision-making in land management and crop cultivation. Sentinel-2, part of the Copernicus program, is particularly renowned for its high-resolution multispectral imagery, which is useful in measuring a variety of agricultural parameters. In their comprehensive study of *Copernicus Sentinel-2A Calibration and Products Validation Status*, the technical specifications and capabilities of Sentinel-2 are explored, "The Sentinel-2 mission offers an unprecedented combination of systematic global coverage of land and coastal areas, a high revisit of five days under the same viewing conditions, high spatial resolution, and a wide field of view (295 km) for multispectral observations from 13 bands in the visible, near infrared and short wave infrared range of the electromagnetic spectrum" (Gascon *et al.*, 2017, p.2). This detailed analysis highlights the satellite's value in monitoring crop health, land use changes, and managing agricultural expansion with precision and accuracy, thereby underlining its pivotal role in precision agriculture through detailed and frequent observations necessary for effective land management.

A significant advantage of using Sentinel-2 in agriculture is the application of the Normalized Difference Vegetation Index (NDVI). This index, crucial for evaluating vegetation health and biomass production, leverages the satellite's ability to capture images across various spectral bands, offering a clear indicator of photosynthetic activity. The article *A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing***,** supports this, noting that NDVI is particularly effective in expressing vegetation status using the optical bands of Sentinel-2, which has been enhanced through its frequent revisit capability to monitor vegetation dynamics closely, “The overall purpose of using NDVI is to improve the analysis of information about vegetation with remotely sensed data. Studies have demonstrated that NDVI is effective to differentiate savannah, … agricultural fields, … forest types, and to estimate various vegetation properties"(Huang *et al.*, 2021, p.2). Their research illustrates NDVI's versatility in differentiating between diverse ecological zones and assessing various vegetation properties.

However, the integration of Sentinel-2 data with other satellite systems, such as Sentinel-1's radar imagery, is vital for overcoming optical limitations and providing all-weather monitoring capabilities. The research seen in *Multisensor Data Fusion for Cloud Removal in Global and All-Season Sentinel-2 Imagery*, addresses the challenges of cloud coverage in optical satellite imagery by exploring advanced cloud removal technologies. They point out that, "Recent advances in cloud removal combine multimodal data with deep neural networks recovering the affected areas…address the challenge of cloud removal in observations from Copernicus mission's Sentinel-2 (S2) satellites. While optical imagery is affected by bad weather conditions and lack of daylight, sensors based on synthetic aperture radar (SAR) as mounted on Sentinel-1 (S1) satellites are not and, thus, provide a valuable source of complementary information" (Ebel *et al.*, 2020, p.5866). This integration is crucial for achieving high-quality de-clouding, ensuring that agricultural monitoring remains uninterrupted by atmospheric conditions.

Sentinel-2's open-access policy has had a significant impact on agricultural monitoring. This policy allows not only large-scale industrial farms but also smallholders to utilize high-resolution data for managing their crops effectively. The study of *Sentinel-2 Data for Land Cover/Use Mapping*, emphasises the transformative impact of this policy, particularly in developing countries. They remark, "The free access policy drives the increasing use of Sentinel-2 data, especially in developing countries where financial resources for the acquisition of remotely sensed data are limited"(Phiri *et al.*, 2020, p.2291). This accessibility is crucial not just for its economic benefits, but also for levelling the playing field, allowing farmers from various socioeconomic backgrounds to benefit equally from advanced agricultural technologies. Sentinel-2 guarantees that all farmers, regardless of their financial status, have the tools they need to improve agricultural output and sustainability. This approach effectively brings the advantages of contemporary precision agriculture techniques to regions and populations who have previously been neglected or disregarded in the global agricultural scene.

Despite the benefits, there are challenges associated with the use of Sentinel-2 data. The main concerns are the satellite's temporal resolution, which may not record quick environmental changes, and cloud coverage, which can conceal crucial data. Ebel et al. (2020)

suggest a methodological improvement, explaining that while other work typically “trades temporal resolution for obtaining a single cloud-free observation” their approach “predicts one cloud-free output per cloudy input image and, thus, allows for sequence-to-sequence translation”(Ebel *et al.*, 2020, p.5867). Furthermore, Huang et al. (2021) caution that NDVI calculations can be sensitive to atmospheric conditions and pixel-level factors, noting, “the calculation of NDVI is sensitive to atmosphere, soil, and pixel components. The spectral response to these factors is not exactly the same in the two spectral bands used for NDVI calculation, complicating NDVI behaviour patterns”(Huang *et al.*, 2021, p.4). This awareness is vital for accurately interpreting the satellite data, cautioning the need for careful consideration to avoid misinterpretation of the data.

High Nature Value Farmlands (HNV)

High Nature Value (HNV) farmlands represent crucial agricultural areas where extensive farming practices support significant biodiversity. These lands are especially important in Europe for preserving agricultural biodiversity since they are characterised by low-intensity farming, diversified ecosystems including semi-natural vegetation, and traditional land management approaches that less heavily depend on the use of chemicals. These kinds of conditions promote a great variety of flora and wildlife, many of which are rare or at risk in more heavily cultivated areas. The importance of HNV farmlands in maintaining such biodiversity is highlighted by multiple European initiatives, such as, *High Nature Value Farmland in Europe An estimate of the distribution patterns on the basis of land cover and biodiversity data*, which notes this by saying, “The need for measures to prevent the loss of high nature value farmland is widely acknowledged. Conservation of biodiversity on agricultural land is an explicit objective of the Pan-European Biodiversity and Landscape Strategy (PEBLDS), the Bern Convention, the European Landscape Convention, and, at EU level, the Habitats and Birds Directives and Rural Development Policy"(Paracchini *et al.*, 2008, p.1). These policies and conventions showcase the commitment to preserving the ecological richness of HNV farmlands, recognising their critical role in sustaining Europe's agricultural biodiversity.

The identification of HNV farmlands incorporates both biophysical and socioeconomic factors. Biophysically, these areas are evaluated based on habitat diversity, the presence of species critical to European conservation, and the prevalence of traditional farming practices that promote ecological diversity. HNV farmlands seem to be generally separated into three types, Type 1 with a high proportion of semi-natural vegetation, Type 2 consisting of a mosaic of low-intensity agriculture and natural features like hedgerows and stone walls, and Type 3 supports rare species or significant proportions of European or global populations. The study of *Mapping and monitoring High Nature Value farmlands: Challenges in European landscapes* explains that "This categorisation of three broad types of HNVF expresses the relationships between the farming systems and practices, and habitats and species regarded as of high nature conservation value"(Lomba *et al.*, 2014, p.143) thereby reinforcing how these classifications are deeply interconnected with the conservation goals that define HNV farmlands.

Socioeconomically, HNV farmlands often support small-scale farming that sustains local communities and maintains age-old agricultural traditions. The importance of these sustainable practices is emphasised in the Common Agricultural Policy (CAP) changes by aligning with the EU's Common Monitoring and Evaluation Framework (CMEF) specific indicators, which directly impact the management of HNV farmlands. According to *The monitoring and evaluation framework for the common agricultural policy 2014–2020*, "Under the 2013 reform, 30 % of direct payments will be linked to European farmers' compliance with sustainable agricultural practices which are beneficial to soil quality, biodiversity and the environment in general, such as crop diversification, the maintenance of permanent grassland or the preservation of ecological areas on farms."(Directorate-General for Agriculture and Rural Development (European Commission), 2015, p.4). This policy demonstrates the EU's commitment to promoting biodiversity through granted sustainable practices, demonstrating a systemic approach to maintaining the ecological integrity of HNV farmlands.

