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Burning or cutting? Comparing methods for bird conservation in the reedbeds of Lake Neusiedl/Fertő

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Abstract Lake Neusiedl/Fertő has Europe's second-largest reed area (180 km^2), and it is home to some of the largest populations of reed birds on the continent. In recent years, reed die-back and the extensive formation of a thick litter layer of broken reed have led to a dramatic decline in some reed bird species. Management measures to renew reedbeds and conserve their avifauna include reed burning, but this practice faces legal challenges in Austria. To get a first assessment of the feasibility of fire management, we compared reedbeds that had been burnt one year before with old reedbed sites and regularly harvested sites based on abundance indices of a set of characteristic reed bird species. This was achieved by conducting point counts in burnt and old reedbeds, and by comparing our results with counts in harvested areas, which involved a total of 88 point count locations. Our results show that the abundance patterns of the focal species in the burnt area are similar to those in the cut areas. However, there were differences as well, for example, the Water Rail *(Rallus aquaticus)* was significantly more abundant at the burnt site. As expected, we found fewer "old reed specialists" in the burnt area compared to the old reed sites. Although this study provides only a snapshot of the spatio-temporal processes in the reed belt, our findings suggest that burning does not have a negative impact on the bird assemblage compared to reed harvesting.

Keywords: fire management, reed die-back, reed age, *Phragmites australis*, controlled burning

Összefoglalás A Fertő-tó/Neusiedler See Európa második legnagyobb egybefüggő nádasával (180 km^2) rendelkezik, és a kontinens legjelentősebb nádi madárpopulációinak ad otthont. Az elmúlt években a nádpusztulás és az avas nád vastag rétegben való felhalmozódása bizonyos nádi madárfajok jelentős állomány-csökkenéséhez vezetett. A nádas megfiatalítására és madárvilágának megőrzésére irányuló kezelési intézkedések közé tartozik a nádégetés, de ez a gyakorlat Ausztriában jelenleg jogi korlátokba ütközik. Ezen élőhely-kezelési gyakorlat megvalósíthatóságának felmérése céljából összehasonlítottunk egy előző évben leégett nádterületet rendszeresen aratott és idősebb nádas területekkel, kiválasztott madárfajok abundanciája alapján. Az adatfelvételezést 88 mintavételi helyszínen pontszámlálással végeztük, beleértve a leégett, idős és aratott nádasokat. Eredményeink azt mutatják, hogy a leégett területeken megfigyelt madárfajok abundanciája hasonló az aratott területekéhez. Voltak azonban különbségek is, például a guvat *(Rallus aquaticus)* szignifikánsan gyakoribb volt a korábban leégett területen. A várakozásoknak megfelelően kevesebb „öregnád-specialistát" találtunk az égetett területen, mint az idősebb nádasokban. Bár ez a tanulmány csak egy pillanatfelvételt nyújt a nádasban lejátszódó tér- és időbeli folyamatokról, eredményeink arra utalnak, hogy a nádégetésnek nincs negatív hatása a madárvilágra a nádaratáshoz képest.

Kulcsszavak: tűzmenedzsment, nádpusztulás, nádas kora, *Phragmites australis*, kontrollált égetés

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Introduction

Europe has lost 80% of its wetlands in the past millennium (Verhoeven 2014). Thus, it is crucial to protect such remaining habitats and to restore lost ones (Čížková *et al.* 2013, Hu *et al.* 2017). Common reed *(Phragmites australis)* is a characteristic colonizer of numerous wetland habitats, and reedbeds are also known to have shrunk Europe-wide (Graveland 1998), posing a threat to numerous species that are evolutionarily adapted to, and thus, dependent on them. The Lake Neusiedl/Fertő is the westernmost steppe lake in Europe, located in Austria and Hungary (Dinka *et al.* 2010, Tolotti *et al.* 2021) with an average water depth of 1.2 meters (Soja *et al.* 2013). It is surrounded by an extensive reed belt (180 km^2), the second-largest contiguous reed area in Europe, following the Danube Delta (Csaplovics 2019), and it is home to numerous species of conservation concern (Dvorak *et al.* 2024). This unique ecosystem at the western edge of the Pannonian Ecoregion is especially vulnerable to the impacts of climate change (Soja *et al.* 2013, Dokulil *et al.* 2021). Considering its size and the bird populations it sustains, it is evident that the reed belt of Lake Neusiedl/Fertő requires protection and management in an ecologically reasonable way. Management measures should be designed carefully based on a scientific basis, taking into account the characteristics of this fragile lake ecosystem (Nemeth *et al.* 2022).

After the last dry-up in 1865–1870, the reed belt around Lake Neusiedl/Fertő has expanded dramatically, mainly due to the lowering and stabilization of formerly highly variable water levels. A major influence on the extension of the reed areas resulted from the construction of a drainage channel called Hansági-főcsatorna (Einserkanal) in 1909, and later from the weir system at Mekszikópuszta in 1965. In the last century, reed growth had been influenced by increased nutrient input from unmanaged sewage from nearby municipalities, and it is still impacted by agricultural activities around the lake (Wolfram *et al.* 2014, Csaplovics 2019, Nemeth *et al.* 2022). Consequently, the water regime of Lake Neusiedl/Fertő has been dramatically altered by technical interventions.

Currently, the lake is facing the issue of reed die-back and a massive accumulation of biomass. Reed die-back can be seen as a natural succession state that offers, at least for some time, niches for different fungal, insect, and bird species, such as the old-reed specialist Moustached Warbler *(Acrocephalus melanopogon)*. However, the recent breakdown of reed stands has an overall devastating effect on reed birds (Nemeth & Dvorak 2022). Reed stands have collapsed in one direction, forming a thick litter layer (hereinafter: mats) up to one meter high *(Figure 1)*. According to Perlinger (2022), the area covered by mats of broken reed reached 17 km^2 on the Austrian side in 2019. However, based on aerial images taken between 2020 and 2024, the extent may well have increased since then (E. Nemeth *pers. obs.*).

Reed die-back is a phenomenon that has been reported from various locations across Europe (Armstrong & Armstrong 2001, Engloner 2009, Dinka *et al.* 2010, Tóth 2016). At Lake Neusiedl/Fertő, die-back processes of reed have been reported since the 1970s (Csaplovics 1985, Dinka & Szeglet 1999, Dinka *et al.* 2010). Armstrong *et al.* (1996) describe the process and causes of reed die-back, which includes an environment flooded by stagnant water, the accumulation and microbial decomposition of organic matter (fallen leaves, decaying

Figure 1. Aerial photo of mats of broken reed ©Erwin Nemeth 2024
1. ábra Légifelvétel a felhalmozódott avas nádrétegekről ©Erwin Nemeth 2024

stems, dead rhizomes), and subsequent oxygen depletion. This is followed by anaerobic decomposition, which leads to the production of phytotoxins (sulfides, ammonia, and organic acids) that damage rhizomes and prevent aeration through the aerenchyma, resulting in reduced growth and die-back. It has been reported that mechanical damage to reed rhizomes causes and exacerbates the effect of reed die-back (Armstrong & Armstrong 2001).

