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Significance of the local anthropogenic effects in the dynamics of wild geese wintering on the Ramsar Site Lakes by Tata (Wetland City Tata)

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Abstract The Old Lake of Tata, an important wild goose roosting site in Central Europe, is unique in its location being in the middle of a city with a population of 24,000. Consequently, the site is subject to intensive human disturbances. Goose migration and wintering on the lake was studied for over 37 years (1984–2021). In addition to weather, hydrological, and feeding conditions, particular attention was focused on human influences (which were deemed generally disruptive, but also beneficial in some cases) that can induce significant changes in the population dynamics of the 30,000–50,000 wild geese from 13 species wintering here. Almost without exception, the largest observed changes in the abundance of wild geese roosting overnight on the Old Lake are due to anthropogenic effects. In the majority of cases, the most significant population changes are due to impacts associated with the operation and upkeep of the lake and the New Year's Eve fireworks. As a result, the winter operation of the Old Lake has been regulated by the Wild Goose Preference Mode since 2011, and the City of Tata has banned the use of fireworks during the winter period since 2018. Consequently, the conditions for wild goose migration have improved significantly. However, the situation of the Old Lake is still quite fragile and more conservation measures are needed to protect it further.

Keywords: wild goose migration, anthropogenic impacts, Tata, Ramsar

Összefoglalás Közép-Európa egyik legfontosabb vadlúd gyülekezőhelyének számító tatai Öreg-tó világviszonylatban is egyedülálló abban a tekintetben, hogy egy 24 000 lakosú város közepén helyezkedik el. Ebből adódóan rengeteg emberi zavaró hatás éri. A tavon zajló lúdvonulást és telelést 37 éven át (1984–2021 között) vizsgáltuk. Az időjárási, hidrológiai, táplálkozási körülmények mellett különös figyelmet fordítottunk azokra az emberi (általában zavaró, de néhány esetben kedvező) hatásokra, amelyek az itt telelő 13 fajba tartozó 30 000–50 000 vadlúd dinamikájában jelentős változásokat képesek indukálni. Az Öreg-tavon éjszakázó vadludak mennyiségében megfigyelt legnagyobb ütemű változások hátterében szinte kivétel nélkül valamilyen antropogén hatás áll. Az esetek többségében a tó üzemeltetésével összefüggő hatások, illetve a szilveszteri tűzijátékok okozzák a legjelentősebb állományváltozásokat. Ebből kifolyólag az Öreg-tó téli üzemeltetésében 2011-től bevezették a vadludakat preferáló üzemmódot, 2018-tól pedig Tata városa megtiltotta a tűzijátékok téli időszakban történő használatát. Mindezek eredményeként máris jelentősen javultak a vadlúdvonulás feltételei. Az Öreg-tó azonban még így is meglehetősen sérülékeny helyzetben van, aminek csökkentése érdekében további természetvédelmi intézkedések szükségesek.

Kulcsszavak: vadlúd vándorlás, antropogén hatás, Tata, Ramsar

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Introduction

The Old Lake of Tata is one of the most important wild goose s sites in the Pannonian region. Few Ramsar wetland areas in the world are subject to such a wide range of anthropogenic effects. This is due to its special location, which is practically in the middle of a city. The geese roosting here are subject to a number of human influences that often cause them to rouse en masse (Musicz 1992, 1998), and may even result in tens of thousands of geese leaving the wintering area in a matter of days (Musicz 2018a, 2018b). At the same time, there are also opposite effects that positively influence the arrival of geese and their stay in the area. From a nature conservation point of view, it is particularly important to explore both positive and negative anthropogenic factors affecting the population dynamics of wild geese.

Several studies have emphasized the importance of the Old Lake in Tata on wild goose migration in Europe (Sterbetz 1976, Fog 1982, Lebret 1982, Philippona 1983, Van den Bergh & Philippona 1986, Musicz 1990, 2014, Faragó *et al.* 1991, Faragó 1995, 1996). The Old Lake is among the top five wild goose roosting sites in Hungary in terms of annual maximum numbers of wild geese, but it is also where the highest numbers of wild geese in Hungary were observed in the winter of 2011/2012 and 2013/2014 (Faragó 2012, 2015).

Considering the effects influencing the migration dynamics of wild geese, publications have focused mainly on weather factors, climate change, and feeding conditions, while less attention has been paid to anthropogenic effects. Research on anthropogenic effects has largely been conducted on hunting aspects (Faragó 1982, 1995, Ebbinge 1985, 1991) and on correlations with agriculture (Fox *et al.* 2005, Rosin *et al.* 2012).

Few studies have addressed the relationship between water level fluctuations in wetlands and the migratory activity of different aquatic species. For the Hungarian-Slovakian section of the Danube, a study by Faragó and Hangya (2012) showed a clear correlation between water levels and bird numbers. In the case of artificially maintained and protected wetlands influenced by sluice systems, such as the Old Lake in Tata, optimal water level determination is of key importance from a nature conservation point of view, as noted by Musicz (1998, 2018a).

Relatively few publications address the conservation aspects of fireworks, despite the increasing human impact on bird populations and protected areas (Shamoun-Baranes *et al.* 2011, Karolewski *et al.* 2014). The use of fireworks, especially on New Year's Eve, is considered to be a dominant anthropogenic impact. The practice likely causes adverse changes in an increasing number of wetlands. The Old Lake of Tata is in a particularly vulnerable situation in this respect. Fireworks disturbances have occasionally displaced tens of thousands of wild geese from wetlands covered by the Ramsar Convention (Musicz 2018a, 2018b).

This study aims to answer the question of whether the two anthropogenic factors (lake management and fireworks) could be responsible for the sudden population fluctuations and regional dispersal of tens of thousands of wintering wild geese on the Old Lake of Tata.

Materials and Methods

Territory

The lakes by the Tata Ramsar site are located in the northwestern part of Hungary, in the long valley of the Által-ér river. A series of fish ponds, interspersed with karst springs, meadows, and ploughland comprises the site. The oldest wetland in the 1,897 hectare area (listed since 1989) is the Old Lake (N 47.64° E 18.33° N). With a water surface of 2.2 km^2, the lake is a priority aggregation site for northern wild goose species arriving to the Pannonian region *(Figure 1)*.

The Old Lake of Tata is the only Ramsar site in Europe that is almost completely encircled by a town. Although the lake is surrounded by monuments and houses, it provides a traditional resting place for tens of thousands of wild geese. It is one of the oldest fishponds in Hungary, with a dam that can be traced back to Roman times, a royal castle built in the 14th century, and a sluice system built in the 18th century *(Figure 2)*. The lake, a major tourist destination and the site of numerous festivals, is drained and fished every autumn.

Figure 1. Location of the Old Lake of Tata Ramsar site in Hungary
1. ábra A tatai Öreg-tó Ramsari terület földrajzi elhelyezkedése Magyarországon

Figure 2. Roosting wild geese on the Old Lake surrounded by the town of Tata (Photo: J. Milinte)
2. ábra Gyülekező vadludak a város által körülvett Öreg-tavon (Fotó: Milinte J.)

