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Monitoring population change using 'citizen science' data: case study of the Hungarian White Stork *(Ciconia ciconia)* population between 1999 and 2021

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Abstract In Hungary, changes in the White Stork population are monitored using two methods that involve a large number of volunteers: nest surveys since 1941, and since 1999 within the framework of the Common Bird Monitoring Scheme (MMM) programme. In our article, we briefly present the results of the nest survey data between 1999 and 2021, the population trend calculated on the basis of them, and the comparison of the latter with the trends shown by the MMM programme, which – among other species – counts all stork individuals on 2.5×2.5 km sample areas. Both sets of data show a decreasing trend, but there is a significant difference between them, which may be partly due to the inaccuracies of the nest database, considering the fact that the MMM also counts non-breeding adult and immature individuals. However, both methods have the characteristics that make them suitable for monitoring population trends.

Keywords: White Stork, national census, breeding population, citizen science

Összefoglalás Magyarországon két, önkénteseket nagy számban bevonó módszerrel is zajlik a fehérgólya-állomány változásainak nyomon követése: az 1941 óta végzett fészekfelmérésekkel és 1999 óta a Mindennapi Madaraink Monitoringja (MMM) program keretében. Cikkünkben röviden bemutatjuk a fészekfelmérések 1999 és 2021 közötti adatainak összesített eredményeit, az ezek alapján számított populációs trendet, és utóbbit összevetjük a 2,5×2,5 km-es mintaterületeken – többek közt – valamennyi gólyaegyedet felmérő MMM-program által mutatott trendekkel. Mindkét adatsor csökkenő trendet mutat, de közöttük szignifikáns eltérés mutatkozik, ami részben a fészekadatbázis pontatlanságaiból fakadhat, részben abból, hogy az MMM a nem költő öreg és a még nem ivarérett egyedek számlálását is végzi. Jellegzetességeiket figyelembe véve azonban mindkét módszer alkalmas a populációs trendek nyomon követésére.

Kulcsszavak: fehér gólya, országos felmérés, költőállomány, csökkenés, közösségi tudomány

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Introduction

Large datasets collected by volunteers are generally suitable for carrying out scientific research (Fraisl *et al*. 2002). There are good examples of large and/or long scale bird studies involving volunteers, such as the more than hundred years old Christmas Bird Count (Bock & Root 1981), or the continent-wide mapping activities of the European

Bird Atlas 2 (Chokiewicz & Sikora 2020). The White Stork has been a popular and a well monitored bird species for a long time as the first international census was organised almost a century ago, in 1934 and further international nest counts were organised in 1974, 1984, 1994/1995 and 2004/2005 (Thomsen 2013, Kaatz *et al*. 2017). Citizen ornithologists collect a lot of information on the species in several countries every year, but as the White Stork population stabilized, the focus of researchers and conservationists seems to have shifted to other priority species, so these data collected by the wide public are not fully analysed and published. Only a few scientific articles were published on the annual changes of national or regional populations in the last decade, for example in Germany (Kaatz *et al*. 2017), Poland (Kaługa *et al*. 2016, Kopij 2017, Sikora 2017, Bialas *et al*. 2020), Slovenia (Denac 2010), Turkey (Onmuş *et al*. 2012), Ukraine (Grischenko & Yablonovska-Grishchenko 2019). The last international analysis was published on the 2004/2005 census (Thomsen 2013).

In Hungary, the first national White Stork census was organised in 1941, it was repeated in 1958, 1963, 1968, then in 1974 (in the year of the international census) and since then, in every five years. Data were collected by teachers and students, postmen, volunteer ornithologists, national parks staff members and since the foundation of the MME/BirdLife Hungary in 1974, the members of the national ornithological society (Homonnay 1964, Marián 1962, 1968, 1971, Jakab 1978, 1985, 1987, 1991, Lovászi 1998, 2004, Lovászi *et al.* 2013, 2016, 2020). The Monitoring Centre of the MME created an online stork database in 2005 (www.golya.mme.hu). Approximately 2,000 volunteers uploaded data of almost 14,000 nesting sites and more than 117,000 breeding data. These records were collected by a wide range of people, not in a framework of a preliminary designed monitoring. In spite of the immense amount of information, only the regular, five-year national censuses have been analysed and published so far (Lovászi *et al.* 2013, 2016, 2020).