Several strategies exist for managing reed habitats, including cutting, prescribed burning, and grazing (Ostendorp 1987, Báldi & Moskát 1995, Vadász & Csörgő 2009, Biró *et al.* 2020). Reed harvesting, once widespread around the lake, traditionally took place on frozen surfaces, which prevented mud compaction and rhizome damage (Dvorak *et al.* 2024). However, global warming has reduced suitable ice conditions, limiting this practice (Führer 2010). Additionally, prescribed burning, which was formerly used to prepare areas for cutting, is now prohibited. As stated in the Austrian Air Pollution Control Act (BGBl. I Nr. 137/2002), the burning of materials is only permitted in incineration plants (Bundeskanzleramt Österreich 2025). Therefore, climate change combined with socioeconomic changes over the past centuries has altered the harvesting practices.

Today, reed cutting is performed using heavy machinery. At previously unused sites, the process involves flattening reed vegetation in winter to prepare it for mowing the following year (Nemeth *et al.* 2022). Flattening and mowing can cause ground compaction and damage to reed buds in more deeply flooded reedbeds. This results in diminished regrowth and ultimately leads to reed die-back. By examining satellite imagery, it is evident how the harvesting machines damage the reedbed *(Figure 2),* and how certain parts of the contiguous

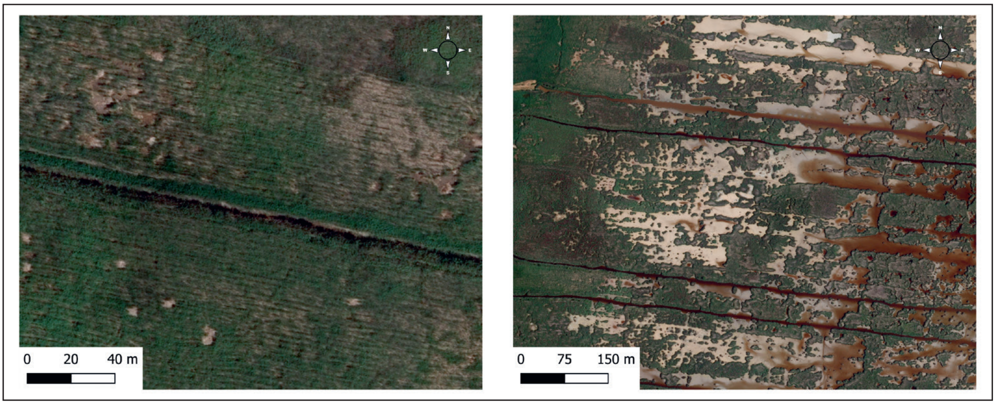

Figure 2. Marks of reed harvesting machines (left) and patchy vegetation due to reed die-back (right) near Mörbisch (Fertőmeggyes) Source: ESRI Satellite Imagery

2. ábra A nádarató gépek nyoma (balra) és a nádpusztulás által gyérré vált növényzet (jobbra) Mörbisch (Fertőmeggyes) közelében Forrás: ESRI Satellite Imagery

reed area have transformed into a habitat with patchy reed growth surrounded by open water. Conversely, in older uncut areas of the reedbelt, the formation of mats of broken reed creates unfavorable conditions. To address both issues, the reintroduction of fire management has been proposed (Nemeth *et al.* 2022).

Several studies have investigated the ecological impacts of reed cutting and reed burning on birds (Báldi & Moskát 1995, Ostendorp 1995, Goc *et al.* 1997, Graveland 1999, Valkama *et al.* 2008, Vadász & Csörgő 2009, Moga *et al.* 2010, Mérő *et al.* 2015, Antoniazza *et al.* 2018). The meta-analytical review by Valkama *et al.* (2008) concluded that long-term management leads to a reduction of avifauna by approximately 60%, mainly due to the decline of invertebrates and the absence of certain structural elements. Nonetheless, there is a fundamental difference between long-term and short-term management: while long-term management (i.e. yearly recurring management practices over many years) reduces bird densities, short-term management (1–2 years) enhances habitat quality (Valkama *et al.* 2008, Vadász & Csörgő 2009).

Several studies have focused on the ecological effects of burning in older reedbeds (Báldi & Moskát 1995, Valkama *et al.* 2008, Mester *et al.* 2015). Although the necessity for such a project has been emphasized (Nemeth *et al.* 2022, Nemeth & Dvorak 2022), no study has yet been conducted on this topic at Lake Neusiedl/Fertő. To address this gap, we compared burnt, cut, and old reedbeds based on their bird assemblage within the framework of a project initiated by the Federal State of Burgenland (Land Burgenland) to evaluate the effects of prescribed burning (Land Burgenland 2024). Since the area of the initial test burning in Jois (Nyulas) was considerably smaller than anticipated (Berner *et al.* 2025), we used a larger, accidentally burnt area in Breitenbrunn (Fertőszéleskút) in our assessment *(Figure 3)*.

We focus on eight passerine species and two non-passerine species that breed in the reed belt of Lake Neusiedl/Fertő. The objective of our study is to examine differences in this set of characteristic bird species between previously burnt reed areas, cut reed of similar age, and older reedbeds similar to the reed stands that existed before the fire.

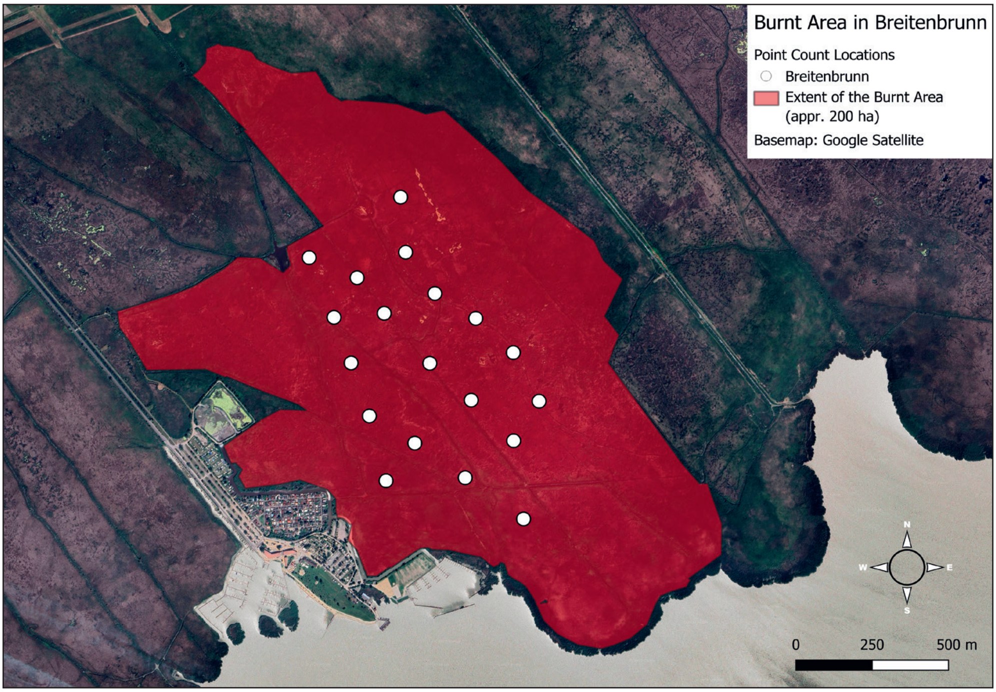

Figure 3. Extent of the burnt areas and locations of the point counts near Breitenbrunn (Fertőszéleskút)
3. ábra A leégett területek kiterjedése és a mintavételi pontok helyszínei Breitenbrunn (Fertőszéleskút) közelében

Material and Methods

Study area

The study area encompasses the Austrian part of the reed belt surrounding Lake Neusiedl/Fertő. During the fieldwork in 2024, two sites were surveyed: a one-year-old reedbed that had previously burnt in Breitenbrunn and an old reedbed (over 15 years old) in Illmitz. In 2019, counting points were distributed throughout the entire Austrian portion of the reed belt, excluding the national park area.