Studied wild goose species

Out of the 13 species of wild geese recorded to date, the Greater White-fronted Goose *(Anser albifrons)*, the Tundra Bean Goose *(Anser serrirostris)*, and the Greylag Goose *(Anser anser)* are considered to be the most common species at the Old Lake of Tata. The species usually occur or have occurred in groups of thousands or even tens of thousands. As our studies have focused on exploring the migratory dynamics of anthropogenic influences associated with large goose populations, our findings are primarily relevant to these species of geese. The combined share of the 10 other wild goose species occurring at the Old Lake of Tata comprises less than 1–2% of the population.

Greater White-fronted Goose

In the 37-year period under study, the Greater White-fronted Goose arrived to Hungary in the winter of 1989/1990 in the smallest numbers (maximum 15,100 individuals). In the winter of 2019/2020, the number of individuals wintering in Hungary exceeded 200,000 (Faragó 2020), while in the winter of 2020/2021 it was 265,000 (Faragó 2021c).

Until the mid-1990s, the species occurred in very small numbers (typically in the few hundreds) in the Tata area, constituting only 2–5% of the wild goose populations (Musicz 1990, 1998). It has since spectacularly replaced the role of the formerly dominant Tundra

Bean Goose at the Old Lake, and now accounts for at least 95% of the wintering wild goose masses in Tata (Musicz 2016). In recent years, the Old Lake has become a major aggregation site for the Greater White-fronted Goose in Hungary. The maximum wintering population on the lake exceeded 55,000 by 2020 (Faragó 2021c, Pellinger *et al.* 2021).

Greylag Goose

The Hungarian breeding population of Greylag Goose is estimated to be at least 2,000 pairs (Pellinger 2009, Faragó *et al.* 2016). In the 2010s, peak numbers of between 25,000 and 50,000 individuals were observed during migration periods in Hungary, usually in October or November (Faragó 2011, 2017, 2018, Faragó *et al.* 2016).

The Greylag Goose generally migrates through the Old Lake of Tata in small numbers. In the 1980s and 1990s, groups of fewer than 100 individuals were usually observed, followed by increasing numbers of 200–400 individuals since 1998 (Musicz 2014, 2016, Musicz *et al.* 2016). The Greylag Goose has been present on the lake in numbers that have occasionally reached several thousand specimens since the winter of 2007/2008, but typically only for shorter periods (maximum 2,500 specimens – Pellinger *et al.* 2021).

Tundra Bean Goose

The Tundra Bean Goose has been listed as a separate species in the IOC World Bird List since 2019 (Gill *et al.* 2021), it was previously part of the Bean Goose species as the tundra subspecies of the Bean Goose *(A. f. rossicus)*, together with the taiga subspecies *(A. f. fabalis)* and several other species. In this paper, we follow the IOC and Hungarian nomenclature. Our findings include the results for the former species *A. fabalis.*

The wintering population of the Tundra Bean Goose in Hungary peaked in November 1984 with 196,750 specimens (Faragó 1996, 2010, Faragó & Pellinger 2009), but in 1999 the maximum was less than 60,000 individuals and since 2012 it has not reached 10,000 individuals (Faragó 2014, 2015, 2016, 2017, Faragó 2021a, Faragó *et al.* 2017). In the winter of 2017/2018, only 362 individuals were recorded during January (Faragó 2021b). In parallel with the collapse of the wintering population in the Pannonian region, the numbers in southwestern Poland have exploded over the last decades (Ławicki *et al.* 2010a, 2010b, Wuczyński *et al.* 2012).

In line with the national trend, the Old Lake of Tata has also seen dramatic Tundra Bean Goose declines over the past two decades (Musicz 2016, 2018a, Musicz *et al.* 2016). In the winter of 1986/1987 the Old Lake saw a peak abundance 36,400 specimens; by the winter of 2019/2020, this number had dwindled to a mere 62.

A close relationship and area shift between the line of Lake Fertő – Kis-Balaton – western basin of Lake Balaton – Dráva river basin and the line of Old Lake – Lake Velence – Dinnyési-Fertő – Soponyai fish ponds – lower Danube for the wintering of the Bean Geese in Hungary is well known (Faragó & Pellinger 2009).

Frequency of monitoring

A complete survey of the wild goose population was conducted on more than 2,000 monitoring days between 1 October and 31 March 1984–2021 (during 37 wintering seasons) at the Old Lake of Tata. On average, counting was completed 2–3 days per week, but during periods of unusual winter water levels in the Old Lake and during fireworks around New Year's Eve, observations were conducted on a daily basis to take rapid population changes into account. Surveys were mainly performed during the mornings, but we also monitored flocks of geese arriving to the lake during the day and groups moving around the town, and occasionally observed the area around the Old Lake in the evening and at night. During the days around New Year's Eve, we recorded fireworks usage and, concurrently, the number of geese leaving the lake as well as the direction of their flight.

Examination of particularly rapid and significant stock fluctuations

We focused our analyses on particularly rapid and intense population changes where the number of wild geese roosting on the Old Lake increased or decreased by tens of thousands of individuals within a few days. Among the population declines, we examined 10 cases where the wild goose population declined by at least 80% within a few (<10) days and where the decline was as large as 10,000 individuals. Over the last 37 years, there have been several cases where the absolute decline exceeded 10,000. Cases where the absolute decline in numbers was very large, but the rate of decline was smaller in terms of rates, are not described. For example, in December 2020, the number of wild geese decreased from 50,500 to 17,800 in four days, but this decrease of 32,700 individuals did not reach 65%. In our study, we analysed the 10 fastest population declines. A more detailed case study is presented to describe the circumstances of the highest rate of population decline between 24 December 2008 and 3 January 2009.

Among the population increases, we analysed 10 cases where the number of geese overnighting at the site increased at least threefold within a few (<10) days, and where the increase exceeded 15,000 individuals. The circumstances of the fastest rate of population increase between 1 November 2017 and 7 November 2017 are presented in a more detailed case study.

In all cases, we analysed weather conditions in Hungary and Europe, the results of synchronous observation of wintering sites in Hungary in a given month (and in previous and subsequent months), and focused on the current state of the Old Lake of Tata (water level, possible ice cover), local anthropogenic influences, and the feeding sites. All factors have been considered in an attempt to identify the natural and anthropogenic causes of the large decline in wintering wild goose numbers.

Examination of meteorological factors

From the whole 37-year period, the meteorological data provided by the Hungarian Meteorological Service was analysed for the Tata region and categorized by months. The data included precipitation amount, the number of frosty days, the number of severe days

(with minimum temperatures below –10 °C), coldest temperatures, the number of days with wind speeds above 15.0 m/s (stormy), the number of days with snow cover, and monthly maximum snow depth. We have considered European weather fronts, the unusually mild mid-winter periods, and in some cases, we even considered nearby earthquakes.

Investigating other wild goose roosting sites

Monthly standardized observations (Faragó 1995, 1996, 1998, 2008a, 2008b, 2010) covering 21 of the most important wild goose roosting sites in Hungary, conducted since 1984 within the framework of Hungarian Wild Goose Monitoring, provided the opportunity to monitor the distribution, spatio-temporal patterns, and redistribution of wild goose populations. These synchronous counts of waterfowl take place once in the middle of the month, and they naturally provide limited opportunities for comparison with the much more frequent monitoring surveys in Tata. However, in the case of a major population change in Tata, information from nearby wintering areas was exchanged orally as well (e.g. the Ipoly Valley, Slovakian areas, Dinnyési-Fertő, Csákvári-rét).

