Avian Influenza (H5N1) Outbreak Report in Wild Birds – Hula Valley, Israel A Comparison of Two Outbreaks (2021/22 and 2024)

Nadler-Valency, R.,[1] Lourie, E.[1,2] and Sela-Klein, D.[3]

[1] Agamon Wildlife Rehabilitation Center, Tel-Hai Academic College & KKL-JNF, Israel.
[2] Hula Research Center, Department of Animal Sciences, Tel-Hai College, Israel
[3] MIGAL – Galilee Research Center, Israel

* **Corresponding author:** Rona Nadler-Valency Email: ronanadlerv@gmail.com

ABSTRACT

This document reports two avian influenza (H5N1) outbreaks among Eurasian cranes (*Grus grus*) in the Hula Valley, Israel, comparing the 2021/22 and 2024 outbreaks. The report details epidemiological aspects, including confirmed cases, mortality rates, and survival estimates, highlighting the significant impact on the crane population, with a 20-27% mortality rate in the first outbreak and a much lower rate of 1.4-2.6% in the second. The study also discusses epidemic management strategies, such as carcass removal, water level management, and diversionary feeding, and their potential to mitigate outbreaks. The ecological impact, including effects on other bird species and long-term changes in the crane population dynamics, is discussed. The findings emphasize the importance of early detection, herd immunity, and adaptive management practices in controlling future outbreaks. Abstract in Hebrew is provided in the Appendix.

Key words: Avian Influenza; H5N1; Common crane; Eurasian crane; Hula Lake

BRIEF BACKGROUND

The Hula Valley, is an agricultural and conserved marshland area, nestled within the northern part of the Syrian African Rift River valley, which serves as a major stop-over site for migrating birds along the Eurasian-African migration routes. Following global outbreaks of avian influenza virus in Asia since 1996, H5N1 HPAI strains have been detected in domestic and wild bird populations in Israel from 2006. The winter of 2021 outbreak was by far the most predominant within a wild bird population and some estimated 8,500 Eurasian (or Common) cranes (*Grus grus*) died due to H5N1 virus infection (1).

The purpose of this update and analysis was to understand the virulence factors of H5N1 within the overwintering Eurasian crane population in the Hula Valley, comparing two outbreak episodes (2021/22 and 2024). Additionally, this report opts to provide relevant information regarding management and ecological aspects of these outbreaks.

METHODS AND RESULTS

Confirmed H5N1 cases

In Israel, wild birds are sampled for influenza surveillance through a combination of efforts by veterinary services and wildlife organizations. During an identified outbreak, passive surveillance by means of observing and testing birds that are found sick or dead was the usual detection method (1). Samples were taken via tracheal and cloacal swabs in the field and sent to the Laboratories of the Kimron Veterinary Institute, Beit Dagan, Israel.

In the following section we provide a spatial and chrono-

Table 1. First confirmed cases of H5N1 in wild cranes and other birds in the Hula area during the two outbreaks: 2021 and 2024. AWRC: Agamon Wildlife Rehabilitation Center. INPA: Israeli Nature & Parks Protection Authority

Country	Address	Date detected	HPAI strain	Bird species	Official classification	Sampling method	Submitting agency
Israel	Hula Lake (agriculture fields)	8/12/21	H5N1	Eurasian crane	wild bird	morbidity/mortality	AWRC
Israel	Hula Lake (tourist bike lane area)	10/12/21	H5N1	Eurasian crane	wild bird	morbidity/mortality	INPA
Israel	Hula Lake	16/12/21	H5N1	Eurasian crane (N=10)	wild bird	morbidity/mortality	INPA
Israel	Hulata	9/1/24	H5N1	Peregrine falcon	wild bird	morbidity/mortality	AWRC
Israel	Lehavot Habashan	31/1/24	H5N1	Eurasian crane	wild bird	morbidity/mortality	INPA
Israel	Hula Lake	1/2/24	H5N1	Eurasian crane (N=3)	wild bird	morbidity/mortality	INPA

Table 2: Summary of the estimated mortality rates and percent of total cranes dead for the two H1N5 outbreaks in Hula Valey, Israel, during the two outbreaks (2021/2 and 2024). Estimates represent the mean and maximal daily death rates, the maximal number of overwintering cranes, and the estimated range of the percent of dead cranes at the end of each outbreak.

Parameter	2021	2024	Minimal difference (2021/2024)
Mean daily death rate	186	1.6–23	X 8
Max daily death rate	411.5	8–82	X 5
Mean Crane population (wintering)	32,000	15,000	X 2.3
% dead overall (approx.)	20–27%	1.4-2.6%	X 7.7

logical depiction of the two H5N1 outbreaks in the Hula Valley.

Since cases were confirmed within a flock, mortalities were assumed to be H5N1 positive, and thus, samples were taken only from other wild species within the outbreak area. Prior to these confirmed cases, the first H5N1 case was confirmed in Israel in backyard poultry in late September and in wild birds (Black stork) in early October. Both incidents were within a 50-60 km radius of the Hula area.

The following table (Table 1) represents a chronological description of the first reported/confirmed cases of H5N1 in wild cranes and other birds in the Hula area during the winters of 2021 and 2024. Note that prior to these cases, H5N1 was detected in commercial turkey farms.

Estimated mortality rate within the wintering crane population at the Hula Valley

It was assumed that the first crane was exposed to H5N1 during the winter of 2021/22 in the Hula Valley (2, in. prep.). When naïve populations, not previously exposed to the pathogen, are exposed to highly pathogenic avian influenza strains, they typically exhibit early morbidity and high mortality, typical clinical signs, such as severe neurological disorders and high levels of shedding, and are considered to be highly contagious to other birds through contact (3). These pathologies were significantly more pronounced during 2021/22 compared to the second 2023/4 outbreak (Table 2).