Number of points and their selection

Observation data from a total of 88 points were used in our analysis. The locations in 2024 (Breitenbrunn and Illmitz) included 19 and 10 point count locations, respectively. Data from 2019 consisted of 30 points from old reed sites, 16 points from cut reedbeds aged one to four years, and 13 points from a cut reedbed less than one year old. In the two survey years, we chose different sites with no overlap of the counted areas (see *Figure 4*). A minimum distance of 150 meters was kept between neighboring points to prevent spatial overlap and to guarantee independent sampling. The point count locations in Breitenbrunn

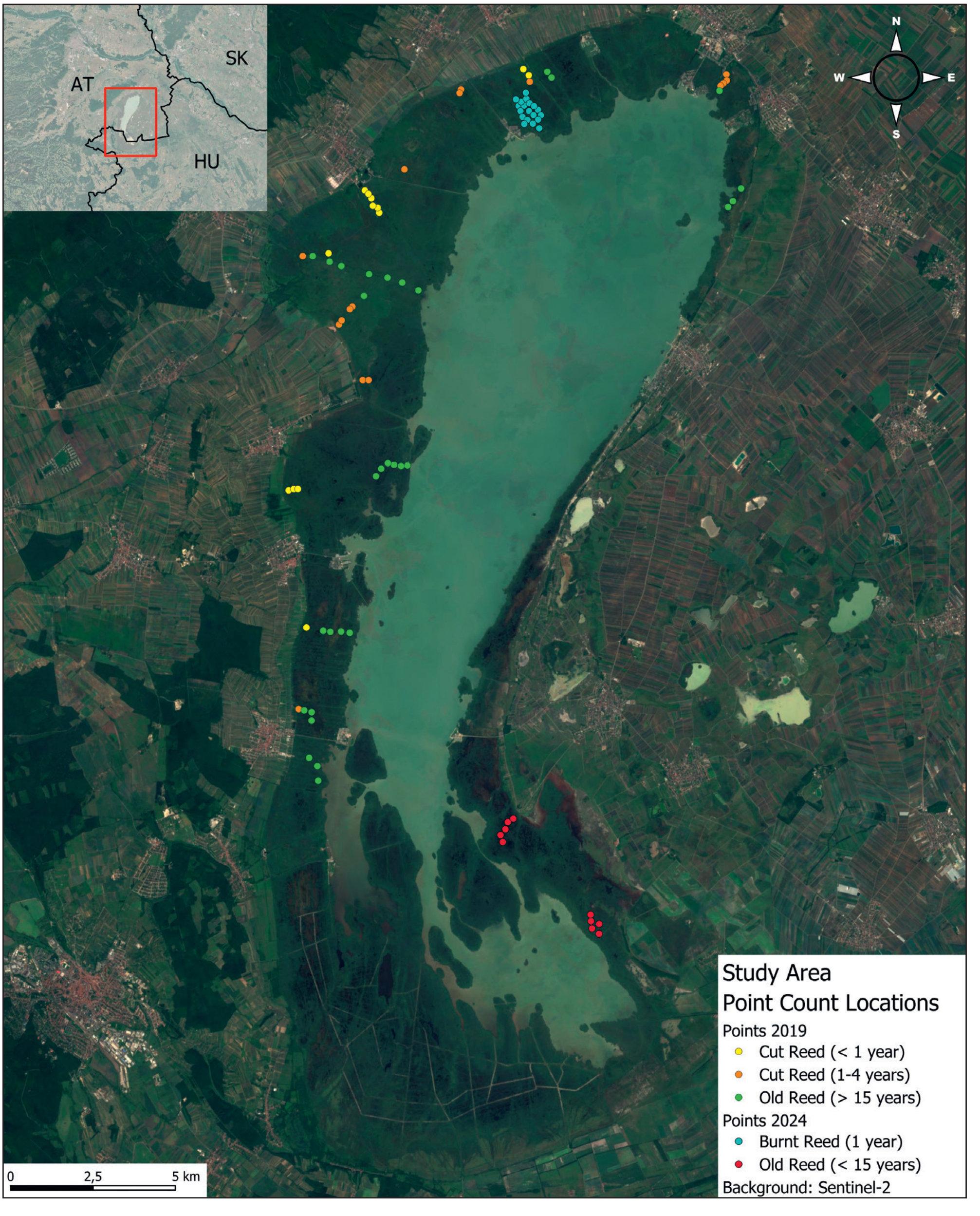

Figure 4. Study area and point count locations (2019–2024)
4. ábra A kutatási terület és a pontszámlálás helyszínei (2019–2024)

were preferentially selected using GIS software, with the aid of Sentinel-2 satellite imagery (European Space Agency 2023), to ensure they were situated in areas where reed had not been cut since the fire event.

Bird species

The Water Rail *(Rallus aquaticus)* is a short-distance migrant found in its breeding ground between mid-March and the beginning of October, although overwintering has also been reported (Csörgő *et al.* 2009, Dvorak *et al.* 2024). It prefers reedbeds, fens, and marshes with shallow water and dense vegetation (Dvorak *et al.* 2024).

The Little Crake *(Zapornia parva)* is a long-distance migrant, and it can be found between the end of March and the end of September at Lake Neusiedl/Fertő (Csörgő *et al.* 2009, Dvorak *et al.* 2024). It prefers old reedbeds with a mosaic of reed patches, open water, and channels (Nemeth *et al.* 2022).

The Bluethroat *(Luscinia svecica)* is a long-distance migrant that can be observed between the end of March and October in Central Europe (Csörgő *et al.* 2009, Dvorak *et al.* 2024). At Lake Neusiedl/Fertő, it is now bound to anthropogenically altered habitats, such as channels and dams, or to dried-up open water areas within the reed belt in years with low water levels (Grüll 2001, Dvorak *et al.* 2024).

The Savi's Warbler *(Locustella luscinioides)* is a long-distance migrant found in Europe between April and October (Csörgő 1995b, Csörgő *et al.* 2009). It prefers extensive, unmanaged reedbeds occasionally with Typha (Csörgő 1995b, Haraszthy 2019b), and it is known to use higher reed stands along channels as singing posts (Dvorak *et al.* 2024).

The Moustached Warbler is a short-distance migrant that returns from its wintering ground in March and can be observed until October, occasionally even in November (Csörgő 1995b, Csörgő *et al.* 2009, Dvorak *et al.* 2024). It breeds in extensive reedbeds with dense, old reed (Nemeth *et al*. 2022).

The Sedge Warbler *(Acrocephalus schoenobaenus)* is a sub-Saharan migrant found in its breeding grounds between April and October (Csörgő *et al.* 2009, Dvorak *et al.* 2024). It breeds in the transition zone of reedbeds with sedges and low shrubs (Csörgő 1995b, Haraszthy 2019b, Dvorak *et al* 2024).

The Common Reed Warbler *(Acrocephalus scirpaceus)* is a long-distance migrant present in its breeding grounds between April and October (Csörgő *et al.* 2009). It prefers homogenous reedbeds (Csörgő 1995b), and its distribution was found to be relatively equal among reed age classes at Lake Neusiedl/Fertő (Nemeth & Dvorak 2022).