However, challenges remain in fully supporting HNV farming systems despite these reforms. Lomba *et al.*, (2014) criticises the effectiveness of these policy adjustments, arguing that as "current policies create an operating environment in which HNV farming systems face a choice between intensification (e.g. higher stocking rates, switch to fast maturing commercial breeds) or abandonment of farming altogether"(Lomba *et al.*, 2014, p.143). This argument shows that while here have been strides towards better environmental protection within the CAP, these measures may still fall short of providing the necessary support to properly maintain HNV farmlands, making them vulnerable and under threat to intensification pressures or abandonment.

Monitoring these High Nature Value (HNV) farmlands is critical for their protection and for informing relevant agriculture policies. Traditionally, due to the scattered and diverse nature of these lands, their monitoring has been challenging, both physically and logistically. However, advancements in satellite remote sensing technology, notably the Copernicus programme's Sentinel satellites have significantly enhanced the ability to monitor these areas effectively. Ebel *et al.*, (2020) highlight the capabilities of such missions, stating that their goal is "to reliably provide noise-free observations at a high frequency, a prerequisite for applications relying on temporally seamless monitoring of our environment, such as change detection or monitoring"(Ebel *et al.*, 2020, p.5866). This technology allows for broad-scale, reliable evaluations of changes in land cover and usage without extensive field surveys, making it a cost-effective solution for monitoring.

Despite these technological advances, the integration of satellite data with ground-based information remains crucial. A study entitled, *High Nature Value farmland identification from satellite imagery, a comparison of two methodological approaches* examined the effectiveness of using these remote sensing techniques and high-resolution satellite imagery for monitoring High Nature Value farmlands. Finding that although the satellite data is incredibly valuable it can only reach its full potential in monitoring high nature value farmlands when combined with on-ground data, arguing that "The real added-value of the high-resolution satellite data can be exploited only if it is combined with the relevant "in situ" information, such as LPIS, land cover/land use data, topographic maps, HNV farmland registers, and ground truth"(Hazeu *et al.*, 2014, p.111). This approach stresses the need for a hybrid monitoring strategy that blends advanced remote sensing with detailed local knowledge to ensure accurate and comprehensive monitoring of these ecologically significant areas.

To conclude, the review of Sentinel-2's role in agriculture highlights its profound impact on enhancing precision in land management. this technology provides detailed, high-resolution imagery that enables effective monitoring of land use changes. The use of the Normalized Difference Vegetation Index (NDVI) has proven especially valuable in assessing vegetation health across diverse environments. Integration with Sentinel-1 helps overcome problems like as cloud coverage, ensuring dependable data under any weather circumstances. While technology has evolved substantially, combining ground-based data and local knowledge remains essential for accuracy. These insights demonstrate the crucial role of satellite remote sensing data, particularly in the use of monitoring High Nature Value farmlands. Furthermore, these key findings will prove to be vital components throughout my research in utilising similar methods to analyse the unique patterns of agriculture on Inis Oírr.

Environmental Scan

AranLife Project

The AranLife project, financed with €2.4 million from the EU's LIFE+ programme, was an innovative effort that merged scientific understanding with traditional agricultural techniques to maintain the Aran Islands' distinctive habitats. From September 1, 2013, to September 30, 2018, the initiative aimed to improve the ecological significance of these islands, which, while spanning just 46 square kilometres, are an area of outstanding biodiversity with 500 plant species, accounting for half of all Irish flora.

Teagasc has highlighted the ecological significance of the islands and how it has a significant high nature value area, noting, “The islands are of such high value for nature that over 75% of the land area has been legally designated as Natura 2000 sites under European legislation”(Ó hUallacháin, 2012).This rich biodiversity, however, comes with its own set of challenges. The tiny size of island farms, along with the heavy labour necessary for traditional agricultural practices, provide significant challenges. Many farmers are keen to preserve ancestral farming techniques, but the decline in farming activity had led to under grazed pastures and overgrown fields, threatening the local ecosystem.

The AranLife project addressed these challenges by encouraging farmers to adopt practices that enhance the quality of farm habitats. This programme sought to not only conserve but also revitalise ancient knowledge and techniques critical to the island's natural balance and did this by working alongside the island's own farmers. However, it’s important to note that as the Islands are Gaeltacht regions with Irish as the main language, a bilingual procedure was necessary, the final report documents that while this was acknowledged in the beginning financially, the extra time appointed to this procedure was not, “Whilst allowance for this was considered in the overall costings, in reality, the time burden was also increased”(de Brúch, 2018). Actions taken by the project team members and local farmers to enhance these farmlands included enhancing grazing access, clearing encroaching scrub to restore grassland vegetation, constructing water infrastructure for cattle, fixing mineral shortages in animal feeds, and determining appropriate grazing levels to maintain species diversity.

Throughout the project, it became evident that the Aran Islands also play a crucial role as breeding grounds for various plant species and for wildlife such as lapwings, butterflies, and bees. All of which rely on these meticulously maintained farm habitats, “Working with farmers on the island, the project addressed issues that affected grazing, including access improvements, removing encroaching scrub to return areas to grassland vegetation, supplying a water infrastructure to facilitate grazing livestock, correcting mineral deficiencies in the livestock diet and identifying the optimum grazing level to maintain species richness”(de Brúch, 2018).

The AranLife project demonstrates how combining traditional agriculture techniques with current conservation measures may result in sustainable ecosystem management. It serves as a model for similar conservation projects across the world, demonstrating that with the proper support and resources, traditional farming can adapt and survive, conserving a way of life while safeguarding the environment.

Thus, the AranLife project serves as a significant foundation and a source of inspiration for my research project, which focuses on using Sentinel-2 satellite data to analyse the unique agricultural patterns on Inis Oírr. Like AranLife, my study aims to blend traditional agricultural practices with modern technological insights to showcase the islands unique farming patterns which support sustainability and biodiversity. While AranLife used direct intervention and community interaction on the ground, my study expands on this notion by utilising modern satellite imagery to monitor and analyse the unique agricultural areas from a larger viewpoint. This technique not only compliments Aran LIFE’s hands-on tactics, but also adds a new layer to environmental monitoring, enabling for more accurate and data-driven decision-making to preserve the delicate balance of these unique farming practices and ecosystems. However, it’s crucial to acknowledge the differences in scale and resources between the AranLife project and my own. The AranLife initiative benefited from millions in funding, extensive government support, and a large team over an extended period. In contrast, my project operates with more limited resources and a smaller scale. Recognising these inequalities allows me to establish reasonable expectations and modify the scope of my study accordingly.

Case Studies on High Nature Value Farming in Ireland, North Connemara and the Aran Islands

This study conducted by the Heritage Council on the Aran Islands and North Connemara provides a comprehensive examination of High Nature Value (HNV) farming and its implications for biodiversity and cultural preservation in these regions. The main focus of the research was to assess how traditional agricultural practices contribute to the conservation of a unique landscape and support diverse habitats, which are crucial for the sustainability of local flora and fauna. In conducting the study, researchers gathered data through field observations, interviews with local farmers, and analysis of farming techniques that have been passed down through generations. The research highlighted the traditional practices such as livestock grazing and the cultivation of potatoes and vegetables, which play a significant role in shaping the distinctive agricultural landscape of the Aran Islands. However, from interviews and surveys taken, showed that farming practices on the Aran islands are limited, claiming that they were "mainly confined to raising beef cattle for finishing on the mainland, and potato and vegetable growing for home use"(Smith, Bligh et al., 2010).

These practices have not only helped to maintain the structural integrity of the landscape, characterized by limestone pavements and intricate systems of dry stone walls, but also support the biodiversity that these structures harbour. Describing the islands as a key example of a traditional high nature value landscape as, "past and present farming have combined to create and maintain the present mosaic of habitats, characterised by the network of drystone walls and rocky, wildflower-rich fields"(Smith, Bligh et al., 2010).

