

Mapping Natura 2000 Habitat Conservation Status in a Pannonic Salt Steppe with Airborne Laser Scanning

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(a)



(B)



(C)

Figure S1. The three most widespread alkali grassland types of the study site. **(A)** Alkali short steppe; **(B)** Alkali open sward; **(C)** Alkali meadow. Photos by B. Deák.

Table S1. Score sheet of the Hungarian Natura 2000 conservation status evaluation scheme for grasslands. Parameters that could not be measured in the field or with ALS are in italics.

| | Favorable Quality | Score | Unfavorable Quality | Score |
|---------------------|---|--------------|--|--------------|
| Naturalness | naturalness of stand ≥ 4 or <i>naturalness of stand increased since the last survey</i> | +10 | naturalness of stand < 3 or <i>naturalness of stand decreased since the last survey</i> | -5 |
| Species Density | <i>species density has not decreased substantially or increased since last survey</i> | +10 | <i>species density decreased significantly since last survey</i> | -1 |
| | | | species density varies significantly | -1 |
| Inner Patchiness | does not differ considerably from the characteristics of the habitat | +5 | considerably differs from the characteristics of the habitat | -1 |
| Vertical structure | does not differ considerably from the characteristics of the habitat | +5 | has less layers than characteristic of the habitat | -1 |
| Species pool | does not differ considerably from the characteristics of the habitat | +10 | dominant species are not typical for the habitat | -5 |
| Litter Accumulation | not present or present, but has no considerable effect on the vegetation | +5 | cover of litter $> 50\%$ | -1 |
| | | | <i>cover of litter increased significantly since the last survey</i> | -1 |
| | | | cover of standing dead grasses and sedges $> 70\%$ | -1 |
| | | | <i>cover of the standing dead grasses and sedges increased considerably since the last survey</i> | -1 |
| | | | litter accumulation results in a decrease in grass cover | -1 |
| | | | litter accumulation results in a decrease in diversity | -1 |
| | | | litter accumulation results in the spread of weeds | -1 |
| | | | litter accumulation results in the spread of invasive species | -10 |
| | | | area effected by erosion $> 30\%$ | -1 |
| | | | <i>area effected by soil erosion increased considerably since the last survey</i> | -1 |
| Soil Erosion | not present or present, but has no considerable effect on the vegetation or present, but its effect on vegetation is favorable (e.g., in alkaline grasslands) | +5 | erosion results in the spread of weeds | -1 |
| | | | erosion results in the spread of invasive species | -10 |
| Spread of Shrubs | <i>total cover of the shrubs has not increased significantly since the last assessment</i> | +5 | pattern of the shrubs is random | +5 |
| | | | shrubs form a closed stand | -1 |
| | | | <i>shrubs grow in groups, the total cover of patches has increased significantly since the last assessment</i> | -1 |
| | | | vegetation under the shrubs is weedy | -1 |
| | | | there are one or more woody invasive species that threatens the habitat | -10 |

Table S1. *Cont.*

| | Favorable Quality | Score | Unfavorable Quality | Score |
|-------------------|--|-------|---|-------|
| Weeds | absent, or not significant (total cover of segetal weeds <15% and the cover of ruderal weeds and weeds typical for pastures <20% and the cover of spreading grasses is <30% <i>and</i> the total cover of invasive weeds = 0%) | +5 | significant amount (total cover of segetal weeds is $\geq 15\%$ or the cover of weeds and weeds typical for pastures $\geq 20\%$ or cover of spreading grasses is $\geq 30\%$ or the total cover of invasive weeds >0%) | -1 |
| Disturbances | absent | +5 | at least one disturbing factor is present and effects or has destroyed >10% of the stand | -10 |
| Future Threats | absent | +5 | a direct effect can be expected within the next 5 years | -5 |
| Traces of Animals | slight effects, increases the number and diversity of favorable microhabitats | +5 | effects >50% of the area and has destroyed it | -2 |
| Landscape Context | the habitat patch is neighboured by one or more natural habitats | +5 | the habitat patch is adjacent to a stand of invasive species that that threatens the habitat | -10 |
| | the closest similar habitat is <100 m | +5 | | |