Increased attention has been paid to the accurate population assessment of wild geese roosting in nearby (<15 km) ponds, as in recent years it has become clear that the Old Lake of Tata has an intensive migratory dynamic link, mainly with the ponds of Ferencmajor, the Lake Asszony, and increasingly also with Lake Boldogasszonyi and the nearby Danube sections. The lakes, pond systems, and Danube stretches around Tata and in fact form a coherent wintering region for wild geese (Musicz 2021, Pellinger *et al.* 2021).

Use of unique tagging data

The ringing data supplied by the Hungarian Centre for Bird Ringing also provided important input for the interpretation of the extremely rapid population declines. Data with local (Tata and Komárom-Esztergom County) relevance were selected. In the case of the Greater White-fronted Goose, 486 observations (data records) of 54 ringed specimens were analysed up to 2018. For the Greylag Goose, we studied the records of 57 ringed individuals with 1,315 local references, while for the Bean Goose, we reviewed the records of 54 specimens ringed abroad with 280 occurrence records in Tata and its region. Ringing records that occurred within a few weeks time (max. 1 month) of the occurrence date in the Tata area in other parts of Hungary or in other European countries are of primary importance for the present study. Those cases are especially valuable where only a few days elapsed between two observations because these could indeed provide meaningful information concerning rapid population changes.

The number of wild geese with a *neck ring* has increased in Europe since 2010, so the most relevant data for our analysis are from the last 5–8 years.

Particularly valuable information for the spatio-temporal processes of major population fluctuations was provided by GPS-equipped Greater White-fronted Goose and Greylag Goose that were already in, arriving, or departing from the Tata area at the time of rapid population changes. In the case of Tundra Bean Goose, no tagged specimens have been found in Tata in recent years.

Anthropogenic impact assessment

The anthropogenic influences on the wintering conditions of wild geese are particularly diverse and intense in the Old Lake area due to its proximity to the city. Over the past 37 years, we have observed a variety of disturbance factors (Musicz 1992, 1998, 2018a). The impacts associated with the operation and upkeep of the lake (i.e. the artificial shaping of the water level) and the disturbance caused by fireworks are of particular significance. In addition, there are intermittent or occasional disturbances from kayakers, ice sailors, ice skaters, bird photographers, visitors walking into the mud of the drained lake, fishing boats, small aircraft flying low into the lake airspace, drones, and paragliders.

A separate group of disturbances are the various light effects that, unfortunately, are increasingly common in the Old Lake area. Street lights and decorative lights on the lakeshore, vehicle headlights, and the effects of light from people wearing headlamps are becoming increasingly significant disturbances. Larger scale disturbances include, in particular, the proliferation of greenfield industrial projects, road construction, the opening of gravel pits, and the large number of wind farms. Waterfowl hunting has been banned at the Old Lake since 1993 and is, therefore, not covered in this article.

Analysis of water level data and other lake characteristics

The prevailing water level and ice cover of the Old Lake is an important environmental factor for wild geese wintering in Tata. Winter water level data and other status characteristics for the last 37 years were provided by the North-Transdanubian Water Management Directorate, but were also supplemented by our own observations (occasional maps of the ice hummocks in different parts of the lake).

Fireworks activity testing

Among the environmental factors affecting wintering wild geese in Tata, the disturbance caused by fireworks at the end of the year is by far the most important. These disturbances were detected partly by field monitoring and partly by a webcam installed at the Old Lake from mid-November to mid-February 2017. This was supplemented in 2018 by a webcam on the observation tower on Kálvária Hill near the lake, which provides additional 24-hour surveillance throughout the year. The webcams, operated by a solar panel, provide real-time continuous monitoring, but also the possibility to retrospectively monitor the previous 6-hour period.

Statistical methods

For data processing and statistical interpretation Past v3.17 software was used (Hammer *et al*. 2001).

Results and Discussion

Over the past 37 years, the annual maximum number of wintering wild geese on the Old Lake of Tata has varied widely. There were years (1989/1990, 1993/1994) when the maximum number of wild geese on the Old Lake was less than 5,000, while in December 2013, the number exceeded 53,000 and reached 55,000 in November 2020. In the 1980s and 1990s, Bean Goose was clearly the dominant species at Old Lake until the autumn of 2000, when a national reversal occurred: the Greater White-fronted Goose became the dominant species. This natural reversal had also occurred nine years earlier. In the following five years, the Tundra Bean Goose population culminated in higher numbers, but from 2006 onwards, the Greater White-fronted Goose became the dominant species, a process that is still continuing today. In the meantime, the proportion of Greylag Geese has fluctuated between 1% and 5%. By 2020, the proportion of Tundra Bean Goose in the population had fallen to just a few thousandths *(Figure 3)*.

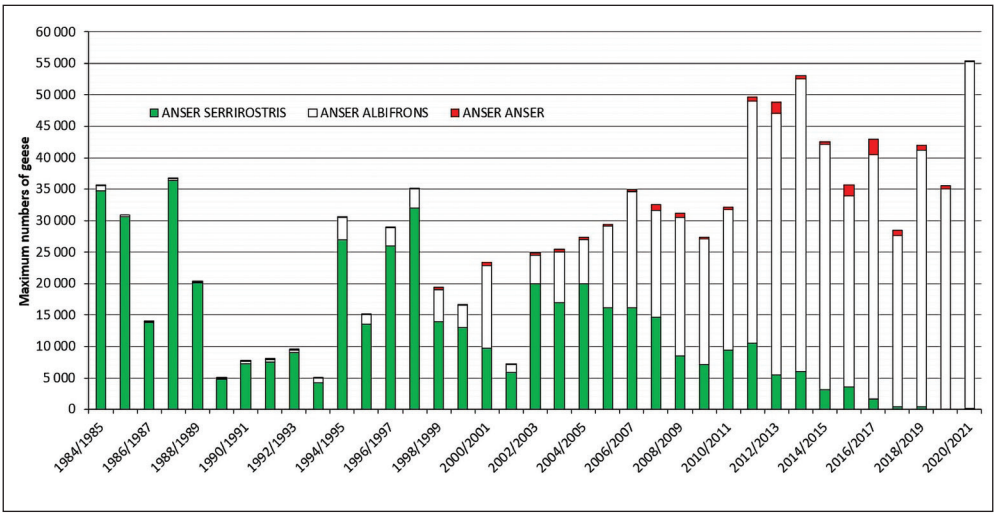

Figure 3. Maximum wintering number of wild geese on the Old Lake of Tata between 1984 and 2021
3. ábra A vadludak maximális telelő mennyisége a tatai Öreg-tavon 1984–2021 között

Several fluctuations in the dynamics of geese are usually observed each wintering season, both before and after the culmination. These changes, which are mostly due to natural migration ecology and European weather fronts, are spectacularly complemented by sudden population declines, and often the culmination phase is also marked by such sudden inflows. On several occasions in recent years, tens of thousands of wild geese have arrived to the Old Lake in this manner.