The study specifically pointed out that these traditional farming methods are less intensive than modern agricultural practices, which tends to be more beneficial for maintaining biodiversity. The low-intensity farming allows for the preservation of natural habitats within the farmland, supporting various plant and animal species. This notion of HNV farming, which is prevalent in regions like the Aran Islands, is based on the complex link between agricultural techniques and the preservation of habitat diversity as "the relationship between farming, our landscape and our natural heritage, and our cultural traditions and practises, is one of mutual inter-dependence"(Smith, Bligh et al., 2010).

However, the study also addressed several challenges facing HNV farming in these regions. It noted a decline in some traditional practices, such as the cultivation of specific crops and the maintenance of dry stone walls, which are essential elements of the cultural landscape. This decline is due to various factors, including economic pressures, changes in social structures, and a lack of interest among younger generations in pursuing traditional farming. This reduction in these practices poses risks not only to the cultural heritage of the area but also to the biodiversity and unique fauna and flora that these farming practices support on the high nature value farmlands, seen in Connemara and on the Aran Islands. These pressures are taken note of in an interview conducted by this study with a beef farmer on Inis Oirr, however, he makes sure to reiterate the fact that although yes these pressures and challenges exist, “farmers on the Island are not in it to make money, but for the love of farming and to keep going what has been done on the Island for years”(Smith, Bligh et al., 2010). This direct quote serves as a testament to the unique farming methods practised on Inis Oirr.

To address these issues, the study emphasises the significance of policy support for HNV farming. It suggests that conservation efforts should be integrated into agricultural policy to create incentives for farmers to maintain and revive traditional farming practices, as the love for this way of farming may not be enough to uphold and maintain these practices in years to come. They remark that farmers' engagement in decision-making processes is critical for designing solutions that are both ecologically sustainable and commercially feasible.

The Heritage Council's report points out the fundamental significance of traditional farming in protecting biodiversity and cultural landscapes, stressing the need for policies that support these practices and active community participation to conserve them for future generations. It argues for a collaborative approach to preserving these unique agricultural systems, emphasising the critical link between its farmers and environmental protection in places of natural and historical significance, such as those seen in Connemara and the Aran Islands. While this study involved hands-on research with local farmers to understand traditional farming and my project uses Sentinel-2 satellite imagery to offer a wider and more detailed view of how these practices shape the landscape of Inis Oírr over time. Nonetheless, these insights from the Heritage Council’s study have been invaluable to my research on Inis Oírr by providing vital background contextualisation for my use of Sentinel-2 satellite data.

Tools & Methods

Introduction

This section outlines the tools and methodologies utilized to explore and analyse the unique agricultural patterns on Inis Oírr using Copernicus Sentinel satellite data. This advanced satellite technology provides critical high-resolution imagery that captures the intricate dynamics of the island's farming practices and their ecological impacts.

The chosen approaches, which include thorough satellite imagery analysis and the use of vegetation indices such as NDVI, are critical for measuring the health and distribution of vegetation. These techniques are crucial for recording and understanding the unique farming methods on Inis Oírr, as well as their impact on local biodiversity.

This section will therefore, go over how to analyse satellite data using ESA SNAP software, how to create time-lapse visualisations to follow seasonal changes, and how to calculate indices to assist in tracking and monitoring agricultural and ecological differences. Each approach and tool used is specially designed to provide a complete perspective of the agricultural environment, revealing how traditional farming practices exist on this unique island.

Data Collection

Satellite Data

This study's main data came from the Copernicus Sentinel-2 satellite, which is part of the European Union's Earth observation programme meant to monitor changes in land surface conditions, "Sentinel-2 offers improved data compared to other low to medium spatial resolution satellite images (e.g., Landsat), especially in temporal and spatial resolution"(Phiri *et al.*, 2020). The Sentinel-2 satellite is equipped with a multispectral sensor that collects data from 13 spectral bands, including visible, near infrared, and short-wave infrared. The resolution of these bands varies from 10 metres for basic colour imaging, "10 meters for: B2, B3, B4 and

B8"(Iurist, Statescu and Lateș, 2016a) to 60 metres for specialised applications, "60 meters for B1, B9 and B10"(Iurist, Statescu and Lateș, 2016b), making the satellite ideal for detailed vegetation and land use research.

The analysis mainly used, Bands 4 (Red) and 8 (Near Infrared) are used for NDVI calculations, which help estimate vegetative health and production. NDWI calculations use Band 3 (Green) and Band 11 (SWIR1) to detect soil and vegetation moisture levels.

Temporal Coverage

The data gathering period lasted from January 2018 to March 2024, offering a clear insight of seasonal and yearly agricultural cycles. This timeframe was chosen to depict the distinctive winterage agricultural techniques of Inis Oírr, that involve seasonal grazing patterns. Showing this over a period of 6 years is to demonstrate the set cycle that this winterage system is set in, Showing this over a six-year period demonstrates the set cycle in which this winterage system is placed, demonstrating how each season continues in a similar condition year after year as it is set in the same agricultural system. Sentinel-2's twin satellite design allows for data capture every five days under similar conditions, which in effect greatly minimises gaps caused by cloud cover and assures broad coverage.

Geographical Scope

This research focused on Inis Oírr, the smallest of the Aran Islands, located off Ireland's west coast. This island, which covers around 14 square kilometres, has a unique landscape characterised by limestone pavements and limited vegetation, suitable for examining traditional agricultural practices. The area for the study was precisely outlined using the following coordinates, forming a polygon that captures the essential borders of Inis Oirr to show its agricultural zones:

Location	Latitude	Longitude
Northwest corner	53.070361	-9.557916
Northeast corner	53.070361	-9.500615
Southeast corner	53.043597	-9.500615

Southwest corner	53.043597	-9.557916

Fig. 1. Geographic Coordinates of the Study Area on Inis Oírr

Data Processing

Preprocessing

To ensure the highest quality and most suitable data for analysis, the satellite imagery from Sentinel-2 underwent a series of essential preprocessing steps.

Atmospheric Correction:

The Sen2Cor tool within the ESA SNAP software was used to remove atmospheric distortions from the light that reached the satellite sensors, "Sen2Cor is a Level-2A processor which main purpose is to correct single-date Sentinel-2 Level-1C Top-Of-Atmosphere (TOA) products from the effects of the atmosphere in order to deliver a Level-2A Bottom-Of-Atmosphere (BOA) reflectance product"(Main-Knorn *et al.*, 2017). This adjustment guarantees that surface reflectance measurements remain true and consistent throughout both location and time, which is important for accurate analysis.

Cloud Removal:

Given the frequent cloud cover in the target area, only images with less than 8% cloud coverage were chosen to assure data clarity and usefulness. This adjustment was made in the filter search parameters in the Copernicus browser, where cloud coverage can be adjusted from 0% - 100%. In addition to this, advanced cloud masking techniques were applied using ESA SNAP to further minimize the coverage of clouds and shadows in the selected images

Image Calibration:

Each picture was checked to ensure radiometric and geometric accuracy, ensuring that any observed changes in time-series analysis correctly represent actual changes on the ground, rather than errors in data collection or processing. To do this, each image collected from the data was checked manually, confirming each represented the correct coordinates with clear and accurate resolutions and cloud coverage settings.

Software Tools

The following software programs were used for processing and analysing satellite data:

ESA SNAP:

This was the main tool used for preprocessing steps such as atmospheric corrections, radiometric calibrations, and cloud masking. ESA SNAP's capabilities are specially designed for Sentinel data handling, making it perfect for precise and comprehensive data processing. Datasets of Sentinel 2 satellite imagery data would be downloaded and retrieved from the Copernicus browser in zip file format, then once this software is downloaded and installed correctly, it allows for the upload of a new data product via zip file format.

EOS Land Viewer:

In addition to ESA SNAP, EOS Land Viewer was used for targeted tasks from September 2022 and December 2023. This tool was chosen for its ability to quickly calculate vegetation indices like NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) directly from its interface without the need for extensive data preparation. EOS Land Viewer allowed for the efficient generation of NDVI and NDWI values, thus creating instant analysis and visualisations. This software proved particularly useful for creating dynamic graphs showing the changes in these indices over time. The decision to use EOS Land Viewer for these tasks over ESA SNAP was driven by its user-friendly interface and the streamlined process for generating and exporting visual illustrations of index data, which greatly enhanced the data analysis process and presentation.

