



Bird flu outbreak among sandwich terns

Workshop report: Development and consequences of the recent bird flu outbreak among Sandwich terns in the Wadden Sea and adjacent areas

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Summary

The breeding season of 2022 was characterised by a massive outbreak of highly pathogenic avian influenza (HPAI), which affected many waterbird populations in NW Europe. In particular, Sandwich terns (*Thalasseus sandvicensis*) suffered major losses in the Wadden Sea as well as in the United Kingdom, Belgium and parts of France, Denmark and Sweden. Consequently, the Common Wadden Sea Secretariat (CWSS), as the coordinating unit for Trilateral expert groups on breeding and migratory birds, together with the Wadden Sea Flyway Initiative (WSFI) organized an online workshop on 18-19 October 2022 to discuss the possible drivers of the outbreak, its consequences on Sandwich tern populations and future management options. The primary purpose of the workshop was to bring together a wide variety of multinational stakeholders, including biologists, virologists, site managers, and decision makers to share their knowledge and to better prepare for future outbreaks.

Over two days, more than 70 participants addressed three main topics: (1) status of knowledge on the recent HPAI outbreak in Sandwich terns; (2) future management measures, and (3) the effect of the outbreak on Sandwich tern populations. The agenda of the first day of the workshop included updating the participants on the current knowledge and status of the recent HPAI outbreak and the measures taken in different colonies and countries, followed by knowledge exchange on the general effect of bird flu on wild birds and transmission mechanisms. Participants from Germany, The Netherlands, Belgium, France, the United Kingdom, Sweden, Poland and Denmark shared information on their data, experiences, and management measures taken during the HPAI outbreak in Sandwich tern colonies. On the second day, participants distributed themselves across three groups to address in detail and summarize the following themes: (i) state of knowledge; (ii) management options; and (iii) population modelling.

The main take home messages of the two days of discussion were:

- There is an urgent need to fill gaps in knowledge on the characteristics of the affected sites (environmental variables), virus transmission routes to Sandwich terns and the role of other species, immunity development, as well as the underlying mechanism of the observed age-class differences in mortality.
- We need to establish an early warning system and find ways to check newly arriving birds for physiological signs of HPAI-related sickness.

This can be done with web cameras or drones to minimize disturbance.

- Etiologic confirmation by examining relevant clinical (swabs of diseased/dead birds) or environmental samples (surface water of small freshwater pools adjacent to breeding sites, faecal matter etc.) should be initiated early on.
- Precaution should be taken when entering colonies, collecting dead birds or collecting environmental samples (e.g., guano, infected water) due to potential zoonotic viral properties and risks of disseminating virus with contaminated fomites. Measures should include wearing glasses, masks, gloves, coveralls and carefully cleaning and disinfecting clothes and shoes following colony visits.
- There are both advantages and disadvantages of removing dead birds from colonies, but the current data suggest that removing carcasses at an early stage of the outbreak can significantly reduce the mortality of both adults and chicks. Disturbance should be kept to a minimum especially during the settling phase (egg laying) of the birds, as disturbance can increase aggression or cause abandonment and dispersal, adding to the risk of spreading of the disease.
- If permission can be given, it is of relevance to take blood samples to monitor presence of antibodies. Procedures for proper handling of blood samples should be followed.
- An integrated demographic model is being prepared for the Dutch Sandwich tern population, but the outcomes will only be visible next year. Another model at the European level should be built for the Sandwich tern meta-population.
- It is of relevance to monitor a) the seasonal development of colonies (e.g. by use of drones), b) breeding success, c) the occurrence of ringed individuals (to estimate survival rate, exchange of individuals between breeding sites, and the number of floaters). Standardized data collection procedures should be developed and followed as far as possible.
- Enhance cooperation between different disciplines such as demography, immunology, population dynamics, chemistry, and modelling. Also, mobilize the necessary funding and strengthen the network for better exchange of information and preparation for the future.

A summary of the content of the presentations, the feedback provided by the participants, and the outcomes of the different working groups is presented in this report.

Day 1: Current knowledge on avian influenza outbreaks

The opening and introduction of the workshop agenda

Mr. Bernard Baerends, Executive Secretary of the Common Wadden Sea Secretariat (CWSS), officially opened the workshop, highlighting the severity of the last HPAI outbreak and the necessity to learn from it for the future. He reminded the participants that it is estimated that almost half of the Sandwich tern populations of the Wadden Sea has been wiped out during the 2022 outbreak, particularly in the Western part of the area. This has raised important questions that need to be urgently addressed, such as those regarding the transmission routes of HPAI into the Sandwich tern colonies and the appropriate management strategies if an outbreak occurs in the future. What can be done to protect and support Sandwich terns and other colonially breeding birds in the Wadden Sea and beyond?