Methodologically, estimates of mortality rates were collected differently between the two outbreak-years, due to uncontrollable technical circumstances: During the first outbreak (2021/22) at Hula Lake Park, initial carcass counts were taken remotely, observed using remote cameras positioned at the main body of water where most of the flock had roosted during the night (Figure S1). Each morning, for four consecutive days since the first observation of a dead crane, carcasses were counted from the same camera. Following these counts, aerial photographs of the flock aggregation (body of water and feeding area, Figure 2) were taken in order to direct the efforts of carcass removals more accurately. These data were collected remotely during this outbreak due to the concurrent COVID outbreak in Israel at that time and the strict regulations imposed by the Health Ministry to avoid all contact with suspected birds due to AI-COVID cross-infection warnings. As a result, the total number of cranes was based on the aerial footage, and the number of

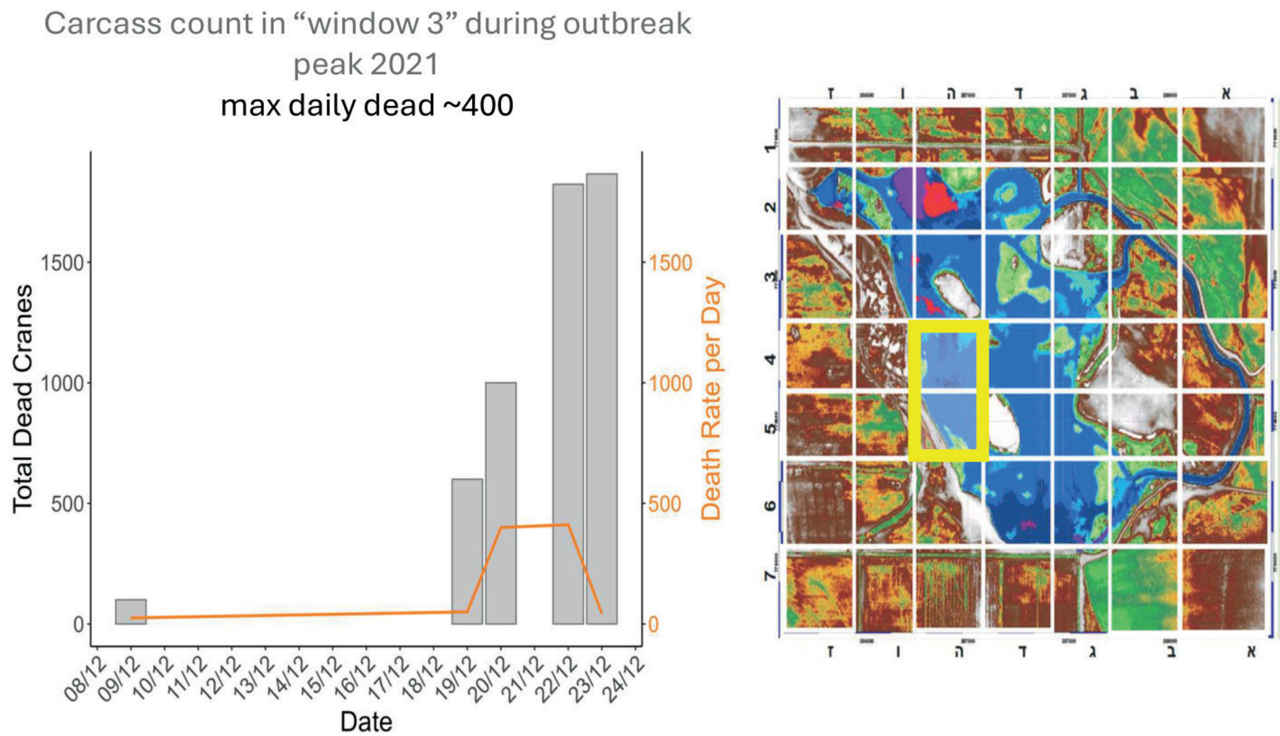

Figure S1. Carcass counts observed from remote camera observing the area depicted in "window 3" (yellow rectangle). Maximum daily death rate is represented as the delta from previous total dead count.

???**(Figure 1):** Spatial analysis: Maps of the Hula Valley 2021 and 2024 outbreaks.????

dead cranes was based on the counts of carcasses that were removed by a removal contractor.

During the second outbreak (2023/24), war in Israel was ongoing. The Hula area was under military restrictions, and aerial photographs were prohibited. Therefore, data collection was performed solely by observations of different professionals of various governmental (KKL – Keren Kayemet Le'Israel INPA- Israel Nature and Parks Authority), NGOs (non-governmental organizations) and local organizations (AWRC – Agamon Wildlife Rehabilitation Center, SPNI (Society for the Protection of Nature in Israel), Hula Research Group) on the ground monitoring the outbreak area using direct count observations. Counts of the dead and the total number of Cranes were reported to the Hula Monitoring Program (KKL), which collated the results of carcasses and cranes per area.

Due to the inconsistency in data collection methods, we present here our *estimated* counts derived from each collection method in the different outbreaks. However, we trust these represent the trends in the outbreaks reliably, and the stark differences between the magnitude of the outbreaks between the two years (Figs 2,3 and Table 3).

Table 3: confirmed H5N1 cases in additional species during 2022 and 2024 outbreaks.

Date	Species	Number	H5N1
4/1/2022	Common kestrel (*Falco tinnunculus*)	1	positive
4/1/2022	Common buzzard (*Buteo buteo*)	1	positive
20/1/2022	Hooded crow (*Corvus cornix*)	1	positive
9/1/2024	Peregrine falcon *(Falco peregrinus)*	1	positive
31/1/2024	Grey Heron *(Ardea cinerea)*	2	positive