Google Earth:

This software was used in capturing visually appealing images of Inis Oírr, particularly showcasing the unique mosaic of stone-walled fields characteristic of the island. Google Earth's advanced zoom capabilities allowed for closer ground-level views, providing clearer and more detailed depictions than are usually possible with broader-scale satellite images. These high-quality images were used for the homepage of the project website to highlight the distinctive, jigsaw-like patterns of the stone-walled fields, enhancing the visual appeal and engaging visitors with the unique agricultural landscape of Inis Oírr.

Data Integration

Data integration was essential for an in-depth analysis of agricultural patterns on Inis Oírr. The research's main objective was to combine multitemporal Sentinel-2 data to track and comprehend changes throughout time:

Multi-Temporal Data Fusion:

By combining data from several gathering dates, the research gained a dynamic depiction of the seasonal and yearly agricultural cycles, further showcasing the islands unique agricultural system called the winterage system. This method allowed for an accurate time-series study, illustrating how this unique farming system is seen across the island throughout different periods of the year. The ability to observe these patterns over a six-year period from 2018 to 2024 provided an in-depth understanding of the seasonal cycle of the winterage farming system and its sustained effects on the island's environment.

The use of solely Sentinel-2 data offered consistency and continuity in the study's findings, as it relied entirely on high-resolution optical imaging to follow changes in vegetative health and land cover with high accuracy. The careful selection of images with less than 8% cloud coverage further ensured clarity for reliable assessments of these agricultural transitions on Inis Oírr.

Data Analysis

Statistical Analysis

To quantitatively assess the satellite data collected, various statistical methods were used. Regression analysis was used to identify trends in vegetation indices (NDVI and NDWI) over time, providing insights into the growth patterns and moisture content of vegetation on Inis Oírr. Additionally, time-series analysis helped in understanding the seasonal changes of agricultural practices, particularly how this demonstrates the age old farming practices and systems seen on the island, particularly the winterage farming system. This system is where livestock graze the limestone grasslands and pavements over the winter and in the summer are sent to the more fertile lowland pastures allowing for plants to grow and flourish on the winterages undisturbed. This system is linked to the islands biodiversity as the “most botanically rich and diverse grasslands and heaths are found on the winterages, owing to the combination of winter grazing and environmental conditions”(Williams *et al.*, 2009). These statistical approaches were crucial for converting raw satellite data into useful insights, allowing for a thorough assessment of this unique agricultural practice on the island.

Spatial Analysis

This research analysed agricultural land sizes on Inis Oírr and compared them to mainland farms in order to highlight the island's distinct land-use features. Using the measurement tool in Google Earth, the average farm size on Inis Oírr was determined to be approximately 6 hectares. This contrasts sharply with the average farm size on the mainland, which is about 32 hectares.

To visually demonstrate this size comparison, an infographic was created using Canva. This infographic featured satellite imagery of a typical farm land parcel on Inis Oírr alongside an image of one of my own family owned fields on the mainland. Each image included exact measurements to provide a clear, comparative view of the farm sizes. This graphic depiction was created to show the great contrasts in agricultural land usage and draw attention to how these differences affect farming techniques and land management on the island.

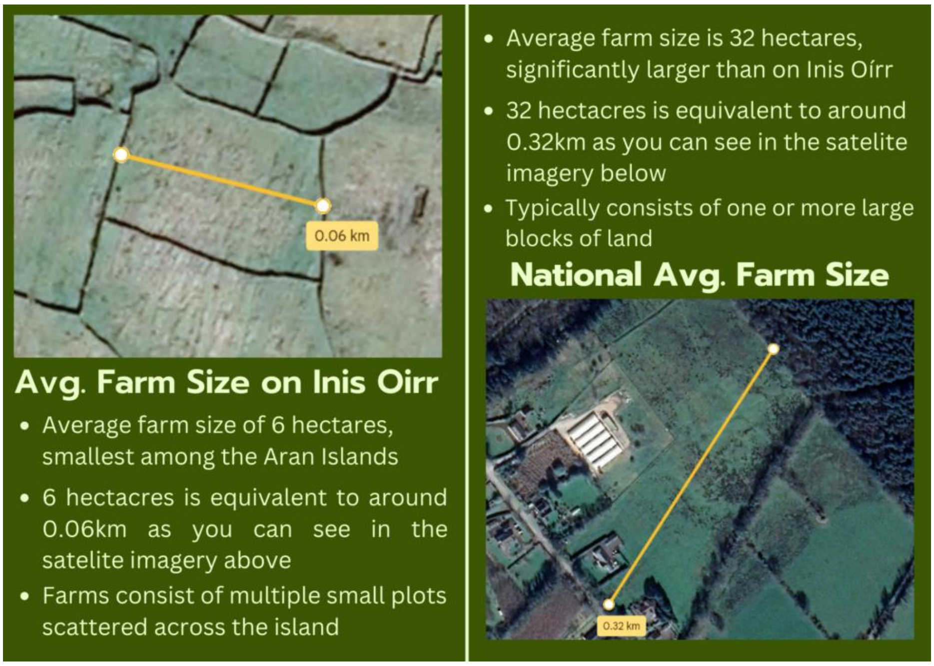

Fig. 2. Spatial analysis of average farm size differentiations on Inis Oirr

Software and Tools

Copernicus Browser: One of the key features utilised in this research was the time-lapse creation tool available in the Copernicus browser. This tool allowed for generating a dynamic time-lapse video that illustrates the seasonal changes and agricultural cycles on Inis Oírr over the study period. By capturing a sequence of images from the same geographic area over time, this tool provided a visual representation of how agricultural practices impact the landscape across different seasons, giving valuable insights into temporal patterns and furthermore showcasing the age old winterage system in practice.

ESA SNAP: The Sentinel Application Platform (SNAP) was frequently used for the initial processing and comprehensive analysis of the satellite datasets. After downloading the datasets via the Copernicus browser, it was then uploaded to SNAP where various features were used to enhance and correct the imagery. Radiometric and atmospheric adjustments were used to account for sensor inaccuracies and atmospheric conditions. SNAP's powerful processing capabilities also enabled the exact extraction and modification of certain spectral bands required, also allowing for the ability to explore the satellite imagery dataset and extract this data by exporting image files, making it an indispensable tool.

EOS Land Viewer: The EOS Land Viewer was used specifically to generate and analyse vegetation indices. This program proved useful in computing the NDVI (Normalised Difference Vegetation Index) and NDWI (Normalised Difference Water Index) from processed Sentinel-2 data. EOS Land Viewer provided an efficient and user-friendly platform to quickly generate these indices, which are necessary figures for evaluating the condition of vegetation and the moisture content of the land on Inis Oírr. The ability to immediately visualise and export these indices across specific time periods allowed for a more thorough evaluation and comparison of data across seasons.

These tools collectively supported the comprehensive analysis required for this study. Copernicus Browser's time-lapse ability, ESA SNAP's sentinel satellite data processing features, and EOS Land Viewer's index generating capabilities all contributed to comprehending the unique agricultural patterns of the winterage system on Inis Oírr.

Digital Artifact Creation

Website Development and Hosting

To effectively disseminate the findings of this research and engage a broader audience, a digital artefact in the form of a website, AranIslandsAgriculture.com, was developed to raise awareness and shed light on the importance of the unique agricultural patterns seen on Inis Oirr. The content management system WordPress was chosen because of its user-friendly interface and versatility in presenting complex information through posts, interactive maps, multimedia features, and data visualisations. The website provides a complete resource for learning about Inis Oírr's agricultural legacy, as well as presenting project approach, results, and visual material.