Effects of water management and pond management on the migration dynamics of geese

The Old Lake is usually in a drained state in winter, with a large, shallow water surface, providing an ideal resting place for the masses of wild geese that come here. According to many years of practical experience, this ideal condition can be observed in the 30–40 cm zone below the '0' graduation (127.55 m.a.s.l.) on the water level gauge near the Vecserei sluice, which is the basis for the official water level data of the Old Lake. At this water level, the total lake basin of 201.5 ha is covered by water for about 120 ha, while the remaining area is a dry land, rising from 10–30 cm deep shallow water. The much lower or much higher water levels, which are radically different from the 'natural' state, are almost without exception caused by human influence and have already been interpreted as anthropogenic effects.

Over the past decades, the water levels in the Old Lake have fluctuated within very wide ranges during the wintering periods from October to March. Unusually low water levels were recorded in the winters of 1984/1985, 1994/1995, and 1995/1996, while in November 1993 or the winter of 2010/2011, water levels were much higher than the long-term average. The 37-year average of December water levels is –48 cm, but there was a month with water levels 1 m lower (1984) and 1 m higher (2010) than that. Similar extremes were observed in January, February, and March *(Figure 4)*.

The significantly differing water levels have proven to be a significant ecological factor over the past decades and can, to a significant extent, determine the temporary reduction or even increase of the role of the Old Lake in migration.

By analysing the monthly water level values and the corresponding monthly geese maxima at the Old Lake, we found that the abundance of geese during October and November is inversely proportional to the water levels. We did not find a strong correlation between the two, but in general, the lower the water level, the easier it is for larger flocks of wild geese

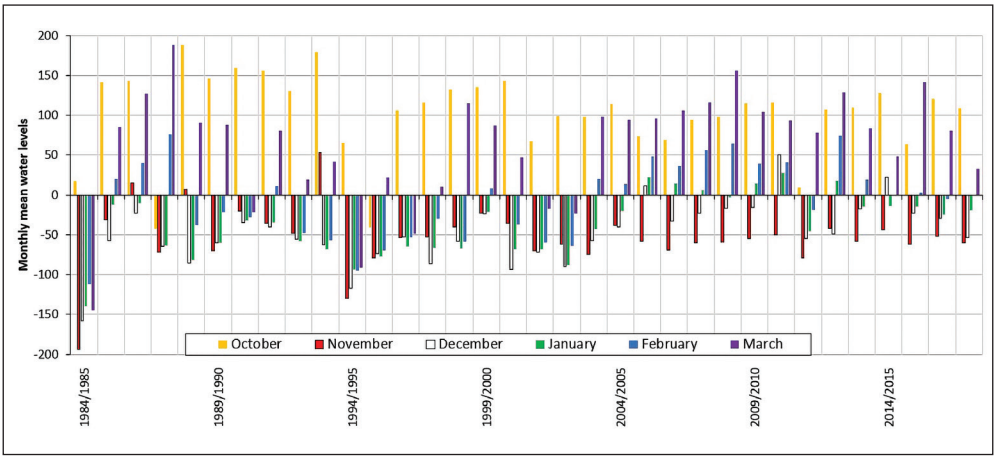

Figure 4. Monthly mean water levels in the winter seasons on the Old Lake Tata between 1984 and 2017
4. ábra A téli időszak havi közepes vízállás értékei a tatai Öreg-tavon 1984–2017 között

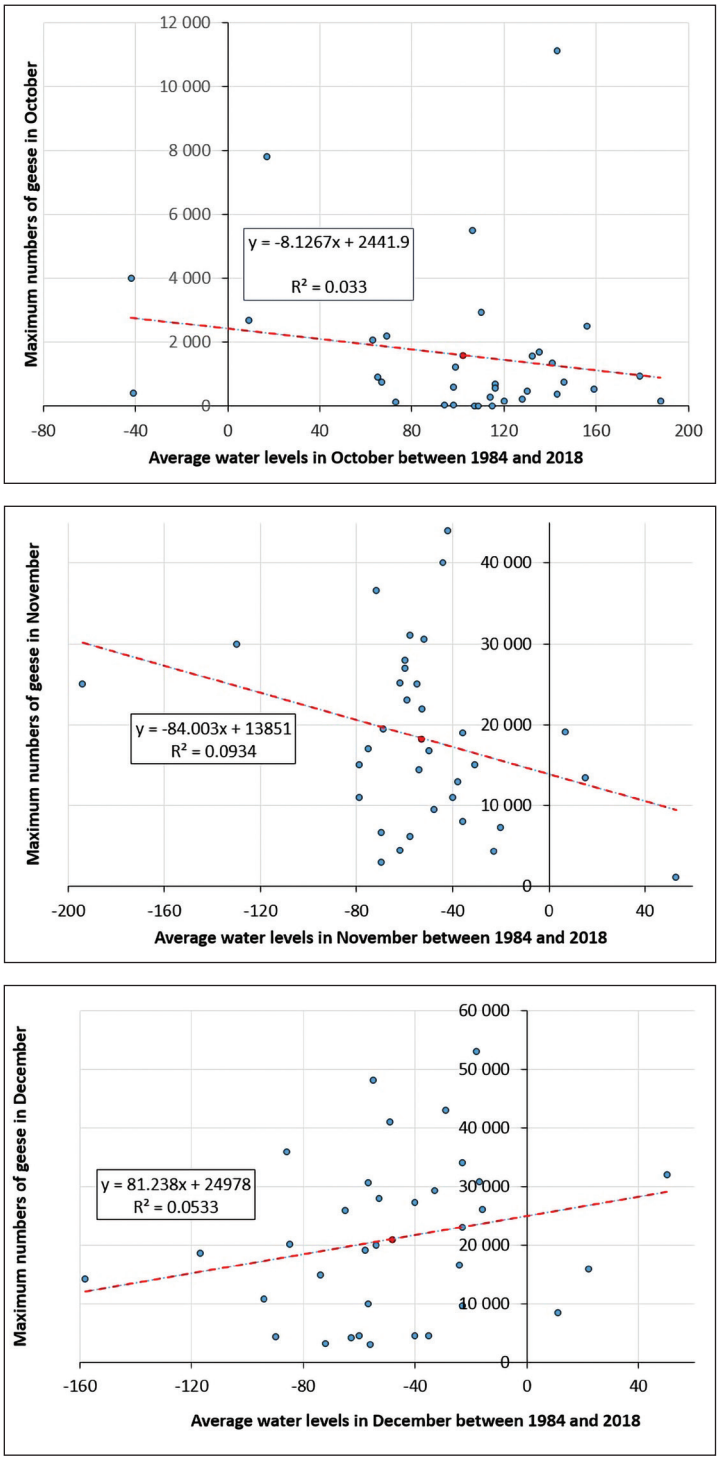

Figure 5. Relationship between the average monthly water depth of the Old Lake and the maximum monthly number of geese between 1984 and 2018 (October-November-December)

5. ábra Az Öreg-tó havi átlagos vízmélységének összefüggése a havi maximális lúdmennyiséggel 1984–2018 időközében (október-november-december hónapok)