The Great Reed Warbler *(Acrocephalus arundinaceus)* is a long-distance migrant found in European reedbeds from April until September (Csörgő *et al.* 2009). It prefers tall, dense, young reed stands with thick reed stems near open water (Leisler 1981, Leisler & Schulze-Hagen 2011, Dvorak *et al.* 2024). Nests are mostly found near the waterside edge of reed stands, typically within 2 m from open water (Csörgő 1995b).

The Bearded Reedling *(Panurus biarmicus)* is mainly non-migratory (Csörgő *et al.* 2009, Dvorak *et al.* 2024). It favors medium-height reed stands and a bent layer of broken stems, and old reed patches that have not been cut or burnt for years (Haraszthy 2019b).

The Reed Bunting *(Emberiza schoeniclus)* is sedentary in the southern edge of its range, while the northern individuals are migratory; the Central European population is partly migratory (Csörgő *et al.* 2009). It requires dry ground for breeding and is typically found in the dry edge zones rather than in the inner parts of extensive reedbeds (Haraszthy 2019b, Dvorak *et al.* 2024).

Bird counts

The point count methodology, which utilizes distance estimation for each bird, follows the approach described by Buckland *et al*. (2001), also employed in the study by Nemeth and Dvorak (2022). The surveys were conducted by two individuals proficient in identifying bird vocalizations. Prior to the start of the project, a joint mapping session was organized with other field experts to assess and ensure consistency between counters.

All counting points were surveyed three times over a two-month period, from the 30th of April till the 30th of June. The mapping was conducted between 4:50 and 11:00 a.m. from a 3.5 m tall ladder, which provided an elevated vantage point for observation. A laser rangefinder (Nikon Laser 550/550) was used to estimate the distance to the locations around each counting point where birds were seen or heard. The counting interval lasted five minutes to maximize the likelihood of registering birds and to minimize the chance of double-counting. During this interval, birds were identified acoustically and, when possible, visually. When birds moved within the counting interval, we measured the distance to the first sighting. Apart from the Bearded Reedling, all species were counted based on territorial song or calls. Since Bearded Reedlings have no conspicuous territorial song, they were recorded at the first location seen. For Water Rail and Little Crake, a 1-minute playback of their territorial calls was played from a speaker after the counting interval to elicit a response from them. The distance to the first response was recorded, and the playback was stopped if a response was heard before the end of the recording. Each observation was recorded in a field notebook, along with the corresponding distance estimate, and later digitized.

For each species, we used the data with the highest number of observations from the three mapping dates for each point. Next, we categorized the observations into three classes: 0–50 meters, 0–100 meters, and all distances within 150 m. Histograms were generated to identify the most appropriate distance class based on the distribution of the observation distances of each species for further statistical analysis. While observation data of the Little Crake and the Common Reed Warbler were analyzed within 0–50 m, the 0–100 m distance class was chosen for the rest of the species.

Statistical analyses

Due to the small sample size (e.g. $n = 10$ for old reed from 2024), the non-parametric Kruskal–Wallis test was used to assess differences in abundance among the reedbed types (burnt, cut, and old). If significant results or at least a trend ($p < 0.1$) were observed, Dunn's *post-hoc* test with Bonferroni correction was conducted to identify pairwise differences.

Since the data came from two different years with varying water levels in the lake, the mean water depth at each point was calculated using a digital lakebed model (Bácsatyai *et al.* 1997). We utilized mean water level data for Lake Neusiedl/Fertő (Wasserportal Burgenland 2024) from May to June of the respective years to compare the water levels (see *Figure 5*). As we were primarily interested in the relative differences between the water levels from the study years, we derived data from the lakebed model that includes the mud layer. The Kruskal–Wallis and Dunn's *post hoc* tests were used to identify differences between the mean water levels. We applied a generalized linear model (GLM) with a Poisson distribution to assess the effect of water depth on bird species abundance. In this model, the number of individuals served as the predicted values, and water level as the predictor. We checked the models for overdispersion. If the dispersion parameter exceeded the value of 1.2, we addressed it by refitting the model using quasi-Poisson errors.

Data analyses were conducted using R v. 4.3.3 (R Core Team 2024) and R Studio (RStudio Team 2024). We used QGIS (QGIS.org 2009) to calculate water depth at various points and to create maps.

Results

Water levels

The analysis revealed significant differences in water depth among several reedbed types (Kruskal–Wallis, $\chi^2 = 58.47$, $p < 0.001$). The burnt site (B1) had the greatest mean water depth, followed by the old reed site from 2019 (O19), with a non-significant difference. This was followed by the cut reed sites younger than a year (C0), old reed from 2024 (O24), and 1–4-year-old cut reed (C1–4). O24 and the cut sites (C0 and C1–4) did not differ significantly from each other *(Table 1, Figure 5)*. The results of the Poisson regressions to test the influence of water levels on different bird species showed no significant effect of water level on any species except the Sedge Warbler. Here, the species were found significantly more often at sites with lower water levels (Poisson regression, $n = 88$, coeff. $= -1.19$, $p = 0.0013$).

Comparison of burnt and cut reedbeds

The comparison of bird abundances from B1, C0, and C1–4 showed that five of the ten species had significant differences in abundance based on the results of the Kruskal–Wallis test *(Table 2, Figure 6)*.

Species that showed the highest abundance in B1, with significant differences, include Water Rail and Bluethroat. The Water Rail was nearly twice as abundant in B1 as in C1–4, and more than five times more abundant than in C0. The number of Bluethroats was more than twice as high in B1 compared to C0 and over ten times higher than in C1–4.

The species with the lowest abundance in B1 were Savi's Warbler, Moustached Warbler, and Common Reed Warbler. Savi's Warbler exhibited the same abundance in C1–4 and C0,

Table 1. Comparison of Water Depths Across Survey Sites using the Kruskal–Wallis test and the *post-hoc* Dunn's test with Bonferroni correction. Significant differences are indicated in bold. B1 = 1-year-old burnt reed, C0 = cut reed (< 1 year), C1–4 = 1–4-year-old cut reed, O19 = old reed from 2019, O24 = old reed from 2024 (Kruskal–Wallis, $\chi^2 = 58.47$, $p < 0.001$)

1. táblázat A vízmélységek összehasonlítása a megfigyelési területeken a Kruskal–Wallis-próba és a *post hoc* Dunn-próba eredményei alapján, Bonferroni-korrekcióval. A szignifikáns különbségek félkövér betűvel jelölve. B1 = egyéves leégett nád, C0 = vágott nád (< 1 év), C1–4 = 1–4 éves vágott nád, O19 = öreg nád 2019-ből, O24 = öreg nád 2024-ből (Kruskal–Wallis, $\chi^2 = 58.47$, $p < 0.001$)

Reedbed type	Mean Depth±SD (cm)	Comparison	Dunn's p
B1	129.25±5.51	C0 vs C1-4	1.00
C0	79.73±28.15	C0 vs O19	**<0.001**
C1-4	66.59±26.71	C1-4 vs O19	**<0.001**
O19	124.84±25.36	C0 vs B1	**<0.001**
O24	73.73±18.53	C1-4 vs B1	**<0.001**
		O19 vs B1	1.00
		C0 vs O24	1.00
		C1-4 vs O24	1.00
		O19 vs O24	**<0.001**
		B1 vs O24	**<0.001**

Figure 5. Distribution of water depths at survey points of different reed age classes
5. ábra A vízmélységek eloszlása a különböző korosztályú nádasok mintavételi pontjainál

significantly higher than in B1. The Moustached Warbler could not be observed in B1 and C0, but it was present in C1–4, albeit in very low numbers. For this species, Dunn's test indicated a significant difference between C1–4 and C0 and between C1–4 and B1. The Common Reed Warbler had the highest abundance in C1–4 compared to all other species and habitat classes, but the difference was significant only between B1 and C1–4.

