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Semi-natural grasslands in Seewinkel: Evaluation of changes in FFH – Habitats Type’s in Natura 2000 and National Park Zone

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Affidavit

I hereby declare that I have written this Master's thesis independently and that no sources or aids other than those indicated have been used. All ideas, quotations, or content taken directly or indirectly from other sources - whether published, unpublished, or generated with the help of artificial intelligence tools - have been identified as such and appropriately cited.

I acknowledge that language-related assistance was provided by the AI tool ChatGPT (OpenAI), which supported me in the rewriting and linguistic correction of sections of the thesis. The intellectual content, analysis, and scientific argumentation presented in this thesis are entirely my own.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, 21.02.2026

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Abstract

Protected areas are key tools for biodiversity conservation, but their effectiveness varies depending on legal frameworks and ecological implementation. This study compares two overlapping protected area categories in Austria's Seewinkel region: the National Park Neusiedler See - Seewinkel (IUCN II) and the Natura 2000 site (IUCN IV). Both aim to preserve species-rich semi-natural grasslands but differ in regulatory enforcement, funding, and land-use governance. Using EU Article 17 conservation status assessments, changes in FFH habitat types were evaluated between 2013 and 2023. Based on this data, it was investigated whether there are differences in conservation status between the protection categories.

Results show substantial shifts: dry grasslands (6210, 6240) expanded, while moisture-dependent habitats (6410, 7210) declined. Critically, habitat type 1530 (Pannonic Salt Steppes) - a highly sensitive ecosystem - showed being supported stronger by the management of the National Park yet declined overall in both area and ecological condition. While National Park zones supported better habitat quality, regression analysis revealed that internal ecological indicators - such as the presence of indicator species and absence of disruptive species - were stronger predictors of conservation status than protection category alone.

The findings underscore that legal designation alone is insufficient. Effective conservation in the Seewinkel requires adaptive, habitat-specific strategies, hydrological restoration, and ecologically targeted agri-environmental measures - particularly to protect vulnerable habitats like the habitat type 1530.

Zusammenfassung

Schutzgebiete sind zentrale Werkzeuge im Naturschutz, ihre Wirksamkeit hängt jedoch stark von rechtlichen Rahmenbedingungen und ökologischer Umsetzung ab. Diese Studie vergleicht zwei überlappende Schutzkategorien im Seewinkel (Österreich): den Nationalpark Neusiedler See–Seewinkel (IUCN II) und das Natura 2000-Gebiet (IUCN IV). Beide zielen auf den Erhalt naturnaher Graslandtypen, unterscheiden sich aber deutlich in Managementintensität, rechtlicher Bindung und Förderinstrumenten.

Diese Arbeit basiert auf Daten der Artikel-17 Erhebungen aus 2013, sowie Wiederholungserhebungen aus dem Jahre 2023. Auf diese Daten aufbauend wurden die Unterschiede in den Erhaltungszuständen zwischen den Schutzkategorien ermittelt.

Die Ergebnisse zeigen deutliche Verschiebungen: Trockene Graslandtypen (6210, 6240) nahmen zu, während feuchte, empfindliche Lebensräume wie 6410 und 7210 stark zurückgingen. Besonders Habitattyp 1530 (Pannonische Salzsteppen) – ein hochsensibles Ökosystem – wird stärker durch die Verwaltung des Nationalparks unterstützt, zeigt jedoch insgesamt einen Rückgang in Fläche und Zustand. Zwar weisen Nationalparkflächen bessere Habitatqualität auf, dennoch ergab die Regressionsanalyse, dass ökologische Faktoren wie das Vorkommen von Indikator- und Störarten stärkere Prädiktoren für den Erhaltungszustand sind als die Schutzkategorie selbst.

Die Studie zeigt, dass rechtlicher Schutz allein nicht ausreicht. Für den Erhalt besonders gefährdeter Lebensräume wie 1530 braucht es anpassungsfähige, Habitat-spezifische Strategien, effektives Wassermanagement und ökologisch zielgerichtete Fördermaßnahmen.

Introduction

Biodiversity loss is one of the most pressing global challenges of our time (Lim, 2019) despite widespread international conservation efforts (IPBES, 2019). According to IPBES (2019), the main drivers of biodiversity decline include changes in land and sea use, direct exploitation of organisms, climate change, pollution, and the spread of invasive alien species. One of the key difficulties in addressing this crisis lies in its complexity: these drivers are rarely isolated but are often deeply interconnected (Hald-Mortensen, 2023).

While today's biodiversity crisis is largely driven by harmful human activities, it is worth noting that certain traditional land use practices contribute positively to biodiversity. Human interactions with natural ecosystems, such as livestock farming and hay making, have played a significant role in creating biodiverse semi-natural habitats (Bostan et al, 2017, Fiedler et al. 2017). Meanwhile, this type of management promoted a variety of species and was often fundamental to their survival (Muller, 2002; Bostan et al, 2017). Over centuries, grasslands became widely distributed across Europe (Habel et al., 2013). The expansion and diversity of production systems have varied significantly between countries (Peeters, 2008), influenced by the biogeographical context and climatic conditions (Habel et al, 2013). These differences have led to a wide range of grassland types. Especially, dry calcareous grasslands are known for a very high number of plant species, often concentrated in small areas (WallisDeVries et al., 2002).

Beyond plant diversity, those habitats also support a wide range of other organisms. Many invertebrates depend on these highly structured and extensively managed habitats (WallisDeVries et al. 2002). Furthermore, several bird species are closely associated with semi-natural grasslands, relying on open habitats with sparse vegetation for breeding and feeding (Canonne et al. 2024). In particular, within intensively used agricultural landscapes, extensively managed grasslands play a vital role in sustaining and promoting populations of a wide range of organisms (Walcher et al. 2025).

However, these rich and ecologically valuable systems are subject of increasing pressure (Habel, et al., 2013). Since the 20th century, the expense of land use intensification – through conversion into fertile pastures, meadows, vineyard or arable fields – alongside the abandonment of traditional management practice and widespread afforestation, has become a significant threat (Schön, 1997; WallisDeVires et al. 2002; Milić et al. 2024). This development has led to extensive habitat loss and fragmentation of grassland landscapes across many regions. In addition, the quality of remaining habitats has declined due to the invasion of competitive grass species and neophytes, often triggered by intensification and increased nutrient input from atmospheric nitrogen deposition (WallisDeVries et al., 2002).

However, the slow disappearance has not gone unnoticed and grassland habitats have been given a high priority for conservation (Milić et al. 2024). This is reflected in the agricultural policies by article 19 of EC-regulation 707/85 and in the FFH directive, where grasslands are classified as habitats requiring targeted conservation (Muller, 2002; Fiedler et al. 2017; Hülber et al. 2017). In this context, protected areas, in particularly those designated under the Natura 2000 network (Directive 92/43/EEC), play a key role in halting biodiversity loss by reducing land use pressure and preserving ecologically valuable systems (Hülber et al. 2017; Schulze et al. 2018).

The Natura 2000 network was established to protect representative habitats and species of community interest and is legally grounded in the Birds and FFH directives (Bostan et al., 2017). Its main goal is to preserve and restore species and habitats listed in the Directives Annexes I, II, and IV. Nevertheless, there is a concern among conservationists about the effectiveness of protected areas (Davis et al. 2014, Gameiro et al. 2020; Yuan et al. 2024). Regarding Natura 2000 sites, where the effectiveness of monitoring and the sufficient application of conservation efforts by responsible authorities is particularly being questioned (Davis et al. 2014).

Biodiversity conservation in cultural landscapes – especially in semi-natural grasslands – depends not only on legal protection but on effective, adaptive and well-funded land management (Abensper-Traun et al., 2004). At the European level, agri-environmental schemes (AES) have been established as key instruments to reconcile agriculture and biodiversity, both inside and outside protected areas (Batáry et al. 2015). In Austria, these goals are primarily implemented through the ÖPUL (Österreichisches Programm für umweltgerechte Landwirtschaft) which represents the national agri-environmental scheme (BMLRT, 2015). ÖPUL offers financial incentives for farmers to adopt environmentally friendly practice, including low-intensity mowing, extensive grazing, or the maintenance of landscape elements (Hülber et al. 2017; BMLRT. 2023). Furthermore, those measures can be combined with nature conservation efforts, followed by financial compensation (BMLRT, 2023).

While AES have helped to slow down habitat degradation in some regions (Batáry et al. 2015; Hülber et al. 2017), their actual effectiveness varies significantly depending on local uptake, land productivity and the ecological targeting of measures (Environnement Alliance, 2019). The programs' payments often fail to fully compensate for the economic losses associated with reduced input or yield (Abensperg-Traun et al. 2004). Moreover, the design and placement of set-aside areas often prioritize farm efficiency over ecological connectivity or habitat quality (Abensperg-Traun et al. 2004).

Although Natura 2000 designations provide a legal framework for conservation - in Austria they rely heavily on complementary instruments like ÖPUL to achieve their ecological goals. However, when subsidies are insufficiently coordinated, or disconnected from site-level conservation measures, the protected status alone may not prevent habitat degradation (Davis et al. 2014).

To better understand how different protection regimes influence conservation outcomes, this study focuses on two overlapping but institutionally distinct protected area categories in the Seewinkel region: The National Park – Seewinkel (IUCN Category II) and the Natura 2000 site (IUCN Category IV). Although both aim to preserve semi-natural grasslands, they differ significantly in their legal obligations, funding instruments, and management constraints. By comparing these two categories, the study seeks to assess how variations in conservation strategies affect the condition of habitats of nature conservation concern.

Protected Area Categories

The National Park Neusiedler See – Seewinkel is subject to the Austrian National Park law since 1993, which gives it a clear legal framework, and includes explicit legal restrictions on land use, binding for both public and private stakeholders (UBA, 2024). Among these, management is guided by the international IUCN Category II standards, aiming to conserve extensive, largely undisturbed ecosystems while permitting limited human access for education and recreation (Dudley, 2008). A key focus of the National Park Neusiedler See - Seewinkel is the preservation of the traditional steppe landscape known as Puszta (Fig. 1; Schön, 1997). This goal is reflected in the management of the buffer zone. According to the management plan National Park Neusiedler See – Seewinkel 2021-2031, the maintenance of the semi-natural grassland habitats is ensured through targeted measures such as controlled grazing, mowing, and specific habitats restorations efforts. In addition, water retention strategies are implemented to stabilize the hydrological conditions and to counteract the ongoing decline in groundwater levels, which are essential for the long-term conservation of the Pannonic Salt Steppes (Habitat type 1530).

FIG. 1 THE NEUSIEDLER SEE – SEEWINKEL NATIONAL PARK IS SHAPED BY A TRADITIONALLY MANAGED LANDSCAPE OF THE PANNONIAN STEPPE (PUSZTA). THIS MOSAIC-LIKE LANDSCAPEIS CHARACTERIZED BY A RICH INTERPLAY OF TEMPORARY WETLANDS, DRY GRASSLANDS, AND SALINE MEADOWS, BLENDING INTO ONE ANOTHER.

In contrast, the designated Natura 2000 area covers the entire Neusiedler See and its surrounding landscape, extending across the Leithagebirge and covering approximately 57.125 ha. The study area for this research is located on the eastern side of the lake, specifically in the municipalities of Podersdorf, Illmitz and Apetlon. The land-use in this area is highly heterogenous, featuring a fine-scale mosaic of intensively and extensively managed parcels. While Natura 2000 sites are integrated into national legal systems, their effectiveness largely depends on site-specific conservation objectives and voluntary management plans (Suske et al. 2015). Importantly, human activities are permitted within Natura 2000 sites as long as they are compatible with the overarching goal of maintaining a favorable conservation status (Gray, 2016). According to the Austrian agri-environmental program ÖPUL, reported measures for maintaining cultural landscapes and semi-natural grasslands in this region include single cut meadows, fallow land (Wechselwiesen) mostly originating from abandoned vineyards, traditionally grazed areas and rotational pastures. Participation in ÖPUL is based on a legally binding baseline of environmental requirements that all farmers must comply with. However, the type and extent of additional agri-environmental measures implemented are voluntary and can be selected individually (ÖPUL, 2023). These may include general biodiversity-friendly practices, as well as more targeted nature conservation measures listed in the ÖPUL catalogue. Furthermore, Natura 2000 specific measures are available but not mandatory (ÖPUL, 2023). As a result, the uptake and effectiveness of such measures depend largely on the willingness and commitment of individual land users, resulting in highly variable implementation frequency and ecological outcomes across the landscape (Davis et al. 2014).

The Seewinkel region offers a valuable context to examine these dynamics more closely. It represents a rich socio-ecological history and is an ideal case study area to reflect changes concerning semi-natural habitats. In addition, it contributes to a contrasting pair of protection categories. Understanding the current condition of its grassland ecosystems, it requires a closer look at the region's transformation, ecological characteristics, and the environmental pressures it faces today.

Neusiedler See – Seewinkel

Human settlement and land drainage transformed the original landscape of the Neusiedler See – Seewinkel, once dominated by dense oak forests and swamps, into a mosaic of grasslands and salt marshes. The agricultural production was limited to grazing, in part to marshy pastures and grasslands (Schön, 1997). Over time, human interventions became increasingly intensive. Extensive landscape restructuring through water excavation, drainage construction, and canal network expansion has significantly reduced surface water levels (Soja et al., 2013). Consequently, groundwater has also declined, as it is exclusively recharged by precipitation (Zimmermann-Timm & Teubner, 2021). After the second world war, degradation and loss of grassland habitats have accelerated (Zulka, 1998). By around 1950, traditional grazing practices had largely been abandoned and replaced by arable farming and viticulture (Prinz et al., 2009). Agricultural intensification, combined with the region's already warm and relatively dry climate (annual precipitation around 600 mm) has led to increased reliance on groundwater for irrigation (Cotera et al, 2023). This, in turn, has caused a significant drop in groundwater levels, reducing the number of salt pans in the Seewinkel substantially from approximately 140 to 40 (Zimmermann-Timm & Teubner, 2021). Moreover, climate change is expected to further disrupt Europe's water balance in the coming decades (Cotera et al, 2023) and might lead to a long-term change in the local ecosystems (Zimmerman-Timm & Teubner, 2021).

Despite these challenges, Zulka et al. (2024) identified the Seewinkel as the country's top biodiversity hotspot based on an irreplaceability analysis, with 125 conservation objectives. This unique biodiversity is supported by the area's mild, dry Pannonian climate, which allows many steppe species typically found in more southern and eastern regions to thrive (Schön, 1997). The region is also characterized by numerous shallow salt pans that periodically desiccate – which host a variety of salt-tolerant (halophytic) plants. In line with these ecological features and the boundary between the Eastern Alps, Carpathians and the Pannonian Basin (Embleton-Hamann, 2022), the Seewinkel harbors a variety of coexisting specialized species (Zulka et al. 1998) and priority habitat types listed under Annex I of the FFH Directive (Ellmauer, 2004). Furthermore, being located along the East Atlantic migratory flyway, the region serves as a crucial resting and feeding site for many bird species (Schön, 1997).