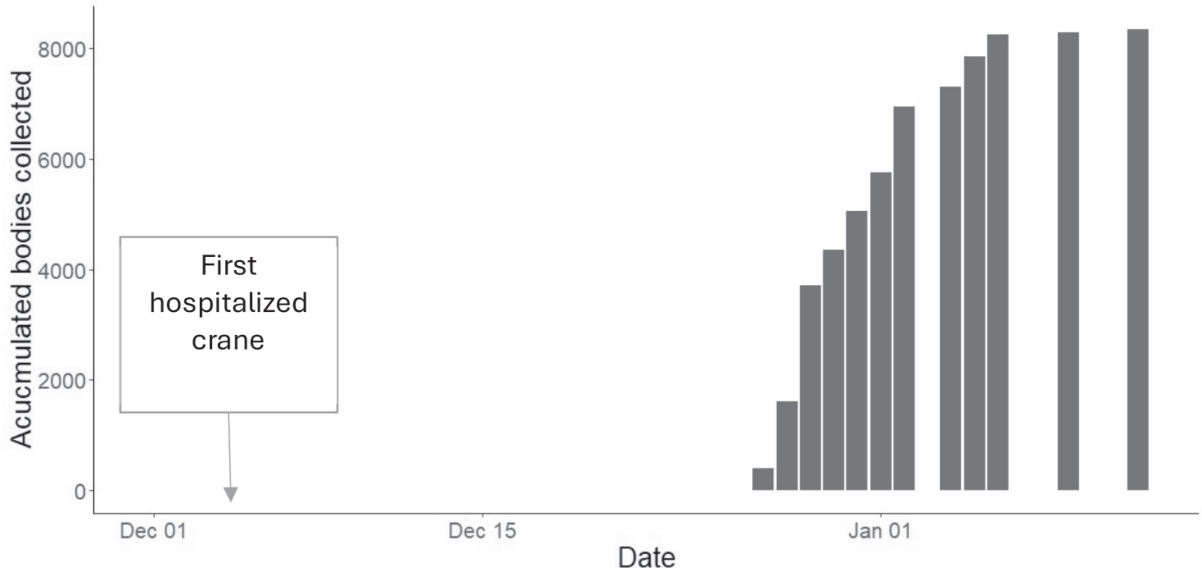

Figure 2: Accumulated number of Eurasian crane carcasses collected during 2021-2 from the roosting-lake and surrounding fields, since the first hospitalized crane detected in the Hula region in 2021. The maximal daily death rate reached 2100 cranes.

Estimated mortality rate during 2021-22

The total number of overwintering cranes in 2021/2 before the outbreak was estimated at 35,000 individuals based on standard yearly crane censuses.

The number of reported dead cranes per day amounted to a mean daily death rate of 186 (Figure 2). This outbreak lasted 35 days (from the first confirmed case in the crane population on 8/12/2021 to the last carcass retrieval on 12/01/2022).

In 2021, during the first outbreak, we used two sources of monitoring-data to estimate the mortality rates of Eurasian cranes following the outbreak. Since different teams made the observations and recordings, the methodology was substantially different, covering the entire period from the outbreak to its official end. (1) Using counts of the total carcasses collected and removed from the area (submitted by the removal contractor to the Hula monitoring program) (Figure 2). (2) Direct observations and counts of dead-cranes using a remote camera of one section of the roosting lake (Figure S1).

Estimated mortality rate during 2024

The total number of overwintering cranes in 2023/4 was estimated at a maximum of 15,200 individuals in the Hula Valley (in 2024 there had been two counts – one 15.2K, and another 10.4K. In the Agamon Lake Park census counts were lower and averaged 11.5K that year – information provided by Idan Talmon (Movement Ecology Lab, The Hebrew University, Israel). The number of reported dead cranes amounted to a mean of 1.6-23 deaths per day (Figure 3). This outbreak lasted 41 days (from the first confirmed case in the crane population on 31/1/24 to the last death on 12/3/24).

Mortality rates were estimated based on routine monitoring of two regions where the cranes forage around the fields surrounding the Agmon Lake (Figure 3). These included the “Dalet” area, where the diversionary feeding operations occurred until the 7th of February 2024 (Figure 3, dotted line), and the “Kavnoa” area, which included open agricultural fields, without diversionary feeding. Note that these areas were the most intensively used by cranes, but do not encompass all their local distribution range. In each of these regions, the number of carcasses was recorded every 1-4 days from 31/01/2024 to 07/03/2024. In addition to the number of carcasses, the total number of cranes was counted for a subset of these dates (Figure 3, blue bars).

From the daily carcass-counts, we estimated the mean mortality rates for each region (Figure 3) and estimated the range of mortality rates representative of the entire region (Table 3). In addition, the percentage of dead cranes was