The CWSS and the Wadden Sea Flyway Initiative (WSFI) have been working for more than three decades on conservation issues not only in the Wadden Sea area, but also at the flyway level. Both aim to bring together stakeholders as well as people with relevant expertise to address environmental issues. In case of this workshop, site managers, biologists, virologists, NGOs, and decision makers, including many international participants, responded to the call. The overarching goal of bringing all this expertise together is to learn from each other about the status and effect of the 2022 HPAI outbreak on tern colonies, the management measures taken during the last outbreak, and how to tackle future outbreaks.

Mr. Baerends thanked the more than 70 attendees for the quick response to exchange their experiences and to take part in these important discussions. He also thanked the three keynote speakers for their willingness to share their knowledge with the participants and announced that a wider international workshop will be organized beginning of 2023 on the consequences of HPAI outbreaks on wild birds and to determine concrete steps for the future.

Session 1 on the status of the Sandwich tern population during the recent HPAI outbreak

Communication 1: Bird flu epidemic of Sandwich terns on Hallig Norderoog 2022

By: Veit Hennig, Ulrich Knief, Matthias Haupt, Jannis Dimmlich and Bernd Hälterlein

Mr. Bernd Hälterlein gave the presentation on behalf of his collaborators. The Hallig Norderoog is a national park owned by the Verein Jordsand since 1907, dedicated for nature protection and in particularly breeding birds. Over the last century, the island regularly hosted 3000-4000 breeding pairs of Sandwich terns. Breeding success is estimated since 2010 and in the past two years the number of breeding pairs is monitored with drones to minimize disturbance. Then, a chronological history of the HPAI outbreak in the breeding colonies of Sandwich terns was shared. There were more than 5000 breeding pairs and of those an estimated number of 600 adults died. Almost all chicks died, but 29 out of 885 chicks ringed early June were observed at the traditional roosts in Denmark later in the season. Most of the chicks died within 10-20 days since the first sign of the outbreak. The HPAI infection started mostly during the first half of July, after a subcolony of additional 1000 breeding pairs had formed. In this subcolony, most of the ringed dead adults had Dutch rings, whereas in the main colony most ringed dead birds had German rings. Drones were used to map dead birds and to assess the spatial dynamics of the infection in the colonies. Finally, it was mentioned that black headed gulls were also affected by HPAI, but common terns that bred close to the Sandwich terns were not affected.

Communication 2: National Park Hamburgisches Wattenmeer

By: Janne Lieven and Jens Umland

Ms. Lieven shared the status of the 2022 bird flu outbreak in the national park Hamburgisches Wattenmeer and the lesson learned. They faced the difficulty that the veterinarian authorities were responsible for the measures taken against the avian flu outbreak, and these authorities reside 100 km away from the colonies. Thus, adequate monitoring of the outbreak was hindered by the legal conflict between different management authorities. Consequently, most data at hand were collected in touristic public areas, which showed large mortality in black headed gulls. The main goals developed from the last outbreak are: (1) to overcome the lack of communication between the

stakeholders, (2) to overcome the lack of staff in the park dealing with the bird flu issue (currently only two people), (3) to resolve the legal/different interests between authorities concerned with avian flu and (4) to provide proper training for the staff on how to deal with similar outbreaks.

Communication 3: Sandwich terns-Avian influenza 2022 The Netherlands / Belgium

Mardik Leopold

Mr. Leopold started by saying that the large numbers of infected gannets washed ashore months before the HPAI outbreak in Sandwich terns should have been an early warning sign. In addition, more than 350 thousand infected poultry were killed monthly in the Netherlands, just before the outbreak¹. As a management measure, dead chicks were removed from Sandwich tern colonies, which improved survival of the remaining chicks². It was predicted that the removing of dead birds every two days had reduced mortality by 80%. The recommendation therefore is to regularly remove dead birds, especially when case numbers are still low (not in the exponential phase). The disadvantage of this measure is an increase in disturbance of breeding pairs, with the risk of them abandoning the colony and breeding elsewhere, and as a result spreading the HPAI into new areas. In the Netherlands, more than 350 dead ringed chicks with known history were found that can be used to further study the effect of HPAI on Sandwich terns.