Table S2. Attribute table of field measured CS calibration/validation plots. AM: Alkali Meadow; SG: Alkali short grassland (steppe); OG: Alkali open grassland (sward). Background colors of lines correspond to the main vegetation type (green: alkali meadow; yellow: alkali short grass or open sward). CS parameters that differ from the majority of the plots are marked in bold; type of human disturbance is indicated by hatching of the cell.

| Training Plots | | | | | | | | | | | | | | | | |
|----------------|----|------------------------|-------------|-----------------|------------|--------------------|--------------|--------|--------------|--------|-------|-------------|----------------|-----------------|-----------------|--|
| ID | CS | Type ratio | Naturalness | Species density | Patchiness | Vertical structure | Species pool | Litter | Soil erosion | Shrubs | Weeds | Disturbance | Animal traces | Local landscape | Broad landscape | |
| 4 | B | AM | 10 | -1 | 5 | 5 | 10 | -1 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 8 | B | SG 0.5 OG 0.3 AM 0.2 | 10 | 0 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 10 | A | AM | 10 | 0 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | 5 | 5 | 5 | 5 | |
| 11 | C | AM | 0 | -1 | 5 | -1 | -5 | 5 | 5 | 0 | 5 | -10 | -2 | 5 | 5 | |
| 12 | B | AM 0.5 SG 0.35 OG 0.05 | 10 | 0 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 13 | B | SG 0.4 OG 0.15 | 10 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 21 | A | SG 0.5 AM 0.5 | 10 | -1 | 5 | 5 | 10 | -1 | 5 | 0 | 5 | 5 | 5 | 5 | 5 | |
| 23 | B | AM 0.8 | 0 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | -2 | 5 | 5 | |
| 24 | B | SG 0.86 AM 0.14 | 0 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 26 | B | SG 0.55 OG 30 AM 15 | 10 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| | | | | | | | | | | | | -10 | Vehicle tracks | | | |
| | | | | | | | | | | | | -10 | Overgrazing | | | |
| | | | | | | | | | | | | -10 | Undergrazing | | | |
| 1 | A | SG 0.83 AM 0.1 OG 0.7 | 10 | 0 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | 5 | 5 | 5 | 5 | |
| 2 | B | AM | 10 | 0 | 5 | -1 | 10 | -3 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 3 | B | SG 0.95 OG 0.05 | 10 | -1 | 5 | 5 | 10 | -1 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 6 | A | SG 0.5 AM 0.4 OG 0.1 | 10 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | 5 | 5 | 5 | 5 | |
| 9 | B | AM | 10 | -1 | 5 | 5 | 10 | -1 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 14 | B | AM | 0 | -1 | 5 | 5 | 10 | -2 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 15 | A | SG 0.3 OG 0.2 AM 0.5 | 10 | -1 | 5 | 5 | 10 | -1 | 5 | 0 | 5 | 5 | 5 | 5 | 5 | |
| 22 | B | AM 0.5 SG 0.47 OG 0.03 | 0 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | -2 | 5 | 5 | |
| 25 | B | SG 0.5 AM 0.25 OG 0.1 | 10 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | -10 | 5 | 5 | 5 | |
| 27 | B | SG 0.7 OG 0.1 AM 0.2 | 10 | -1 | 5 | 5 | 10 | 5 | 5 | 0 | 5 | 5 | 5 | 5 | 5 | |

Table S3. Confusion matrix and classwise accuracy indicators of the land cover scenario. Overall accuracy and total pixel count are marked in bold. Where no dimension is indicated, quantities are in pixels.