Enhancing the Website with Plugins

To enhance the site's design and functionality, key WordPress plugins were used. Elementor helped create clean, engaging pages that smoothly integrate interactive maps and dynamic visualisations. The Google Maps plugin was useful for showcasing detailed and interactive maps of Inis Oírr, directly linking geographical specifics with our case studies and analysis. These technologies enhanced not just the site's appearance and usability, but also user interactions, making the material more accessible and engaging.

CSS ID & Classes

To further enhance the site's appearance and design, CSS ID and classifications were created to ensure a seamless design throughout each post. This created a practical design applied to each heading title of the site's posts. The CSS ID was labelled as "featured-content" and the CSS Classes was labelled as "visual-posts". This created a heading style which ensured the title was centred on the page in large bold text featuring a black font and a beige circular boxed background. The following CSS was integrated through the additional CSS section of the customisation area on the home page:

```
/* This ID targets the specific featured content section */
#featured-content {
  background-colour: #f5f5f5; /* Light grey background */
  padding: 70px;
  border-radius: 20px; /* Rounded corners */
}


/* This class can be reused for any similar sections */
```

```
.visual-posts h2 {
  colour: #333333; /* white text for headings */
  font-weight: bold;
  margin-bottom: 10px;
}

.visual-posts a {
  colour: #333333; /* Theme colour for links */
  text-transform: uppercase; /* Uppercase text for CTAs */
  font-weight: bold;
  text-decoration: none;
        font-size: 20px; /* Adjust the value as needed */



}

.visual-posts a:hover {
  text-decoration: underline; /* Underline on hover for links */
}



.visual-posts {
  width: 95%; /* This makes the box full-width */
  text-align: centre; /* This centres the text inside the box */
}
```

Domain Acquisition

A domain name was purchased through Reclaim Hosting to provide the website with a professional and recognisable online presence. This chosen domain name, AranIslandsAgriculture.com, directly reflects the project's focus, making it easily recognizable and accessible. Reclaim Hosting was chosen for its dependable service, which ensures the website's stability and accessibility, resulting in a dedicated platform for conveying this research's discoveries.

The research used several methods and approaches to study the unique agricultural patterns of Inis Oírr, emphasising the crucial role of satellite imagery and analysis software in understanding these agricultural patterns. Using these tools and methods effectively illustrated and analysed seasonal and unique agricultural changes on the island using ESA SNAP for deep image processing, EOS Land Viewer for providing crucial vegetation indices, and Google Earth for improving visual presentations.

Implementation / Artefact Description

This section details the practical implementation of the methodologies and tools outlined in the "Tools and Methods" section, focusing on their application in exploring and analysing the distinctive agricultural patterns of Inis Oírr, thus showcasing the winterage system. This study looks at the long-term impact of traditional farming systems on the island's biodiversity and agricultural sustainability using Copernicus Sentinel satellite data, ESA SNAP, and other analytical tools. These tools and methods provided the necessary data and visualisations to not only observe but also assess how these age-old farming practices impact the ecological and environmental fabric of Inis Oírr, addressing the role of sustainable agriculture and low-impact farming in maintaining biodiversity in this unique landscape.

Application of Satellite Data and Software Tools

The implementation of this project heavily relied on Sentinel-2 satellite's accurate and detailed data, as well as an array of complex software tools developed to handle and visualise it. The research utilised satellite imagery analysis, time-lapse visualisations, and high-resolution imaging to examine the distinct agricultural patterns of Inis Oírr.

Satellite Imagery Analysis:

Sentinel-2 imaging, which has been praised for its high resolution and multispectral capabilities, was used to track changes in vegetation and land use during the research period. To analyse vegetative health and soil moisture levels, the EOS Land Viewer generated the NDVI (Normalised Difference Vegetation Index) and NDWI (Normalised Difference Water Index). These indices gave important insights into the condition of the island's vegetation, showing shifts in vegetation and water content that reflect the seasonal changes associated with the winterage system. For example, increases in NDVI throughout the spring indicate strong vegetation growth, which is critical for understanding the effects of traditional grazing methods on plant recovery and biodiversity, as it shows how the flora can flourish in these heavily limestone induced winterage farming areas after the winterage grazing period is complete.

Time-Lapse Visualizations:

Time-lapse visualisations were generated using the Copernicus browser to showcase the changing farming methods on Inis Oírr. These visualisations patched together a sequence of detailed satellite images gathered over a six-year period to show seasonal transitions and the resulting changes in land use and plant cover. The time-lapse video clearly showed how the winterage system, in which livestock are grazed on different fields seasonally, showing how this impacts the landscape, supporting its ecological balance and fertility of the soil through these seasonal cycles.

High-Resolution Imaging:

Google Earth assisted in capturing high-resolution images of Inis Oírr's unique landscape, which showcased the detailed and intricate mosaic of stone-walled fields, a characteristic feature of Inis Oírr's landscape. The shots offered striking visual evidence of traditional land-use patterns, demonstrating how small-scale, patchwork farming has shaped the physical and agricultural surroundings of the island. The clarity and detail of these photographs make them an excellent resource for improving the website's visual appeal and accurately representing the jigsaw like mosaic's these stone walled fields represent.

Fig. 3. Home page of the digital artefact using these high resolution imagery to represent the jigsaw like mosaics of the stone walled fields on Inis Oirr

Data Analysis and Interpretation

The implementation of data analysis was essential for converting satellite data into useful insights, addressing the impact of traditional farming and the unique patterns of agriculture seen on Inis Oírr. This stage used statistical and spatial analysis to assess time-series satellite images, linking the findings with historical farming practices.

Statistical and Spatial Analysis:

Using time-series analysis to follow changes in the NDVI (Normalised Difference Vegetation Index) and NDWI (Normalised Difference Water Index) throughout several seasons and years. These indices, extracted from Sentinel-2 data using ESA SNAP and EOS Land Viewer, are important markers of vegetation health and soil moisture levels. Regression analysis helped link seasonal variations in these indices to traditional farming activities, mainly the winterage system. This system takes place generally between late October – late march, these indices represent this such as the higher spectrum of water index during these months as "drinking water is more readily available during winter in this usually free-draining karst landscape" and the low water index during the summer months, shows the period of time where the limestone absorbs the suns heat due to the minimal rainfall, " while the limestone habitats, with their thin rendzina soils, provide a warm, dry 'lie' for stock"(Williams *et al.*, 2009).

Normalised Difference Vegetation Index			
scene_id	view_id	date	cloud
S2B_tile_20220811_29UMU_0	S2/29/U/MU/2022/8/11/0	11/08/2022	0
S2A_tile_20230420_29UMU_0	S2/29/U/MU/2023/4/20/0	20/04/2023	0
S2A_tile_20230622_29UMU_0	S2/29/U/MU/2023/6/22/0	22/06/2023	0
S2A_tile_20231229_29UMU_0	S2/29/U/MU/2023/12/29/0	29/12/2023	0

Fig.4. Represents the sentinel satellite data in preparation for gathering the NDVI values

min	max	average	std	variance	q1	q3	median	p10	p90
-0.6549	0.8527	0.2293	0.4454	0.1984	-0.2825	0.671	0.3546	-0.3333	0.7454
-0.4776	0.8647	0.264	0.4106	0.1686	-0.2238	0.643	0.4037	-0.2789	0.7295
-0.5479	0.8388	0.253	0.3861	0.1491	-0.1787	0.6251	0.3648	-0.232	0.7081
-0.5448	0.511	-0.0774	0.2202	0.0485	-0.3008	0.1232	-0.0624	-0.3451	0.2062

Fig. 5. Represents the specialised indices gathered from this data to calculate the NDVI values