Over the past decades, the region has been placed in various protection categories due to its ecological value: a biosphere reserve (1977), a nature and landscape protection area (1980), a Ramsar site (1983), and Austria's first transboundary National Park (1994). Since 2000, the area has also been designated as Natura 2000 site under the Birds and FFH Directives (Gemeiner, 2008). These overlapping protection classifications reflect not only the ecological value of the area, but also the urgency of addressing ongoing environmental pressures.

While all categories aim to maintain biodiversity, they differ substantially in their legal obligations, implementation strategies, and conservation instruments. In this context, it becomes crucial to examine how protection translates into concrete habitat management especially regarding semi-natural grasslands, which are among the region's most threatened and conservation-relevant habitat types. This is especially relevant given the high diversity of Annex I habitats occurring within the Seewinkel, many of which are directly dependent on targeted conservation measures and low-intensity land use. Among the most prominent are:

1530 Pannonic Salt Steppes and Saltmarshes*

The unique setting of the region supports both maritime and continental species such as *Artemisia santonicum, Tripolium pannonicum* and *Bolboschoenus maritimus* (Albert, n.d.). A mosaic of salt steppes and meadows is shaped by diverse abiotic factors such as variations in soil types, groundwater levels, soil chemistry, habitat heterogeneity, and spatial isolation (Albert et al., 2020). Additionally, local weather—particularly variable precipitation and strong winds—contribute to the formation and diversity of saline habitats, resulting in the highest richness of halophyte species in Europe (Albert, n.d.). These habitats are threatened by land abandonment and high nitrogen input (Muller, 2002). In the Seewinkel region, groundwater levels play a critical role in determining soil salinity. A disrupted water balance can significantly affect the salt regime, resulting in habitat degradation and species loss (Zimmermann-Timme & Teubner, 2021).

6210 Semi-Natural Dry Grasslands and Scrubland Facies on Calcareous Substrates

This habitat type reflects sub-mediterranean to sub-continental influences (Wrbka et al, 2001; Willner, 2015). These secondary semi-arid grasslands, often harboring species like *Bromus erectus*, *Salvia pratensis* and *Briza media*, depend on traditional extensive land-use practices such as mowing and grazing to maintain ecological structure and species diversity (Ellmauer, 2004). They are particularly known for their high orchid diversity. Fertilization and abandonment result in biodiversity loss, with fertilization favoring nutrient-demanding grasses and abandonment promoting shrub encroachment (Ellmauer, 2004).

6240 Sub-Pannonic Dry Grasslands*

These grass steppes are characterized by a high proportion of species with an Eastern European distribution, underlining the transitional biogeographic nature of the region (Willner et al., 2004). Typically found on fine-textured soils shaped by the area's arid climate, they support narrow-leaved tussock-forming grasses such as *Festuca* and *Stipa* (Willner et al., 2004; Willner, 2015). Like other dry grasslands, they are sensitive to both fertilization and abandonment, which lead to a loss of typical species and overall structural simplification (Ellmauer, 2004).

6260 Sub-Pannonic Steppes on Sand*

These dry habitats are characterized by open and patchy structures, shaped by periodic disturbances, intense solar radiation, and strong winds (Ellmauer, 2004). Combined with the requirement for calcareous and sandy soils, these conditions determine the species composition, which is dominated by tussock-forming grasses as well as low-growing winter and spring annuals, typically characterized by species such as *Festuca vaginata, Cynodon dactylon* and *Saxifraga tridactylites* (Ellmauer, 2004). The decline of grazing results in the loss of open patches and the translocation of sand, which are essential processes for these habitats. Similarly, fertilization and abandonment lead to significant structural and compositional changes (Ellmauer, 2004).

6410 *Molinia* Meadows on Calcareous, Peaty, or Clayey-Silty Soils (*Molinion caeruleae*)

These low-productivity grasslands are associated with fen soils and occur under moist to seasonally fluctuating hydrological conditions (Wrbka et al., 2001). Historically, they were managed through low-intensity practices such as late-season mowing, typically without the use of fertilizers (Ellmauer, 2004). Their nutrient-poor substrates support a high diversity of plant species despite low biomass productivity, characterized by species such as *Molinia caerulea, Betonica officinalis* and *Serratula tinctoria* (Kącki & Michalska-Hejduk, 2010). These habitats are particularly sensitive to water-table imbalance and fertilization, which can lead to species loss and community shifts (Kapitany, 2021).

6510 Lowland Hay Meadows

These species-rich habitats are adapted to a wide range of site conditions. Variations in soil moisture – ranging from moderately dry to periodically moist – and differences in nutrient availability strongly influences their species (Tischew et al., 2018). Traditionally, they were managed as moderately fertilized meadows, mown twice per year and dominated by tall grasses such as *Arrhenatherum elatius*, *Dactylis glomerata, Festuca pratensis*, accompanied by a variety of herbaceous species depending on local conditions (Tischew et al., 2018). However, changes in traditional management practice and abandonment have led to declining species diversity and a shift in species composition (Ellmauer, 2004).

7210 Calcareous Fens with *Cladium mariscus* and Species of the *Caricion davallianae**

These fens are fed by lime-rich groundwater and are usually dominated by *Cladium marisucs* (Ellmauer, 2004). They require little to no active management when natural hydrological conditions are intact but are highly sensitive to drainage and nutrient input (Kapitany, 2021).

These habitat types reflect the transitional biogeographical position of the Seewinkel situated at the edge of the Alps, the Carpathians and the Pannonian Basin. Their conservation depends on finely regulated hydrological conditions and the continuation of extensive management practices, making them especially vulnerable to both land-use changes and climate variability (Euller et al. 2014; Albert et al. 2016; Newbolt et al. 2018; Cotera et al. 2023).

Research Objective and Research Question

The aim of this study is to evaluate and compare the ecological effectiveness of the Natura 2000 site and the IUCN Category II National Park by analyzing the development of the conservation status of regional grasslands. This study investigates whether these two protected area categories differ in their ability to support and maintain a favorable conservation status of regional grasslands over time.

To achieve this, I compared newly collected data from 2023 with the Article 17 dataset from the 2013 reporting period. The conservation status, as defined by the EU, serves as a key indicator in this analysis. It provides a structured and policy-relevant basis for evaluating ecological trends. Despite its potential, this approach has rarely been used in scientific literature to assess the performance of different protection categories (Davis et al., 2014). Therefore, the study fills a methodological gap and contributes to a more systematic evaluation of conservation outcomes. However, it is not sufficient to assess only the broader protection categories; degradation often occurs within habitats themselves, with some types being especially prone to transition into less valuable or ecologically impoverished forms. Identifying these transitions helps reveal which habitats are most vulnerable and where conservation efforts may be failing. Furthermore, even if certain habitats remain present, their ecological condition may have deteriorated, highlighting the importance of evaluating conservation status changes over time. To do so, I used conservation status as an indicator to investigate whether the condition of FFH habitat types in the Seewinkel region has changed between 2013 and 2023. To deepen this understanding, the study also integrates habitat-specific ecological indicators. These variables offer critical insights into the underlying ecological processes that influence habitat quality. By linking conservation status to ecological indicators, the study aims to investigate if observed trends are more strongly driven by protection effects or by internal habitat dynamics.

Given the status of the Seewinkel region as one of Austrians most important biodiversity hotspots (Zulka et al., 2024), and the continued ecological pressures such as groundwater depletion, land use intensification and climate change, it is crucial to understand not only whether habitats are improving or degrading, but also which protection strategies are most effective in preventing further loss.

The study addresses these issues through five research questions:

1. Has the conservation status of the analyzed sites improved or deteriorated between 2013 and 2023?
2. Do sites within the National Park (IUCN II) show better conservation status development than those in Natura 2000 (IUCN IV)?
3. How has the proportional distribution of FFH habitat types changed between 2013 and 2023 within each protected area category?
4. Which habitat types have undergone transformation into other FFH habit types over the 10-year period?
5. Are ecological indicators more effective than protection category in explaining differences in conservation status development across FFH habitat types?

Methods

Study Area

The study was conducted in the Seewinkel region, Nordburgenland, the flattest (< 25 m elevational range) and lowest area in Austria, with an average altitude of 113 m above sea level (Embleton-Hamann, 2022). Annual precipitation in the region averages around 600 mm, while temperature extremes range from approximately 40°C in summer to –20 °C in winter (National Park Neusiedler See – Seewinkel, n.d.). The landscape is shaped by a mosaic of land uses, with vineyards, arable fields and grasslands being the predominant land use types (Prinz et al., 2009). Livestock farming is practiced by only a small number of farmers; most grazing animals are located within the National Park and are used for targeted landscape management (Management Plan Neusiedler See – Seewinkel, 2025). The Seewinkel is characterized by several distinctive environmental features. Most notably, it contains around 40 shallow saline lakes, whose number has strongly declined from more than 140 since 1858 due to drainage measures and the construction of the so-called Einser-Kanal, a channel which carries water off the Neusiedler See (Zimmermann-Timm & Teubner, 2021).

Original Survey

Survey plots, each covering an area of 1 km × 1 km, were distributed across two conservation zones: IUCN Category II (National Park Neusiedler See – Seewinkel, designated as a Conservation Zone) and IUCN Category IV (Natura 2000). Due to the high number of landowners and the small-scale landscape structure, the National Park is not a continuous area but is integrated into the mosaic of the Natura 2000 site. To reflect this overlap, a third category “II, IV” was defined, including all meadow areas that fall under both protection categories.

A total of 11 sampling units were surveyed (Fig. 2). Within each unit, all grassland habitats (including grassland like fellows) were sampled, FFH habitat types were identified (Appendix; Fig. 12-22), and their conservation status was systematically assessed.

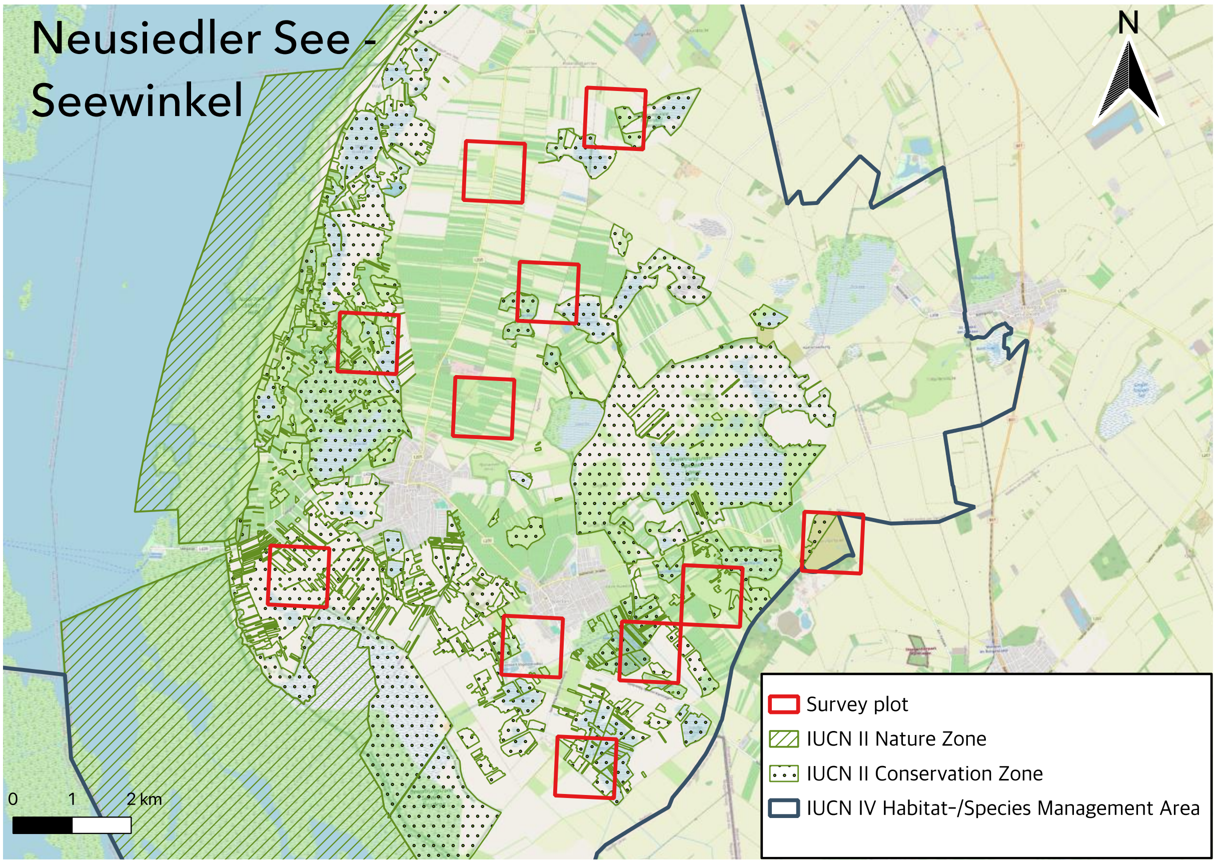

Fig. 2 Samlping plots of 1km x 1 km distributed across two conservation zones in the Seewinkel region; Source: data.gv.at, Umweltbundesamt GmbH, BM für Landwirtschaft Region und Tourismus (BMLRT).

Field Survey

Field data were collected during May, June, and September 2023. The identification of habitat types was conducted using the habitat types of Annex I of the FFH Directive. These resources ensured accurate classification and description of the EU habitat types according to Ellmauer (2004). Species were identified in the field, their dominance was estimated, and clear habitat boundaries were determined through the presence of indicator species pointing to alternative habitat types. Based on this information, the conservation status was assigned for each recorded habitat using the standardized catalog. Additionally, a catalog of conservation-relevant quality indicators was created and assessed for each sampling site using a standardized Likert scale (see Appendix; Fig. 23). The indicators included: degree of hemeroby, species richness, proportion of characteristic or conservation relevant species (e.g, red-listed or indicator species), proportion of disturbances indicators or invasive neophytes, habitat heterogeneity, value-defining features, current management intensity, direct disturbance or threats on site, and negative edge effects from adjacent areas. Each indicator was scored on an ordinal scale ranging from low to very high. This approach provided a standardized framework to evaluate habitat quality and to capture both ecological conditions and potential pressures in a comparable way across sites.

Data Analysis

All information was digitized and mapped using QGIS. Additional datasets were generated through QGIS Tools (Insert) and Geoinformation dataset form NATURA 2000 – FFH – 2013 and Naturschutzgebiete Österreich 2025 from Umweltbundesamt (2024), were adapted to match the sampling units. Data I collected during the field survey was also digitized and an attribute table was generated in QGIS. All data was exported to an excel table and afterwords the data got cleaned and prepared for R statistics.