The MME/BirdLife Hungary started a monitoring programme of common birds in 1999 (Szép *et al*. 2012, Nagy 2022), involving trained volunteers, using a standard protocol.

Our goal in this study was to analyse whether the White Stork data collected by volunteers was suitable to monitor the trends of the species and to compare the usability of a big, but lower quality database to a dataset collected using a well-designed protocol.

Materials and Methods

We analysed data of the online White Stork database of the MME/BirdLife Hungary, collected and uploaded by volunteers. This database was established in 2005, but it was possible to upload archive data also. Data collection is based on nesting sites: registered users can create a new nesting site with its location (‘address’) and can add information on the nest basement, geographical coordinate, presence or lack of nest holder ‘basket”, quality of the nest holder, presence of dangerous electric poles around, type of the electric pole holding the nest, and other comments. Photographs can be uploaded to the nesting site. The system allows the upload of annual data to the nesting sites (empty nest holder without nest material, unoccupied nest, lonely stork, unsuccessful pair, successful pair, number of young hatched and fledged). Daily observation can also be uploaded, which provide data on e.g. the presence of storks, egg laying, fighting, mortality cases. It is important that nesting site can be an empty nest holder facility without any nest material.

We used data of years between 1999 and 2021, aligned with the dataset of the Common Bird Monitoring Scheme (see below). Local coordinators organise regional nest counts every year, involving volunteers, regularly covering all nests in a village or district. As data can be uploaded by independent volunteers also, in many cases we have data on single nests within a settlement (for example beside a main road), but there are no information on other nesting sites of the same settlement. In addition, the coverage of settlements is substantially different between years. As a result, we have a large number of nests and settlements without information in particular years (there are lot of lacking data in the database).

Our analysis was based on the number of breeding pairs in settlements. As we do not have data from each year from all the nests, before the analysis, we deleted data of years when number of reported pairs was less than 80% of the average of the given settlement between years to decrease the effects of partially covered settlements. Nesting sites without valid breeding data were excluded from the analysis. We analysed data of 2,221 settlements (covering 82.5% of the area of Hungary). During trend analysis, we excluded further three settlements where breeding was not detected.

As a comparison, we used the dataset of the Common Bird Monitoring Scheme (MMM) of the MME/BirdLife Hungary. This programme is a point-based counting method using grid cells with a semi-random sampling design. The survey is based on randomly selected 2.5×2.5 km UTM squares (Universal Transverse Mercator geographic coordinate system). Observers count birds for five minutes at 15 points; these points are randomly selected out of 25 central points of 0.5 km segments of the 2.5×2.5 km UTM square. Surveys were carried out from 1999, twice between mid-April and mid-June, counting birds within 50, 100 and 200 m radius circles (Szép *et al*. 2012, Nagy 2022). We considered data of 220 pieces of 2.5×2.5 km UTM squares, which were surveyed at least in two separate years during 1999–2021 using standard protocol and White Stork was observed at least in one year. The observers in the MMM programme able to survey White Storks both at their nests and their foraging areas. Because of the random sampling protocol of the MMM programme, the surveyed areas covered dominantly by agricultural and forest habitats (85%), but the coverage of two habitats (wetlands and urban) frequently used by White Stork was low (<15%) (Szép *et al*. 2012).

The package rtrim (Pannekoek & van Strien 2001, Bogaart *et al*. 2016) was used to analyse the trend of number of breeding pairs in the settlements and the number of individuals surveyed in the 2.5×2.5 km UTM squares in the frame of the MMM monitoring. The package implements a variety of log-linear models (including Poisson regression) which can handle data of sites in year(s) when observations were missing, by the use of models that make assumptions about the structure of the counts and considering imputed counts, time-total and indices. In the case of the analysed data series, we investigated overdispersion and serial correlation and considered specific models when its level was high. We investigated trend changes by considering models expecting changepoint for each years as a full model and using stepwise model selection to indentify significant changepoints based on Wald statistics. Model goodness of fit-test and comparison of models by the use of Akaike's Information Criterion (AIC) were made. Overall trends for the entire period was estimated. Modelling and statistical testing was run in R v4.2.1 (R Core Team 2022).