Normalised Difference Water Index

scene_id	view_id	date	cloud
S2B_tile_20220811_29UMU_0	S2/29/U/MU/2022/8/11/0	11/08/2022	0
S2A_tile_20230420_29UMU_0	S2/29/U/MU/2023/4/20/0	20/04/2023	0
S2A_tile_20230622_29UMU_0	S2/29/U/MU/2023/6/22/0	22/06/2023	0
S2A_tile_20231229_29UMU_0	S2/29/U/MU/2023/12/29/0	29/12/2023	0

Fig. 6. Represents the sentinel satellite data in preparation for gathering the NDWI values

in	max	average	std	variance	q1	q3	median	p10	p90
0.7073	0.7172	-0.0527	0.4986	0.2486	-0.5358	0.5398	-0.2419	-0.5961	0.5737
0.7844	0.6402	-0.111	0.4679	0.2189	-0.535	0.4651	-0.3118	-0.6014	0.5121
0.7068	0.6944	-0.0803	0.4408	0.1943	-0.5035	0.4314	-0.2425	-0.5657	0.4729
0.2875	0.6078	0.2753	0.1857	0.0345	0.1158	0.4711	0.2632	0.0359	0.5048

Fig. 7. Represents the specialised indices gathered from this data to calculate the NDWI values

Interpretation of Implementation Results:

Sentinel-2 imagery's NDVI and NDWI analysis shed light on how traditional agricultural techniques impact vegetation and moisture levels on Inis Oírr. The NDVI data over specified dates indicates a pattern in vegetative health that aligns with the agricultural schedule, demonstrating its effect of the winterage system.

NDVI Analysis: NDVI values were usually higher throughout the spring and summer months (April and June data), with averages of 0.264 and 0.253, indicating robust growth of vegetation, most likely due to favourable weather conditions and proper grazing management. These higher values indicate that rotational grazing, a vital part of the winterage system, helps to sustain healthy vegetation. In contrast, the winter months saw a considerable reduction in NDVI values (December data), with an average of -0.0774, indicating vegetative inactivity along with decreased agricultural activity as the livestock graze on the robust limestone areas (not the soft soil) during these periods.

NDWI Analysis: The NDWI data demonstrated variations in moisture levels throughout the year. Spring and summer (April and June data) showed slightly negative average NDWI values, suggesting reduced surface moisture, which corresponded to the drier circumstances of these seasons. The December readings showed a positive average of 0.2753, suggesting higher moisture levels, most likely due to more rainfall and lower evaporation rates during the winter months. This is favoured for the winterage seasons as the karst limestone regions contain suitable rain catchers which the cattle utilise.

Digital Artifact Development

AranIslandsAgriculture.com was created to effectively share study findings about the unique agricultural techniques and biodiversity of Inis Oírr. The website functions as a complete platform, using multiple multimedia aspects to improve user engagement and understanding.

Website Features and Content:

The website is designed to present notable research findings in the form of interactive maps, time lapsed and graph visualisations, allowing users to visually learn changes in agricultural trends. Detailed infographics highlight the characteristics of high nature value farmlands, while time-lapse visualizations depict the dynamic changes throughout the seasons. Each section of the site is designed to provide insights into different aspects of the island's agriculture and ecology, from sustainable farming practices to conservation and biodiversity. AranLife's multimedia material, such as image galleries and videos produced in Irish, enriches the story by making information more accessible and entertaining. Additionally, the site features an innovative interactive jigsaw puzzle based on a clear Sentinel-2 image of Inis Oírr, inspired by Tim Robinson's description of the landscape as a complex jigsaw puzzle, “Aran, an incredible jigsaw puzzle of little fields where farmers clear their stoney patches and mark their every increasing subdivision of their holdings by building walls...”(Wall, 2008), which allows users to engage with the landscape’s unique structure creatively.

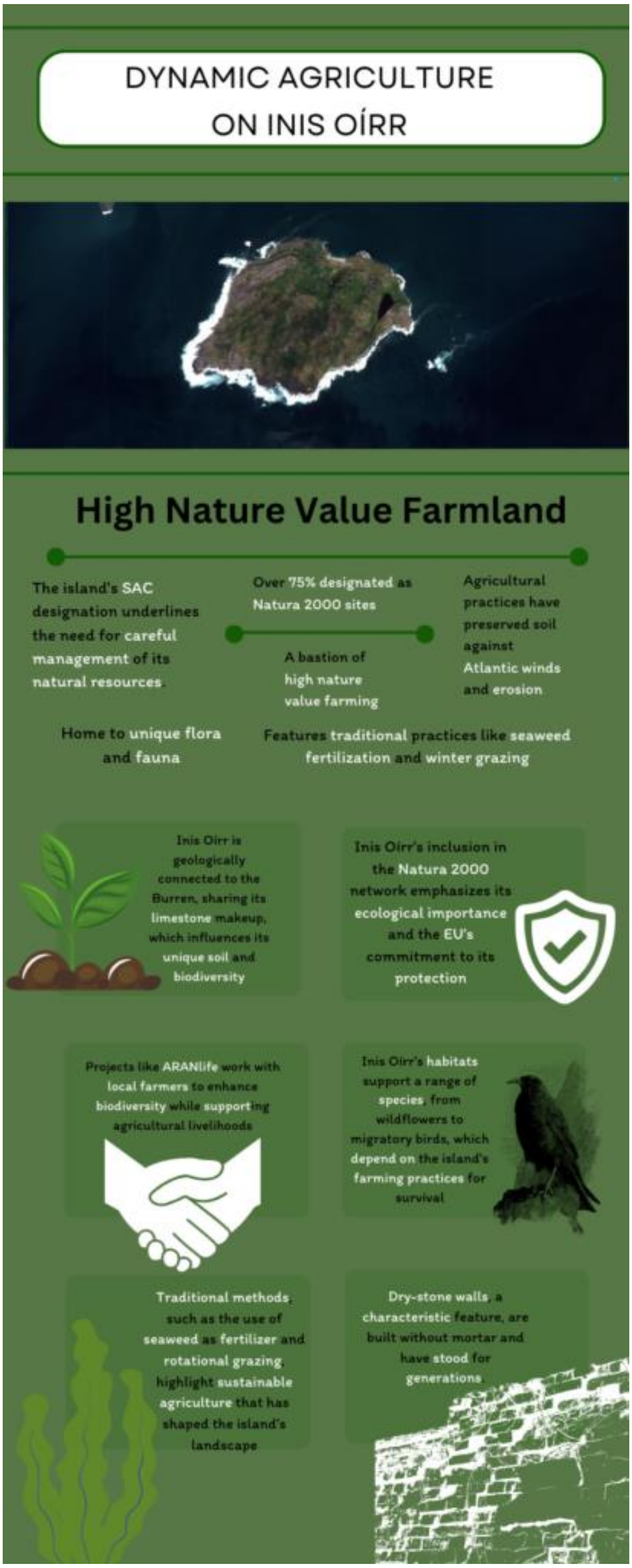

Fig. 8. Infographic representing the characteristics of high nature value farmlands on Inis Oirr

Practicality for Users:

The website is designed to benefit a wide range of users, including local farmers, environmental groups, and potentially even policymakers. The website presents data in visual, textual, and interactive formats, allowing for a more complete knowledge of the ecological and agricultural dynamics of Inis Oírr. This strategy helps users understand the importance of traditional agricultural methods and their influence on biodiversity, therefore raising the effort for sustainable practices. The use of case studies and personal testimonies, such as an interview with a local farmer (obtained through the national heritage council's case studies(Smith, Bligh et al., 2010)), provides real-life scenarios that further illustrate the study results' real-world implications.

Analysis

This research uses high-resolution satellite data to understand the intricate link between traditional agricultural techniques on Inis Oírr and their ecological implications thus representing its unique pattern of agriculture harnessed from the age - old winterage farming system. By employing Sentinel-2 imagery and powerful analytical tools such as ESA SNAP and EOS Land Viewer, this study evaluates vegetation health and land use changes, providing insights into sustainable agriculture practices. The next subsections go over the integration and processing of satellite data, followed by a statistical and interpretative analysis that summarises how these methods affect local biodiversity and ecosystem stability, thereby illustrating the island's distinguished agricultural patterns.