All statistical analyses and visualizations were performed in R (Version 4.2.2). The following packages were used throughout the analysis: ggplot2 - for data visualization (boxplots, bar charts and alluvial plots); dplyr - for data manipulation; readxl - for importing Excel datasets; ggalluvial - for visualizing habitat transition over time; ggsankey – for observations distributed across different groups.

Given the limited sample sizes for some FFH habitat types, formal statistical testing was not applied to all comparisons. Instead, explorative statistics were used to assess differences in conservation status across habitats and protection categories. To ensure comparability across protection categories and habitat types of varying sizes, most bar charts in this study display proportional distribution rather than absolute counts. This approach accounts for differences in total area or sample size across categories and allows for an interpretation of relative trends over time. Where sample sizes allowed for it, non-parametric tests were conducted: specifically, the Kruskal-Wallis test was used to evaluate differences in conservation status between IUCN II and Natura 2000 (IUCN IV) protection categories.

For the analysis of habitat change dynamics, between 2013 and 2023, an alluvial plot was generated using ggalluvial based on absolute counts rather than proportion values. This format was chosen because the focus of the analysis was to illustrate how many habitat units transitioned from one type to another over time. Unlike proportional representations, which normalize for scale, count-based flows provide insight into the actual frequency of transitions, which is essential for evaluating habitat change.

To assess changes in the conservation status of habitat types between 2013 and 2023, a ranking system was developed by assigning numerical values to each conservation category (A=3, B=2, C=1). The change in conservation status (Change Ranking) was then calculated in Microsoft Excel using the formula: *Change Ranking = (Value in 2013 - Value in 2023) * - 1*. For example, if habitat type 6510 had a conservation status of A in 2013 (assigned value = 3) and C in 2023 (assigned value = 1), the ranking change was computed as follows: *Change Ranking = (3 - 1) * -1 = -2.* A negative value indicates a decline in conservation status, while a positive value reflects an improvement. A ranking of zero would indicate no change in conservation status over time. This ranking system enables a quantitative assessment of conservation status trends across different habitat types over the ten-year period. A Change Ranking value of -3 indicates that the respective habitat type has undergone a transformation into a different habitat type. This transition is considered a strong indicator of ecological degradation, as it suggests that the original habitat could no longer be sustained under prevailing environmental conditions. A Change Ranking value of -4 indicates that the respective habitat type was recorded in 2013 but had completely disappeared by 2023. This loss is attributed to a transformation into a new land-use type, such as agricultural fields or artificial seeding areas.

To assess whether the conservation status development of FFH habitat types is influenced more by protection category or by ecological control factors an ordinal logistic regression model was applied. Using following packages: ordinal – for running cumulative link models (clm); car – to assess multicollinearity via Variance Inflation Factors (VIF); pscl – for evaluating model fit (Pseudo R^2); wrtiexl – for exporting regression outputs. The dependent variable in the model was the conservation status of each habitat, coded ordinally. The main independent variable was the protection category. Initially, several control variables were included in the model: *species richness*, *indicator species*, *negative indicator species*, *habitat heterogeneity*, *value-defining features*, *disruptive effects*, and *negative edge effects* (Appendix Fig. 10 & 11). However, during the model validation process, it became clear that many of these predictors either showed very low variances or lacked a clear distribution. In practice, this meant that several variables received the same or very similar values across most sampling sites which limited their ability to differentiate between habitat and contributed to poor model fit and multicollinearity issues. To address this, the model was refined to include only two robust ecological indicators: Indicator species – for habitat quality and disruptive species – representing negative ecological pressure. The final model achieved acceptable fit according to log-likelihood values, Akaike Information Criterion (AIC) and Pseudo R^2 values (McFadden's R^2 between 0.21-0.39). It was used to address the extent to which changes in conservation status can be explained by protection categories versus internal ecological dynamics. The statistical analyses were conducted using a significance threshold of $p < 0.05$.

To complement the habitat-level analysis, a targeted assessment of land-use practices under the Austrian agri-environmental program (ÖPUL) was conducted for selected landscape windows within the IUCN IV (Natura 2000) area. The aim was to evaluate whether specific management types – particularly Wechselwiesen (alternating meadows) – tend to support certain FFH habitat types more than others. Given the central role of agriculture in the Seewinkel region, this analysis offers additional insight into how agri-environmental measures influence habitat representation and potentially affect conservation outcomes within protected landscape.

Within the landscape windows, only two land use categories as defined by the Austrian agri-environmental program (ÖPUL) could be identified. “Wechselwiesen” alternating meadows are classified as arable forage crops, that are temporarily managed as grassland within crop rotation systems. These areas are not permanently established grasslands but are used alternately for mowing or grazing and arable cultivation, depending on agricultural needs (BMLRT, 2023). While the second category comprises grasslands that may only be mown once per year (BMLRT, 2023). Due to the insignificant presence of the second category, it was excluded from further analysis. The proportional representation of habitat types under this management regime was visualized using a Sanky diagram created in R, using packages ggplot2 and ggsankey.

In addition to the core research questions, a separate graphic was generated to show the total area covered by each habitat type in 2013 and 2023, along with their corresponding conservation status. While this figure is not directly tied to a specific research question, it provides important contextual information for interpreting overall habitat dynamics. The graphic highlights not only which habitats have increased or decreased in extent, but also whether those changes were accompanied by improvements or deteriorations in ecological condition.

Results

Conservation Status by Protection Category

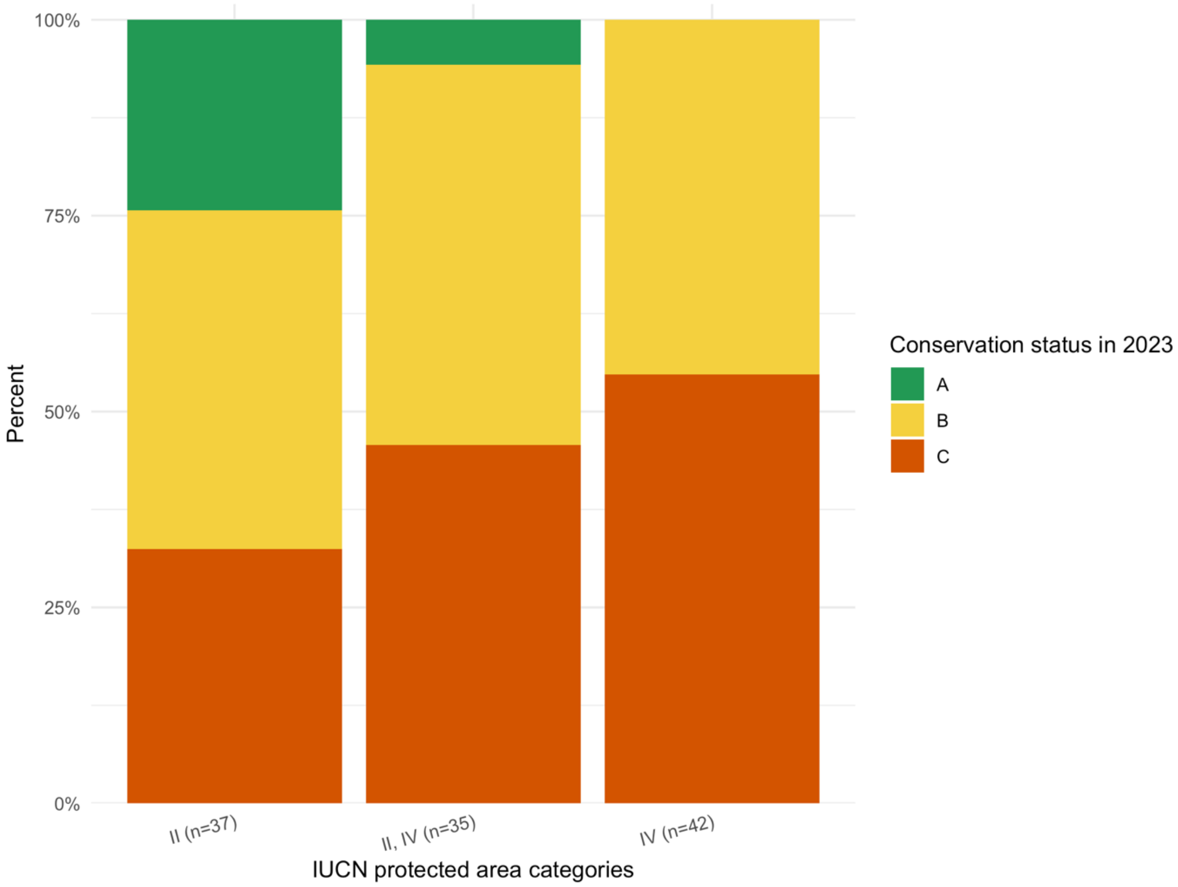

FIG. 3 PERCENTAGE DISTRIBUTION OF CONSERVATION STATUS CLASSES (A–C) ACROSS PROTECTION CATEGORIES IN 2023: II = NATIONAL PARK AND IV =NATURA 2000. FFH HABITAT TYPE OVERLAPPING BOTH CATEGORIES ARE INCLUDED IN II, IV.

The comparative analysis of conservation status in 2023 shows variation across the protection categories IUCN II, IUCN II, IV and IUCN IV. Category II (National Park) sites exhibited a higher proportion of favorable conservation status compared to Category IV (Natura 2000) sites (Fig. 3). A Kruskal-Wallis test confirmed that this difference was statistically significant ($p = 0.004$; Appendix Tab. 2), while no significant differences were observed between the combined category II, IV and the other two groups.

Shifting Proportions in Habitat Distribution over Time

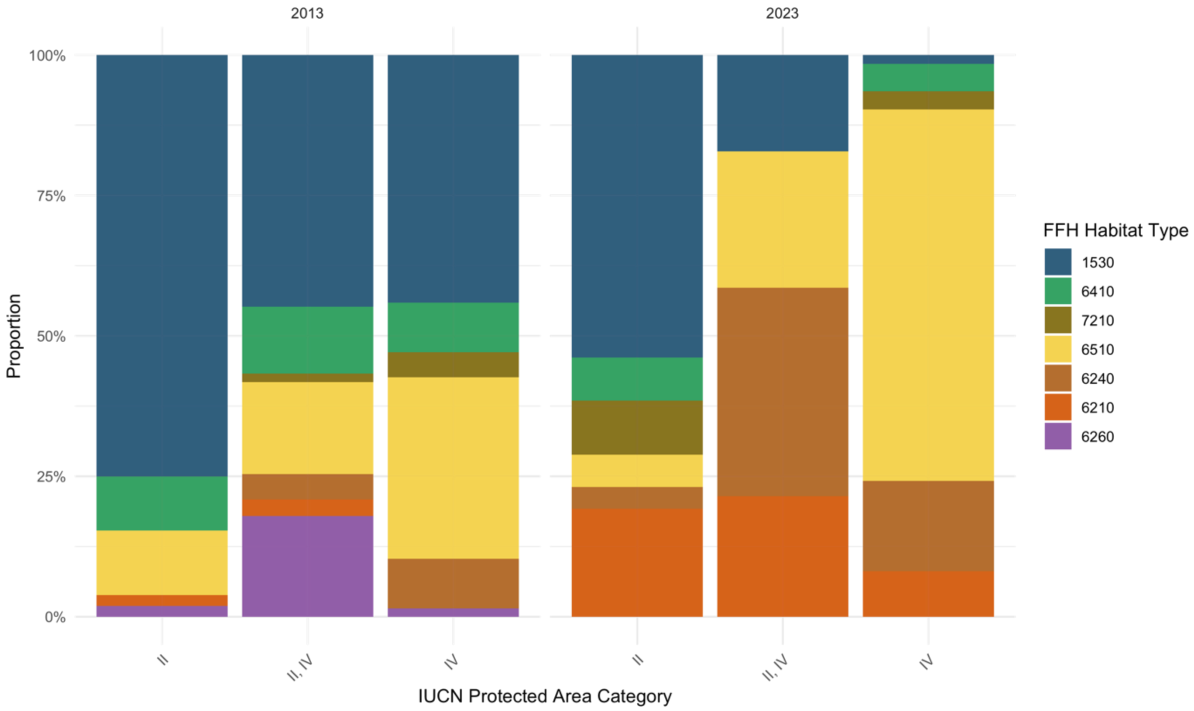

Fig. 3 Proportional distribution of FFH habitat types across IUCN protected area categories in the years 2013 and 2023. The stacked bar chart shows proportions of each FFH habitat code within each IUCN category.

As illustrated in Figure 4, clear shifts in the proportional distribution of habitat types across the protection categories were recorded between 2013 and 2023. In 2013, salt steppes and salt marshes (habitat type 1530) represented the highest proportional coverage within the IUCN Category II areas, comprising nearly 75% of the total survey plots. Habitat types within Categories II, IV and IV showed nearly equal distributions at that time. However, by 2023, notable shifts were observed. The proportion of habitat type 1530 in IUCN Category II areas had declined to approximately 50%. In Category II, IV, the share was halved, and in the lowest protection category, salt habitats were nearly absent, within the survey plots. In 2013, *Arrhenatherum* grasslands 6510 were the second most frequent habitat type within Category IV. By 2023, the proportional share had increased markedly, accounting for approximately 70% of the area in this category. Habitat type 6420 showed an increase in proportional coverage compared to 2013 and was most frequently recorded within the overlapping areas of category II, IV. FFH habitat type 6210 was present only in small proportions within Categories II and II, IV in the study area in 2013. Over the ten-year period, its representation increased fourfold in both categories. Notably, in 2013, this habitat type was entirely absent in categories IV, but by 2023, it demonstrated an increase in proportion. Within the survey plots, Pannonic Sand Steppes (6260) were recorded in 2013 but were not detected in 2023.