| Cohen's Kappa: 0.834 | Alkali Grassland (1530) | Non-Alkali Wetland | Artificial Surface | Trees/Shrubs | User's Accuracy [%] | Pixel Count | Quantity Deviation [pix] | Allocation Deviation [pix] | F1- Score [%] |
|-----------------------------|------------------------------------|-------------------------------|-------------------------------|---------------------|--------------------------------|--------------------|-------------------------------------|---------------------------------------|--------------------------|
| Alkali grassland (1530) | 76,011 | 1287 | 221 | 82 | 98.0 | 77,601 | 5420 | 3180 | 95 |
| Non-alkali wetland | 5498 | 15,421 | | 2220 | 66.6 | 23,139 | 5850 | 3736 | 76 |
| Artificial surface | 1012 | 192 | 18,411 | 1339 | 87.9 | 20,954 | 2317 | 452 | 93 |
| Trees/shrubs | 500 | 389 | 5 | 9919 | 91.7 | 10,813 | 2747 | 1788 | 81 |
| Producer's accuracy [%] | 91.6 | 89.2 | 98.8 | 73.1 | 90 | | Total | Total | |
| Pixel count | 83,021 | 17,289 | 18,637 | 13,560 | | 132,507 | 8167 | 4578 | |

Table S4. Confusion matrix and classwise accuracy indicators of the main “vegetation categories” scenario. Overall accuracy and total pixel count are marked in bold. Where no dimension is indicated, quantities are in pixels.

| Cohen's Kappa 0.625 | Loess Grassland | Alkali Short Steppe | Alkali Open Sward | Alkali Meadow | Carex | Juncus | Non-Alkali Wetland | Vegetation Background | User's Accuracy [%] | Pixel Count | Quantity Deviation | Allocation Deviation | F1-Score [%] |
|----------------------------|------------------------|----------------------------|--------------------------|----------------------|--------------|---------------|---------------------------|------------------------------|----------------------------|--------------------|---------------------------|-----------------------------|---------------------|
| Loess Grassland | 1722 | 499 | | 375 | | | | 339 | 58.7 | 2935 | 355 | 1716 | 62 |
| Alkali Short Steppe | 246 | 12560 | 2664 | 2050 | 341 | 3 | | 293 | 69.2 | 18157 | 1079 | 9036 | 71 |
| Alkali Open Sward | 34 | 2170 | 5380 | 206 | | | | 454 | 65.3 | 8244 | 1848 | 5728 | 59 |
| Alkali Meadow | 47 | 285 | 154 | 26486 | 1093 | 25 | 13 | 1169 | 90.5 | 29272 | 8281 | 5572 | 79 |
| Carex | | | | 796 | 2423 | 15 | 57 | 6 | 73.5 | 3297 | 1410 | 1748 | 61 |
| Juncus | | | | 1646 | 222 | 4422 | 201 | 661 | 61.8 | 7152 | 1989 | 1482 | 72 |
| Non-alkali Wetland | 1 | 676 | 771 | 1810 | 258 | 5 | 8450 | 719 | 66.6 | 12,690 | 3325 | 1830 | 77 |
| Vegetation Background | 530 | 888 | 1123 | 4184 | 370 | 693 | 644 | 5146 | 37.9 | 13,578 | 4791 | 7282 | 46 |
| Producer's Accuracy [%] | 66.7 | 73.5 | 53.3 | 70.5 | 51.5 | 85.6 | 90.2 | 58.6 | 71 | | Total | Total | |
| Pixel Count | 2580 | 17,078 | 10,092 | 37,553 | 4707 | 5163 | 9365 | 8787 | | 95,325 | 11,539 | 17,197 | |

Table S5. Confusion matrix and classwise accuracy indicators of the association scenario. Overall accuracy and total pixel count are marked in bold. Where no dimension is indicated, quantities are in pixels.