Communication 4: Impact of HPAI on Sandwich terns: The Belgian case

Wouter Courtens, Eric Stienen and Hans Matheve

Mr. Courtens first shared the history of the Sandwich tern colonies in Belgium and their displacement as a response to disturbance. Fox predation hindered the breeding of Sandwich terns for 15 years, but they returned after the establishment of anti-fox electrified fences. This was followed by an overview of the chronological dynamics of the HPAI outbreak in Sandwich terns and the management measures taken. The first recovery of HPAI was on June 3rd, and because there were no restrictions on working in colonies, it was decided to remove carcasses of dead birds three times weekly, but with extreme caution. During the visits, additional data were collected on species present, the

¹ Gonzelas et al 2022 WBVR report 2211632. <https://www.wur.nl/en/research-results/research-institutes/bioveterinary-research/show-bvr/bird-flu-at-poultry-farms-in-20222023.htm>

² Rijks JM, Leopold MF, Kühn S, et al. Mass Mortality Caused by Highly Pathogenic Influenza A(H5N1) Virus in Sandwich Terns, the Netherlands, 2022. *Emerging Infectious Diseases*. 2022;28(12):2538-2542. <https://doi.org/10.3201/eid2812.221292>

number of individuals, mortality, and rings. Mortality seemed to decline with the removal of carcasses and with time. A very successful colony established close to early badly infected colony. Contrary, a smaller colony that settled on the exact same spot as that early infected colony was erased. Further, HPAI infection caused significant breeding failure, but many surviving birds initiated a replacement clutch later in the season. A serological study was conducted to shed light on the immunity development in Sandwich terns as well as genetic erosion in the population in response to the HPAI outbreak.

Communication 5: Impact of HPAI on Sandwich terns: A case from France

Alexandre Sibille, presented by Kristine Meise

This presentation reports on the status of the HPAI outbreak in a reserve in north western France close to the North Sea. The reserve is a breeding site for many seabirds including Sandwich terns that have been breeding there since 1996. A management plan was implemented in 2018 to reduce predation pressure on the Sandwich tern colonies, particularly by foxes. The 2022 HPAI outbreak caused a tremendous loss in the colonies, not only Sandwich terns but other breeding species as well. It is estimated that between 55% and 80% of the breeding adults died. About 3 weeks after the onset of the epidemic, the decision was made to pick up all the dead birds on the colony. This management action may have allowed the epidemic to be limited to a part of the colony, as several later born chicks survived until fledging.

Communication 6: HPAI outbreak in the Sandwich tern colonies of the Lower Saxon Wadden Sea in 2022.

Florian Packmor

Dr. Packmor shared the results of the daily dead bird survey on Minsener Oog during the 2022 HPAI outbreak. The survey was conducted along a beach not far away from the main nesting site. Sandwich tern cadavers represented 70% of the total number of dead birds found. The establishment of the national park had significantly increased the breeding population on Minsener Oog, but regular ups and downs as well as switching between breeding sites are observed. Before the HPAI outbreak, the total number of Sandwich terns counted on Minsener Oog this year was the highest ever recorded. The colony was hit by HPAI during late May/early June. The chronological development of the outbreak was recorded by means of a daily dead bird survey along the eastern coast of the island. To avoid contamination and double counts of dead birds, carcasses were buried. The mortality of Sandwich terns on the island followed a bell-shaped curve, with a peak around the 21st of June. After the

breeding season, the colonies were also checked for dead birds and their age classes. Only few juveniles seem to have survived the outbreak, and the ring recovery indicates a strong connection with other Sandwich tern colonies in the region. The carcasses recovery in three sites indicated that one colony was for sure hit by HPAI, another one was likely affected at a certain point, and the last one that bred earlier in the season was likely uninfected by HPAI. Overall, 35% of the adults were confirmed dead and the fate of the rest is unknown.

Communication 7: Sandwich terns breeding in the UK

Rebecca Jones

Ms. Jones gave an overview of the Sandwich tern populations in UK. The UK holds about 9.6% (12500 pairs) of the global population of Sandwich terns. The largest colonies are in the north at Norfolk coast, Coquet Island, and the Farne Islands. The HPAI outbreak in the Sandwich terns in the UK showed different spatio-temporal dynamics. Sandwich terns in Scotland, Wales, Northern Island, and the Republic of Ireland were generally unaffected by HPAI. The eastern coast of England was most affected, while the west coast was hit only later in the breeding season, after tern chicks had mostly fledged. Overall, the peak mortality occurred between mid-June and mid-July, especially when chicks started to move around. In total, 1441 dead adults were counted (8% of the England breeding adult population), while estimates by site managers indicated that at least 1800 (10%) adults died. Several issues were encountered during the outbreak including the lack of clear guidance on management measures, such as collecting dead birds, and delays initiating mortality reporting systems. Not all records of dead birds and information about the outbreak were shared. Many questions remained unanswered, for example why some colonies were affected (eastern coast) and others not (western coast). Did environmental factors play a role in the observed differences? Is the removal of sick and dead birds and disinfection of the environment (e.g. with salt) effective in reducing mortality?