Habitat Type Transition

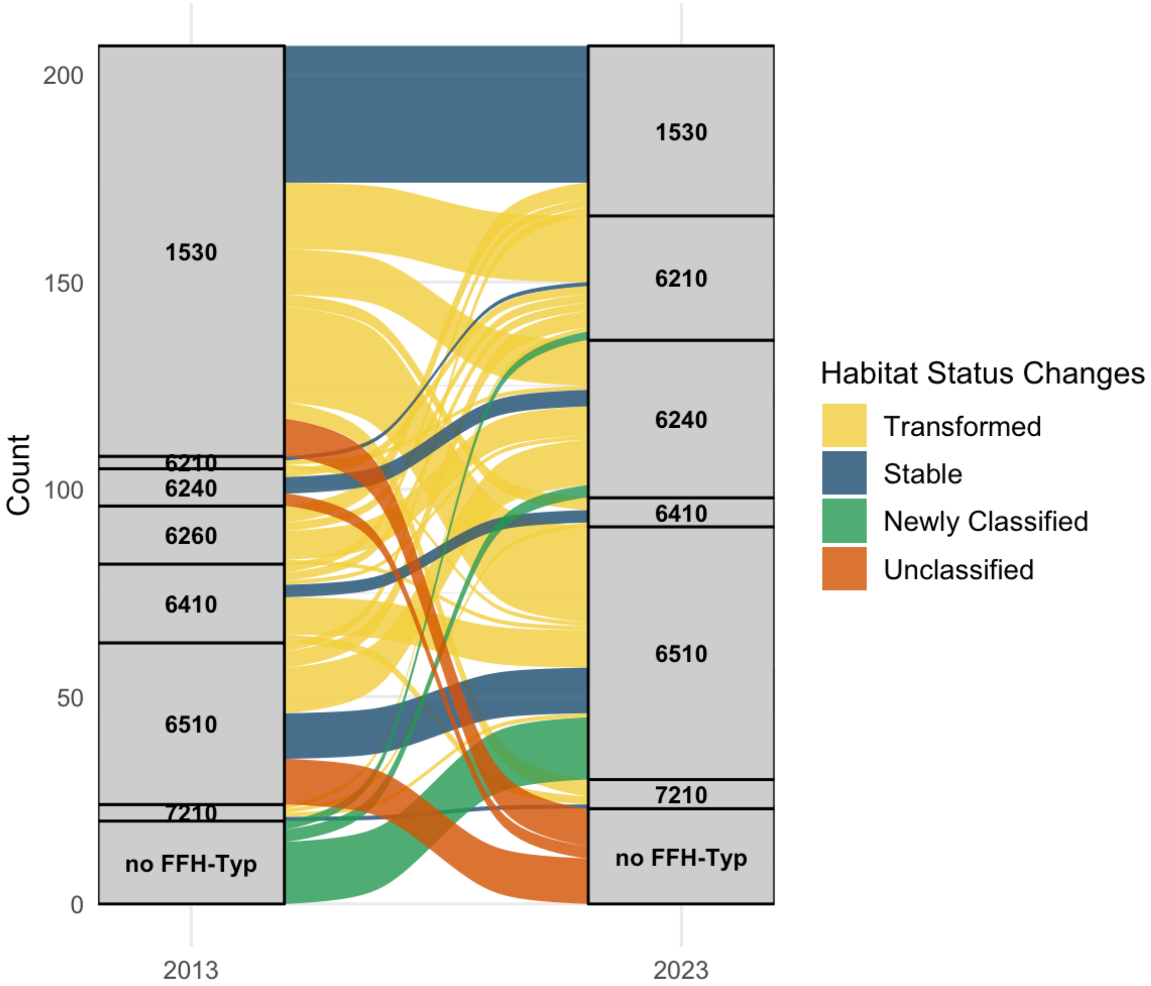

FIG. 4 THIS ALLUVIAL GRAPH ILLUSTRATES THE CHANGES IN FFH HABITAT TYPES OVER A PERIOD OF 10 YEARS. THE DIFFERENT CHANGE TYPES REVEAL THE TRANSFORMATION OF FFH HABITAT TYPES (N=207) AS FOLLOWS: 1) TRANSFORMED – REPRESENTS TRANSFORMATIONS FROM ONE FFH HABITAT TYPE TO ANOTHER, 2) UNCLASSIFIED – INDICATES FFH HABITAT TYPES THAT HAVE BEEN CONVERTED INTO A DIFFERENT LAND USE TYPE, SUCH AS ARABLE LAND, 3) NEWLY CLASSIFIED – REFERS TO FFH HABITAT TYPES THAT WERE NOT RECORDED IN 2013, EITHER BECAUSE THEY DID NOT EXIST AT THE TIME OR WERE CLASSIFIED UNDER A DIFFERENT LAND USE TYPE, 4) STABLE – INCLUDES FFH HABITAT TYPES THAT HAVE REMAINED THE SAME OVER THE 10-YEAR PERIOD.

In 2023, six grassland habitats were identified in the study area, three of which are classified as priority habitats: 1530, 6240, and 7210. As illustrated in Figure 5, FFH Habitat 6260 was no longer recorded within any of the protection categories. By 2023, this habitat type had completely transitioned into different habitat types, primarily into Sub-Pannonic Dry Grasslands (6240). A similar transformation is observed in *Molinia* Meadows (6410), where only a small ratio of the habitat has remained stable, while the majority were classified as Lowland Hay Meadows (6510). The Pannonic Salt Steppes and Salt Marshes (1530), which represented the dominant habitat type in the study area in 2013, had decreased to nearly half their former extent, due to transitions into other habitat types, mainly into 6210, 6240, and 6510. Semi-Natural Dry Grasslands on Calcareous Substrates (6210) showed a notable increase, with the number of sites expanding more than tenfold, closely followed by habitat type 6240. Among all habitat types, 6510 exhibited the most variation across the different categories. Calcareous Fens with *Cladium mariscus* (7210) appear to have increased in count. However, when examining the area shares (Fig. 6) of individual habitats, a clear reduction was observed in the total area of 7210.

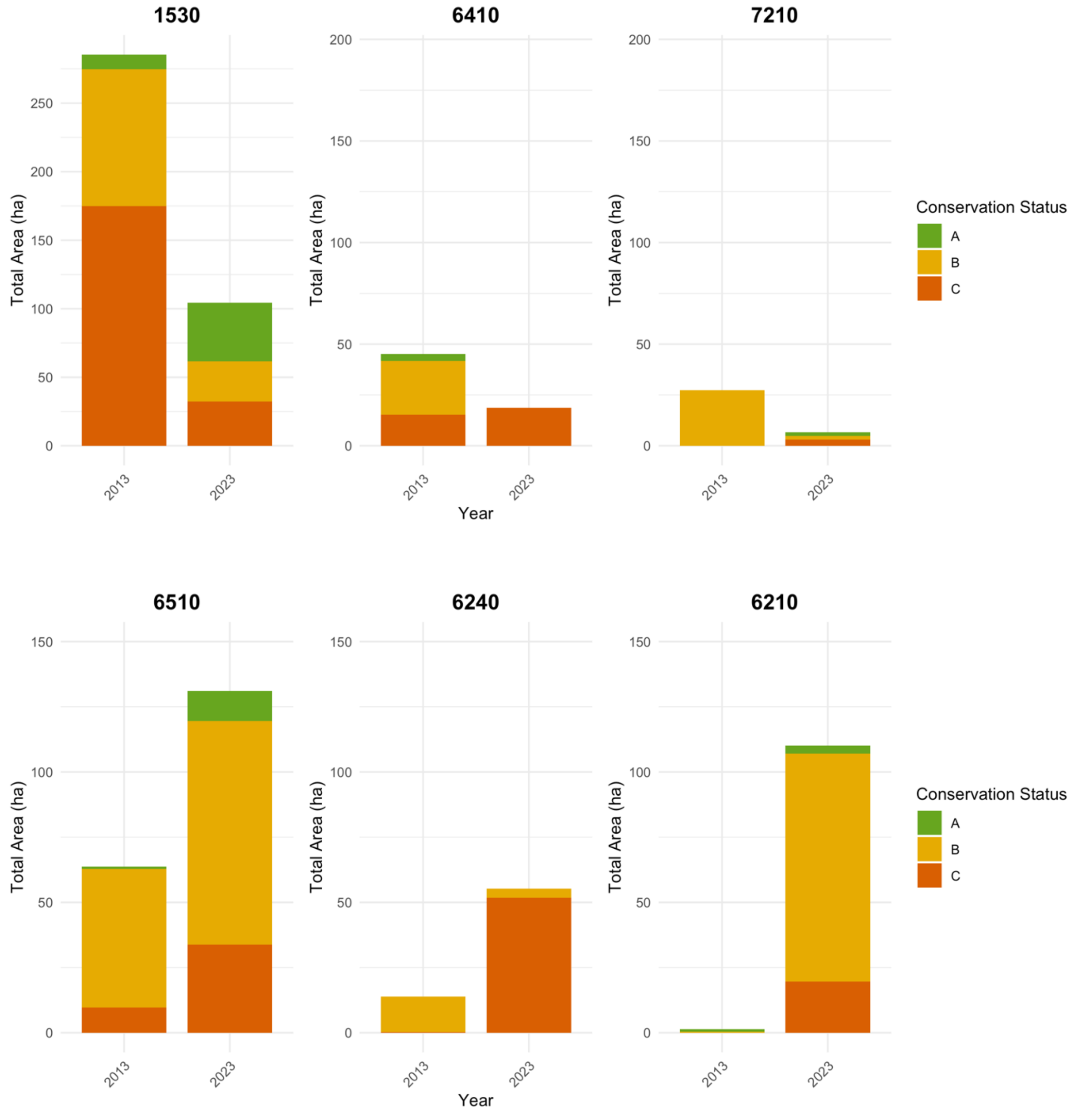

FIG. 5 THE BAR CHART COMPARES THE TOTAL AREA IN HECTARES OF EACH INDIVIDUAL FFH HABITAT TYPE FOR THE YEARS 2013 AND 2023. IN ADDITION, THE AREA SHARES HAVE BEEN ANALYZED BASED ON THEIR CONSERVATION STATUS, CATEGORIZED AS A (EXCELLENT), B (GOOD), AND C (POOR). THIS ALLOWS FOR A DETAILED ASSESSMENT OF HOW THE EXTENT AND CONDITION OF EACH HABITAT TYPE HAVE CHANGED OVER THE TEN-YEAR PERIOD.

Overall, the total meadow area declined from 426.17 ha in 2013 to 415.39 ha in 2023, representing a loss of 10.78 ha. However, not all habitat types were equally affected. While 1530 (Pannonic Salt Steppes and Salt Marshes), 6410 (*Molinia* Meadows), and 7210 (*Cladium mariscus*) experienced a reduction in study area. 6510 (Lowland Hay Meadows), 6240 (Sub-Pannonian Dry Grasslands), and 6210 (Semi-Natural Dry Grasslands on Calcareous

Substrates) showed an increase in size (Appendix; Tab.3 & Fig. 6). Both graphs (Fig. 4 & Fig. 5) reveal an expansion of dry grasslands (6240, 6210), reflecting a broader trend toward drier habitat conditions. Lowland Hay Meadows (6510), while typically more mesic and resilient to fluctuating moisture and nutrient levels, also expanded in area, indicating favorable conditions for their development.

The area classified as excellent conservation status (A) saw a notable increase, rising from 16.10 ha in 2013 to 59.44 ha in 2023. The area with good conservation status (B) remained relatively stable, with a slight decrease from 220.83 ha in 2013 to 200.79 ha in 2023. Meanwhile, habitats categorized as having poor conservation status (C) experienced a relatively small decline, from 200.06 ha in 2013 to 158.90 ha in 2023.

Conservation Status Trends per Habitat Type

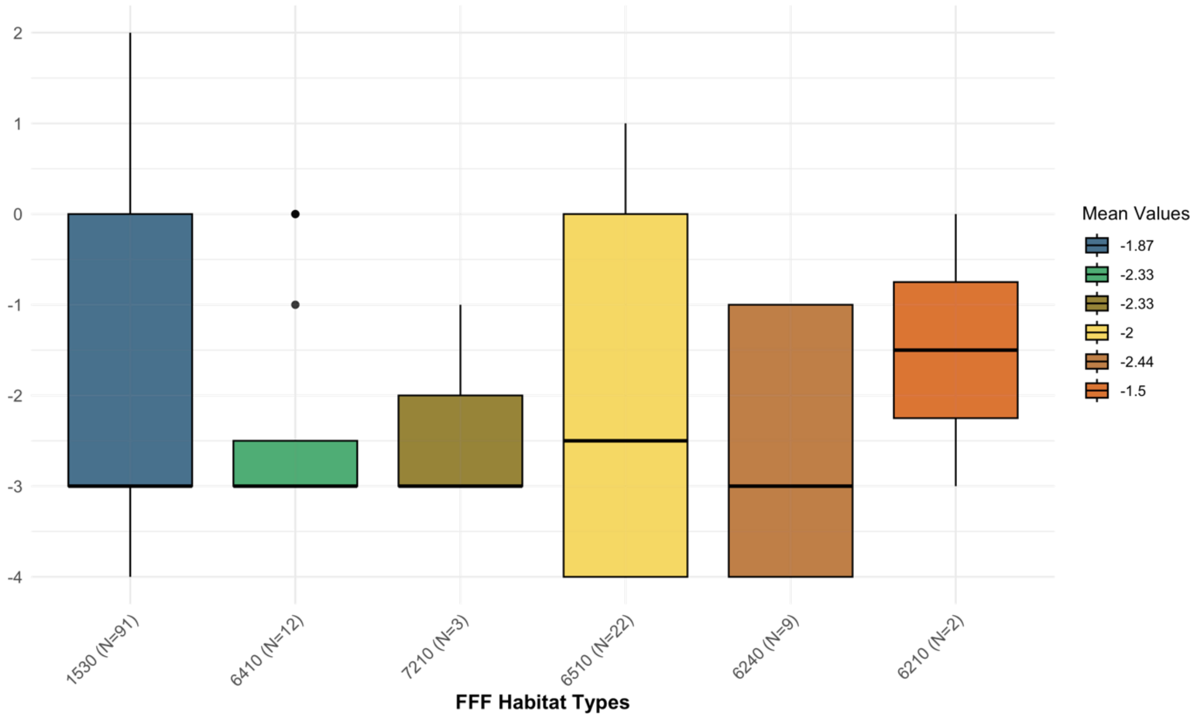

Fig. 6 Changes in the conservation status of each FFH habitat types between 2013 and 2023. A ranking system was developed by assigning numerical values to each conservation category. A negative value indicates a decline in conservation status, while a positive value reflects an improvement. A ranking of zero would indicate a stable conservation status over time.

The development of conservation status between 2013 and 2023 is illustrated in Figure 7. Habitats 6410 and 7210 showed a decline in conservation status, with an average change of -2.33 ranks. Although habitats 6240, 6510, and 6210 expanded in both area and number, their conservation status development is negative. Habitat 1530 exhibited a substantial change, with over half of its area converting into a different FFH habitat type. Despite this, it achieved the highest conservation status (*A*) among all habitat types in 2023 and ranked as the second-best score. Nevertheless, habitat 1530, like all other habitats, shows an overall negative trend in conservation status – 1.87. The most substantial change was observed in habitat 6260, which completely transitioned into different habitat types within the surveyed areas. As a result, habitat 6260 is not represented in the boxplot. The value of -3 was assigned to indicate its conversion into another habitat type, which is why it holds a ranking of -3.