| Cohen's Kappa 0.579 | Achilleo–Festucetum | Artemisio–Festucetum | Limonio–Festucetum | Camphorosmetum Annue | Pholiuro–Plantaginetum | Puccinellion Limnsae | Secondary Saline Grassland | Agrostio–Alopecuretum | Agrostio–Beckmannietum | Agrostio–Glycerietum | Carex | Juncus | Glyceria Maxima | Phragmites Australis | Typha | Vegetation Background | User's Accuracy [%] | Pixel Count | Quantity Deviation | Allocation Deviation | F1-Score [%] |
|----------------------------|---------------------|----------------------|--------------------|----------------------|------------------------|----------------------|----------------------------|-----------------------|------------------------|----------------------|-------|--------|-----------------|----------------------|-------|-----------------------|---------------------|---------------|--------------------|----------------------|--------------|
| Achilleo–Festucetum | 8288 | 433 | | 116 | 215 | 54 | 606 | 1788 | 12 | | | | | | | 34 | 71.8 | 11546 | 2435 | 6516 | 65 |
| Artemisio–Festucetum | 1692 | 2125 | 1 | 52 | 421 | 96 | 846 | 30 | | | | | | | | 519 | 36.8 | 5782 | 2702 | 1910 | 48 |
| Limonio–Festucetum | 73 | 2 | 37 | | | | | 249 | 4 | | 329 | | | | | 135 | 4.5 | 829 | 784 | 16 | 8 |
| Camphorosmetum Annue | 360 | 6 | | 301 | 97 | 202 | 4 | | 1 | | | | | | | 17 | 30.5 | 988 | 349 | 676 | 37 |
| Pholiuro–Plantaginetum | 500 | 7 | | 30 | 1115 | 30 | 288 | 14 | 11 | | | | | | | 6 | 55.7 | 2001 | 264 | 1772 | 52 |
| Puccinellion Limosae | 577 | 184 | | 57 | 16 | 1223 | 315 | 374 | 3 | | | | | | | 79 | 43.2 | 2828 | 868 | 1474 | 51 |
| Secondary Saline Grassland | 1303 | 210 | | 70 | 129 | 319 | 258 | 109 | | | | | | | | 29 | 10.6 | 2427 | 670 | 4338 | 9 |
| Agrostio–Alopecuretum | 272 | 10 | 4 | 1 | 24 | 1 | 31 | 16235 | 339 | 387 | 871 | | 16 | | | 468 | 87 | 18659 | 6116 | 4848 | 75 |
| Agrostio–Beckmannietum | | | 1 | | | | | 2837 | 244 | 3 | 1014 | 62 | 1726 | | | 214 | 4 | 6101 | 4000 | 3714 | 4 |
| Agrostio–Glycerietum | | | | | | | | 2 | | 916 | 10 | | 23 | | 1 | 492 | 63.4 | 1444 | 185 | 1056 | 60 |
| Carex | | | | | | | | 45 | 40 | 180 | 2814 | 62 | 150 | | 3 | 3 | 85.4 | 3297 | 2158 | 966 | 64 |
| Juncus | | | | | | | | | 1201 | | 391 | 4443 | 279 | 10 | 146 | 682 | 62.1 | 7152 | 1484 | 2450 | 69 |
| Glyceria maxima | | | | | | | | | 8 | 138 | 11 | 13 | 2896 | | | 2 | 94.4 | 3068 | 2409 | 344 | 68 |
| Phragmites australis | | | | | | | | | | | | | | 6975 | | 9 | 99.9 | 6984 | 6 | 18 | 100 |
| Typha | | | | | | | | | | | | 6 | | | 1181 | 3 | 99.2 | 1190 | 870 | 18 | 73 |
| Vegetation Background | 916 | 103 | 2 | 12 | 248 | 35 | 749 | 3092 | 238 | 5 | 15 | 1082 | 387 | 7 | 729 | 6686 | 46.7 | 14,306 | 4928 | 5384 | 56 |
| Producer's Accuracy [%] | 59.3 | 69.0 | 82.2 | 47.1 | 49.2 | 62.4 | 8.3 | 65.5 | 11.6 | 56.2 | 51.6 | 78.4 | 52.9 | 99.8 | 57.3 | 71.3 | 63 | | Total | Total | |
| Pixel Count | 13,981 | 3080 | 45 | 639 | 2265 | 1960 | 3097 | 24,775 | 2101 | 1629 | 5455 | 5668 | 5477 | 6922 | 2060 | 9378 | | 88,602 | 15,115 | 17750 | |