Communication 8: Highly pathogenic avian influenza (HPAI) in Sandwich terns in Sweden 2022

Caroline Bröjer, Patrik Olofsson, Mikael Kristersson and Rolf Larsson

Ms. Bröjer works for the National Veterinarian Institute (SVA) that has the responsibility to deal with HPAI outbreaks. They have an online application in place for the public to report dead animals, which allowed tracking the numbers of dead birds. Detailed information of the 2022 HPAI outbreak in Sandwich terns was available for four sites: Falkaholmen, Norrören, Landgrens holme, and Eneskärs kläppar. Falkaholmen has around 400

breeding pairs, and 53 adults and the majority of chicks died during the outbreak. Norrören has around 125 breeding pairs, and 15 adults and the majority of chicks died. Landgrens holme has around 415 breeding pairs, and only 10 adults were found dead, but around 95% of the chicks died. HPAI also hit the black headed gull but not the avocets. Eneskärs kläpar has around 75 breeding pairs, and 4 adults and more than 40 chicks died. No increased mortality was observed in six Sandwich tern colonies located further north. A spill over of HPAI to mammals were also observed in Sweden.

Communication 9: Bird flu in Danish Sandwich terns colonies

Thomas Bregnballe

Mr. Bregnballe shared the history and dynamics of the 2022 HPAI outbreak in the Danish Sandwich tern colonies. Mortality and spread of the virus in Sandwich terns were site-dependent: some sites suffered greater losses than others. However, all colonies of the Danish key sites had low breeding success, and most of the chicks died during the outbreak. Similar to the UK, spatio-temporal differences of the HPAI outbreak in Sandwich terns occurred. The outbreak started in the southern colony at Sprogø located in Storebælt (i.e. not far from the German Baltic Sea coast) with the first adults recorded dead on May 19th, while in the colonies in the north-western part of the country adult mortality started around mid-June. Further, both black-headed and herring gulls were hit by the HPAI outbreak. With regard to managing the outbreak, Denmark is facing the difficulty that there is currently no institution that has taken on the task of monitoring possible future outbreaks of HPAI in breeding colonies of coastal birds. It has not been to be decided whether or not dead birds should be removed from the colonies and who should do this.

Communication 10: Avian influenza and mortality in gulls and terns

Anders Pape-Møller, Einar Flensted-Jensen, Arne Urvang, Karsten Laursen

Mr. Pape-Møller first gave an overview on head and bill coloration in terns, which is related to sexual behaviour and mate attraction. The abundance of Artemia (brine shrimp) as well as the yellow coloration of the bill and beak volume is important for the breeding performance of Sandwich terns. Interestingly, the Sandwich terns' morphological features may affect the survival probability of avian influenza infection. It seems that infected Sandwich terns laid their first egg later than uninfected birds. On average, infected birds weighed less than uninfected individuals. Surprisingly, there was a relationship between the size of the yellow tip of the beak and surviving an HPAI infection: birds with large yellow tip did not survive the infection.

Further, it seems that HPAI was correlated with the size of the black crest, body mass, migration routine, moult, time of reproduction, and the yellow tip of the beak.

Session 2 on the knowledge of the effect of HPAI on wild birds, particularly Sandwich terns

Keynote 1: The bird flu outbreak among Sandwich terns in north-western Europe in 2022

Thomas Bregnballe, Ulrich Knief, Wouter Courtens and Leigh Lock

This work is a joint effort of a multi-national team to gather all available information on the 2022 HPAI outbreak in Sandwich colonies in north-western Europe. The main drawback of this approach is that not everyone collected data from infected colonies, nor were the collected data gathered in the same way. There was strong spatial clustering of the HPAI infection, with the most severe outbreak seen in France and the Netherlands. Most of the colonies around the North Sea suffered some losses, whereas colonies on the Atlantic coasts of Great Britain and in the Baltic Sea were less affected. In total, among 61,764 breeding pairs, 16,678 adult Sandwich terns were reported found dead in the colonies (13.5% of the breeding birds), mostly in the Netherlands, Germany, France, and the UK. The fledgling success was generally very low. The extent of the outbreak was not correlated to the size of the colony, but rather to the distance to next infected colonies. Sandwich terns can easily fly 60-100 km to visit other colonies, which may explain the rather quick spread of the virus between countries. For example, one or a few infected birds may have visited the affected French colony at Platier d'Oye National Nature Reserve and moved to one of the Dutch colonies and then to the Danish colony in Storebælt. Thereby the flu may have spread to neighbouring colonies. In a similar way, one or a few infected individuals may have turned up at Coquet Island in NE England and from there transmitted the virus to the other British Sandwich tern colonies later in the season.