Table 2. Comparison of the number of individuals of the respective species (means±standard deviation) counted at the one-year-old burnt reedbed (B1, n = 19), the less-than-one-year-old cut reed areas (C0, n = 13), and the 1–4-year-old cut reed areas (C1–4, n = 16) using Kruskal–Wallis tests and *post-hoc* Dunn's tests with Bonferroni correction. Significant differences are indicated in bold

2. táblázat Az egyéves leégett nádas (B1, n = 19), a kevesebb mint egyéves vágott nádas (C0, n = 13) és az 1–4 éves vágott nádas területek (C1–4, n = 16) pontjainál regisztrált egyedszámok fajonkénti összehasonlítása (átlag±szórás) a Kruskal–Wallis-próba és a *post hoc* Dunn-próba eredményei alapján, Bonferroni-korrekcióval. A szignifikáns különbségek félkövér betűvel jelölve

Species	**B1**	**C1-4**	**C0**	**χ^2**	**Kruskal–Wallis p**	**Dunn's p (B1 vs C1-4)**	**Dunn's p (B1 vs C0)**	**Dunn's p (C0 vs C1-4)**
Rallus aquaticus	2.37±1.26	1.31±1.20	0.46±0.78	16.73	**<0.001**	**0.04**	**0.001**	0.10
Zapornia parva	0.47±0.84	0.38±0.72	0.31±0.48	0.15	0.93	1.00	1.00	1.00
Luscinia svecica	1.42±0.61	0.13±0.34	0.69±0.85	22.84	**<0.001**	**<0.001**	**0.02**	0.09
Locustella luscinioides	0.63±0.68	1.69±0.79	1.69±1.18	13.48	**0.001**	**0.001**	**0.08**	1.00
Acrocephalus melanopogon	0.00±0.00	0.25±0.58	0.00±0.00	6.26	**0.04**	**0.04**	1.00	0.06
Acrocephalus schoenobaenus	0.47±0.70	0.81±1.22	0.77±0.93	0.70	0.70	0.86	0.63	1.00
Acrocephalus scirpaceus	2.26±1.24	3.63±0.81	2.77±1.09	11.77	**0.003**	**0.001**	0.42	0.06
Acrocephalus arundinaceus	1.84±0.96	1.56±1.55	1.69±1.25	1.77	0.41	0.28	0.68	0.96
Panurus biarmicus	0.32±0.48	0.63±0.72	0.69±0.63	3.32	0.19	0.28	0.13	0.98
Emberiza schoeniclus	2.47±1.22	1.81±0.83	1.62±0.87	5.22	0.07	0.17	0.05	0.77

Species that displayed no significant differences across habitat classes include Little Crake, Great Reed Warbler, Sedge Warbler, Bearded Reedling, and Reed Bunting. However, the Little Crake and Great Reed Warbler had their highest abundance in B1, while the Sedge Warbler and Bearded Reedling were most abundant in C1–4. The Bearded Reedling was nearly half as abundant in B1 compared to the other cut areas, a pattern that was similar for the Sedge Warbler. While the Great Reed Warbler had higher numbers in C0 than in C1–4, the Little Crake showed the opposite. The Reed Bunting was most abundant in B1, followed by approximately one-third lower values in C1–4 and C0.

Comparison of burnt and old reedbeds

Data from B1 was also compared to the two old reed habitats (O19 and O24). The results revealed that nine of the ten species showed significant differences in abundance *(Table 3, Figure 7)*.

Species such as the Water Rail, Bluethroat, Great Reed Warbler, and Reed Bunting had the highest counts in B1. The Water Rail exhibited a pronounced difference between the survey years rather than between reedbed types. For instance, B1 had nearly four times higher abundance than O19. The Bluethroat exhibited the lowest abundance in O19, which

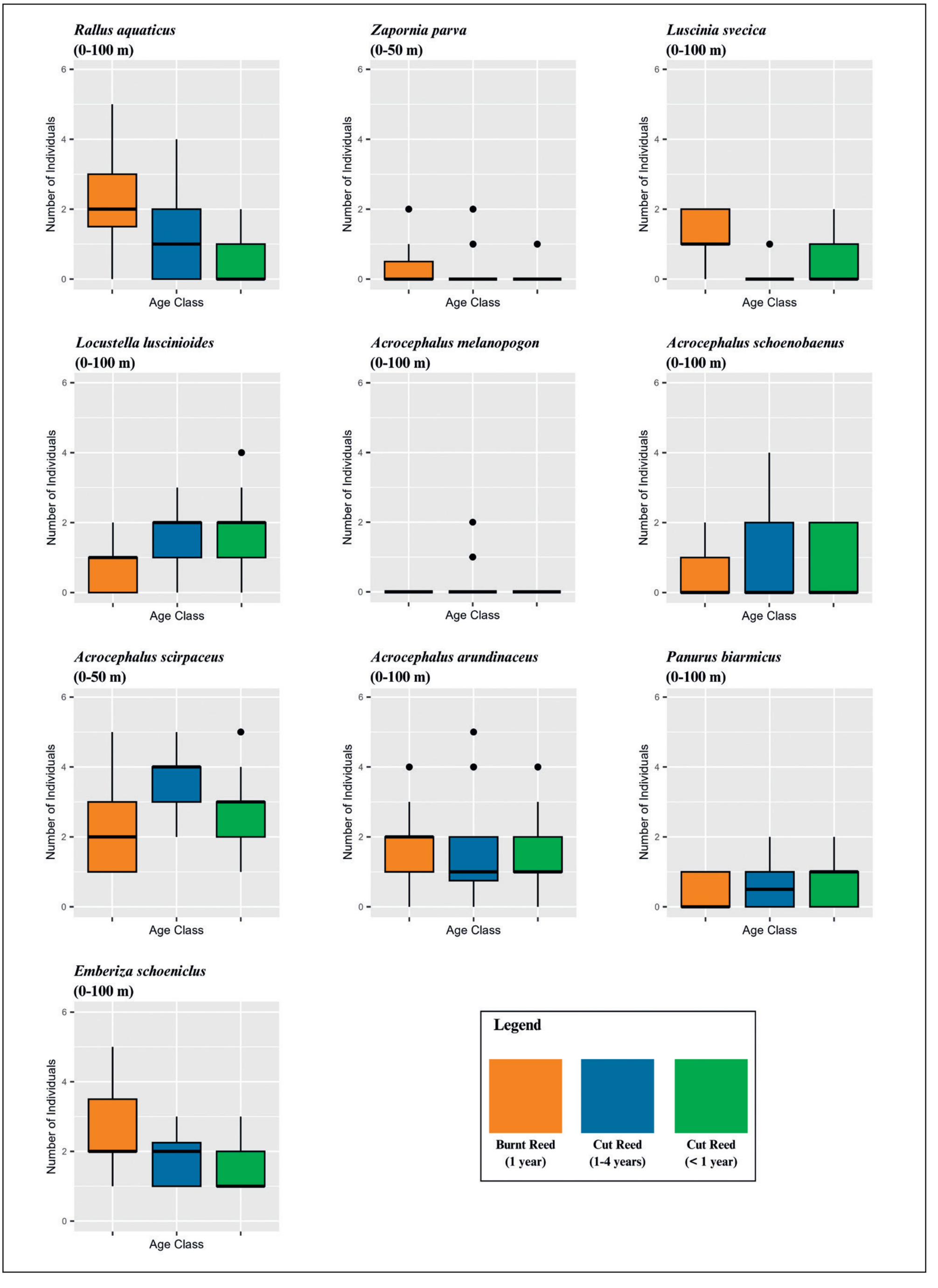

Figure 6. Distribution of the number of observations in burnt and cut reed areas by species using a box plot. Common Reed Warbler and Little Crake within a 50 m radius