Data Integration and Preliminary Processing

Data Integration

This study made sole use of Sentinel-2 satellite imagery, which was chosen for its high resolution and multispectral capabilities. From January 2018 to March 2024, the time lapsed imagery captures the seasonal pattern of farming practices on Inis Oírr, demonstrating the traditional winterage system.

Preprocessing Steps

Prior to analysis, satellite images underwent thorough preprocessing to ensure accuracy. To reiterate, these steps included the use of atmospheric correction, by using the ESA SNAP programme, atmospheric distortions were reduced to better reflect true surface conditions. Cloud reduction was also performed, images with cloud coverage of more than 8% were excluded to guarantee clarity and precision in the study. Advanced techniques from ESA SNAP were also used to improve cloud detection and removal. To ensure uniformity throughout the collection, radiometric and geometric calibrations were done consistently to each image.

Statistical Analysis of NDVI and NDWI Indices

The statistical analysis primarily focused on examining the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI) to understand the vegetative and moisture patterns on Inis Oírr. The indices were calculated from Sentinel-2 satellite data, see figures 5 & 7 for these exact calculated indices which included spectrum measurements necessary for measuring the condition and health of vegetation, as well as water content in both vegetation and soil. The analysis spanned from September 2022 to December 2023, aligning with winterage system cycle practised on the island. A time-series analysis was performed to investigate the variations and trends in NDVI and NDWI values throughout this time period. Descriptive statistics such as minimum, maximum, mean, standard deviation, and percentiles offered a thorough overview of the indices' distribution across time.

Normalized Difference Vegetation Index (NDVI) Results:

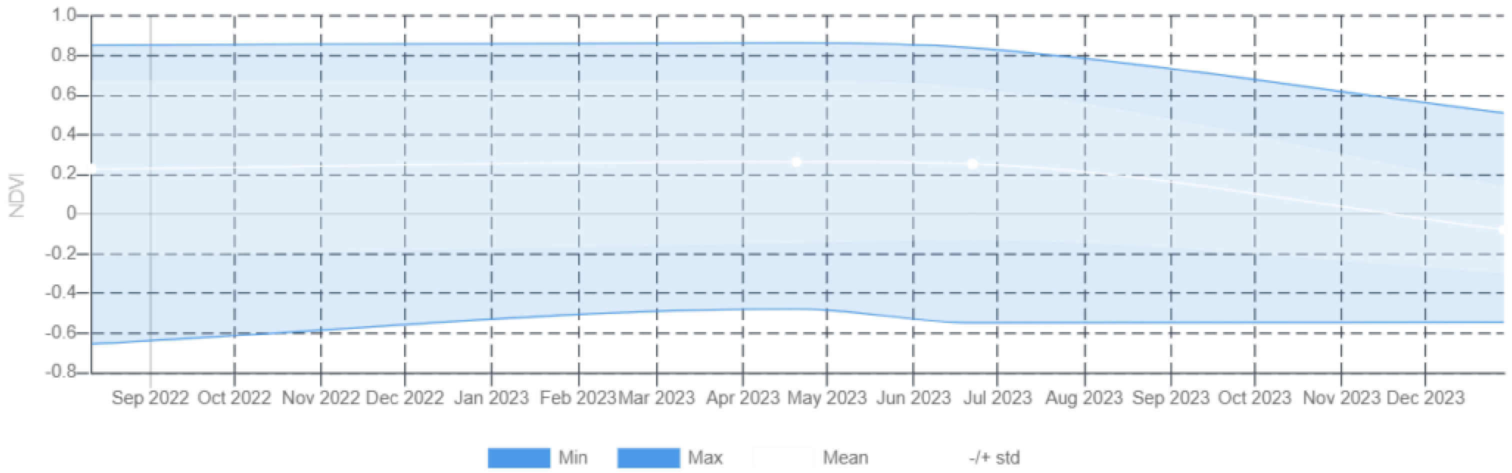

Fig. 9. Graphical Representation of the NDVI of Inis Oirr's Terrain, Sept '22 – Dec '23

The NDVI data showed a seasonal pattern that corresponded with the unique farming patterns on Inis Oírr. NDVI values were highest in the spring and summer, with mean values peaking at 0.264 and 0.253, indicating strong vegetative growth during these seasons of active farming. This is consistent with the post-winterage rebound, in which grazing pressure is reduced as the livestock are moved to the soft soil summerage land areas, and the unique flora may grow again, as seen by the April and June data points.

On the other hand, the winter months saw a fall in NDVI values, with December showing a mean of -0.0774. This drop reflects an inactive vegetative condition and signifies the final stage of the winterage cycle, in which grazing occurs on non-arable limestone pavements, sustaining the softer soil fields for spring growth.

Normalized Difference Water Index (NDWI) Results:

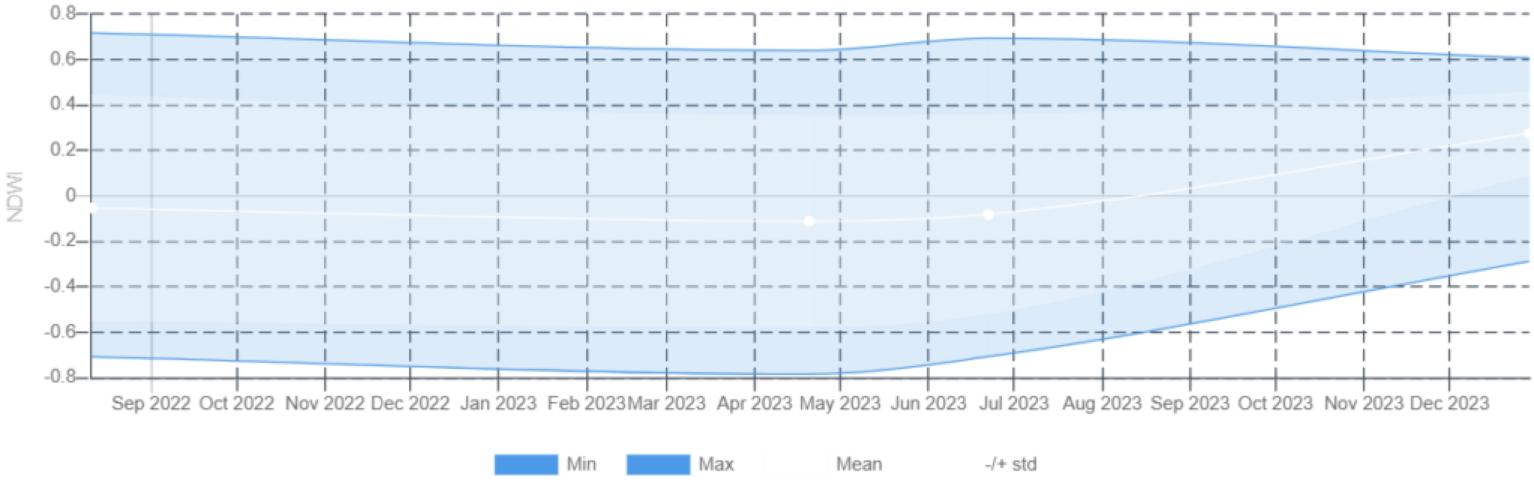

Fig. 10. Graphical Representation of the NDWI of Inis Oirr's Terrain, Sept '22 – Dec '23

For NDWI, the data indicated variations in soil and vegetation moisture levels. The average values being slightly negative during the spring and summer seasons reflect the typical dry conditions. Notably, the positive mean of 0.2753 in December shows the island's increasing moisture levels, most likely due to winter rains. Thus supporting traditional knowledge that allows for winter grazing on moisture-retaining limestone terrains which contain specific rain catcher structures to utilise this increase in moisture levels to their and the cattle's advantage.