Between 1991 and 2018, the NW European Sandwich tern population had been steadily increasing. Monitoring in 2023 will reveal to what extent the number of breeding birds has declined as a result of this year's outbreak. Numbers of Sandwich terns reported from the Danish coasts where many Sandwich terns gather before migration indicate that numbers have markedly decreased in the late summer and autumn of 2022 compared to the average for the 10 previous years.

The presentation of Mr. Bregnalle was followed by a thorough discussion on how to improve the survival estimates during the HPAI outbreaks. The take home messages from this discussion are:

- The number of fledged chicks needs to be taken into account in population and survival analyses.
- It seems that the HPAI outbreak in Sandwich terns was country-specific: for instance, only few birds in the only colony in Poland were affected, while most of the colonies in the Netherlands were affected.
- Include a temporal component in the analysis, as the survival of the early and late breeders seems to differ. In the Netherlands, early breeders suffered greater mortality than later ones.
- The role of existing stagnant freshwater bodies in spreading the virus needs to be assessed. I.e. geese and/or ducks as carriers could transmit bird flu to pools that are close to Sandwich tern colonies and that are used for bathing and preening by both Sandwich terns and geese and/or ducks.
- The dispersal of infected birds into new territories needs to be assessed. It is relevant to know whether or not an infected bird would be able to fly for example 200 km to another colony and transmit the virus to the breeders in that colony.
- Preventing pairs from breeding to reduce densities in colonies is unlikely to be successful and could increase movement of infected individuals, contributing to the spread of the disease.
- The carryover effect of HPAI infection on the wintering population should be investigated.
- The role of immunity development on the performance of colonies as well as the age effect need to be incorporated. Previous results have shown that older swans in the UK survived HPAI, while younger ones suffered greater mortality³.
- To fully understand the impact of the outbreak one also needs to understand the effect of HPAI infection on the lifespan of immune individuals and their reproductive performance.

³Hill Sarah C., Manvell Ruth J., Schulenburg Bodo, Shell Wendy, Wikramaratna Paul S., Perrins Christopher, Sheldon Ben C., Brown Ian H. and Pybus Oliver G. 2016. Antibody responses to avian influenza viruses in wild birds broaden with age. Proc. R. Soc. B.2832016215920162159. <http://doi.org/10.1098/rspb.2016.2159>

Keynote 2: Common tern meets birdflu— the sad story of 2022

Dr. Sandra Bouwhuis

Dr. Bouwhuis shared the status of the 2022 HPAI outbreak in a well-studied common tern population at the Banter See in Germany. The population is monitored since 1992 using transponders and antennae, which allowed collecting detailed life-history data at the individual level and for many generations. Weight, presence, phenology (e.g., arrival date), clutch size, and both chick and adult survival are registered for each tagged individual. The first victim of HPAI was found dead on May 29, and since then a 4-times daily collection of carcasses was put in place. The mortality increased exponentially for 30 days before levelling off. A genetic analysis confirmed that H5N1 was the cause of the death, and distinct genetic clusters suggest two infection events. In total, 510 birds were found dead during the breeding season. Both males and females suffered from a similar mortality rate (26%), and thus the effect of HPAI in common terns was not sex specific. Although younger birds had a higher survival probability than older ones, the age-specificity of arrival date is the reason behind the observed differences in mortality in the different age-classes: older birds arrive and breed earlier than younger birds, therefore were hit harder. Further, breeders significantly suffered greater mortality (34%) than non-breeders (13%). They also investigated HPAI transmission among breeding partners. Out of 232 pairs of which both pair members were transpondered (and thus known), both partners of 37 pairs were found dead within 0-12 days of each other, in 86 pairs one partner was found dead, whereas 43 ‘widows’ were seen >12 days after their partner had been found dead, and 29 of those were still seen after the last bird has been found dead. These latter birds are likely to have been immune to HPAI. Finally, it was mentioned that 510 dead birds have been collected and stored to analyse the physiological cause of death. Plans are to investigate the carryover effect on the population in the future, and analyse blood samples to be taken from all breeding birds in 2023 to assess antibody prevalence.

The presentation of Dr. Bouwhuis was followed by a thorough discussion on the lessons learned from the HPAI outbreaks in common terns, the relevance of the findings for the outbreak in Sandwich terns, and the long-term monitoring of the population. The take home messages from this discussion are:

- It is important to check whether the same strain of H5N1 or different ones hit the different countries. Dr. Bächlein (LAVES) confirmed that two strains of H5N1 were detected in the Banter See colony. Dead birds can be used to check whether H5NI has mutated over time.