6. ábra A leégett és vágott nádterületeken észlelt megfigyelésszámok eloszlása fajonként, doboz-diagramm segítségével. A cserregő nádposzáta és a kis vízicsibe 50 m sugarú körön belül

Table 3. Comparison of the number of individuals counted for each species (mean±standard deviation) among the points of the burnt reedbed (B1, n = 19), the old reedbed from 2024 (O24, n = 10), and the old reedbed from 2019 (O19, n = 30), using the Kruskal–Wallis tests and *post-hoc* Dunn's tests with Bonferroni correction. Significant differences are indicated in bold

3. táblázat Az egyével leégett nádas (B1, n = 19), a 2024-es öreg nádas (O24, n = 10) és a 2019-es öreg nádas területek (O19, n = 30) pontjainál regisztrált egyedszámok fajonkénti összehasonlítása (átlag±szórás) a Kruskal–Wallis-próba és a *post hoc* Dunn-próba eredményei alapján, Bonferroni-korrekcióval. A szignifikáns különbségek félkövér betűvel jelölve

Species	B1	O24	O19	χ^2	Kruskal-Wallis p	Dunn's p (B1 vs O24)	Dunn's p (B1 vs O19)	Dunn's p (O24 vs O19)
Rallus aquaticus	2.37±1.26	2.20±1.62	0.63±0.81	23.84	**<0.001**	0.92	**<0.001**	**0.003**
Zapornia parva	0.47±0.84	1.20±1.03	0.50±0.57	5,54	0.063	**0.03**	0.79	0.08
Luscinia svecica	1.42±0.61	1.30±1.06	0.03±0.18	39.08	**<0.001**	0.68	<0.001	<0.001
Locustella luscinioides	0.63±0.68	1.90±0.74	2.77±1.38	28.14	**<0.0001**	**0.009**	**<0.001**	0.29
Acrocephalus melanopogon	0.00±0.00	1.30±0.82	1.00±1.08	20.44	**<0.001**	**<0.001**	**<0.001**	0.27
Acrocephalus schoenobaenus	0.47±0.7	1.40±1.07	0.50±0.94	8,61	**0.01**	**0.02**	1.00	**0.006**
Acrocephalus scirpaceus	2.26±1.24	2.20±1.32	3.53±1.33	12,86	**0.002**	1.00	**0.002**	**0.01**
Acrocephalus arundinaceus	1.84±0.96	0.40±0.52	0.50±0.78	23.61	**<0.001**	**<0.001**	**<0.001**	1.00
Panurus biarmicus	0.32±0.48	2.10±1.10	1.13±0.78	23.61	**<0.001**	**<0.001**	**0.001**	**0.04**
Emberiza schoeniclus	2.47±1.22	2.10±0.57	0.63±0.93	27.87	**<0.001**	1.00	**<0.001**	**<0.001**

significantly differs from O24 and B1, with B1 showing a slightly higher abundance than B24. The abundance of the Great Reed Warbler in O19 and O24 did not differ significantly; there was a negligible difference between the reedbed types. However, B1 differed highly significantly from both old reed classes. The Reed Bunting was present in much higher numbers in 2024, with no significant difference between B1 and O24, the former being the highest. O19 showed values more than three times lower compared to O24 and was nearly four times lower compared to B1.

The Moustached Warbler, Sedge Warbler, and Bearded Reedling exhibit the highest populations in O24, with all three species ranking second in abundance in O19, followed by B1. The Moustached Warbler was not observed in B1, and the difference between O19 and O24 was not significant. The Sedge Warbler was almost three times less abundant in B1 and O19 compared to O24. The Bearded Reedling was nearly twice as abundant in O24 as in O19 and more than six times more abundant in O24 than in B1.

Savi's Warbler and Common Reed Warbler exhibit the highest counts in O19. No significant difference could be detected between the two old reed sites for Savi's Warbler; however, B1 had nearly 4.4 times and three times lower abundances compared to O24 and O19, respectively. Conversely, the abundance of the Common Reed Warbler in B1 and O24 did not differ significantly, while a significant difference was observed between O19 and the other two categories, with O19 showing about 1.5 times lower values.

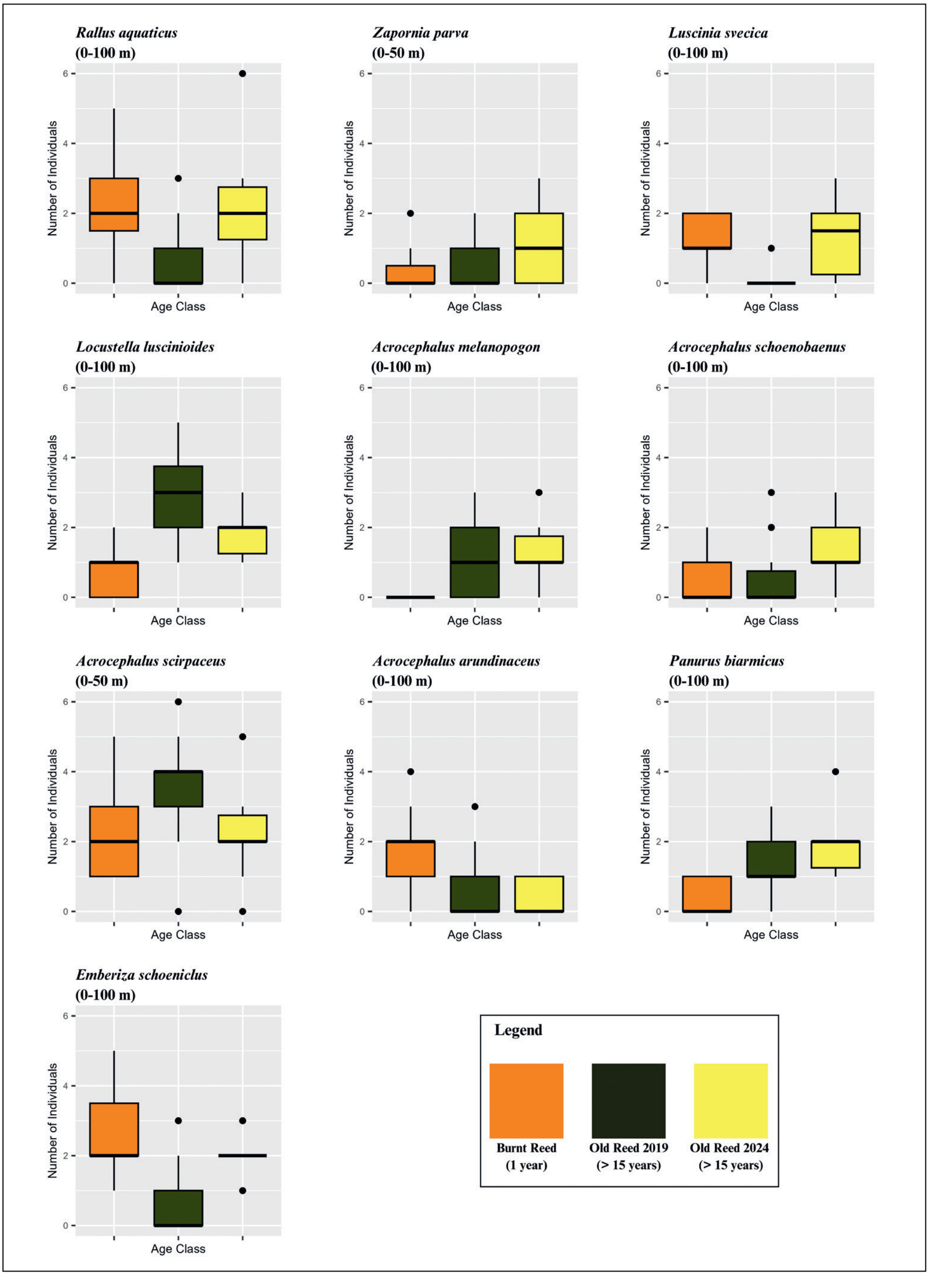

Figure 7. Distribution of the number of observations in burnt and old reed areas by species using a box plot. Common Reed Warbler and Little Crake within a 50 m radius