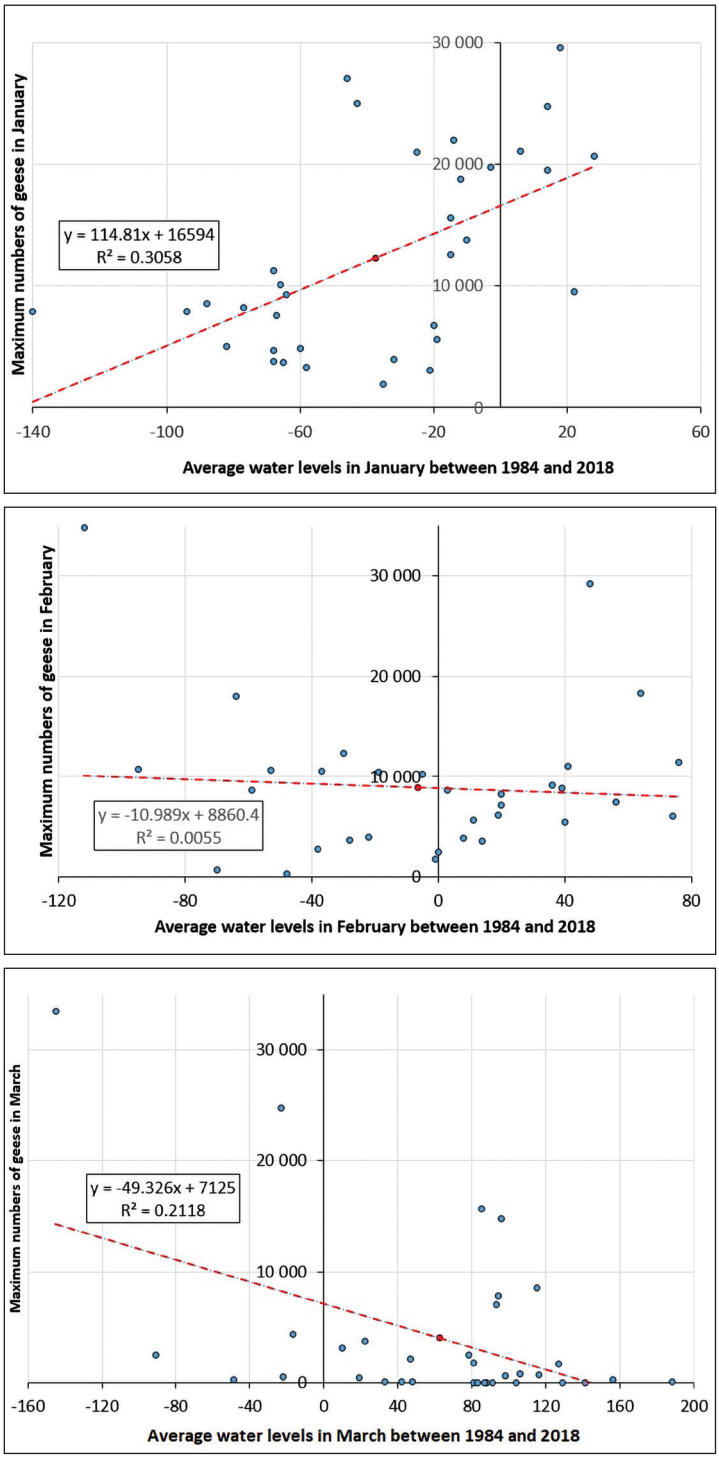

Figure 6. Relationship between the average monthly water depth of the Old Lake and the maximum monthly number of geese between 1984 and 2018 (January-February-March)

6. ábra Az Öreg-tó havi átlagos vízmélységének összefüggése a havi maximális lúdmennyiséggel 1984–2018 időközében (január-február-március hónapok)

to develop on the lake during the fall. It is interesting to note that the largest October goose peak (11,100 individuals) occurred in October 1986, when the monthly mean water level was 143 cm. It is also noteworthy that 30,000 geese were recorded during a November (1994) water level of –130 cm (i.e. extremely low) *(Figure 5)*.

In the months of December and January, the correlation between water levels and wild goose abundance is reversed and a linear relationship can be observed, although again with very low R^2 values. For optimal lake management, it can be argued that higher water levels should be aimed for allowing more wild geese to gather on the lake. To facilitate fishing, the lake bed is often almost completely dry in December *(Figures 5, 6)*.

In February and March, there is also an inverse correlation between monthly water level values and goose maxima *(Figure 6)*. Nevertheless, for the benefit of the wild geese, significantly lower water levels than the long-term averages would be desirable both in February and March.

Given the extremely wide range of water levels, there is a range (around 60 cm) that can be considered optimal for wild geese and other waterfowl. Out of the annual maximum abundances recorded over the past 37 years, 29 (i.e. almost 80% of the cases) fell within the –43 cm ± 30 cm water level range *(Figure 7)*.

At this water level range, about 60–130 hectares of the 201 hectare lake basin are covered by water of varying depths, but predominantly shallow (10–60 cm). Large reefs appear in the middle of the lake at these levels.

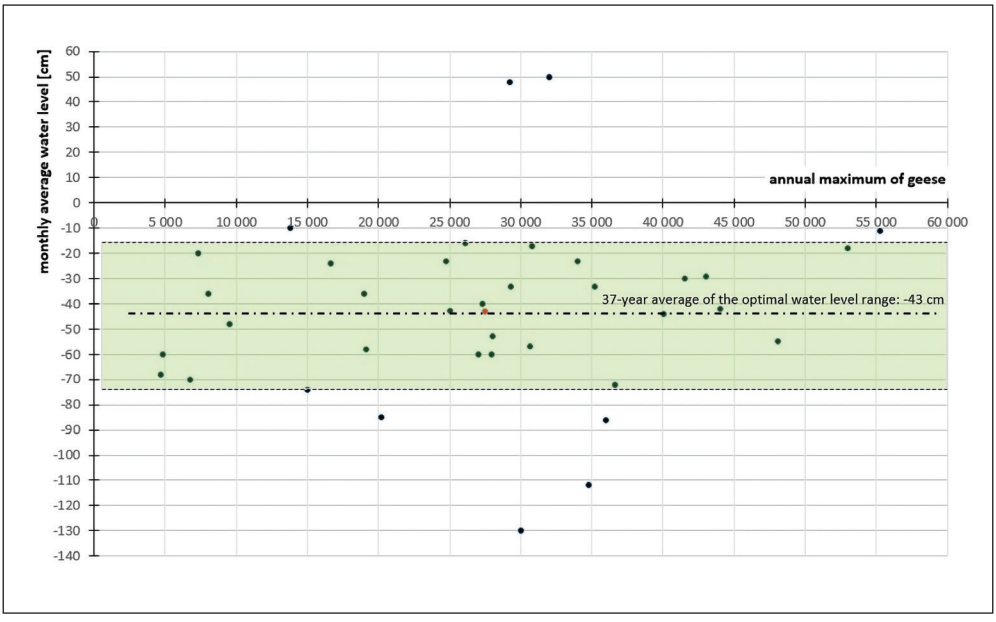

Figure 7. Relationship between the annual maximum of wild geese wintering on the Old Lake and the average monthly water levels between 1984 and 2021 (the optimal water level range is marked with a green field)

7. ábra A tatai Öreg-tavon telelő vadludak éves maximumainak összefüggése az adott havi közepes vízállás értékekkel 1984–2021 között (az optimális vízszint tartomány zöld mezővel jelölve)

Effects of fireworks on wild goose population dynamics

Given the fact that the Old Lake is located in the middle of a town with a population of around 24,000, fireworks in the town during the migration and wintering season (especially on New Year's Eve) are a major shock to the masses of wild geese resting on the lake. Tens of thousands of geese can flee from the lake overnight and recovery usually takes days, if not weeks. On New Year's Eves between 1984 and 1995, the average rate of abrupt decline was 42%; between 1995 and 2007 it was 44%; while between 2007 and 2017 there was an increasing frequency of events in which up to 90–100% of the geese assembled on the lake fled (Musicz 2018a, 2018b).