- Check for cross contamination among different species, and the first species that showed symptoms. It is important to further study the transmission mechanism of HPAI between species, and the role of common feeding and breeding grounds in that. It is unlikely that cross contamination between the two species happened at the feeding ground as Sandwich terns mostly feed offshore, while common terns feed in shallow zones.
- At the population level, the mortality curve of the Banter See population is very similar to that of the Sandwich terns from Minsener Oog. Comparison at the individual level is harder to achieve, as there is no similar monitoring scheme on an individual level for Sandwich terns.
- It has been observed that healthy birds attack sick birds, which might further spread the virus. The question remains whether removing sick birds is a good prevention measure (some may survive and build immunity) and whether it is legal.
- It is likely that the use of dead birds as an indication of transmitting species is biased as ducks and mallards do not seem to die from the HPAI, but still can transmit the virus. The use of predicting models as well as spatial network analysis (cluster analysis) can be used to shed more light on the transmission dynamic between colonies and the sources of the outbreak.
- Previous study showed that HPAI could survive for months in nature and can be transmitted through e.g. water bodies⁴, and thus the survival time of the virus should be taken into account in modelling the origin and spread of the outbreaks.
- The role of the environmental parameters in the survivability of HPAI should be investigated and taken into account for the development of mitigation measures. For instance, HPAI outbreak in barnacle geese early in the breeding season might have loaded the environment with the virus.
- Natural or artificial barriers may affect the spread of the virus within colonies, as it prevents movement of chicks, but results are controversial.

⁴ Ann Kathrin Ahrens, Hans-Christoph Selinka, Thomas C. Mettenleiter, Martin Beer & Timm C. Harder (2022) Exploring surface water as a transmission medium of avian influenza viruses – systematic infection studies in mallards, Emerging Microbes & Infections, 11:1, 1250-1261, <https://doi.org/10.1080/22221751.2022.2065937>

- Age-specific effects should be assessed to integrate in population modelling and survival analysis. Therefore, information on age-classes of dead birds needs to be collected.

Keynote 3 on HPAI in wild birds, Germany 2022: History, epidemiology, virology and transmission

Timm Harder, Anne Pohlmann, Jacky King, Christian Grund, Martin Beer

Mr. Harder first gave an overview of the history of avian influenza epidemiology in wild birds⁵. Apparently, all influenza A viruses found in human and other mammals originate from an avian pool. Highly pathogenic variants occasionally arise in case viruses of subtype H5 or H7 start circulating in gallinaceous poultry. HP variants arise spontaneously and unpredictably, but once formed these viruses are horizontally transmitted among poultry and spill back to wild bird populations similar to low pathogenicity viruses, HPAI-infected herded geese and ducks in rice paddies in southern China are believed to have acted as an important spill-over source to wild water birds since 1996. Virus excretion with faeces is the main pathway of transmitting AIV, including HP variants, to other species. Virus-contaminated shallow and stagnant waters are an important transmission source of all AIV. Viruses retain infectivity in freshwater for longer periods compared to marine water. Both increasing temperature and salinity seem to decrease the rate for HPAI transmission. However, migratory birds and illegal transport of poultry are the main causes of the global spread of the virus. HPAIV infects all the vital organs of the avian body including the brain, heart, and liver. Mortality due to HPAI infection is species dependent: some species suffer high mortality while others (several dabbling duck species, in particular mallards) are more resistant and do not die from the infection, making them potential carriers of the disease. Worldwide, there is a strong correlation between poultry and wild bird infections. In Europe, the HPAI outbreaks have been usually seasonal (winter), but the latest wave peaked in summer, which never happened before. In Germany, the outbreak was mainly focused on coastal areas, and was characterized by mass mortality in colonially breeding seabirds. It is possible that seabirds encountered the virus at their southern breeding grounds before migrating northward. There are signs of a spill over of HPAI from wild birds to mammals (terrestrial carnivores) and poultry.

The presentation of Mr. Harder was followed by a thorough discussion on the transmission mechanisms of HPAI and the potential measures to reduce mortality. The take home messages from this discussion are:

⁵ D.J. Alexander & I.H. Brown. 2009. History of highly pathogenic avian influenza. Revue Scientifique et Technique. <http://dx.doi.org/10.20506/rst.28.1.1856>

- The health of humans, poultry, and birds is interlinked through the environment, and thus environmental sampling could enhance our understanding of spill over mechanisms.
- Environmental sampling, however, has not yet given significant results due to the low probability of detecting viruses in large water bodies. Smaller stagnant freshwater pools in the vicinity of breeding colonies may be more promising targets.
- Another technique is to use sentinel stations⁶, which, however, are not useful as an early warning tool.
- The carryover effect should be studied in wintering grounds in Africa.
- Removal and burying or burning the dead birds reduces virus load in the environment and seems to reduce mortality.
- The data at hand suggest that migratory birds have both been victims and vectors during the recent HPAI outbreak.
- Despite the EU having a strict regulation in transporting poultry and stamping out infected poultry holdings, secondary spread of HPAIV between neighbouring holdings, and, by transport, to other regions may be a factor in virus spread as well.
- The survival models of Sandwich tern population are based on daytime counts only, and future modelling should take into account night counts. Circadian rhythms in foraging and resting behaviour of different species may have consequences on the conclusions we draw from daytime activities.
- The presence of bird faeces at roosting sites should also be taken into account in transmission models and for potential mitigation measures.