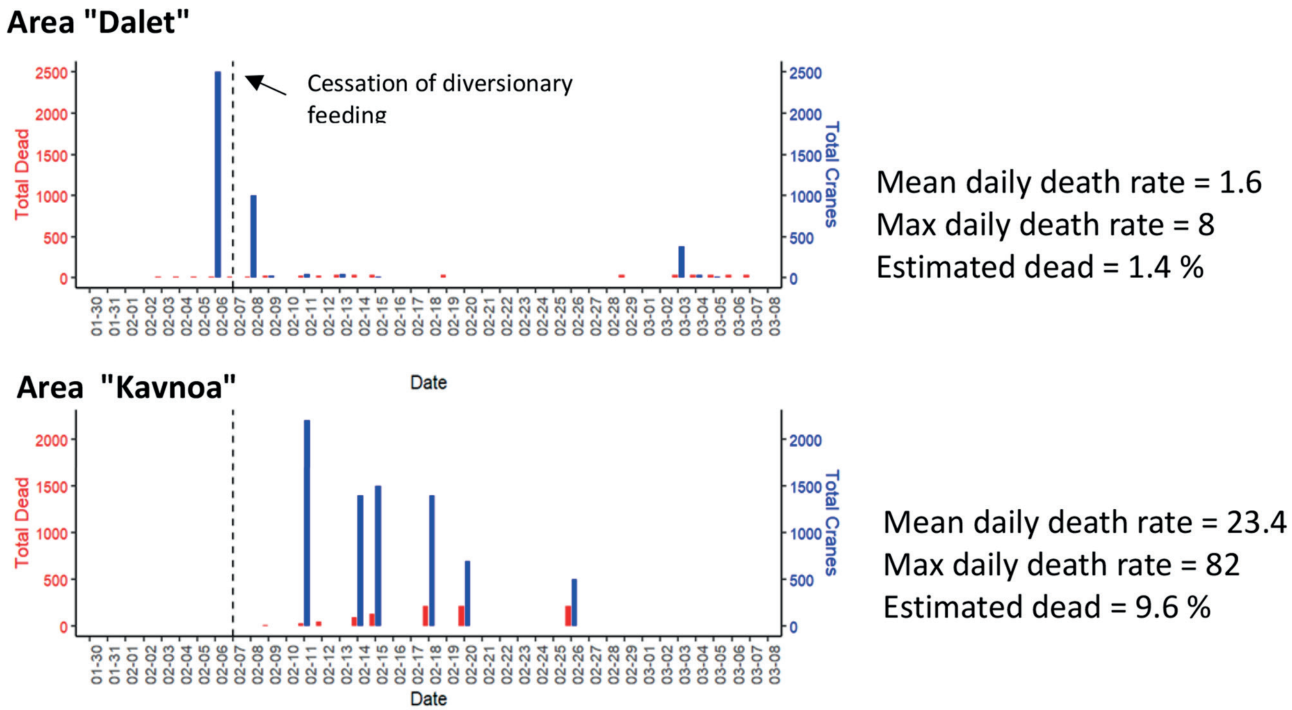

Figure 3: Trends in the number of dead (red bars, left y-axes) and total number of cranes (blue bars, right y-axes), counted during continuous observation-based monitoring of two areas: "Dalet" (top panel) and "Kavnoa" (bottom). From these data, the mean and the maximal death rate were calculated (right-hand side of each panel). Note that the total number of cranes shifted from "Dalet" to "Kavnoa" after the 6th February (dotted line), most likely due to the cessation of the diversionary feeding in "Dalet".

estimated as the total number of dead cranes to the total number of cranes observed per region (Table 3).

The percentage of mortality at the end of each outbreak was calculated from the number of carcasses removed at the termination of the outbreak (Table 2).

a. The number of dead cranes from the area (submitted by the removal contractor of the Hula monitoring program) in 2024 was estimated to be between 223 to 400 carcasses based on the final bird counts, which represented 1.4-2.6% of the wintering crane population.

b. The number of dead cranes from the area during 2021/22 was estimated to be between 8,565 to 8,665 carcasses, which represented 20-27% of the wintering crane population.

Estimated survival rate

Gremillet *et al.* (4) (2023) described the presence of antibodies within some juvenile northern gannets, suggesting that an immune response in individuals within the population, who were exposed to HPAIV and survived, develop an immune response that could potentially protect against future infections. These findings coincide with a controlled study (5) in Mallards (*Anas platyrhynchos*) showing a significant correlation between avian influenza virus antibody concentrations in female mallards and the yolk of their eggs. The duration of the protective antibodies however is unknown, and further longitudinal monitoring needs to be made to fully understand the persistence of the immune response (4).

The proportion of dead cranes from the known population of the overwintering flock in the two outbreaks was calculated. To better understand the survival rate from the H5N1 Influenza virus within the flock we presumed the following:

1. During the first outbreak of 2021/2 – a naïve population and one main roosting site, we observed very high contractability of the virus. Many cranes exhibited clinical signs characteristic of initial exposure to the virus, showing typical (3) neurological symptoms as well as general weakness and remaining at the roosting site during the day for a period of about four to five days, on average, before showing signs of recovery (2).

2. During the second outbreak (2024) – previously exposed population, we observed lower infection rates, fewer deaths, and clinical symptoms were limited to weakness. Since the water level at the main roosting site was too high, cranes were scattered over several alternative shallow water roosting sites (flooded fields). Cessation of diversionary feeding commenced early in the season, which further contributed to the crane dispersal.

Therefore, the estimated survival rate was calculated as flock size minus dead cranes = sick but survived (an estimated 73-80%).

Other affected species

Avian Influenza is known to affect other avian species as well as mammalian in recent outbreaks (6,7) other dead animals within the outbreak area were sampled. We recorded species names of official confirmed cases in the Hula Valley during the two outbreaks (Table 3). To our knowledge, apart from the 2021 concurrent Influenza outbreak in Israel within several wintering Great White pelicans *(Pelecanus onocrotalus)*, the outbreak in the Hula Valley was limited mostly to the Eurasian crane, with little infection to other species.

During the 2021-22 outbreak, several individuals of other species of waterbirds were found dead in agricultural fishponds surrounding the outbreak area, however they were not sampled. These species included: Great White pelicans (n=4), Great egret (*Ardea alba*) (n=6), one Black Stork (*Ciconia nigra*) and one Pygmy cormorant *(Microcarbo pygmaeus)*. Unfortunately, within the Hula Valley mammals were not tested in the 2021-22 outbreak, and fortunately during the 2023-24 outbreak, no dead mammals were found for sampling.

Following the 2021-22 outbreak, all involved parties (KKL, INPA, Environmental & Agricultural ministries) consulted with professionals around the world to develop protocols to contain and attempt to prevent future outbreaks in the Hula Valley. Those recommendations addressed the following management issues: crane population dynamics within the human-wildlife conflict, water level and turnover at roosting site, carcass removal, biosecurity and constant monitoring. We provide here data regarding these management practices, comparing the two outbreaks.

The potential role of diversionary feeding (human-wildlife conflict mitigation):

The feeding of cranes in the Hula Valley is part of a management program to mitigate human-wildlife conflicts (8). To mitigate this conflict, diversionary feeding of corn seeds is spread in designated fields to attract cranes away from crop-fields together with deterring practices (noise and light) from these crops. These efforts have been taking place for over twenty years and offer a semi-sustainable coexistence between farmers and cranes in the region. The criticism of this mitigation program is directed at the dependence of wintering cranes on the feeding stations and the interference to natural stop-over behavior it may lead to (8). Other studies criticize diversionary feeding as a means leading to overcrowding, thereby increasing the risk of disease transmission amongst wildlife and causing a nutritional imbalance which could potentially weaken the birds' immune systems (9).