Table 1. Breeding results uploaded to the database (HO: unoccupied nest, HE: lonely stork, HPo: unsuccessful pair without fledged nestling, HPm: successful pair, HPa: all breeding pairs reported)

1. táblázat Az adatbázisba feltöltött költési eredmények (HO: lakatlan fészek, HE: magányos gólya, HPo: sikertelen pár kirepült fióka nélkül, HPm: sikeres pár, HPa: összes felmért költőpár)

Year / Év	Empty nest holder / Üres fészektartó	Nest attempt / Fészek kezdemény	HO	HE	HPo	HPm	HPa
1994	12	7	140	26	158	1,241	1,399
1995	16	2	36	4	78	406	484
1996	21	1	51	8	68	553	621
1997	25	1	127	35	165	390	555
1998	25	4	86	10	86	624	710
1999	160	7	268	38	273	1,848	2,121
2000	142	2	159	15	105	1,157	1,262
2001	186	2	224	38	271	1,255	1,526
2002	261	2	439	44	239	1,360	1,599
2003	447	4	572	58	340	1,921	2,261
2004	1,013	13	788	85	367	3,423	3,790
2005	658	8	1,198	158	766	1,527	2,293
2006	919	39	1,352	115	574	2,515	3,089
2007	968	40	1,078	108	273	2,552	2,825
2008	872	31	637	53	195	2,121	2,316
2009	1,849	89	1,269	121	601	2,858	3,459
2010	1,475	96	848	68	875	2,198	3,073
2011	1,442	93	668	48	284	2,964	3,248
2012	1,623	71	742	74	389	2,669	3,058
2013	1,628	59	793	62	361	2,917	3,278
2014	2,441	128	986	93	680	4,050	4,730
2015	1,764	51	1,015	84	531	2,527	3,058
2016	1,272	42	880	78	401	2,000	2,401
2017	1,393	60	879	63	380	2,082	2,462
2018	1,415	71	958	88	329	1,987	2,316
2019	2,528	80	1,386	83	609	3,017	3,626
2020	1,725	73	929	57	359	2,411	2,770
2021	1,285	40	647	39	333	1,932	2,265

Results

Our dataset included 111,778 nest occupation data in the White Stork database from the years 1999–2021 (including empty nest holders and unoccupied nests, *Table 1*). In total, 62,826 data were reported about real nesting (successful or unsuccessful nesting pairs, *Table 2*).

Table 2. Breeding success uploaded to the database (JZG: total number of nestlings fledged, JZa: average number of nestlings for all nests, JZm: average number of nestlings for successful nests)

2. táblázat Az adatbázisba feltöltött költési siker adatok (JZG: kirepült fiókák száma, JZa: összes köl-tőpár fészkenkénti fiókaátlaga, JZm: sikeres párok fészkenkénti fiókaátlaga)

Year / Év	Number of fledglings / Fiókaszám						JZG	JZa	JZm
	1	2	3	4	5	6			
1994	50	281	475	339	72	2	3,765	2.73	3.09
1995	16	101	171	96	11		1,170	2.47	2.96
1996	36	139	201	131	38	6	1,667	2.69	3.03
1997	58	166	110	50	4		940	1.70	2.42
1998	32	166	264	127	18		1,754	2.53	2.89
1999	113	417	626	526	150	10	5,739	2.71	3.12
2000	49	200	398	356	131	10	3,782	3.03	3.31
2001	157	434	491	147	8		3,126	2.07	2.53
2002	104	445	578	214	12		3,644	2.29	2.69
2003	135	594	840	305	17		5,148	2.31	2.72
2004	207	767	1,421	883	120		10,136	2.69	2.98
2005	235	615	501	152	16		3,656	1.60	2.41
2006	341	741	944	408	66	1	6,623	2.15	2.65
2007	142	566	1,010	679	130	3	7,688	2.74	3.04
2008	111	464	872	542	111	1	6,384	2.78	3.04
2009	236	879	1,222	441	37		7,609	2.23	2.70
2010	433	809	655	220	27		5,031	1.67	2.35
2011	122	466	880	900	437	17	9,581	3.08	3.40
2012	215	830	1,189	331	31		6,921	2.32	2.67
2013	206	649	1,088	755	164	9	8,662	2.68	3.02
2014	321	942	1,416	1,086	249	10	12,102	2.57	3.01
2015	244	852	1,005	365	43		6,638	2.18	2.65
2016	166	608	803	323	38	2	5,285	2.26	2.72
2017	170	630	886	326	38	1	5,588	2.30	2.72
2018	126	395	673	543	190	3	6,075	2.69	3.15
2019	331	747	1,081	627	66		7,906	2.28	2.77
2020	146	642	1,070	458	34		6,642	2.45	2.83
2021	173	578	721	342	29	1	5,011	2.30	2.72