Influence of Ecological Indicators on Conservation Outcomes

TAB.1 RELATIONSHIP BETWEEN THE INDEPENDENT VARIABLE (IUCN CATEGORY) AND THE DEPENDENT VARIABLE (CONSERVATION STATUS), WHICH WAS CATEGORIZED AS 1 = A (EXCELLENT), 2 = B (GOOD), AND 3 = C (POOR). ADDITIONALLY, OTHER FACTORS WERE INCLUDED AS CONTROL VARIABLES.

The regression analysis revealed that none of the IUCN protection categories is a significant predictor of conservation status (Tab. 1). In contrast, ecological indicators showed strong predictive power. The presence of indicator species was significantly associated with better conservation status (p = 0.000), while disruptive species correlated with a decline in habitat quality (p = 0.033). These findings highlight the importance of integrating habitat-specific ecological indicators into conservation assessments, as they more accurately reflect the internal ecological dynamics than protection status alone.

Variable	Estimate	Std. Error	z-value	p-value	Chi²	p-Value
IUCN II, IV	0.327	0.515	0.634	0.526		
IUCN IV	-0.085	0.542	-0.157	0.875	12.296	**0.002**
Indicator Species	-1.306	0.320	-4.085	**0.000**	25.083	**0.000**
Disruptive Species	0.664	0.311	2.136	**0.033**	4.562	**0.033**
(n=114, Log-Likelihood = -84.89, AIC = 181.78, Pseudo-R²-Werte 0.21- 0.39)						

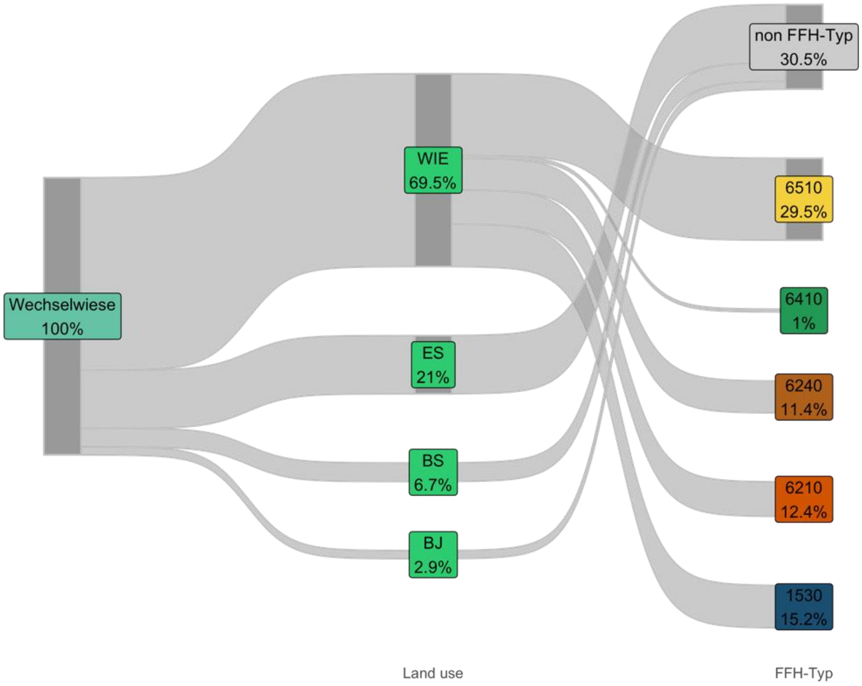

FIG. 8 THE ILLUSTRATION REPRESENT THE RELATIONSHIP AND THE DISTRIBUTION IN PERCENT BETWEEN THE ÖPUL-DEFINED LAND-USE CATEGORY "WECHSELWIESE" AND THE FOUR OBSERVED LAND USE TYPES: (WIE) MANAGED GRASSLAND, (ES) SOWN AREAS, (BS) ADVANCED FALLOWS, (BJ) EARLY-STAGE FALLOWS, WITHIN THE NATURA 2000 AREA. MANAGED GRASSLANDS FULLY ASSIGNED TO SPECIFIC FFH HABITAT TYPES.

The alternating meadows were by far the most frequent land use type within the Natura 2000 area and were therefore attributed to a 100% share, corresponding to 117.33 hectares (Fig. 8). Within this category, the analysis revealed four distinct land-use types: managed grassland (95.66 ha), sown areas (18.27 ha), advanced fallows (2.80 ha), and early-stage fallows (0.60 ha), with managed grasslands comprising the largest share at 69.5 % (Fig. 8). All grassland areas could be assigned to specific FFH habitat types. All FFH habitat types described in the study were represented, except for habitat 7210 Calcareous Fens. 6410 *Molinia* Meadows was present but contributed minimally with just 1%. *Arrhenatherum* grasslands accounted for the largest proportion, consistent with previous analyses (Fig. 5; Fig. 6; Fig. 7), confirming that this habitat type dominates the studied units within the Natura 2000 site. This was followed by habitat types 6210 and 6240, which exhibited relatively similar proportions. A total of 30.5% of the area was classified under other land use types and could not be assigned to any FFH habitat category.

Discussion

Overview and Interpretation of Key Findings

The results of this study indicated strong spatial-temporal shifts in the extent and quality of FFH habitat types in the Seewinkel region between 2013 and 2023. Dry grassland habitats such as 6210 Semi-Natural Dry Grasslands and 6240 Sub-Pannonic Dry Grasslands have expanded considerably, while moisture-dependent habitats like 1530 Pannonic Salt Steppes, 6410 *Molinia* Meadows, and 7210 Calcareous Fens have decreased in both area and conservation quality (Fig. 6). While expansion in some habitats might suggest resilience, these trends mask deeper ecological degradation. Even those habitats that gained area - such as 6240, 6210, and 6510 (Fig. 6) - showed overall negative trends in conservation status. When focusing only on sites that remained in the same habitat type across both years, a consistent decline became evident (Fig. 7), highlighting that apparent improvements in coverage can mask underlying ecological degradation.

However, the analysis also reveals how protected area categories have supported different habitat types over time. Habitat 1530 (Pannonic Salt Steppes) presents a particularly illustrative case. Although over half of its area transitioned into other habitat types (Fig. 5), it still achieved the highest share of excellent conservation status among all habitats and the second-best average (-1.87) conservation ranking overall (Fig. 7). This outcome may be explained by the fact that much of its remaining area lies within the National Park (IUCN II) (Fig. 4), where targeted management practices – such as controlled grazing and hydrological restoration – are applied. These strategies are well suited to the ecological sensitivities of salt habitats and likely contributed to maintaining high-quality patches despite broader area loss. This example highlights how habitat-specific management, rather than designation alone, can support ecological stability.

Although the regression analysis (Tab. 1) did not identify protection category as a statistically significant predictor of conservation status, the group comparison (Fig. 3) conducted in this study showed a significant difference between Category II and IV areas. In 2023, sites in Category II display a higher proportion of favorable conservation status than sites in Category IV (Kruskal-Wallis χ^2=8.287, df=2, p=0.0159; post hoc II vs IV p_adj=0.013; Appendix Tab. 2). These results indicated that, within the study area, National Park sites currently maintain better conservation conditions than Natura 2000 sites. This suggests that while legal designation alone may not determine outcomes (Marino, 2015), the type of protection still plays a meaningful role in shaping habitat trajectories over time.

Drivers of Habitat Changes

The habitat change in the Seewinkel region is likely influenced by land use, particularly human-induced changes to the hydrological system. This is reflected in the observed shifts in habitat types - especially in moisture-dependent ecosystems - between 2013 and 2023. These patterns may be linked to hydrological changes reported in previous studies, such as drainage projects, canal construction, and agricultural irrigation, which are known to lower surface and groundwater levels in the region (Zimmermann-Timm & Teubner, 2021). Moisture-sensitive habitats such as 1530 Pannonic Salt Steppes, 6410 *Molinia* Meadows and 7210 Calcareous Fens decline in both extent and ecological quality, which may reflect the sensitivity of these systems to altered water availability (Joyce et al., 2016).

These land-use pressures may be further reinforced by climate change. Rising temperatures, stronger evaporation, and more frequent droughts reinforce the drying trend already set in motion by human activity (Cotera et al., 2023). As shown in this study, this has contributed to a gradual shift toward drier habitats - particularly the expansion of 6210 Semi-Natural Dry Grasslands, 6240 Sub-Pannonic Dry Grasslands, and 6510 Lowland Hay Meadows. These habitat gains reflect broader ecological changes, favoring species adapted to arid conditions while threatening those dependent on stable water availability and low nutrient levels (Newbold, 2018; Kapitany 2025).

Changes in land management may also have contributed to habitat transformation. The reduction or abandonment of traditional practices such as seasonal mowing or grazing has led to vegetation succession and a loss of structural diversity (Schön, 1998; Muller, 2002; Hülber et al., 2017). Many semi-natural habitats in the Seewinkel region rely on low intensity management to maintain their biodiversity. Where these practices have declined, more competitive species and scrub encroachment have increasingly taken over (Kącki & Michalska-Hejduk, 2010). This aligns with the findings of this study, which show a decline in conservation status across all habitat types - regardless of area changes. As Muller (2002) emphasizes, these habitats correspond to highly diverse ecological features, varying in pH, climate, hydrological regime, and trophic level, but they all share one common need: extensive agricultural management is essential for their long-term conservation.

Effectiveness of Conservation Measures

Moreover, the AES - although developed to support biodiversity-friendly farming - have shown limited success in stopping biodiversity loss. As Hülber et al. (2017) point out, these schemes may slow down the rate of decline but rarely lead to real improvement. This is consistent with the results of this study, where habitats such as 6410 *Molinia* Meadows, 1530 Pannonic Salt Steppes, and 7210 Calcareous Fens continue to decline despite being covered by conservation measures. A key reason for this is that AES are often too broadly structured and not adapted to the specific needs of vulnerable habitats or species (Davis, 2014). In many cases, uptake is driven more by economic incentives than by ecological goals (Gameiro, 2020).

This issue becomes particularly relevant in Category IV areas (Natura 2000), where AES are the primary conservation instrument (Davis, 2014). These areas aim to combine land use with ecological protection but often lack the regulatory strength and active management needed to maintain habitat quality (Wrbka et al., 2008). This is reflected in the findings of this study: within the sampled Natura 2000 landscape windows, Wechselwiesen represented the agri-environmental management type. While some habitats, such as 6510 Lowland Hay Meadows, have expanded under this framework, they tend to be more tolerant of nutrient input and offer less biodiversity value. At the same time, more sensitive habitats like 6410 and 7210 are declining. Even though certain habitat types are supported, Category IV areas show the lowest overall conservation status in 2023 (Fig. 3), highlighting clear differences in the effectiveness of protection categories. This indicates that Wechselwiesen, as a management regime, may be insufficient to support high-value or hydrologically sensitive habitats.

In contrast, the outcomes in Category II areas (National Park) suggest a more positive trend. These areas appear to benefit from more targeted management strategies, including grazing and mowing, as well as hydrological retention efforts and a general reduction of human disturbance. This is reflected in the data: although salt habitats like 1530 have decreased in area overall, they are still most commonly found in Category II zones (Fig. 4). Taken together, these observations indicate that the type of protection may influence habitat quality and ecological function, although further research would be needed to confirm these patterns more robustly.

FIG. 9 NATURA 2000 AREA (IUCN IV), LOWLAND MEADOWS. LEFT: THE SOIL AND MOISTURE CONDITIONS ARE MODERATELY DRY BUT INTERMIXED WITH PATCHES OF MODERATE WETNESS, CREATING A MOSAIC OF MICROHABITATS THAT SUPPORT A HIGH NUMBER OF SPECIES. RIGHT: DOMINATED BY TALL GRASS SPECIES AND NUTRIENT-LOVING INDICATOR PLANTS, THESE AREAS HAVE A MORE UNIFORM AND LESS DIVERSE VEGETATION STRUCTURE.

Ecological Implications and Shifts in Habitat Types

The transformations observed in this study indicate more than shifts in land cover; they may point to ecological changes that affect habitat quality and stability. In the sampling plots, complete transformation of habitat type 6260 Pannonic Sand Steppes into 6240 Sub-Pannonic Dry Grasslands were recorded, and moisture-dependent habitats such as 6410 and 7210 showed a tendency toward degradation. These results should, however, be interpreted with caution. Part of the apparent change may reflect observer bias, since the assessment in 2023 was carried out by a different surveyor than in 2013. Differences in interpretation, especially in boundary setting and the use of indicator species, may therefore contribute to the observed shifts (Fig.9). Nevertheless, as Joyce et al. (2016) point out, fragmentation and loss of water availability can trigger negative feedback loops that make recovery harder and push ecosystems beyond a point where restoration is still possible.

Semi-natural plant communities are especially vulnerable to such changes. As described by Kącki and Michalska-Hejduk (2010), these habitats are sensitive to even small shifts in nutrient levels or hydrological conditions. Whether due to abandonment of management, intensive agriculture, or climate change, these pressures favor generalist species and lead to a loss of diversity - which is called biotic homogenization. This affects not only plant communities but also animals. For example, many bird species rely on structurally diverse grasslands maintained through extensive grazing or mowing (Milić et al., 2024). When that diversity disappears, so do the species that depend on it.

Altogether, the landscape in Seewinkel appears to be shifting from a mosaic of species-rich, semi-natural habitats to a more simplified system dominated by generalist vegetation types. While some of these may be more resilient in the short term, they come at the cost of ecological quality and uniqueness. This trend threatens the long-term role of Seewinkel as a biodiversity hotspot and clearly shows that there is an urgent need for more adaptive and targeted conservation strategies.

Recommendations and Outlook

The findings of this study show that effective conservation in the Seewinkel region - and in similar cultural landscapes - requires an approach that is not only legally grounded but also adaptive and well-coordinated. Protected areas play an important role, but without appropriate management, monitoring, and stakeholder involvement, their implementation alone is often not sufficient to stop ongoing habitat loss.

A key priority must be water retention and restoration. The decline in conservation status across nearly all FFH habitat types shows that action is urgently needed. As Schön (1997) already pointed out, every effort should be made to “keep water in the system for as long as possible.” This could include deactivating traditional drainage systems and restoring more natural hydrological dynamics, following the recommendations of Joyce et al. (2016) to increase resilience to climate change.

In addition, the effectiveness of AES (agri-environmental schemes) needs to be reconsidered. Current measures are often too general and fail to deliver targeted support where it's most needed. Future policy should focus on result-oriented schemes that reward biodiversity outcomes - not just participation. This study shows that habitats like 7210, 6410 and 1530 continue to decline despite being included in AES.

Another important step is to improve coordination across protection categories. The complex structure of National Park zones, Natura 2000 areas, and private farmland in Seewinkel calls for a clear and unified conservation strategy. Creating cross-sectoral governance structures could help reduce fragmentation in decision-making and strengthen accountability (Apostolopoulou & Pantis, 2009; Zhang et al. 2025).