In some years, significant population shifts have occurred within the Pannonian region as a result of New Year's Eve fireworks. In particular, a close population dynamical link was observed between the Old Lake of Tata and the Dinnyési-Fertő (60 km) in 2005–2010. Between 26 December 2006 and 1 January 2007, the number of geese at the Old Lake decreased by about 24,000, while on the Dinnyési-Fertő the number increased by 29,000 on 1 January. In December 2017, a Greater White-fronted Goose ("Lilly17"), equipped with a satellite transmitter, stayed in the Tata area for 18 days. After the New Year's Eve fireworks on December 31, it fled to the Kiskunság saline lakes area, about 105 km to southeast (Musicz 2018b).

Fireworks do not always cause geese to flee long distances. Since the 2010s, wild geese have increasingly found temporary shelter in nearby fishponds (within 15 km) or sections of the Danube.

To reduce the disturbing effects of fireworks, the Municipality of Tata – on the initiative of citizens – created a municipal decree in October 2018 to ban the use of fireworks between 1 November and 28 February. The ban covers most of the inner area of Tata and some areas outside the city. This local ordinance is also a national example, as Tata is the first city in Hungary to restrict the use of fireworks for nature conservation purposes (protection of wintering wild geese on the lake) (Musicz 2018b).

To date, we have experienced three New Year's Eve events since the regulation was introduced, and these have been very positive, with an average of 85% of the overnight geese masses remaining on the lake during these three events, compared to an average of 31% in the previous ten years *(Figure 8)*.

The data for the 10 years before and three years after the ban are normally distributed according to the Shapiro-Wilk test. The F-test indicates no significant difference between the variances ($F=2.094$; $p=0.358$). According to the two-sample t-test applied on this basis, the means are significantly different ($t=3.0506$, $P=0.011$).

The vast majority of Tata's population adheres to the restrictions; however, some fireworks explosions on New Year's Eve continue to occur, but these are orders of magnitude less disruptive than before.

Cases of particularly rapid decline of wild goose populations

Over the past 37 years, the largest decline in the population of wild geese on the Old Lake occurred between 24 December 2008 and 3 January 2009, when all the wild geese (more

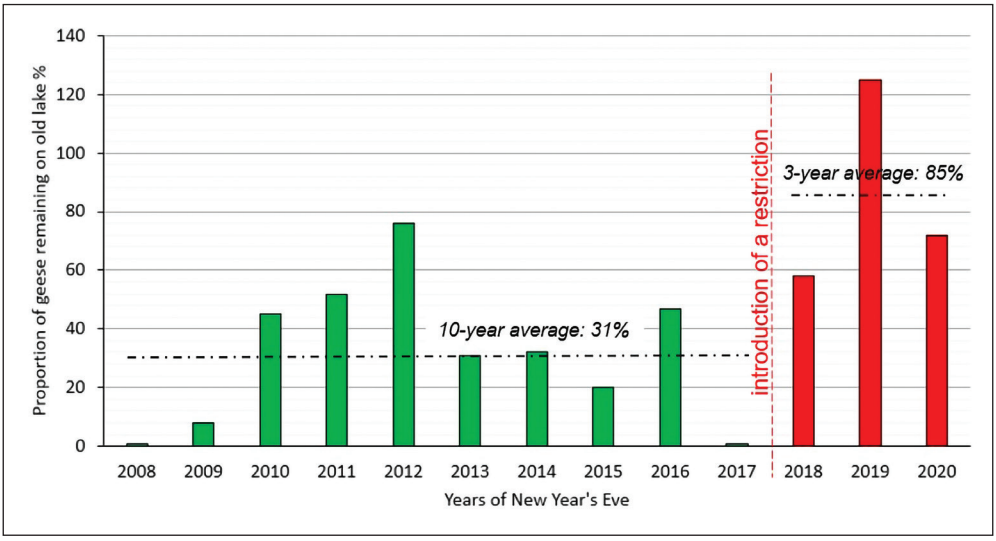

Figure 8. The proportion of wild geese remaining on the Old Lake of Tata during the New Year's fireworks

8. ábra A szilveszteri tűzijátékok ellenére a tatai Öreg-tavon maradó vadludak aránya

than 23,000 specimens) left the area within 10 days. This was surpassed in volume by the second half of December 2019, when nearly 32,000 wild geese left the lake in nine days (this was a 92% decline). In addition to natural factors, fireworks and excessively high water levels in the lake were responsible for the significant population declines in the vast majority of cases, but light effects and disturbance by skaters on the lake were also notable *(Table 1)*.

Case study of the fastest rate of decline of the wintering wild geese on the Old Lake – between 24 December 2008 to 3 January 2009

The situation of wild goose migration in Tata and major wintering areas in Hungary

2008/2009 brought the greatest number of wild geese (nearly 160,000) to Hungary at a somewhat unusual time (February). In both December and January, a group of around 120,000 wild geese was observed in the country. In these two months, the national maximum was recorded in Tata with 31,000 and 27,000 specimens respectively. Between these two dates, however, there was a very sharp drop in numbers on the Old Lake. The steep decline was caused by the fireworks that accompanied New Year's Eve. As a result, approximately 23,000 geese left the Old Lake within 10 days.

At the same time, the number of geese on Lake Fertő and in the ponds of Rétszilas increased spectacularly (by 16,000), but the most striking increase occurred in 2008 at Dinnyési-Fertő, which is the traditional wintering site closest to Tata. On 30 December 2008, only 3,300 geese spent the night there, but two days later the number suddenly rose to 18,000 (verbal report by L. Fenyvesi), while the number of geese on the Old Lake dropped to less than 100.

Table 1. The most significant and fastest population decreases of wintering geese as well as their natural and anthropogenic causes on the Old Lake of Tata between 1984 and 2019

1. táblázat A telelő vadludak legnagyobb és leggyorsabb ütemű állománycsökkenései, valamint azok természetes és antropogén okai a tatai Öreg-tavon 1984–2019 között

Date	Goose population of the Old Lake of Tata at the period's beginning/end	Rate of decrease [%, individuals]	Natural factors	Anthropogenic effects
24.12.2008. 03.01.2009.	23,200 0	100.0% 23,200	Lake freezing over	Fireworks, skaters
24.12.2017. 01.01.2018.	11,000 0	100.0% 11,000	Warm front, full moon	Ideal water level but fireworks
20.02.2006. 25.02.2006.	29,300 140	99.5% 29,160	Overly warm weather	Too high water level
28.12.2020. 06.01.2021.	17,700 1,050	94.1% 16,650	Mild, cloudy and cold, clear days alternate	Ideal water level but fireworks
17.01.2013. 25.01.2013.	21,000 1,450	93.1% 19,550	Snow cover, earthquake	Too high water level
18.12.2019. 27.12.2019.	34,300 2,700	92.1% 31,600	Lots of rain	Disturbing lighting, fireworks, too high water level
31.12.2009. 01.01.2010.	18,100 1,500	91.7% 16,600	Warm front, full moon	Fireworks
29.12.2013. 01.01.2014.	22,000 2,300	89.5% 19,700	Ideal circumstances	Fireworks
16.12.2007. 23.12.2007.	17,000 2,200	87.1% 14,800	Lake freezing over	Ideal water level but skaters
03.02.2009. 07.02.2009.	18,300 2,400	86.9% 15,900	Strong snow	Overly high water level

Some of the geese flushed from the Old Lake by the fireworks were forced to the nearby stretches of the Danube, and the number of geese in the ponds of Ferencmajor a few kilometres away increased from 5,000 to 9,000 during these days. This direct link is also confirmed by the large lynx tagged in late November 2008 in the Old Lake, which was found on 17 January 2009 in the ponds of Ferencmajor.