This diversionary feeding practice offered two management opportunities during the outbreaks (1) to redirect cranes to different feeding sites (i.e., "dry" fields less hospitable to the virus) and (2) aggregation or dispersal of the wintering cranes as per management decisions (See Figure 3).

Water level and turnover management at roosting site:

The water level in the Hula region is managed for several reasons (10): Agricultural development (prevent flooding and maintain suitable conditions for farming), eco-tourism (the creation of the Lake Agmon Park), environmental protection (peat soil quality and underground fire control) and maintenance of water quality (nutrient removal from downstream to Lake Kinneret – Israel's drinking water basin).

During the initial 2021-22 influenza outbreak, the Ministry of Health and Hula Lake Field Manager decided to pause waterflow from Lake Agmon to the downstream of Lake Kinneret in fear of the contamination of the national water basin with H5N1virus until water testing was established. As a result, it is possible that heavier loads of the virus were present in the lake than would have been if water was permitted to flow freely from the lake (see water contamination (part 2, 5.1).

Due to these events, hydrological management of the 2024 outbreak was centered around two practices:

1. Keeping the water level high enough at Lake Agmon and thus avoiding crane roosting at this site. This was

Table 4: water levels in Lake Agmon during the two outbreaks and the corresponding roosting of cranes

Date	H5N1 outbreak	Water level (cm above sea level)	Crane roosting at site (Lake)
31/1/24	2024 start	62.430	No
25/2/24	Mid outbreak	62.270	Yes
12/3/24	2024 end	62.175	Yes
8/12/21	2021 start	62.238	Yes
23/12/21	Mid outbreak	62.167	Yes
12/1/22	2022 end	62.179	Yes

Table 5: onset time to carcass removal during the two outbreaks.

Date	H5N1 outbreak	Date (+ days)	Carcass removal
31/1/24	First confirmed crane	+ 0	No
3/2/24	Initial removal	+3 days	Yes
7/3/24	Final removal	+36 days	Yes
8/12/21	first confirmed crane	+ 0	No
27/12/21	Initial removal	+ 19 days	Yes
12/1/22	Final removal	+ 35 days	Yes

done actively by increasing water flow from the Jordan river to the Hula channels and was also afforded due to natural precipitation conditions that year.

2. Increasing water flow to the downstream (water turnover) as there were no restrictions from the Health Ministry seeing as drinking water chlorination depletes the virus from the water.

Below see (table 4) describing water levels in Lake Agmon during the two outbreaks and the corresponding roosting of cranes.

Carcass removal:

Cranes winter in Israel all over the Hula region but usually roost and flock in specific areas. Therefore, carcass removal (Table 5) was dependent on where the cranes died and the numbers of carcasses. The initial outbreak (2021-2022), demanded determining which authority would oversee the operation and recruit a workforce dedicated to the removal (provided by the ministry of agriculture in accordance with KKL) and therefore demanded time to onset of removal, as well as removal of carcasses from the water which required special aquatic preparation and logistics. Other sporadic carcass removals were performed by either INPA officials, municipality or Agmon Lake employees. In the second outbreak (2023-2024), carcasses were scattered in the various fields which made the retrieval inconsistent but easier and hastier than the first outbreak.

All personnel involved in carcass removal were required by the ministry of health to take prophylactic antiviral medication Tamiflu (oseltamivir phosphate) [Roche, Basel Switzerland] during the entire exposure period.

Biological security:

The following biosecurity measures were implemented in both outbreaks:

1. **Closing the Hula Lake Park and reserve to visitors.** This took some time during the 2021-2022 outbreak. During 2023-2024 outbreak the October war broke out and the site closed beforehand.
2. **Disinfection of vehicles** entering and leaving the Hula Lake Park. Disinfection was performed by manual spraying of Citric acid 3% and a disinfection pool for the feeding lot tractor.
3. **PPE** (Personal Protective Equipment) of personnel handling carcasses.

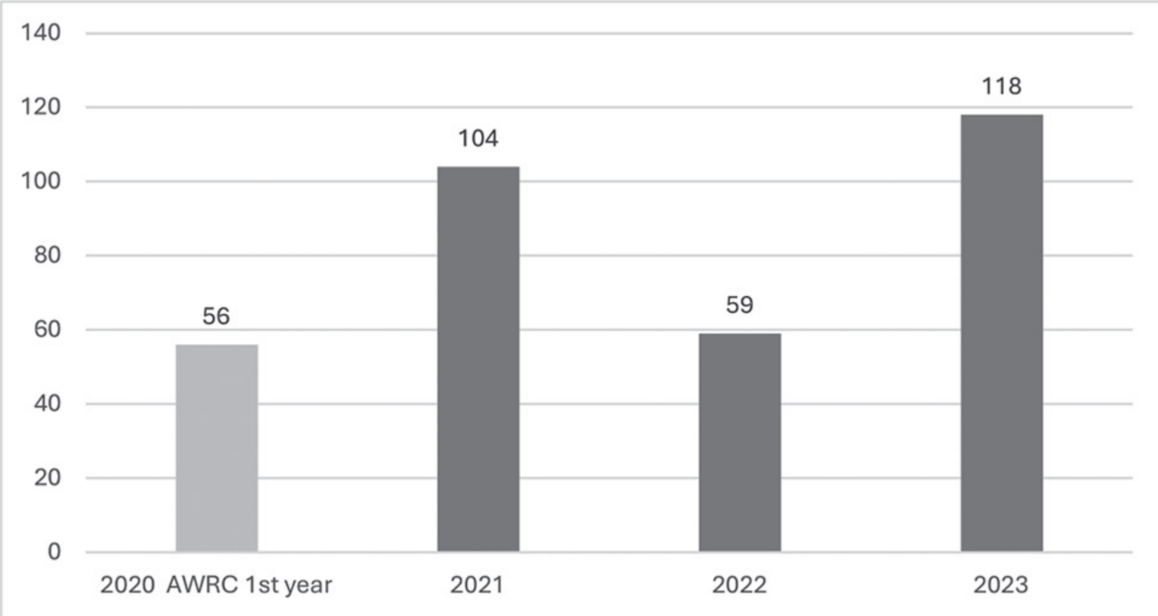

Figure 4: Number of nestlings and fledglings admitted to the AWRC (Agamon Wildlife Rehabilitation Center) per annum.