⁶ Anja Globig et al. 2009. Ducks as sentinels for avian influenza in wild birds. Emerging Infectious Diseases. 10:1633–1636. DOI: 10.3201/eid1510.090439

Day 2: the outcomes of the breakout groups

Session 3 Discussion regarding management and monitoring options

The second day started with the introduction to the three break-out groups and the key objectives.

- (1) The first group discussed the state of knowledge, specifically factors affecting the spread of bird flu, HPAI strain dynamics, lessons learned from past outbreaks, and the necessity to create a handbook for HPAI outbreaks in colonial birds. The main topic to address in this group was the mechanism of the spread of HPAI and its impact on Sandwich colonies.
- (2) The second group focused on the management options, specifically the mitigation measures, their effectiveness, and the necessity to adopt a common strategy. The main topic addressed by this group was the best practice to prevent and mitigate HPAI outbreaks in Sandwich tern colonies.
- (3) The third group focussed on population modelling, specifically the lessons learned from modelling the survival of Sandwich tern population in the Netherlands, scaling up the analysis to EU level, the riddle of the Sandwich terns ring recovery during the last HPAI outbreak. The main topic discussed by this group was related to the type of data that should be collected to improve the population estimates. The summaries of the outcomes of the three groups are presented below:

Breakout group 1: State of knowledge - Discussing factors which may affect the spread of the virus

Moderated by: Thomas Bregnballe

The discussion was centred around the following questions: Are there regional or colony-specific differences in the course of the outbreak? Can we identify specific environmental parameters that affected the spread of the virus? Which management measures have been taken and how can we show the effect these may have had on the spread of the virus?

The group agreed on the necessity to expand the existing dataset of colony-specific numbers of dead and live birds to environmental parameters as well as serology (immunity development), considering the movement of birds between colonies, timing of the outbreak, duration of the infectious stage, and

the role of stagnant water bodies and faeces in spreading the virus. The overall opinion of the group was to aim for an early carcass removal to prevent transmission to other breeding birds as well as to predators (especially mammals) as this transmission increase the risk that the virus mutates and adapts to the mammalian host.

Summary of the discussion

1) New data request from stakeholders

- Environmental data (distance to stagnant water bodies, salinity of water bodies, distance between nests, vegetation, surface structure, natural/artificial barriers, presence of guano).
- Presence of other species (breeding or resting; infected or not - if known; numbers of heterospecifics, especially also those found dead, e.g. common terns and black-headed gulls in 2022).
- Information about dead animals found outside the breeding colonies (where to find information on these numbers to integrate in the analysis?).
- Analysis of the tracking data of infected vs non-infected birds: How far can/will sick birds travel?
- Increase availability of ringing data for population modelling (see discussion group 3).
- Check whether the latest dataset to ensure data on breeding pairs and dead birds (adults/juveniles) are correct.

2) Monitoring protocol for the next years

- Standardized data collection to facilitate data analysis.
- Safety precautions.
- Environmental screening for virus in guano/decomposed birds in colonies.
- Drone monitoring to check for dead birds.

3) Joint risk assessment

- Inter-disciplinary risk assessment (practical WHO guide).
- Develop mitigation measures for each of the risk factors.
- Set up communication channels and put together stakeholders who are in charge of informing about the risk at high level.

- Get people to exchange information and ideas.

4) *Cross-country collaboration*

- Establish contacts with focal points from each country to collect information and to inform about new developments (start with Sandwich tern and then expand (e.g. through AEWA)).

Breakout group 2: Management measures

Moderated by: Florian Packmor

This discussion centred on the following questions: Which mitigation measures have been implemented in 2022? What can be done in the future in terms of management?

The group recommended keeping a close eye on the colony and the remove carcasses as soon as possible to minimize the spread of HPAI. Removal of sick birds should be avoided as its effectiveness is inconclusive (can survive and become immune), and it is illegal in many countries. Minimize disturbance to colonies particularly during the settling phase, and use colony friendly monitoring systems (web camera) as much as possible. Involve more disciplines (e.g., virologist and veterinarian) to tackle specific questions on the biology of HPAI and its impact on the hosts.