Table S6. Confusion matrix and classwise accuracy indicators of the anthropogenic features and disturbances scenario. Overall accuracy and total pixel count are marked in bold. Where no dimension is indicated, quantities are in pixels. Non-alkali wetlands were added as an outgroup besides the vegetation background.

| Cohen's Kappa 0.773 | Non-Alkali Wetland | Weeds | Unpaved Roads | Paved Roads | Buildings | Vegetation Background | User's Accuracy [%] | Pixel Count | Quantity Deviation | Allocation Deviation | F1-Score [%] |
|----------------------------|---------------------------|--------------|----------------------|--------------------|------------------|------------------------------|----------------------------|--------------------|---------------------------|-----------------------------|---------------------|
| Non-alkali Wetland | 8733 | 308 | 458 | | | 3191 | 68.8 | 12690 | 2621 | 2672 | 77 |
| Weeds | 10 | 3405 | 23 | 1 | 5 | 1090 | 75.1 | 4534 | 852 | 2258 | 69 |
| Unpaved Roads | 39 | 1314 | 4751 | 40 | | 3716 | 48.2 | 9860 | 3747 | 2724 | 59 |
| Paved Roads | 1 | 8 | | 8155 | 2 | | 99.9 | 8166 | 30 | 22 | 100 |
| Buildings | | 9 | 2 | | 8435 | | 99.9 | 8446 | 4 | 14 | 100 |
| Vegetation Background | 1286 | 342 | 879 | | | 31,646 | 92.7 | 31,646 | 5490 | 5014 | 86 |
| Producer's Accuracy [%] | 86.7 | 63.2 | 77.7 | 99.5 | 99.9 | 79.8 | 84 | | Total | Total | |
| Pixel Count | 100,069 | 5386 | 6113 | 8196 | 8442 | 39,643 | | 77,849 | 6372 | 6352 | |

Table S7. Confusion matrix and classwise accuracy indicators of the tree/shrub scenario. Overall accuracy and total pixel count are marked in bold. Where no dimension is indicated, quantities are in pixels. Non-alkali wetlands were added as an outgroup besides the vegetation background.

| Cohen's Kappa 0.797 | Non-Alkali Wetland | Invasive Tree/Shrub | Native Tree/Shrub | Building | Vegetation Background | User's Accuracy [%] | Pixel Count | Quantity Deviation | Allocation Deviation | F1-Score [%] |
|----------------------------|-------------------------------|--------------------------------|------------------------------|-----------------|----------------------------------|--------------------------------|------------------------|-------------------------------|---------------------------------|---------------------|
| Non-alkali Wetland | 6917 | 2104 | | | 3669 | 54.5 | 12,690 | 5397 | 752 | 69 |
| Invasive Tree/Shrub | 86 | 5930 | 930 | | | 85.4 | 6946 | 2172 | 2032 | 74 |
| Native Tree/Shrub | 183 | 1057 | 2325 | | 312 | 60.1 | 3867 | 599 | 1886 | 65 |
| Building | | 27 | 13 | 8406 | | 99.5 | 8446 | 40 | 0 | 100 |
| Vegetation Background | 7293 | 9118 | 3268 | 8406 | 30098 | 99.6 | 3025 | 3864 | 214 | |
| Producer's Accuracy [%] | 94.8 | 65.0 | 71.1 | 100 | 88.3 | 88 | | Total | Total | |
| Pixel Count | 7293 | 9118 | 3268 | 8406 | 34069 | | 62,154 | 6036 | 2442 | |