Trends of the number of breeding pairs in settlements

The overdispersion (0.485) and serial correlation (0.373) value were low and the general model expecting different change at each year fits to the data (χ^2=14,421.95, df=29,147, P>0.9, AIC=-42,704.91). Using the stepwise procedure for selection of changepoints of rtrim, the final model which expect change in the trends for 13 different periods, has the lowest AIC value (-42,717.07) and this was used for trend analysis.

The overall change of the number of breeding pairs has a weak non-significant decline (slope=0.999, SE=0.0008, P=0.085) during 1999–2021 *(Figure 1)*. The population showed several declining periods (1999–2002, 2004–2005, 2008–2009, 2011–2013, 2014–2015, 2015–2020) and the same number of increasing periods (2002–2004, 2005–2008, 2009–2011, 2013–2014, 2020–2021). The highest decline was found during 1999–2000 (slope=0.773, SE=0.024, P<0.001) and 2004–2005 (slope=0.772, SE=0.018, P<0.001) periods, the highest increase during 2002–2003 (slope=1.162, SE=0.017, P<0.001) and 2013–2014 (slope=1.118, SE=0.025, P<0.001) periods *(Table 3)*. The estimated mean number of pairs in the settlements which data was considered in the trend analysis was 4,205 pairs (SD=402.583, range=3,577–5,227, n=23).