Long-term biodiversity monitoring must also be reinforced. Stable funding, institutional commitment, and open access to monitoring data are essential to evaluate the actual status of habitats and guide future management. As Davis et al. (2014) emphasize, many problems in EU conservation policies today stem from gaps in data availability and weak knowledge transfer.

Finally, this study underscores the need for future research to:

- explore the relationship between specific management practices and habitat quality at finer scales;
- model future habitat trajectories under different climate and land-use scenarios;
- assess the effectiveness of restoration measures, particularly in wetland and salt steppe systems;
- investigate socio-economic and socio-ecological drivers influencing farmer participation in conservation schemes.

Conclusion

While some habitat improvements were noted, the overarching trend points toward ecological degradation and growing pressure on semi-natural systems. Without suitable and decisive action – guided by scientific evidence and local knowledge – there is a risk that Seewinkel may lose its unique ecological character and its role as one of Austrias key biodiversity hotspots.

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Appendix

Tab. 2 presents the results of the Kruskal-Wallis test, which was conducted to assess differences in conservation status among the IUCN protected area categories (II, IV, and the combined category II, IV). The test yielded a statistically significant result (x^2 = 8.287, df = 2, p = 0.0159), indicating that at least one category differs significantly from the others. To further examine these differences, a post-hoc pairwise comparison was performed. These results suggest that conservation status differs significantly between categories II and IV, while no significant differences were observed between the combined category II, IV and the other two groups.

IUCN PROTECTED AREA CATEGORIES

TEST	Chi_Quadrat	df	p_Wert
KRUSKAL-WALLIS-TEST	8,287	2	0,0159
POSTHOC COMPARISON	Z	P.unadj	P.adj
II - II, IV	-1,806	0,071	0,213
II - IV	-2,849	0,004	0,013
II, IV - IV	-0,946	0,344	1,000

TAB. 3 AREA SHARES IN HECTARE OF EACH INDIVIDUAL FFH HABITAT TYPE BETWEEN THE YEARS 2013 AND 2023. IN ADDITION, THE AREA SHARES HAVE BEEN ANALYZED BASED ON THEIR CONSERVATION STATUS, CATEGORIZED AS A (EXCELLENT), B (GOOD), AND C (POOR). DIFFERENCE WAS CALCULATED TO DETERMINE THE GAIN (GREEN) AND LOSS (RED) OF LAND SHARES.

2023	1530	6210	6410	7210	6240	6510	total ha
A	42,92	3,10	-	1,92	-	11,51	59,44
B	29,44	87,47	-	1,68	3,53	85,71	207,83
C	32,12	19,57	18,63	3,05	51,75	33,77	158,90
	104,47	110,14	18,63	6,65	55,29	130,99	**426,17**
2013	1530	6210	6410	7210	6240	6510	total ha
A	10,76	0,99	3,52	-	-	0,84	16,10
B	99,68	0,36	26,49	27,32	13,66	53,29	220,79
C	174,99	-	15,19	-	0,26	9,62	200,06
	285,42	1,34	45,20	27,32	13,92	63,75	**436,95**
difference	- 180,95	108,80	- 26,57	- 20,67	41,37	67,24	**- 10,78**

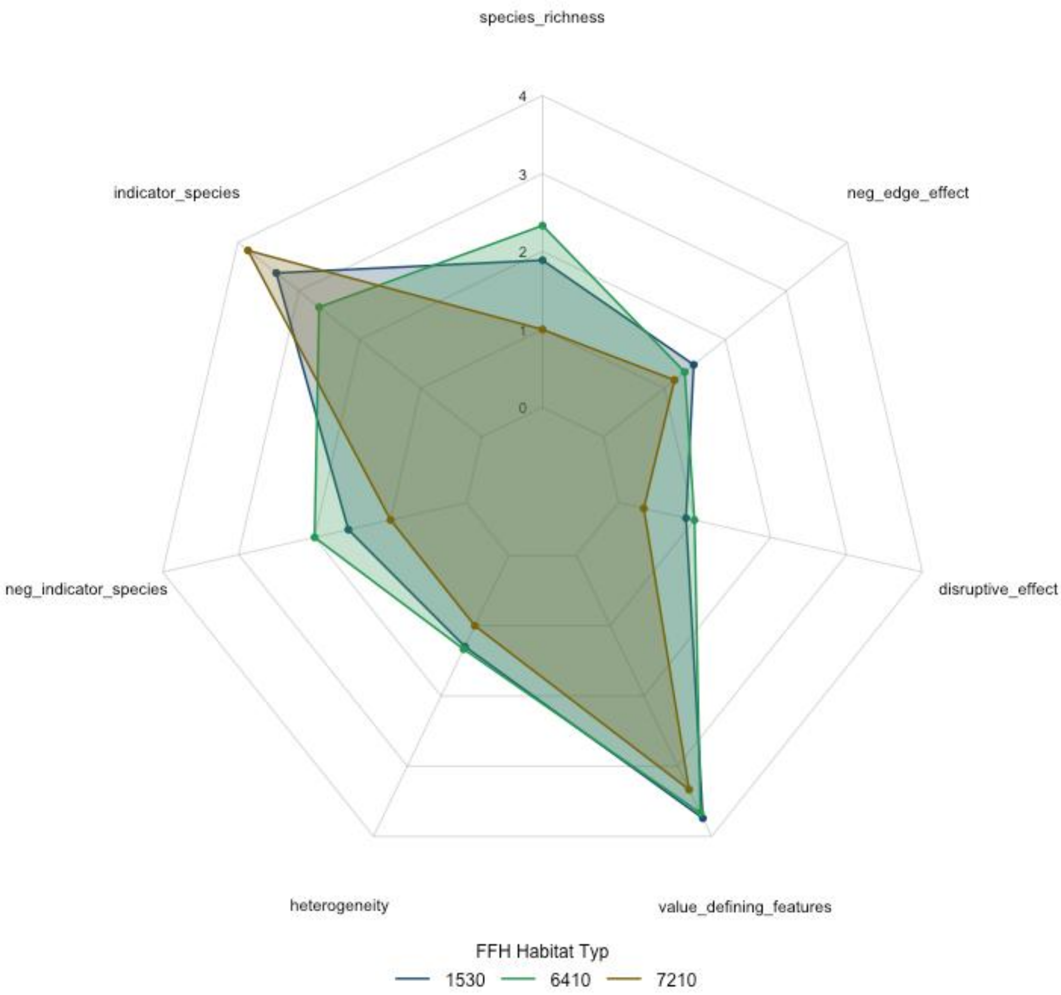

FIG. 10 VISUALIZATION OF ECOLOGICAL INDICATOR PROFILES ACROSS FFH HABITAT TYPES 1530, 6410, AND 7210.

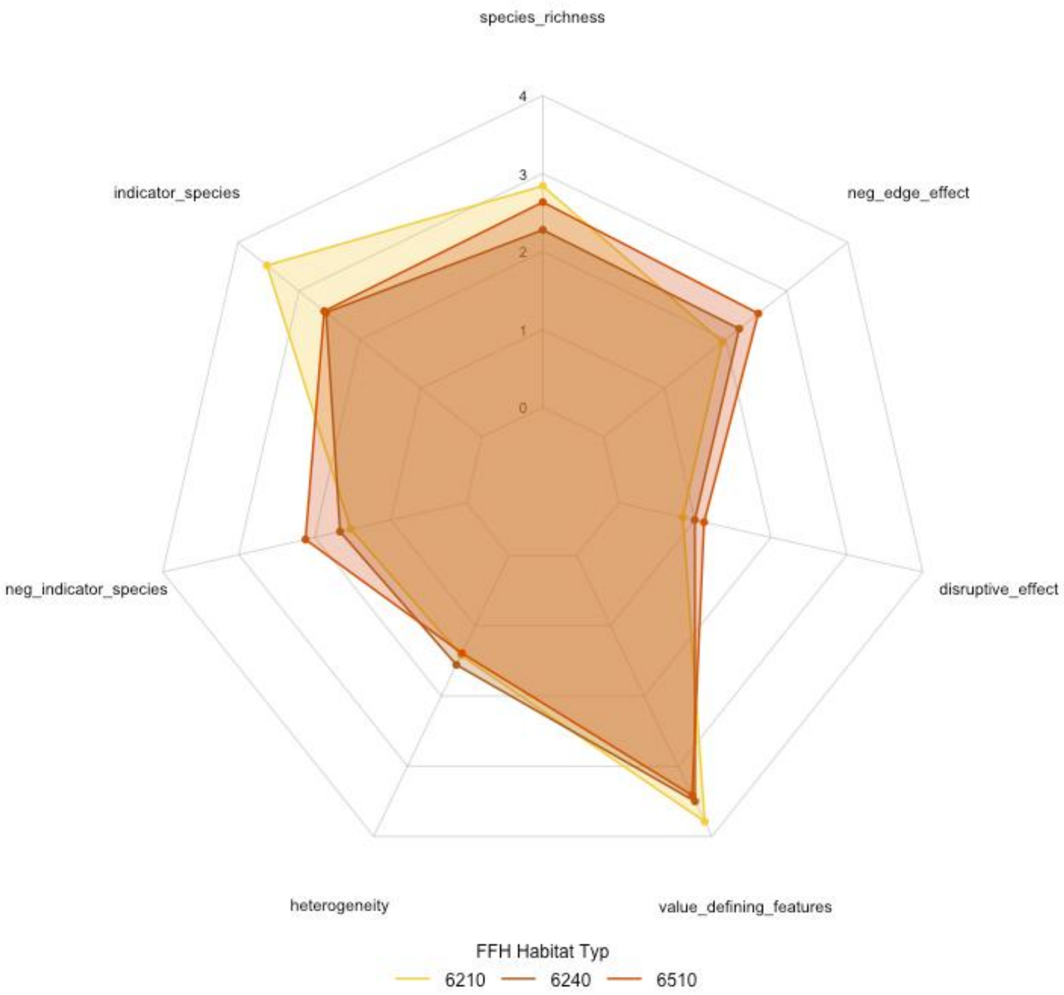

FIG. 11 VISUALIZATION OF ECOLOGICAL INDICATOR PROFILES ACROSS FFH HABITAT TYPES 6210, 6240, AND 6510.

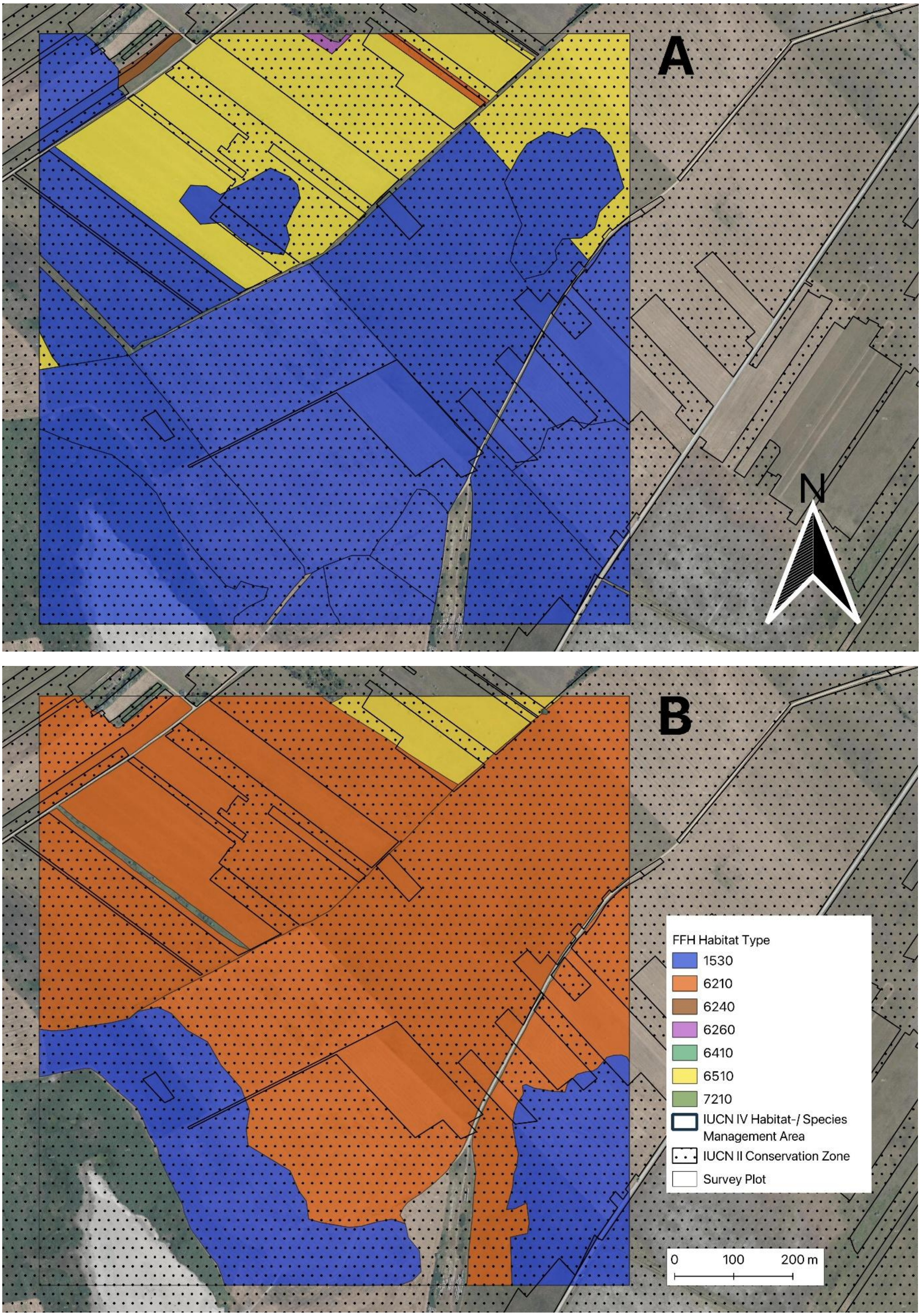

FIG. 12 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM² STUDY WINDOW ID-487 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