Therefore, the concrete statement can be made that on Inis Oírr, traditional agricultural techniques depend on seasonal vegetation and moisture levels, as demonstrated here by this statistical data. This further emphasises the winterage system's long-term influence in promoting a healthy balance between agricultural usage and the preservation of the island's distinctive biological ecosystem.

Spatial Analysis

Geographical Analysis

This study used satellite pictures over a six-year period to conduct a comprehensive geographical analysis of Inis Oírr. This approach allowed for a comprehensive understanding of the distribution and seasonal dynamics of agricultural patterns on the island. The spatial analysis utilised the Copernicus browser's time-lapse capabilities, which produced a series of high-resolution images that showed seasonal changes in the island's agriculture, specifically concentrating on the winterage system, a rotational grazing strategy that is key to the region's farming methods.

The analysis of spatial data involved measuring vegetative health and moisture levels throughout the island's distinctive landscape. The data from the Sentinel-2 imagery showed varying intensities of greenness, indicating the presence of vegetation and its health. The stone-walled fields, a symbol of the island's agricultural heritage, were vividly defined, revealing the patchwork pattern of small-scale farming seen on the island.

The seasonal colour fluctuations in the fields demonstrated the winterage system's impact. Images obtained in the spring months showed an increase in greenness, implying that the grasslands were rejuvenated following the winter grazing. The fields in question turned a rich green in the summer, showing strong vegetation health, which is due to the winterage system's land management procedures. In contrast, images from the winter months showed softer colours, corresponding with lower vegetative activity and the fields' resting period, allowing the soil to recuperate.

Fig. 11. Screenshot from the time-lapsed visualisation depicting the most recent summerage cycle from 30/05/2023

Fig. 12. Screenshot from the time-lapsed visualisation depicting the most recent winterage cycle from 10/01/2024

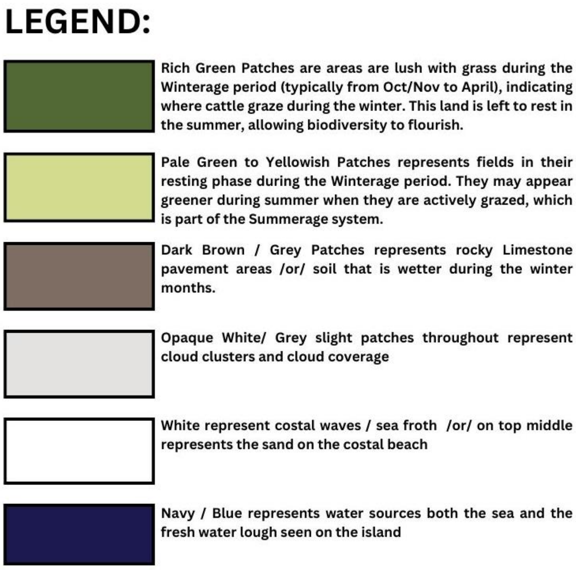

Fig. 13. Legend for deciphering the various colours seen in the time-lapsed visualisation

This analysis provided sheds light into the benefits of the winterage system for soil fertility and vegetative health. By allowing livestock to graze on different fields seasonally, the system not only maintains soil quality but also in effect, sustains an ecosystem which supports a diverse range of flora and fauna. The satellite images also helped identify areas that could be at risk due to changes in these traditional practices or other external factors, such as erosion, as throughout the time series large costal waves are evident. This study found that traditional agricultural practices on Inis Oírr play a significant role in maintaining the delicate balance of biodiversity and agriculture, using spatial analytic tools and time-series satellite data.

Interpretation of Findings

Synthesis of Results

Examining Inis Oírr's agricultural practices via spatial and statistical lenses offers insight into how traditional agriculture may correspond with safeguarding the environment. The spatial analysis depicts the annual agricultural seasonal cycles, showing the practical illustration of the winterage system in the patchwork of greenery that fluctuates with the seasons. Together, the statistical analysis provides measurable proof of the influence of these activities on plant health and soil moisture content, as measured by the NDVI and NDWI values.

Implications

From a broader perspective, these findings contribute to the ongoing discourse on agricultural sustainability and biodiversity conservation. The data suggests that Inis Oírr's low-intensity agricultural techniques, including rotational grazing and seasonal growth cycles, may improve soil health and biodiversity. This understanding is especially important in the current period of time, where intensive agriculture frequently damages environmental stability, being described as “In recent decades, this more traditional style of extensive farming has been increasingly replaced with more commercial, intensive farming, and this has had a significant impact on our wildlife and our landscape, both in Ireland and across Europe”(Smith, Bligh et al., 2010). Inis Oírr demonstrates how traditional approaches may address modern environmental concerns.

Limitations

While the research findings provide strong support in favour traditional agricultural techniques, they are not without limits. One key issue is the possibility of cloud cover obscuring crucial data, even careful image selection with minimum cloud interference. This selection approach may fail to take into account weather patterns that have a substantial impact on agricultural outcomes, limiting the supply of data to work from. Additionally, the lack of on ground observations might lead to inconsistencie between observes indices from satellite data and actual field conditions. If more time and resources could be applied, ideally measuring the

NDVI and NDWI and unique agricultural patterns in person would be a vital resource for strongly backing up these reports even more.

Conclusion

The research of Inis Oírr's agricultural patterns using Copernicus Sentinel satellite data found a positive correlation between traditional farming techniques and conservation of biodiversity. The winterage system, an age-old agricultural practice, is not just a cultural relic, but also a symbol of sustainable agriculture, showing just how poweful the relationship between farmers and the sustainability of the environment can be.

The spatial and statistical analyses conducted reinforced the importance of the winterage system. Statistical analysis, particularly the interpretation of NDVI and NDWI indices, indicated a direct correlation between these practices and the health and moisture levels of the soil and vegetation, emphasizing the crucial role of traditional methods in maintaining biodiversity and promoting ecological balance. These indices were critical in demonstrating the strong vegetative growth and seasonality of the winterage system, which is defined by periodic animal grazing on separate fields, moving livestock to limestone landscaped fields during the winter months, which allows the soft soil summerage fields to rest and recuperate, and vice versa.

This research also emphasised the importance of remote sensing technologies as instruments for environmental monitoring and agriculture management. This research also emphasised the importance of remote sensing technologies as instruments for environmental monitoring and agriculture management. Sentinel-2 satellite data proved useful in gathering high-resolution images throughout various seasons, allowing for an in-depth study of land-use changes and the resulting effects. The data visualisations, including time-lapse animations, provide an immersive understanding of the unique patterns and highlight the resilience of Inis Oírr's terrain under modern agricultural demands. As such, the satellite imagery analysis revealed a clear visual story of the seasonal transitions that are inherent in these unique agricultural patterns.

Furthermore, The digital artefact created, AranIslandsAgriculture.com demonstrates the project's outcomes in not just collecting data but also explaining its value. The website, which includes interactive maps, time-lapse visualisations, and insightful information on high nature value farmlands as a whole, serves as a valuable resource for individuals at all levels.

This body of work adds to the larger discussion over the conservation of High Nature Value farmlands and the preservation of traditional agricultural practices. Inis Oírr demonstrates how less-intensive agricultural techniques can coexist with nature, rather than dominate it. The findings gathered might inform policies and conservation initiatives, pushing for agriculture that preserves biodiversity and supports local farmers.

Nonetheless, the study acknowledges its limitations, such as the fundamental constraints of satellite data interpretation and the need for long-term as well as ground level research to fully understand the ecological processes at work. These limitations do not undermine the findings, but rather recognise opportunities for future study, encouraging a multidisciplinary approach that may combine satellite data with on-the-ground observations to gain a more comprehensive understanding of Inis Oirr's unique agricultural patterns. This continuing research could provide further evidence to support the case for traditional farming methods and their place in modern agriculture, not just as relics of the past but as viable, sustainable practices for the future.

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