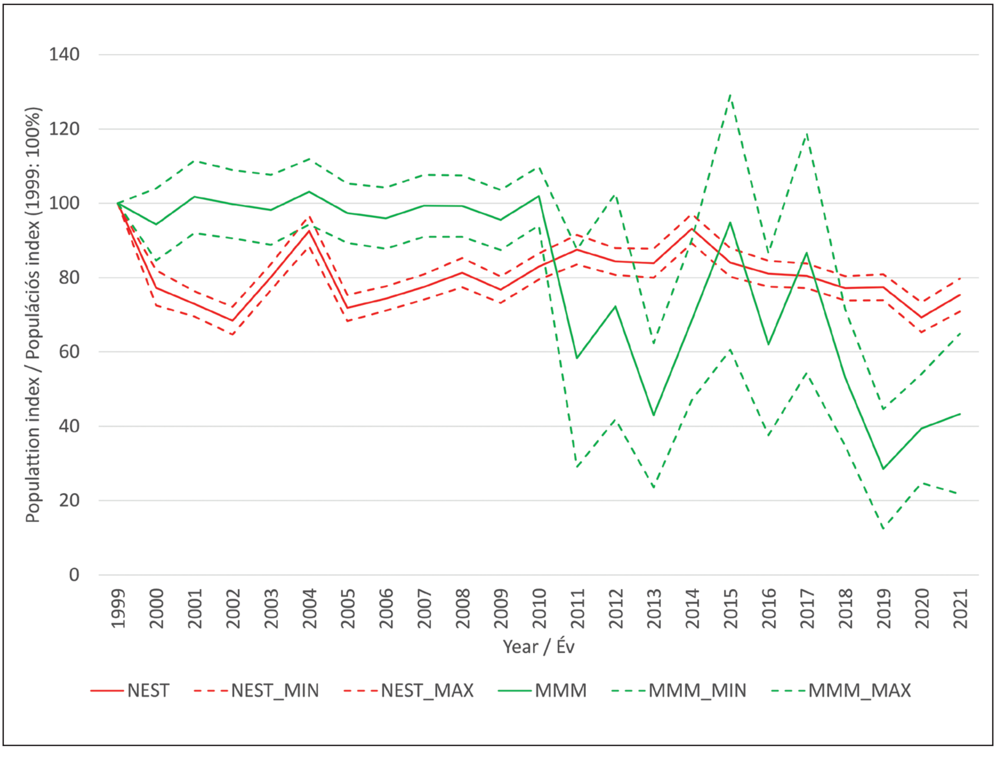

Figure 1. Population indices of White stork in Hungary based on nest survey (NEST) and MMM data (MMM), comparing to 1999 (100%)

1. ábra A magyarországi fehérgólya-állomány változását bemutató populációs indexek, amelyek a fészekfelmérések (NEST), illetve az MMM adatokon alapulnak, 1999 tekintve bázis évnek (100%)

Table 3. Significant changes between years (periods) (slope: trend in the given period (1: no change, <1: decrease – red, >1: increase – green), SE: SE of slope, – : no significant change)
3. táblázat Egyes évek (időszakok) közti szignifikáns változások (change from: kezdő év, change upto: záró év, slope: adott időszakban a trend értéke (1: nincs változás, <1: csökkenés – piros, >1: növekedés – zöld), SE: slope SE értéke, – : nincs szignifikáns változás)

Year / Év	**Number of pairs – settlements model Párok száma – települések szerinti modell**						**Number of individuals – MMM model Egyedek száma – MMM alapú modell**					
change from	change upto	slope	SE	Wald test	df	p	change upto	slope	SE	Wald test	df	p
1999	2000	0.773	0.024	68.185	1	**0.000**	–					
2000	2002	0.942	0.018	18.394	1	**0.000**	–					
2001	–						–					
2002	2004	1.162	0.017	50.024	1	**0.000**	–					
2003	–						–					
2004	2005	0.772	0.018	155.229	1	**0.000**	–					
2005	2008	1.042	0.010	96.643	1	**0.000**	–					
2006	–						–					
2007	–						–					
2008	2009	0.952	0.023	8.694	1	**0.003**	–					
2009	2011	1.064	0.013	12.151	1	**0.000**	–					
2010	–						2011	0.581	0.150	4.409945	1	**0.036**
2011	2013	0.976	0.012	16.430	1	**0.000**	2012	1.229	0.363	2.151699	1	**0.142**
2012	–						2013	0.640	0.163	1.986028	1	**0.159**
2013	2014	1.118	0.025	19.493	1	**0.000**	2015	1.490	0.181	6.165506	1	**0.013**
2014	2015	0.896	0.019	35.815	1	**0.000**	–					
2015	2019	0.979	0.006	12.496	1	**0.000**	2016	0.577	0.120	11.557824	1	**0.001**
2016	–						2017	1.478	0.330	5.997047	1	**0.014**
2017	–						2019	0.603	0.090	8.159412	1	**0.004**
2018	–						–					
2019	2020	0.905	0.026	6.213	1	**0.013**	2021	1.179	0.205	5.128366	1	**0.024**
2020	2021	1.086	0.039	10.058	1	**0.002**	–					
2021	–						–					

Trends of the observed individuals in the MMM programme

The overdispersion (1.64) was high and considered during the modelling, the serial correlation (-0.054) value were low. The general model expecting different change at each years did not fit to the data (χ^2=2,217.41, df=1,279, P<0.001, AIC=-846.26). Using the stepwise procedure for selection of changepoints of rtrim, the final model has eight periods with different change of trends with the lowest AIC value (-861.53) and was used for trend analysis.

The overall change of the number of breeding pairs has a significant decline (slope=0.958, SE=0.009, P<0.001) during 1999–2021, regarded as a moderate decrease *(Figure 1)*. On the base of the final model, the population showed several declining periods (2010–2011, 2012–2013, 2015–2016, 2017–2019) and increasing periods (2011–2012, 2013–2015, 2016–2017, 2019–2021), however Wald test (still be used when model fit is weak, Bogaart *et al*. 2016) did not show significant changes for two periods of 2011–2012 and 2012–2013 (P>0.14). The highest decline was found during 2010–2011 (slope=0.581, SE=0.150, P=0.036) and 2015–2016 (slope=0.577, SE=0.12, P=0.001) periods, the highest increase during 2013–2015 (slope=1.49, SE=0.181, P=0.013) and 2016–2017 (slope=1.478, SE=0.33, P=0.014) periods *(Table 3)*. The estimated mean number of individuals in the surveyed UTM squares in the trend analysis was 167 individuals (SD=51.904, range=60–216, n=23).