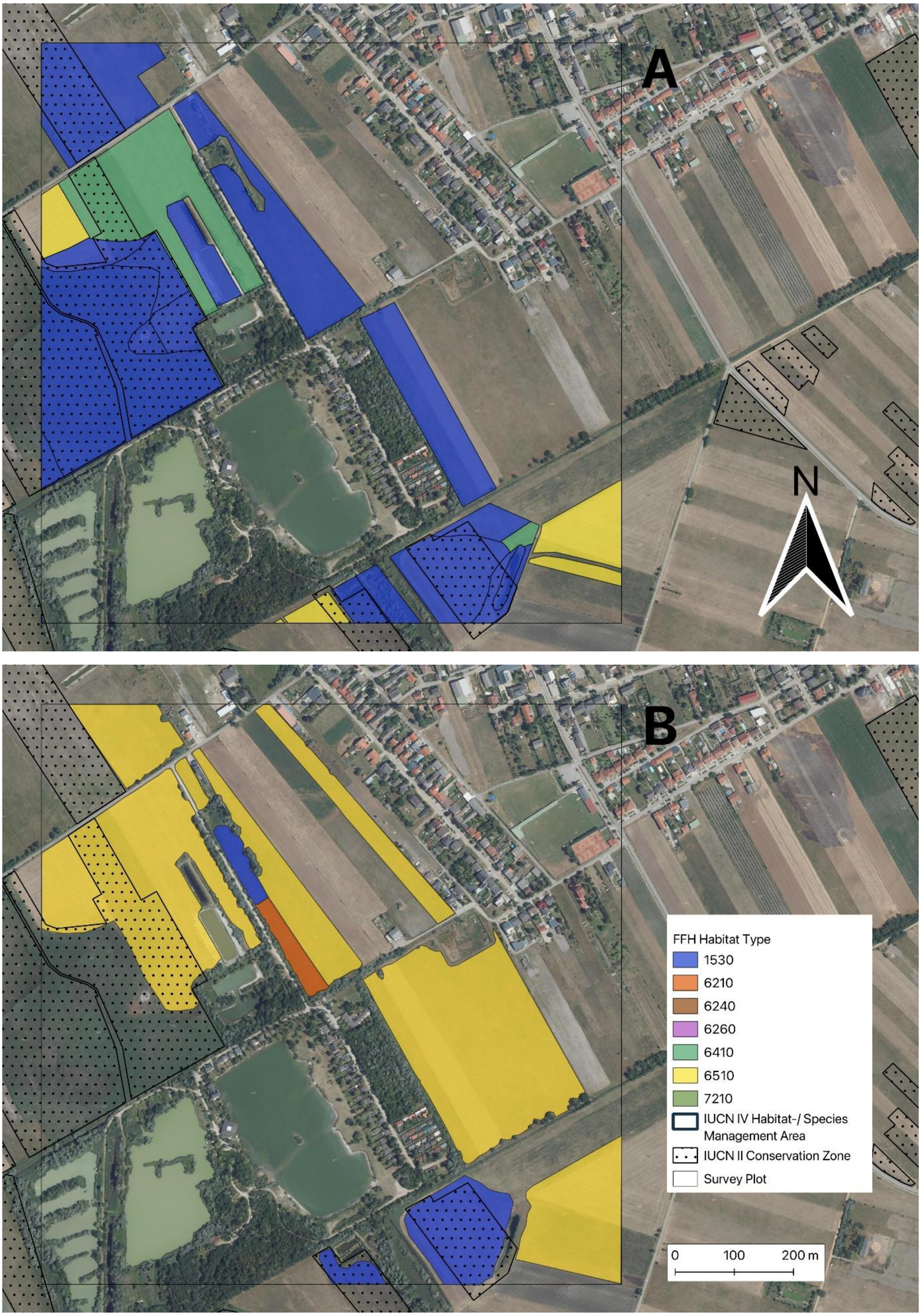

FIG. 13 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM² STUDY WINDOW ID-502 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

FIG. 14 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM² STUDY WINDOW ID-516 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

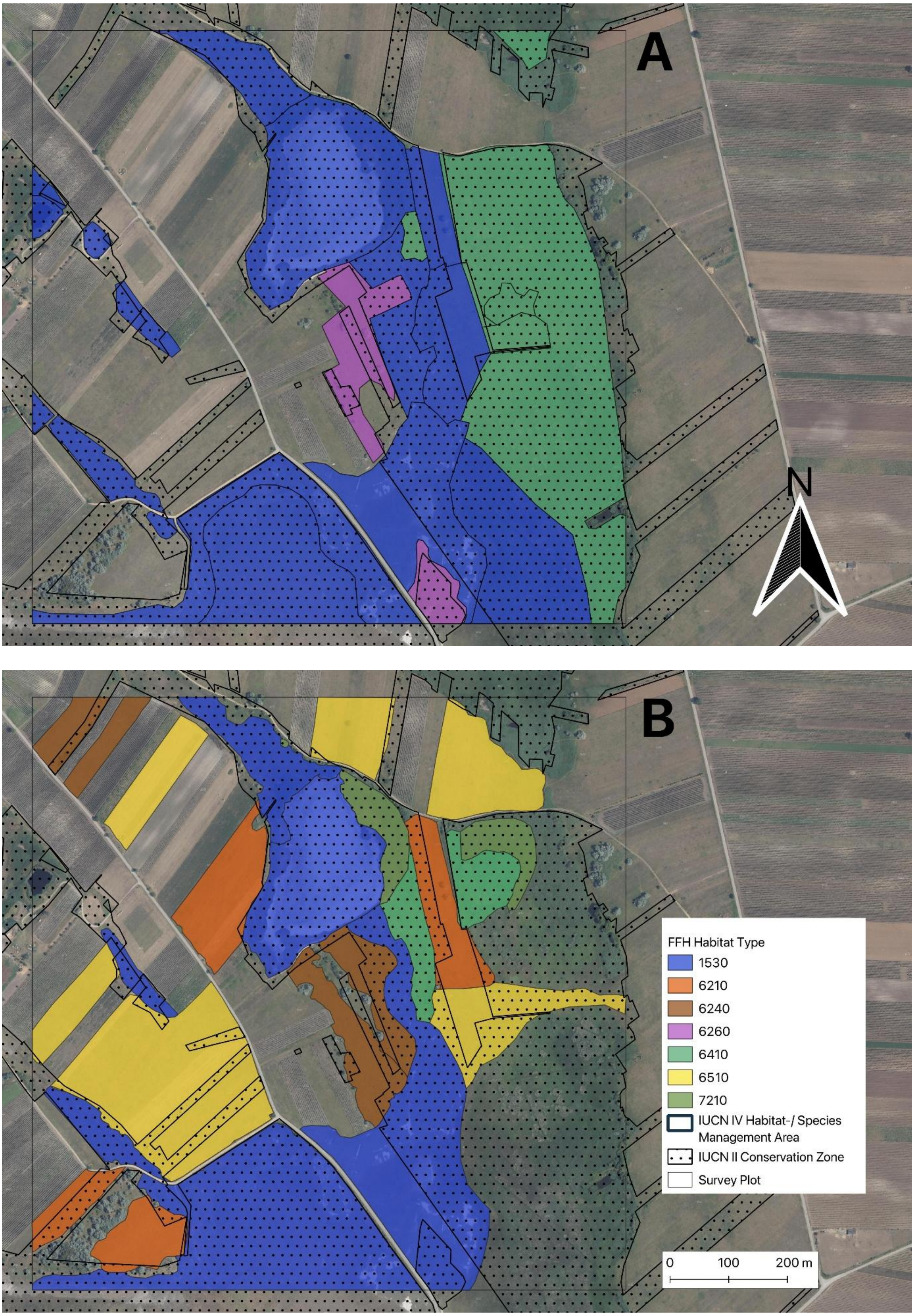

Fig. 15 Spatial distribution of FFH habitats within 1 km^2 study window ID-540 in (A) 2013 and (B) 2023.Seewinkel region; Source: data.gv.at, Umweltbundesamt GmbH, BM für Landwirtschaft Region und Tourismus (BMLRT).

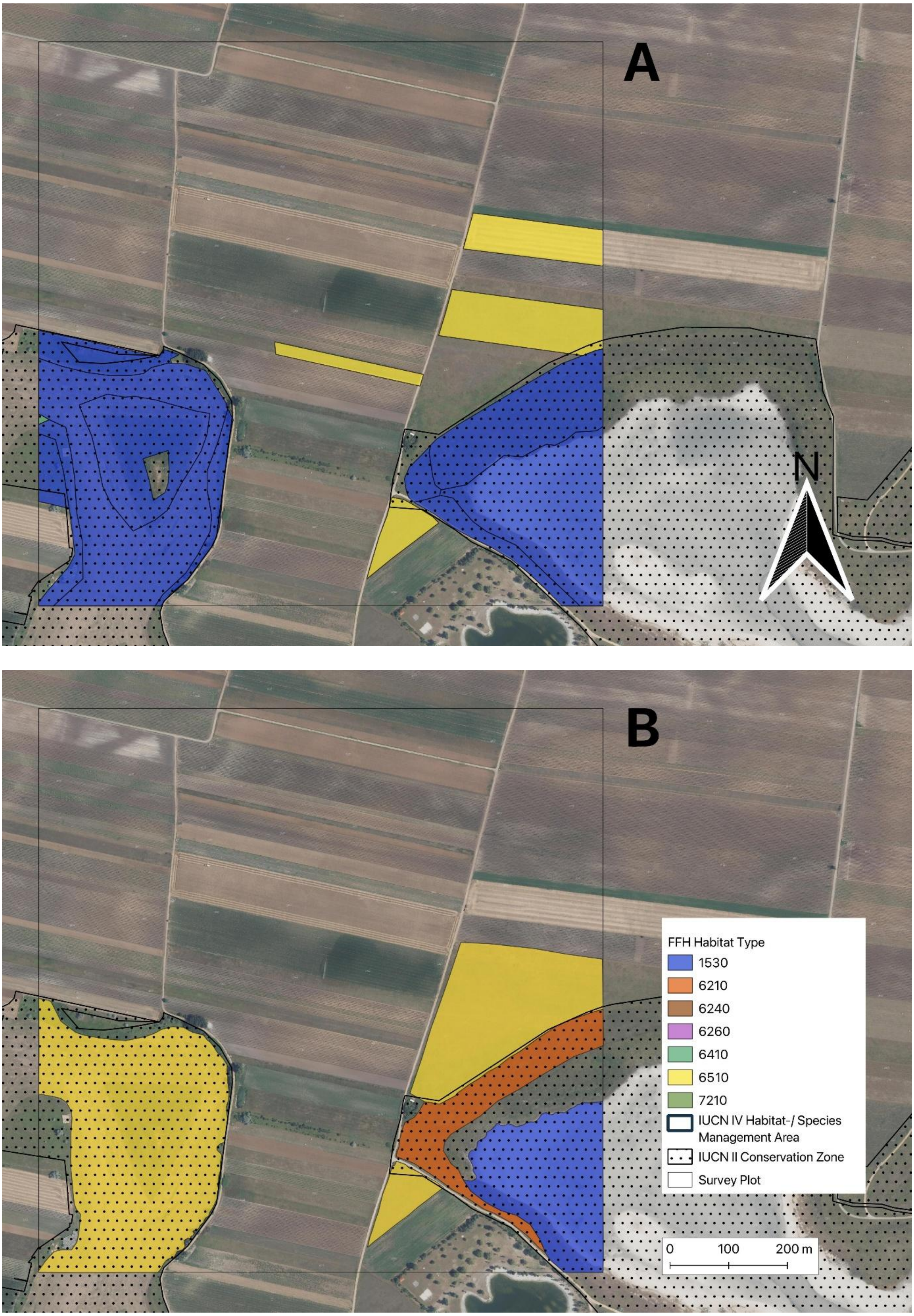

FIG. 16 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM^2 STUDY WINDOW ID-550 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

FIG. 17 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM^2 STUDY WINDOW ID-560 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

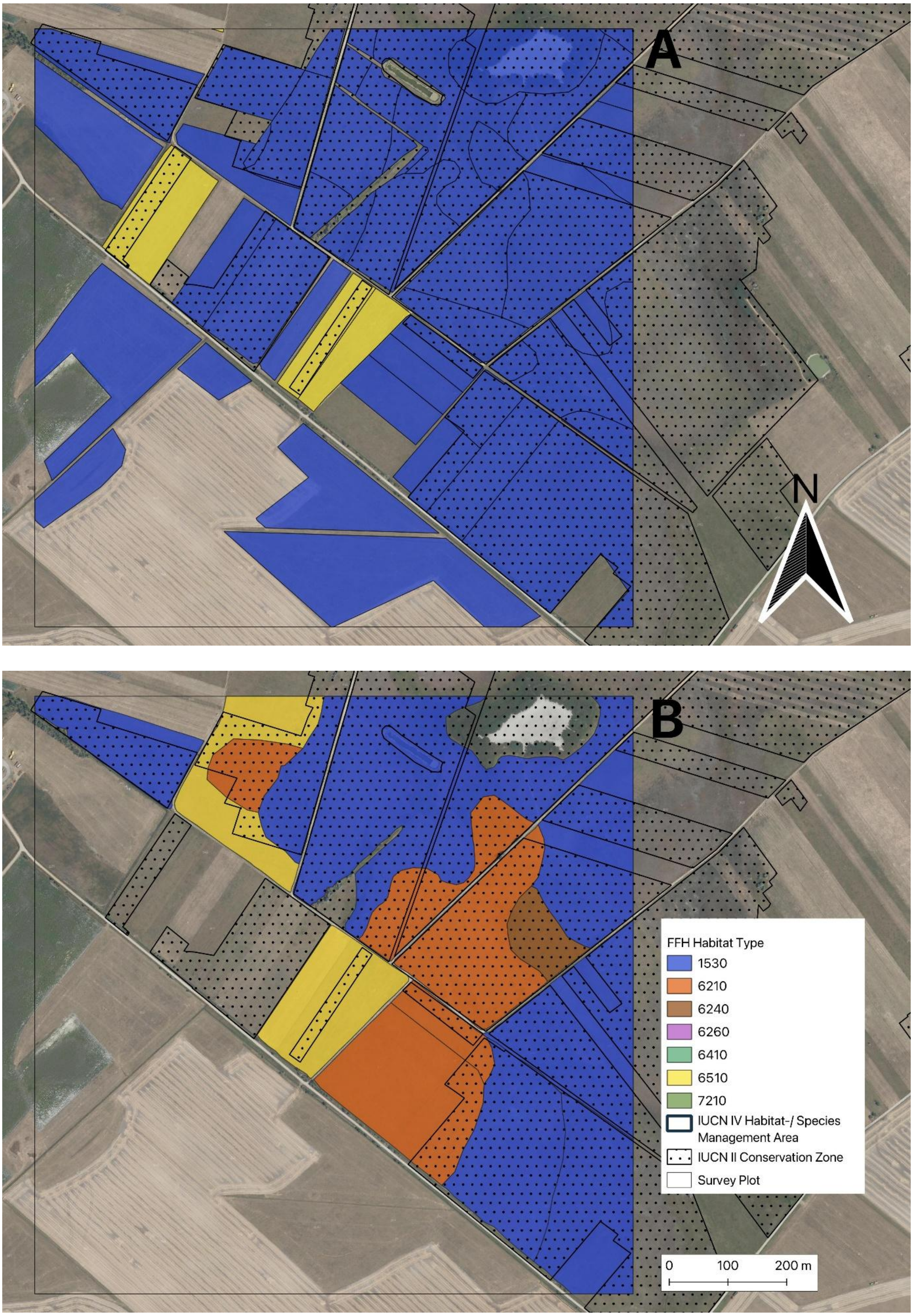

FIG. 18 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM^2 STUDY WINDOW ID-568 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