4. **Shoe disinfection** mats soaked with VIROCID® [CID Lines, Lier, Belgium]

Monitoring

1. Water was sampled for H5N1 virus presence in both outbreaks using various methods utilized by the ministry of health.

During 21/22 outbreak virus levels in the core outbreak area (roosting site in Lake Agmon) were detected, and during the 23/24 outbreak no virus was detected in the water or other sampled areas.

2. Monitoring other species affected in each outbreak. Sampling dead waterbirds carried on also in 2022/23 – between the two outbreaks, where only one bird, a Dunlin (*Calidris alpina*), was found positive with no other implications.

Ecological Aspects

1. **The breeding season** following the outbreak in 2022 showed a significant drop (Figure 4) in nestlings and fledglings (i.e. Common kestrels, Tawny owls, Scopus owls and other species.) admitted to the AWRC. It is possible that this decline mirrored the reduction in population of breeding pairs or birds in the region. In support of this, results from a bioacoustics study in the region, published by Izhar Lavner (2024) revealed a significant decline in the vocal activity of multiple bird species, suggesting a broader impact of the avian influenza pandemic on local species than previously realized (11).
2. **Crane population dynamics** (Contributing author: Talmon Idan, Hebrew University, Movement Ecology Laboratory)

Over the past five years, there has been a significant decline in the size of the wintering population (Figure 5). Notably, this decline began two years prior to the first outbreak and continued thereafter. In both years when outbreaks occurred, counts were conducted before mortality started, ensuring that the numbers for those years were unaffected by the outbreaks. The decline in crane numbers during 2022/23 is most likely a consequence of the massive outbreak that occurred during 2021/22. (the initial outbreak).

DISCUSSION

Considering the pandemic of the H5N1 strain of Avian Influenza in wild populations on a global scale in recent years, the two outbreaks in the Hula region offered the opportunity to better understand the virus dynamics in a natural setting.

The comparison of the two outbreaks enabled us to look

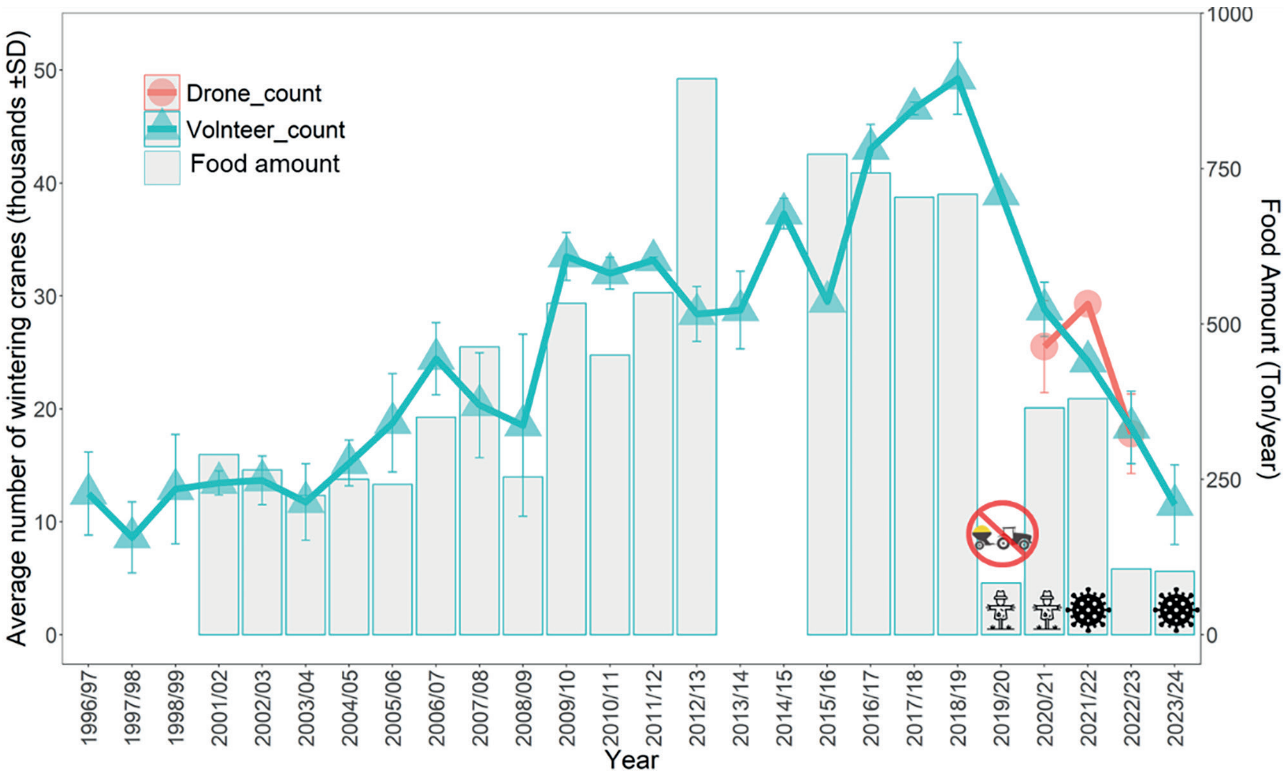

Figure 5: Average number of Eurasian cranes wintering in the Hula Valley over the years of data collection. The average is based on counts by volunteers (turquoise line) and drone surveys (red line) conducted between December 1st and February 15th. An absence of error bars indicates years in which only one count was conducted, thus representing a single value rather than an average. A tractor icon marks years with limited feeding (29 feeding days compared to an average of about 102 feeding days). Gray bars represent the amount of food for each year. A scarecrow icon represents years when unique management actions were implemented, such as nightly harassment from the roosting site and "migration encouragement" (intensive guarding preventing cranes from staying in refuge fields). A virus icon denotes years with avian influenza outbreaks, with at least 8,000 cranes estimated to have died in the first outbreak, and fewer than 400 in the second. Crane count data were provided courtesy of Hula Lake Park-KKL, the Israel Nature and Parks Authority, and the Society for the Protection of Nature in Israel, coordinated by Inbar Shlomit Rubin and Nadav Israeli, with the assistance of Hula Lake Park-KKL guides and KKL volunteers.

at the virus's behavior within a flock of wild birds, regarding virulence factors of contractability, clinical signs, mortality and survival on the one hand, and on the other hand, implement management measures which were built upon conclusions from the first outbreak.