Local, national and European weather patterns

During late December and early January, the weather in western and southern Europe was quiet and uneventful due to anticyclonic effects. High temperatures ranged from 6–12 °C in the west and from 12–17 °C along the Mediterranean. However, it was extremely cold in the Ural Mountains, with daytime temperatures reaching only –5 to –10 °C. Along a frontal system stretching from Scandinavia to the Black Sea, snow fell in many places, with rain in the south. The Carpathian Basin experienced cold, wintry weather. In the Tata region, precipitation (mainly rain) was well above the long-term average from December to March in the winter of 2008/2009.

Table 2. The most significant and fastest population increases of wintering geese as well as their natural and anthropogenic causes on the Old Lake of Tata between 1984 and 2019

2. táblázat A telelő vadludak legnagyobb és leggyorsabb ütemű állománynövekedései, valamint azok természetes és antropogén okai a tatai Öreg-tavon 1984–2019 között

Date	Goose population of the Old Lake of Tata at the period's beginning/end	Rate of increase [x, individuals]	Natural factors	Anthropogenic effects
01.11.2017. 07.11.2017.	20 16,950	847.5x 16,930	Stormy cold front from western Europe, full moon	Water level tending to ideal
10.11.2018. 14.11.2018.	110 41,500	370.0x 41,390	Very mild weather, S wind turns to NW	Water level tending to ideal
31.10.2016. 06.11.2016.	114 16,700	146.5x 16,586	Unusually many geese in Hungary	Water level tending to ideal
11.01.2004. 16.01.2004.	2,700 25,000	9.3x 22,300	Strong warm front, freezing of other lakes in the region	Ideal water level
17.11.2020. 26.11.2020.	5,800 46,900	8.1x 41,150	Humid, foggy weather, first frosty days	Water level tending to ideal
03.01.2010. 13.01.2010.	3,000 19,500	6.5x 16,500	Suddenly mild weather	Rapid coming back of geese disappeared during fireworks
14.02.2006. 20.02.2006.	6,000 29,300	4.9x 23,300	Warm front, Danube flooding	Overly high water level but partly frozen
06.11.2014. 13.11.2014.	7,500 36,000	4.8x 28,500	Cold front from western Europe, goose groups from south	Water level tending to ideal; outstanding feeding conditions
20.12.1987. 27.12.1987.	5,600 26,000	4.6x 20,400	Mild weather, melting ice	Water level tending to ideal
07.11.1987. 14.11.1987.	10,200 36,600	3.6x 26,400	Mild, rainy weather	Strong hunting

The status of the Old Lake of Tata and local disturbances

The shallow waters of the drained Old Lake were largely covered by ice on 27 December 2008. New Year's Eve fireworks were also a major disturbance. The cold weather, which dipped below –10 °C at the beginning of January, caused the ice thickening that a festival of thousands of skaters and ice sailors was held on 10 January, preventing the arrival of the evening geese flocks from taking their overnight accommodation.

Cases of particularly rapid growth of the wild goose population

The most spectacular population increase of wild geese at Old Lake in the past 35 years took place in November 2017, when the number of wild geese at the lake jumped almost 850-fold (to nearly 17,000 individuals) in just one week. Another very spectacular increase of around 370 times occurred in November 2018, when the number of geese jumped from 110 to 41,500 in four days. Each of the 10 fastest growing populations exceeded 16,000 in absolute numbers *(Table 2)*.

Case study of the fastest rate of population growth of wintering wild geese at the Old Lake (between 1 November 2017 to 7 November 2017)

Wild goose migration in Tata and other important wintering areas in the Pannonian region

Regarding the arrival of wild geese in autumn, a new phenomenon has been observed in Tata since 2015: the larger flocks of geese arriving in the area in autumn do not start to gather in the Old Lake, but in the surrounding ponds with less human impact (Lake Asszony, ponds of Ferencmajor, Lake Boldogasszony). By the end of October 2017, the combined numbers of Greater White-fronted Goose, Greylag Goose, and Bean Goose had risen to nearly 5,000 in Lake Asszony, while no overnighting of any groups had occurred on the Old Lake. In the Slovak-Hungarian section of the Danube, water levels were relatively high during this period, so there were no reefs to attract the geese.

After 1 November, however, there was an extremely strong inflow into the Old Lake, partly due to the volume migrating from the surrounding lakes (this was when the water level of the Old Lake became ideal and the reefs began to appear), and partly due to successive new groups coming to the area. By 7 November, nearly 17,000 geese were already congregating on the lake, and by 11 November they had reached 28,000. This number was one of the highest of the 170,000 wild geese present in Hungary in November, with only the 35,000 geese observed in the nearby Lake Velence/Dinnyési-Fertő area being higher. There were also significant numbers of wild geese in the Hortobágy (28,000), the ponds of Biharugra (22,000), Lake Fertő (14,000), and Soponyai (10,000) fish ponds (Faragó 2021b).

With the influx of wild geese in November 2017, four Greater White-fronted Geese and eight Greylag Geese with rings were recovered from Old Lake and the nearby fish ponds. None of the three Hungarian-ringed and one Dutch-marked Greater White-fronted Geese provided any clues as to the direction of their arrival. Most of the six Czech-marked and two Austrian-marked Greylag Geese indicated a likely northwest-southeast migration route.

Local, national, and European weather patterns

October 2017 was much stormier than the multi-year average, with four days reaching wind speeds of 15 m/s. In the final days of October, the Carpathian Basin was also hit by a few days of rain with gale-force winds from northwest. At the beginning of November, sunny but

frosty weather set in, with anticyclonic effects dominating Central Europe. The migratory activity of the assembling geese was probably enhanced by the full moon on 4 November. From 5 November, winds shifted south and much milder weather arrived in the Tata area. Precipitation during November was above the long-term average (48.7 mm).

The status of the Old Lake of Tata and local disturbances

On 3 November, the water level of the Old Lake began to reach ideal levels and the first reefs appeared. There were no major disturbances on the Old Lake or on other lakes around Tata during these days.

In both cases, the influence of weather fronts was detectable, but there was also the anthropogenic factor: the draining of the lake made water levels ideal for the wild geese masses. This has become particularly clear in recent years. Geese are usually already present in large numbers in Hungary and the wider Tata area in early November, but it is only on days when the reefs of the lake emerge that they start to migrate to the Old Lake by the thousands or tens of thousands. Geese are particularly fond of this shallow, reef-strewn stretch of water. This is the reason for six of the 10 fastest population growth rates.