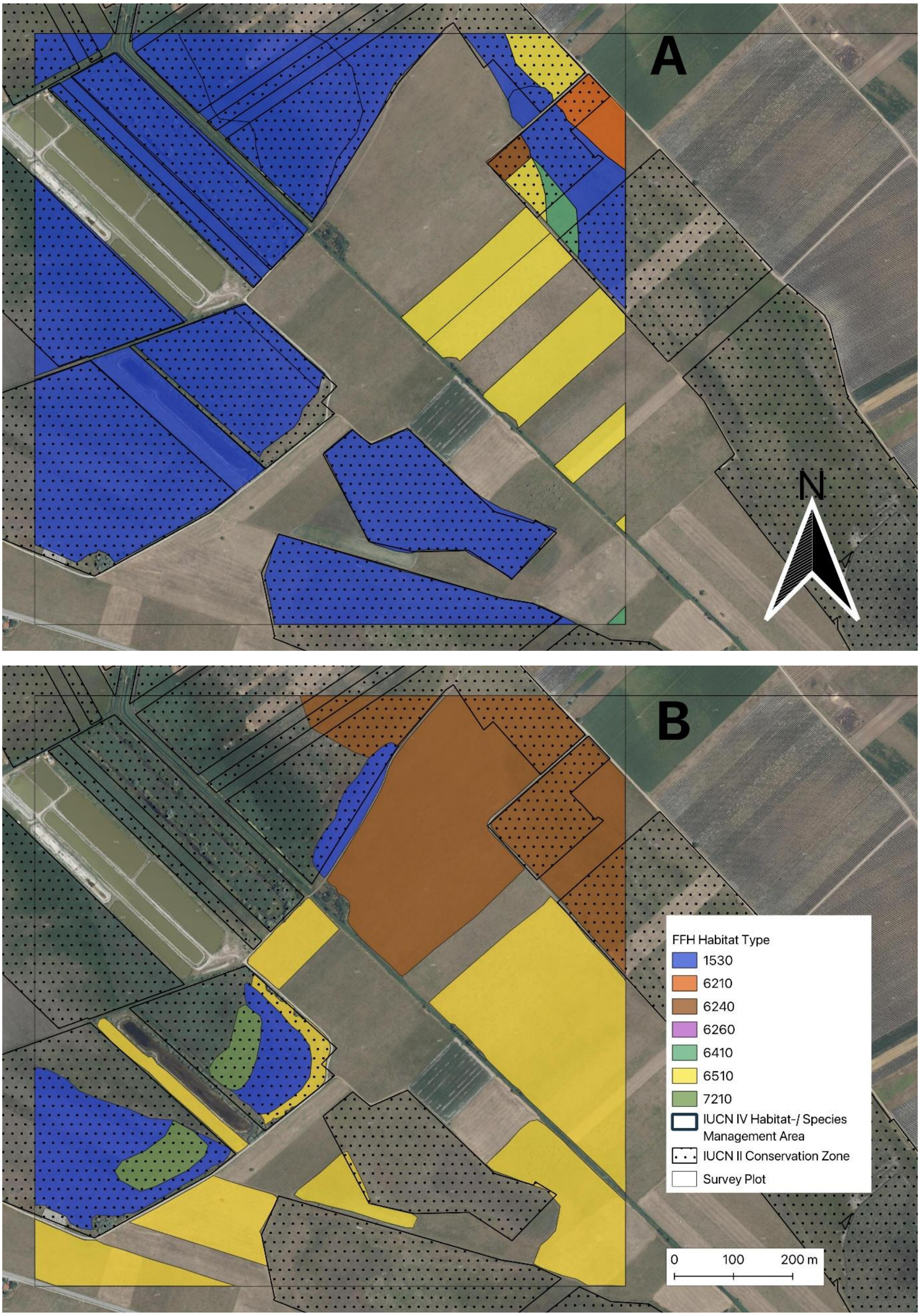

Fig.19 Spatial distribution of FFH habitats within 1 km^2 study window ID-573 in (A) 2013 and (B) 2023.Seewinkel region; Source: data.gv.at, Umweltbundesamt GmbH, BM für Landwirtschaft Region und Tourismus (BMLRT).

FIG. 20 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM^2 STUDY WINDOW ID-585 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

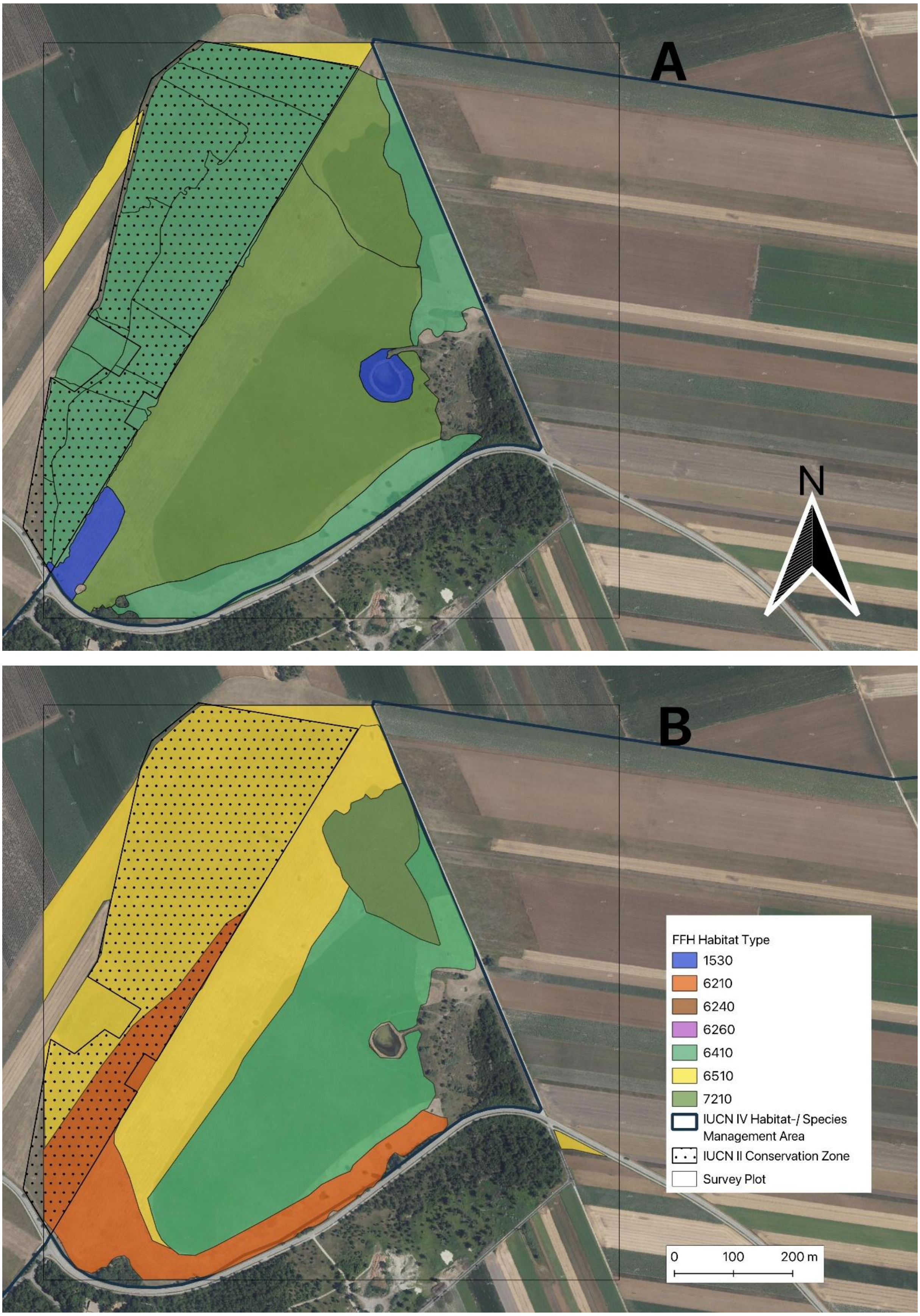

FIG. 21 SPATIAL DISTRIBUTION OF FFH HABITATS WITHIN 1 KM^2 STUDY WINDOW ID-604 IN (A) 2013 AND (B) 2023.SEEWINKEL REGION; SOURCE: DATA.GV.AT, UMWELTBUNDESAMT GMBH, BM FÜR LANDWIRTSCHAFT REGION UND TOURISMUS (BMLRT).

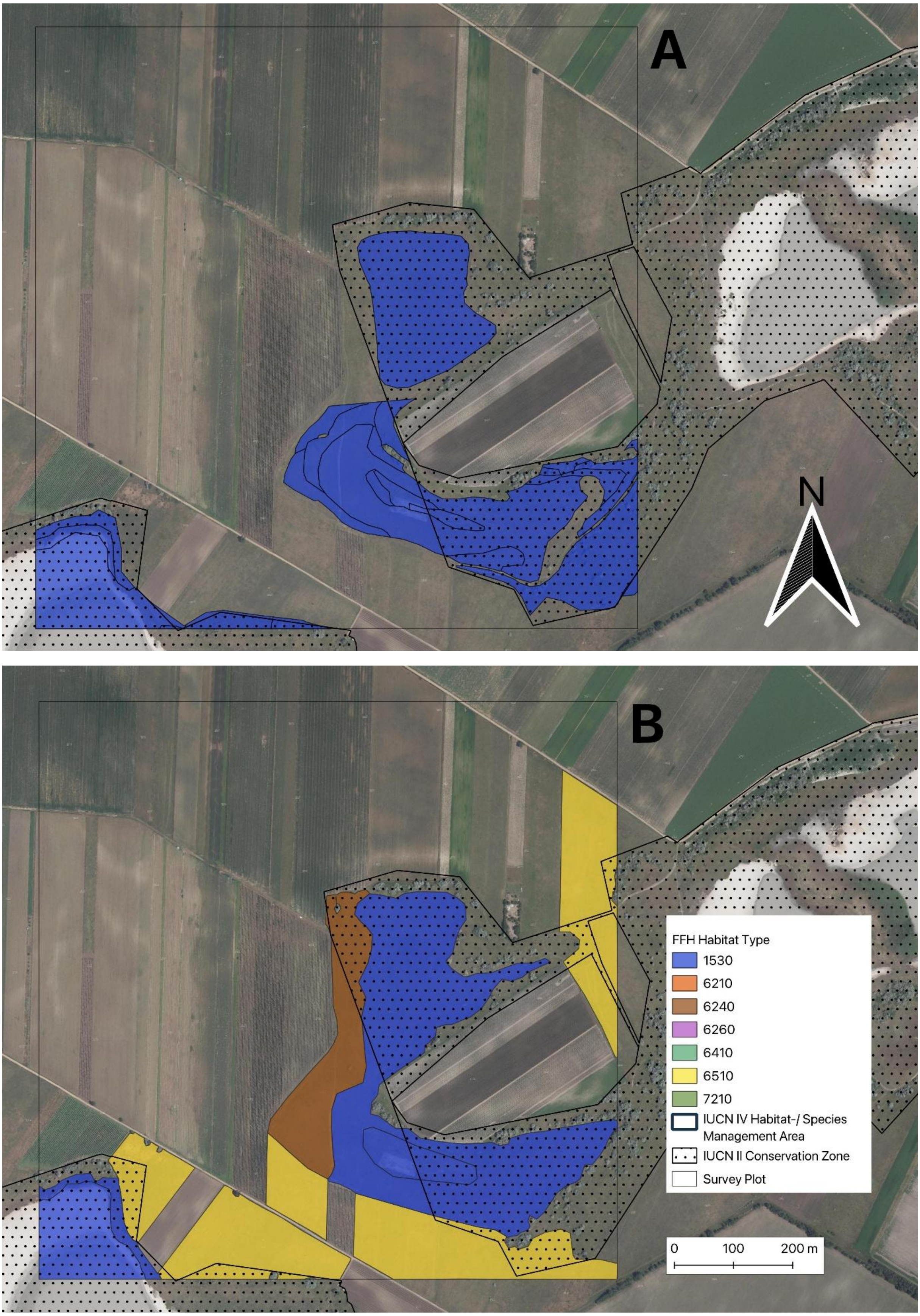

Fig. 22 Spatial distribution of FFH habitats within 1 km² study window ID-627 in (A) 2013 and (B) 2023.Seewinkel region; Source: data.gv.at, umweltbundesamt gmbh, bm für landwirtschaft region und tourismus (bmlrt).

Biotoptyp (lt. Liste >> BKatalog WoiG)	Nutzungstyp (lt. Kart.Anl. Land.Stk.)	FFH-LRT (Code bzw Name)	EUNIS-Kategorie	

Naturschutzfachliche Qualität:

Hemerobie: AH – OLH – MSH – BEU – AEU – POH – MTH

0 - 10 11 - 30 31-50 >50

Artenreichtum: **gering – mittel – hoch – sehr hoch**

Anteil besonderer Arten (RL, Zeigerarten f Ress.tönung) in Prozent:

0 1 – 20 20 – 40 40 - 60 >60

nicht vorhanden - gering – mittel – hoch – sehr hoch

Anteil Störungszeiger und/oder invasive Neophyten in Prozent:

0 1 – 20 20 – 40 40 - 60 >60

nicht vorhanden - gering – mittel – hoch – sehr hoch

1-2 3-4 5-6 >6

Heterogenität der Fläche: **gering – mittel – hoch – sehr hoch**

0 1-2 3-4 5-6 >6

wertbestimmende Merkmale: **nicht vorhanden - gering – mittel – hoch – sehr hoch**

Aktuelle Pflege/Landnutzung: **zu intensiv – optimal – zu extensiv – nicht vorhanden**

Störungseinflüsse/erkennbare akute Gefährdung auf der Fläche:

0 1-2 3-4 5-6 >6

Nicht vorhanden - gering – mittel – hoch – sehr hoch

Negative Randeffekte/Störungseinflüsse von Nachbarflächen:

Flächenanteil: 0% 1-5% 6-10% 11-20% >20%

Nicht vorhanden - gering – mittel – hoch – sehr hoch

Kurzbeschreibung

Anmerkung

Zugehörige Vegetationsaufnahme/Artenliste:

FIG. 23 CATALOG OF CONSERVATION-RELEVANT QUALITY INDICATORS USING A STANDARDIZED LIKERT SCALE.