Concurrent global and regional events, such as the COVID-19 pandemic in 2021 and the October war in 2023, affected the decision-making processes and the reality of the different constraints e.g., extra safety measures taken in 2021 to avoid a COV-19-INFL (H5N1) cross mutation or the inability to produce aerial photographs during the war to monitor dead cranes.

Seeing that a significant number of the cranes survived the first outbreak, we hypothesized that the recurring contractability would be of a less dire outcome due to presumed herd immunity. Management efforts were more precise, and monitoring for HPAI strains in wild populations was and still is, carried out regularly.

However, several findings resulting from this comparison are worth considering to mitigate and better understand future outbreaks:

1. In both outbreaks, the first patient arriving for hospitalization served as a good early indicator of an upcoming outbreak. In both outbreaks, this "heads up" was afforded >30 days before the outbreak peaked.

2. The second outbreak occurred much later during the winter (end of January vs. early December). In the Mediterranean climate of the Hula Valley, this difference greatly affects temperature and precipitation, rendering the early winter more hospitable for the virus than late winter, in which temperatures rise, and low precipitation shortly follows, leading to decreased survivorship of the virus.

3. The first outbreak (2021-2022) was characterized by high proportions of mortality (20-27%), contractability, clinical signs and morbidity. We believe the contributing factors to the magnitude of the outbreak were the naiveite of the crane population to the virus, holding of the water at the roosting site, providing a single roosting site for all wintering cranes in the region, environmental conditions (early winter), and the relatively late retrieval of carcasses (+19 days after first positive crane).

4. This said, we believe about 73-80% of the wintering crane population in 2021-2022 were exposed to the virus and survived, providing a strong herd immunity witnessed in the second outbreak (2023-2024) in which significantly lower mortality rates were observed (1.4-2.6%). Other contributing factors we believe contributed to the lower mortality, apart from herd immunity, were the active water turnover at the roosting site, naturally-occurring high water levels (late winter) and water level management conditions which caused the cranes to avoid the Agmon lake and choose alternative roosting sites in shallow water ponds in the fields. Carcasses were scattered in various fields, which made the retrieval inconsistent, albeit removal began swiftly (+3 days after initial positive crane confirmation).

5. Diversionary feeding of wintering cranes gained a lot of attention in the debates on whether this practice had a strong impact on the disease transmission in both outbreaks. According to the INPA, which is in charge of granting feeding permits to the farmers, the feeding practice had a strong effect on the outbreak dynamics. Accordingly, a cessation of feeding was ordered eight days from the first positive case (2024). The rationale for this decision is that as crane density increases over a longer hours of the day, the likelihood of infection also rises. Additionally, the food is spread on the ground, which is mixed with bird feces, creating a potential pathway for disease transmission. Although we did not observe any significant changes due to this practice and recorded mortality after the feeding had stopped (Figure 3), more information needs to be gathered in terms of how feeding affects virus transmission within a flock in a natural setting as opposed to a housed environment. since the role of supplementary feeding on viral transmission cannot be adequately isolated, since it was conducted in previous years in varying degrees. In our view, only in a controlled experiment where there was no feeding and the presence of the virus within a naive flock is confirmed, would it be possible to firmly conclude whether and how strongly supplementary feeding contributed to the spread of the disease.

Another way to look at the effect of diversionary feeding on disease outbreak outcomes was to compare the recorded mortality from H5N1 outbreaks worldwide in flocking avian populations. To mention a few, in the Netherlands (12) for example: Barnacle geese (*Branta leucopsis*) 4.8% mortality of the nonbreeding population (2020-2021) and 7.4% in 2021-2022, Mute swans (*Cygnus olor*) 7.4% in 2020-2021, Sandwich terns (*Thalasseus sandvicensis*) 17.2% in 2021-2022, Northern gannets (*Morus bassanus)* 32.8% (and probably higher) of the non-breeding population died in 2021-2022. In none of these, mass mortalities was there any form of feeding. However, we do know higher density correlated to higher infection, such as in the case of roosting within a body of water, as some waterbirds in the above-mentioned cases do.

Within this comparison, we need to look at the fact that the initial H5N1 outbreak in cranes in the Hula suffered a 20-27% mortality being the second highest recorded rate to the Northern gannets (32.8%) – to the best of authors' knowledge. Influencing factors that need to be considered are the natural (and artificial) density of each species and their susceptibility to the virus. Since the biology and behavior of species differ (even between waterbirds), the comparison between species may be problematic.

Other dead and sick avian species were collected and sampled throughout both outbreaks. In both cases the confirmed cases were sporadic, and there was no mass mortality observed in other species in the region. As with any influenza outbreak, scavengers are at risk of infection, since they may ingest infected carcasses, and we did observe some positive H5N1 raptor species. Another possible indicator of an underlying outbreak effect was the low number of breeding pairs in the spring following the first outbreak (2022).

FUTURE REFERENCE AND LESSONS LEARNED:

1. During the early detection period, where possible, it is important to redirect the crane population to alternative roosting sites and avoid congregation at the water site as it possible that contractability is higher within the water due to favorable conditions for this particular virus (13).
2. Wherever possible, water turnover should be indicated as early as possible within the outbreak.
3. A plan for carcass removal should be ready at hand, so

that collection and removal of carcasses will be carried out as soon as possible.