In addition to water management, the most important anthropogenic impacts include the rapid return of wild geese scared away by New Year's Eve fireworks and by the heavy waterfowl hunting in the wider Tata area, which repeatedly drives wild geese to the Old Lake. Since 1994, the beneficial effects of the hunting ban at the Old Lake have been clearly visible. Also noteworthy among the anthropogenic effects are the exceptional feeding conditions in some years (e.g. 2014) (much larger area sown with winter wheat).

Conclusions

Wild goose monitoring over the last 37 years has revealed a complex system of local disturbance in the vicinity of the Old Lake in Tata, which has significantly influenced the migration dynamics and spatial dispersal of wild geese in several cases.

The 37-year time series of wild goose maxima clearly identifies the main threats and, at the same time, the effects of positive actions that have opened an 'era', a new chapter in the decades-long history of wild goose migration on the Old Lake. The negative effects of the 1986–1988 dredging and the unusually high water levels of 1988–1994 can be clearly identified. The beneficial effects of the 'wild goose friendly' operation introduced by the lake's manager in 2011 and the ban on fireworks from 2018 are also evident *(Figure 9)*.

Due to disturbance factors in the confined environment of the Old Lake, the dispersal of the wintering goose population in the Tata area is increasing. Within a 15 km radius of Tata, there are now four wetlands where the number of geese occasionally exceed 10,000. At times, more wild geese roost on these than on the Old Lake (Pellinger *et al.* 2021). This trend is likely to increase in the future, which may result in the Old Lake, in combination with the surrounding wetlands, increasingly being able to play a significant role in goose migration.

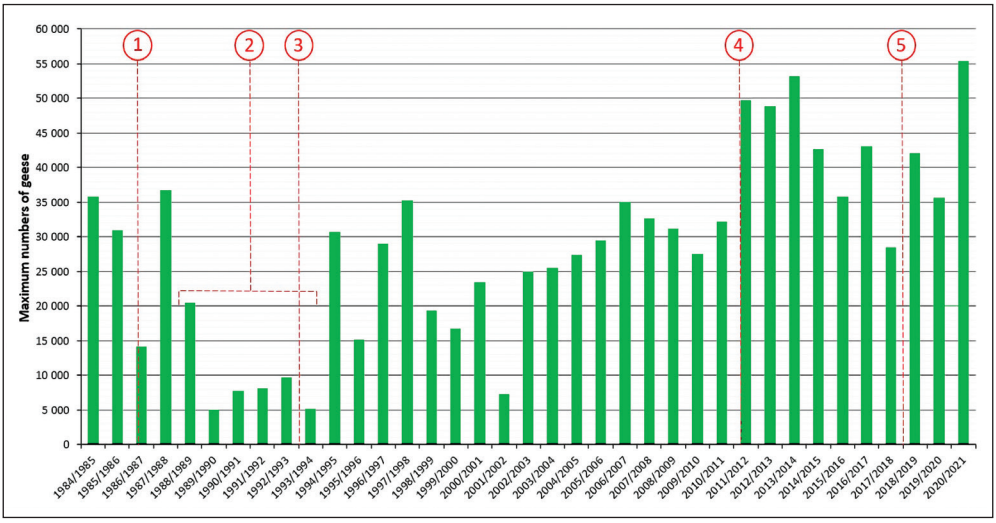

Figure 9. Changes in the annual maximum of geese wintering on the Old Lake of Tata affected by the main anthropogenic effects between 1984–2021 (Legend: 1: disturbing effects of dredging; 2: autumn water level much higher than the multi-year average; 3: start of a ban on waterfowl hunting; 4: start of 'wild goose mode' of water management; 5: start of fireworks ban)

9. ábra A tatai Öreg-tavon telelő vadludak éves maximumainak változása a fontosabb antropogén hatásokkal összefüggésben 1984–2021 között (Jelmagyarázat: 1-tókotrás zavaró hatásai; 2-túl magas őszi vízállás; 3-vízivad vadászati tilalom kezdete; 4-a vízgazdálkodás „vadludas üzemmódjának" kezdete; 5-tűzijáték tilalom kezdete)

The disturbance effects caused by fireworks were so significant that geese sometimes left the whole area of Tata. Sometimes even other wild goose roosting sites (e.g. Lake Fertő, Dinnyési-Fertő, Kiskunság saline lakes) located 50–100 km away experienced noticeable population changes. The most significant disturbance at the Old Lake is undoubtedly resulted by the New Year's Eve fireworks. The restriction of fireworks usage in the winter, which is unique in Hungary, was introduced in 2018, and it has fulfilled the hopes of effectively contributing to the containment of the wild geese population that gather on the Old Lake. It is particularly important that the ban (accepted by the vast majority of the residents of Tata) remains in effect in terms of space and time.

Anomalies (excessively high or low water levels) in the operation of the Old Lake (mainly due to fishing) can also cause notable disturbance. No significant correlation was found between geese leaving and excessive draining of the lake, suggesting that fishing on the Old Lake – subject to compliance with the main nature conservation rules – is compatible with the interests of goose migration. Major draining of the lake will not cause the wintering goose population to leave if the duration of the draining does not exceed 1-2 weeks. This has been the main objective of the lake's manager over the last 10 years, which is probably why the R^2 values for this factor are very low. In the future, other factors (e.g. natural predators in the case of a drying lake bed or even the presence of humans) should be taken into account. Since 2017, this has been increasingly possible to observe with the infra-red webcam installed in the lake bed from mid-November to the end of January.

The population of wintering wild geese on the Old Lake is increasingly a subject to extremely rapid and large-scale changes. All of the 10 most significant population declines of the last 37 years have occurred in the last 15 years, and three of the last four wintering seasons have seen such extreme cases. It is also intriguing that regular overwintering periods are experiencing spectacular growth (sometimes within a month) followed by equally rapid declines. This was the case in the winters of 2005/2006, 2008/2009, 2009/2010, 2017/2018 and 2020/2021. The main causes of these rapid changes can clearly be identified as human impacts (in particular the usage and upkeep of the lake and the fireworks). We concluded that, among the different scales of disturbance, the most significant cause of the sudden decline (6 out of 10 cases studied) was the light and noise of New Year's Eve fireworks. In addition, excessive water levels in the night roosts were also the cause of significant declines in several cases (4 out of 10). The very rapid dynamics of the wintering wild geese population on the Old Lake indicate that these are becoming increasingly vulnerable due to the anthropogenic causes. As a consequence, the lake is expected to become an important place in wild goose migration for increasingly shorter periods of time in the future.

These anthropogenic conditions often amplify the effects of favorable weather and snow conditions. This is particularly true in the case of Tata, where systematic efforts are being made to improve the conditions for the migration of wild geese, a major tourist attraction (the city was awarded the 'Wetland City' prize by the Secretariat of the Ramsar Convention in 2018 in recognition of its efforts in this regard).

Today, the increased vulnerability of the Old Lake of Tata is still somewhat compensated by local conservation measures and the social awareness-raising effect of the wild goose festivals (the Wild Goose Festival of Tata), but to preserve the international (Ramsar) importance of the Old Lake, it is essential to introduce a more comprehensive approach to urban development and management.

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