7. ábra A leégett és idős nádterületeken észlelt megfigyelésszámok eloszlása fajonként, dobozdiagramm segítségével. A cserregő nádposzáta és a kis vízicsibe 50 m sugarú körön belül

The Little Crake was the only species without significant differences based on the Kruskal–Wallis test. Still, the species showed the highest abundance in O24, followed by O19 and then B1. O24 had a slightly more than 2.5 times higher abundance compared to B1, whereas the difference between B1 and O19 was negligible.

Presence-absence data and additional observations

Presence-absence data for the target species are shown in *Table 4*. The Water Rail, the Bluethroat, the Savi's Warbler, the Great Reed Warbler, the Sedge Warbler, the Common Reed Warbler, the Bearded Reedling and the Reed Bunting were detected at all survey sites. The Moustached Warbler was not detected in the burnt reedbed and the young cut reedbed.

Table 4. Presence-absence of species across survey sites
4. táblázat A fajok jelenléte vagy hiánya a megfigyelési helyszíneken

Target species	Burnt reed (B1)	Cut reed (C0)	Cut reed (C1–4)	Old reed (O19)	Old reed (O24)
Rallus aquaticus	+	+	+	+	+
Zapornia parva	+	+	+	+	+
Luscinia svecica	+	+	+	+	+
Acrocephalus schoenobaenus	+	+	+	+	+
Acrocephalus melanopogon	-	-	**+**	**+**	+
Locustella luscinioides	+	+	+	+	+
Acrocephalus scirpaceus	+	+	+	+	+
Acrocephalus arundinaceus	+	+	+	+	+
Panurus biarmicus	+	+	+	+	+
Emberiza schoeniclus	+	+	+	+	+

Discussion

The results of the point counts partially corroborate the already known preference of particular reed bird species towards reed age, as described in Nemeth and Dvorak (2022). Our results demonstrate that the differences between the burnt and old reedbeds are more pronounced than those between the cut and burnt ones. This is evident in the number of significant differences observed in the Kruskal–Wallis tests. While nine out of ten species showed significantly different abundances in the burnt and old reedbeds, only five species differed significantly in the burnt-cut comparison. The species composition of the burnt reedbed resembles that of very young reed areas and shows substantial differences from old ones. The results are interpreted separately for each species.

Water Rail

The Water Rail is less likely to occur in reedbeds younger than five years or older than 15 years (Nemeth *et al.* 2022, Nemeth & Dvorak 2022), while Antoniazza *et al.* (2018) found the higher number of territories in 3-year-old reedbeds. In the reed belt of Lake Neusiedl/Fertő, it tends to colonize the shallowly flooded, dense, older reedbeds with or without sedge undergrowth (Nemeth *et al.* 2022). The results of the counts from 2024 are similar to the occurrence probability indicated in Nemeth and Dvorak (2022), as no significant difference was detected between the burnt and the old reed site. In 2019, however, significantly lower numbers were observed compared to 2024, which may have been caused by higher water levels in previous years, as the species requires shallowly inundated reedbeds (Nemeth *et al.* 2022). Burnt reed showed significantly higher numbers than cut reed, and it also exhibited greater abundance compared to the old reed data from 2024. Additionally, a nest with eight eggs was found at the previously burnt site. This evidence of breeding further supports the conclusion that previously burnt reed can provide suitable conditions for breeding; however, additional monitoring is necessary to study the habitat use of the Water Rail in this reedbed.

Little Crake

The Little Crake is known to inhabit old, inundated reed habitats with a dense layer of broken, old reed stems (Dvorak 1985, Haraszthy 2019a, Dvorak *et al.* 2024). Our comparison between burnt and cut sites, where the species is very rare, did not reveal any significant differences. In the comparison of burnt reed to old reed, the Little Crake was the only species that exhibited no significant difference but only a trend in the Kruskal–Wallis test; however, as expected, the burnt reedbed had substantially lower abundance compared to old reed from 2024. Our results suggest that the one-year-old, previously burnt area provided slightly higher suitability than cut reed sites for this species, while old reed is potentially the most suitable, even if the 2019 abundance data was close to the level of the burnt site. In the burnt area, some old reed patches may have been unaffected by the fire, which may have led to the prevalence of some suitable habitat elements.

Bluethroat

The Bluethroat was more abundant in both the burnt and old reedbeds in 2024 compared to 2019. The Bluethroat requires habitats that combine open water surfaces, dry ground, and reed (Nemeth *et al.* 2022, Dvorak *et al.* 2024). The high numbers in 2024 are hypothesized to be a legacy effect of very low water levels present in previous years, especially in 2022. The Bluethroat typically inhabits anthropogenically modified habitats at Lake Neusiedl/Fertő, such as channels and dams (Grüll 2001, Haraszthy 2019a, Dvorak *et al.* 2024). During the breeding season of 2024, several locations along the dams and channels were not inundated, which, combined with the legacy effect mentioned above, may have facilitated breeding. The findings of Báldi and Moskát (1995) are in contrast with ours, as they found no Bluethroats in the control and burnt areas, while densities in mowed and homogeneous areas (i.e. transition zones with reed and shrubs) were higher.

Savi's Warbler

The Savi's Warbler is known to exhibit an even distribution across various reed age classes, with the exception of the rather unsuitable one-year-old reed (Nemeth & Dvorak 2022). The results from the old-burnt comparison indicate that the species prefers older reed over recently burnt reed, a pattern also noted by Zwicker and Grüll (1985). We found significant differences between burnt and cut sites, with higher abundance in cut sites. This pattern aligns with the findings of Báldi and Moskát (1995) and is likely due to the more effective removal of the litter layer (including bent stems) by the fire. The Savi's Warbler is the only species that displayed a positive correlation with the presence of mats of broken reed; the abundance of the Savi's Warbler only declines when mats of broken reed cover more than half of the reed area (Nemeth *et al.* 2022). The significance of a layer of horizontal stems is reported by Grüll and Zwicker (1993). Furthermore, high densities are also observed in tall, strong, and healthy stands located in the outer lake margin zone and along channels (Dvorak *et al.* 1997). Our results suggest that even a very young cut reedbed supports higher abundance than one-year-old burnt reed, and the lower numbers at the burnt site can be interpreted as a result of effective removal of the bent layer/litter through prescribed burning.