4. A mortality and morbidity assessment should be carried out in a methodological manner and categories of wintering/non-breeding population counts, live (healthy and sick) vs. dead birds should be counted as accurately as possible, instead of relying on the total death toll as the only monitoring metric. Additionally, other relevant measures should be taken during these counts, such as the size and structure of the flocking/roosting sites, water levels, precipitation and weather conditions.
5. Missing evidence of herd immunity may be greatly helped by collecting antibody titers (whole blood-serum) from otherwise healthy animals (such as wildlife coming into a rehabilitation facility due to trauma cases). These antibody levels might aid in assessing the potential future outcomes of outbreaks and may aid in future recombinant vaccinations (thus while considering different strains which may not allow for cross immunity).
6. Outbreaks in the wild are another stress factor building upon other day to day stressors we humans create for wildlife. Human-wildlife mitigation strategies should consider that these stressors may weaken the immune systems of wild populations and should cautiously consider more accommodating options. This paper was presented at "The Israel Zoo Association Annual Research Symposium" held at the Biblical Zoo, Jerusalem, On the 19th February 2025.

ACKNOWLEDGMENTS:

We wish to thank the AWRC team for their efforts in sample collections, Yaron Charka, Efi Naim, Dr. Doron Markel, Inbar Shlomit-Rubin, Dr. Yoni Vortman, Anat Levi, Nathalie Levina, Dr. Boris Even-Tov, Prof. Ran Nathan, Prof. Noga Kornfeld-Shor, Hula Lake Site and KKL workers, Dr. Avishai Lublin, INPA officials, Dr. Roni King, Dr. Tomer Nissimian, Motti Shai, Dr. Roee Davidson, Nadav Israeli, Safed Health Department and Ministry of Agriculture; for your kind assistance and contribution during both outbreaks.

REFERENCES:

1. Lublin, A., Shkoda, I., Simanov, L., Hadas, R., Berkowitz, A., Lapin, K., Farnoushi, Y., Katz, R., Nagar, S., Kharboush, C., Peri Markovich, M. and King, R.: The history of highly-pathogenic avian influenza in Israel (H5-subtypes): from 2006 to 2023. Isr. J. Vet. Med. 78:13–26, 2023.
2. Talmon, I., Pekarsky, S., Resheff, Y. S., Markin, Y., Thie, N., King, R., Lublin, A., Bartan, Y., Getz, W. M., Kamath, P. L., Bowie, R. C. K. and Nathan, R.: Wild-animal tracking enhances emerging disease management. Manuscript in preparation, Hebrew University of Jerusalem; 2025.
3. Tarasiuk, K., Kycko, A., Knitter, M., Świętoń, E., Wyrostek, K., Domańska-Blicharz, K., Bocian, L., Meissner, W. and Śmietanka, K.: Pathogenicity of highly pathogenic avian influenza H5N8 subtype for herring gulls (*Larus argentatus*): impact of homo- and heterosubtypic immunity on the outcome of infection. Vet. Res. 53:108, 2022.
4. Grémillet, D., Ponchon, A., Provost, P., Gamble, A., Abed-Zahar, M., Bernard, A., Courbin, N., Delavaud, G., Deniau, A., Fort, J. and Hamer, K. C.: Strong breeding colony fidelity in northern gannets following high pathogenicity avian influenza virus (HPAIV) outbreak. Biol. Conserv. 286:110269, 2023.
5. Van Dijk, J. G. B., Mateman, A. C. and Klaassen, M.: Transfer of maternal antibodies against avian influenza virus in mallards (*Anas platyrhynchos*). PLoS One 9:1–7, 2014.
6. Pardo-Roa, C., Nelson, M. I., Ariyama, N., Aguayo, C., Almonacid, L. I., Gonzalez-Reiche, A. S., Muñoz, G., Ulloa, M., Ávila, C., Navarro, C. and Reyes, R.: Cross-species and mammal-to-mammal transmission of clade 2.3.4.4b highly pathogenic avian influenza A/H5N1 with PB2 adaptations. Nat. Commun. 16:2232, 2025.
7. Arruda, B., Baker, A. L., Buckley, A., Anderson, T. K., Torchetti, M., Bergeson, N. H., Killian, M. L. and Lantz, K.: Divergent pathogenesis and transmission of highly pathogenic avian influenza A (H5N1) in swine. Emerg. Infect. Dis. 30:738, 2024.
8. Pekarsky, S., Schiffner, I., Markin, Y. and Nathan, R.: Using movement ecology to evaluate the effectiveness of multiple human-wildlife conflict management practices. Biol. Conserv. 262:109306, 2021.
9. Kubasiewicz, L. M., Bunnefeld, N., Tulloch, A. I. T., Quine, C. P. and Park, K. J.: Diversionary feeding: an effective management strategy for conservation conflict? Biodivers. Conserv. 25:1–22, 2016.
10. Gophen, M.: Hydrology and cranes (*Grus grus*) attraction partnership in the management of the Hula Valley-Lake Kinneret landscape. Hydrology 8:3, 2021.
11. Lavner, Y., Melamed, R., Bashan, M. and Vortman, Y.: The bioacoustic soundscape of a pandemic: Continuous annual monitoring using a deep learning system in Agmon Hula Lake Park. Ecol. Inform. 80:102528, 2024.
12. Caliendo, V., Kleyheeg, E., Beerens, N., Camphuysen, K. C., Cazemier, R., Elbers, A. R., Fouchier, R. A., Kelder, L., Kuiken, T., Leopold, M. and Slaterus, R.: Effect of 2020–21 and 2021–22 highly pathogenic avian influenza H5 epidemics on wild birds, the Netherlands. Emerg. Infect. Dis. 30:50, 2024.
13. Domanska-Blicharz, K., Minta, Z., Smietanka, K., Marché, S. and Van Den Berg, T.: H5N1 high pathogenicity avian influenza virus survival in different types of water. Avian Dis. 54:734–737, 2010.