Discussion

Based on formerly published results, the estimated national population of White Stork amounted 5,600 pairs in 1999 (Lovászi 2004), in 2001 a lower value was found (5,000 pairs) (Lovászi 2004), and 5,200 pairs in 2004 (Lovászi *et al*. 2013). In 2014, only a breeding population of 4,950 pairs was estimated (Lovászi *et al.* 2016), and then the number of breeding pairs dropped down to around 4,000 pairs (Lovászi *et al.* 2020, Lovászi & Nagy 2022). These numbers fits the trend calculated by rtrim using nest count data.

The data of Common Bird Monitoring Scheme showed stable population between 1999 and 2010, than indicated rapid decline. The number of birds observed in 1999 halved by the end of the period. The index fluctuated more hectically than the number of breeding pairs, but the peaks in 2004 and 2014–2015 were detected.

Similar peaks was found in Slovenia in 2004 (Denac 2010), and in 2004 and 2014 in Ukraine (Grischenko & Yablonovska-Grishchenko 2019) and Poland (Sikora 2017, Wardecki *et al*. 2021). As these populations also migrate on the same eastern route, it suggests the effect of conditions on the wintering grounds or during the migration (Wuczyński *et al*. 2022).

The difference between the trend indicated by the nests surveys and the data of the MMM programme may be caused by several reasons. The online White Stork database actually provided data for 13,958 nesting sites (7,600 active nests, 4,227 empty nest holder facilities (former nests) and 2,117 destroyed nests) and 117,771 annual data on nest occupancy. It is possible to specify the year of building and cessation of a nest (or a nest holder facility), but observers usually upload only annual breeding data, so we have no information on real actual number of nests. In addition to this, not all nests are covered by observers in each year. To decrease the effects of this inaccuracy of the database, analysis of breeding data combined with environmental databases could be a good basement for a GIS modelling procedure to calculate trends or population sizes.

The participants of the Common Bird Monitoring Scheme count birds on fixed points of randomly selected 2.5×2.5 km UTM squares. The White Stork is the 43rd most common species, observed in 31.7±3.6% of the UTM squares, mainly on agricultural areas, out of the four main habitat types. Forests are not suitable habitats for the species, and fewer counts are conducted on urban areas and wetlands. Due to it, a low number of White Storks (60–216) was observed on the 220 UTM squares involved in the analysis, often in flocks (in 9.4% of the UTM squares more than 4 individuals, max. 42), which can largely explain the poor fit of the full model. In addition, observers detect both breeding and non-breeding individuals. Number of immature storks depends on former years' weather of breeding sites via breeding success (Gyalus *et al*. 2022), on the weather of the wintering grounds via survival rate (Schaub *et al.* 2005) and the rate of individuals summering on non-breeding grounds (Antczak & Dolata 2006). The number of actually non-breeding adult birds is correlated with fitness after wintering, among others (Martín *et al.* 2021). Unsuccessful pairs spend more time far from their nests (as do not lay eggs or defend chicks for example against the weather), increasing the number of observed birds on sample squares. These factors should be involved into the model calculation.

Considering their characteristics, both methods are suitable for monitoring population trends of the White Storks. However, monitoring of population trends based on annual observation of all breeding pairs in settlements could provide more detailed information when large areas, representative to the country, frequently surveyed. In the case of the White Stork in Hungary, the existing online database and network based on large number of participating voluntary people let to follow the trend of the breeding population. Further improvement of the data collection by using the same 2.5×2.5 km UTM grid system, as the MMM program, to measure the density of breeding pairs in the surveyed UTM squares could let to model the spatial distribution, population size and spatial trend of the breeding population in the country on the base of recent experience in this fields (Szép 2022).

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