Moustached Warbler

There was no record of the species in the burnt area, nor in the very young cut site, but the 1–4-year-old previously cut reedbed did have a low number of sightings. The Moustached Warbler requires a bent layer of old reed stems, small open water surfaces, but also reed stems with leaves that serve as cover over the bent layer are essential (Haraszthy 2019b, Nemeth *et al.* 2022). Reedbeds less than 5 years old are known to be rather unsuitable for the species, followed by an optimum in the 5–9-year age class, and then a slowly declining suitability in reedbeds older than 15 years (Nemeth & Dvorak 2022). Zwicker and Grüll (1985) reported maximum densities at an eight-year-old, previously burnt site characterized by the presence of the lesser reedmace *(Typha angustifolia)*. When comparing the burnt reed and the old reed sites, a significant preference is evident towards the old reed sites, supporting previous findings (Leisler 1981, Nemeth *et al.* 2001), and indicating that even old reedbeds beyond their optimum age are more suitable than young reeds. These results are also in line with the findings of Báldi and Moskát (1995), which showed that burning led to the absence of species, while unmanaged sites supported the highest densities.

Sedge Warbler

The Sedge Warbler is a characteristic species of the transition zone between wet reedbeds and lower herbaceous vegetation with reed patches (Cramp *et al.* 1992, Nemeth *et al.* 2022). Our findings did not reveal any significant difference between burnt and cut reed sites; however, cut reedbeds exhibited higher abundances. The old reed area from 2024 was seemingly more suitable than the burnt area, although it did not differ significantly from it. Because parts of the landward side of the reed area are more accessible for cutting machines, the slightly higher abundance in cut areas may have resulted from a greater overlap of the regularly cut zones with the Sedge Warbler's range. According to the results of the Poisson regression, this was the only species in our analysis that is significantly affected by water levels, as Sedge Warblers generally avoid reedbeds with standing water and require periodically dry ground (Dyrcz 2020). It is plausible that the time-lagged effects of the dry years in 2022 and 2023 contributed to the increased numbers in the old reedbed in 2024. Our results are consistent with the findings of Báldi and Moskát (1995), who reported the highest numbers in a heterogeneous habitat, followed by old and cut reed, while noting the lowest counts at a burnt site.

Common Reed Warbler

The Common Reed Warbler is regarded as a reed generalist species and is known to be the most common reed warbler in the reed belt around Lake Neusiedl/Fertő (Nemeth *et al.* 2022). Our results indicate that the burnt area is less suitable for the species than cut areas. Compared to the old reed habitats, the burnt reedbed differed significantly only from the 2019 old reed site. After cutting or burning, this species reoccupies these areas immediately after the regrowth of young reed in early summer, making it impossible to show any statistical differences between reed age classes after the first year (Nemeth *et al.* 2022). Our findings show that the Common Reed Warbler was present in the 1–4-year-old age reed (C1–4) in higher abundance than at the cut site (C0), which aligns with the results reported by Nemeth and Dvorak (2022). The burnt and old reed site from 2024 exhibited the lowest abundances, differing from the findings presented by Báldi and Moskát (1995), who reported the highest numbers in unmanaged areas and the lowest in cut reedbeds (see also Grüll & Zwicker 1993). The greater abundance in the very young cut area compared to the one-year-old burnt area may suggest a negative impact of burning. However, the non-significant difference between the burnt area and the old reed site from 2024 implies that differences in environmental conditions between the two survey years are likely to have played a more decisive role.

Great Reed Warbler

The Great Reed Warbler is one of the species that did not show any significant differences between burnt and cut sites; however, the burnt area was characterized by a slightly higher abundance of this species. The presence of well-spaced, tall and healthy reed stems in the edge zone between the reedbed and the water surface complies with the habitat requirement of this species reported by numerous studies (Leisler 1981, Grüll & Zwicker 1993, Graveland 1998, Báldi 2004, Kennerley & Pearson 2010, Mérő & Žuljević 2014, Haraszthy 2019b, Nemeth *et al.* 2022). It is likely that suitable habitat patches either remained intact or could quickly recover after the fire event. Additionally, inundation is also a crucial factor

(Leisler 1981, Leisler & Schulze-Hagen 2011, Mérő *et al.* 2014). At Lake Neusiedl/Fertő, such conditions are often found at the waterside edge of the reed belt and along dams and channels (Dvorak *et al.* 1997). The species does not favor old reedbeds (Nemeth *et al.* 2022), which aligns with our findings that indicate significantly lower numbers in the older reed sites compared to the others. Nemeth and Dvorak (2022) described 1–4-year-old reed as the most suitable breeding habitat, which is also consistent with our results. The higher abundance in the burnt area may have resulted from the positive effects of burning compared to cutting with heavy machinery. However, in the study by Báldi and Moskát (1995), the Great Reed Warbler was recorded in lower numbers in a burnt habitat than in a cut and an unmanaged site, which contradicts our findings.

Bearded Reedling

The Bearded Reedling is reported to show preference towards reed age classes of 5–9 and 10–14 years, with a slight decline in stands older than 15 years (Nemeth & Dvorak 2022). This species is more frequently found in areas with medium reed height and deeper water (Cramp *et al.* 1994, Nemeth & Dvorak 2022). In response to burning, the species was absent from burnt sites and occurred at higher densities in mowed sites, with the highest densities recorded in unmanaged sites in the study by Báldi and Moskát (1995). Our analysis did not reveal any significant differences across burnt and cut sites, but in old reed, significantly higher numbers of individuals were recorded (both in 2019 and 2024). Despite the fact that reed growth is denser at previously burnt sites (Valkama *et al.* 2008), which is described as an important habitat requirement (Cramp *et al.* 1994, Haraszthy 2019b), it did not affect the abundance of the Bearded Reedling positively in the burnt site we surveyed.

Reed Bunting

The Reed Bunting was found to be the most abundant in the burnt area. While Dunn's test showed a significant difference between the old reed site from 2019 and the burnt one, no significant differences were detected between cut and burnt sites, and between burnt and old reed from 2024. Nemeth and Dvorak (2022) reported higher suitability of young reed age classes for the species than old reed. In the study by Báldi and Moskát (1995), the burnt areas exhibited the lowest mean number of individuals, while mowed areas had slightly higher values; the highest numbers were found in the control areas with older reed. Our results differ from the findings of Báldi and Moskát (1995), as we observed the highest numbers in the burnt area. The old reed site from 2024 had the second highest mean overall and did not differ significantly from the burnt site. Consequently, Reed Buntings had a higher overall abundance in 2024 compared to 2019. This was likely to be influenced by differences in water levels, with lower levels in 2024 than in 2019 (Wasserportal Burgenland 2024), resulting in more suitable conditions, as the species requires dry ground for breeding (Cramp *et al.* 1994, Copete & Christie 2021). Burnt reed still had the highest mean number of observations in both the burnt-cut and burnt-old comparisons, indicating the high suitability of previously burnt one-year-old reed.

Conclusion

Although water level differences and varying environmental conditions between the two survey years pose a limitation to the interpretation of the results of our study, the core findings demonstrate that differences between burnt and cut reed sites were less pronounced than those between burnt and old reed sites; five species differed significantly in the former comparison, while nine did so in the latter. It is essential to focus on the long-term effects of burning and cutting, as these effects become relevant for certain bird species only in subsequent years following a fire. To achieve a more comprehensive understanding of this matter, it is necessary to conduct monitoring over a longer period and to include more sites with varying ecological conditions. Nonetheless, as an initial step toward this, our findings clearly indicate that prescribed burning is a possible alternative to reed cutting as a management tool for reed bird conservation.

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