Summary of the discussion

1. *Mitigation measures*

- Removal of dead birds (and birds not yet dead). When collection starts when carcasses are fresh, this seems to help but starting late seems to make no difference. Drawback: if starting early in the season, birds may feel disturbed and choose other breeding grounds.
- After some days, carcasses do not pose a high risk, but it depends on the species and the presence of scavengers that feed on carcasses and then spread.
- Removal of fresh carcasses late in the breeding season may cause high disturbance, leading to increase aggression which in turn may affect the spread of the disease. Entering the colony at this point therefore needs careful consideration.
- A decision is needed at which point one should start acting (e.g., number of dead birds). It is suggested to monitor colonies closely (e.g.,

by webcams) before engaging in unnecessary disturbance, and check for physiological signs of infection.

- Do nothing and wait for immunity. This could have been a good strategy if HPAI was a natural disease. The experience shows that this strategy could work for some species, especially those with higher survival rates, but many species would benefit tremendously from mitigation measures. The decision for mitigation measures should therefore be species-specific.
- Standardize the species-specific mitigation approach and collection of birds. Take into account the timing (start of mortality, when is it starting to spread). Mitigation measures should be done in the chick-rearing phase not in the nest establishment (egg phase).
- Collect swap samples/blood samples from multiple colonies whenever possible, e.g., during ringing events.
- Disposal of birds: burning and burying of carcasses on site. Burning is likely more effective in killing the virus but may cause disturbance on site and thus burying the carcasses might often be the best solution.
- Involve more scientists from other disciplines in the future: veterinarians, virologists (questions on virus), environmental biologists (sentinels, eRNA sampling).

2. Preventive measures

Are there preventive measures that appear promising for reducing the likelihood of future outbreaks within the colonies?

- Different methods may have an impact as preventive or responsive measures.
- Investigate the use of salt and grounded shells to reduce survival of the virus in the environment.
- Testing environmental samples to detect HPAI did not give good results so far, but a sentinel approach could be promising.
- Test the effectiveness of within-colony fencing to reduce movement of individual within the colony.
- Reduction of predators: Reduce rats as a threat to colony and as possible spreaders of disease.

3. Conservation measures

- We are lacking virologists, while most questions we have are for virologists. A specialized meeting with more virologists and veterinarians is needed.
- Get authorities to pay for testing also wild populations (focus is currently on poultry). Raise attention to this issue.
- Aid recovery of the Sandwich tern population with other conservation measures (e.g. habitat protection and/or restoration, predator removal)

Breaking group 3: Population modeling

Moderated by Wouter Courtens

This group discussed parameters required for population dynamic modelling, data needs for capture-recapture analyses and integrative population modelling. In addition, the group discussed the riddle of the mismatch between numbers of rings recovered and the numbers of dead Sandwich terns in the Netherlands. Four questions were addressed: (1) which data are available, (2) which data should be collected in the future, (3) how could we estimate the effect of HPAI, and (4) what explains the riddle of rings?

The group recommended building an integrated population model for Sandwich terns at the European level. Therefore, one needs to develop a common protocol to collect data needed for the model (N of breeding pairs, N of dead birds, age, emigration/immigration rate, number of floaters), and to increase color ringing events and efforts of reading them.

Summary of the discussion

- Build a European database to estimate population dynamics of Sandwich terns at the regional level; ‘euring’ data is a good start.
- Get better data on the number of breeding pairs, breeding success, survival rate, and exchange between colonies/sites.
- Breeding success is not measured in all places, and often not in the same way. Thus, it is important to provide clear guidelines on how to measure breeding success.
- Other factors that can affect survival of Sandwich terns should not be ignored in the analyses such as age-specific survival (adult vs. juvenile), food availability, and fertilization.

- If no access to colonies is allowed, use cameras to collect data, but correction of estimates of breeding success is not possible without entering the Sandwich tern colonies.
- Number of floaters (individuals prevented from breeding by territoriality, resources availability or other spacing behaviors) has been overlooked in many places and need to be measured in the future.
- There is an integrated population model being run for the Dutch population, but the outcomes will only be visible next breeding season
- Individual based models are the next step, but currently the necessary are lacking.
- It is important to incorporate more disciplines (e.g., ecologist, virologist, and theoretician) to better assess the impact of different parameters (e.g., virology, immunity, and immigration/emigration).

Session 4 Next steps

Led by Mr. Südbeck and Mr. Bregnballe the group summarized the key outcomes of the workshop and discussed the next steps that should be taken to learn from the current outbreak and to be better prepared for future outbreaks. Within the Wadden Sea region the Sandwich tern is now a species of concern and plans need to be put into place on how to move forward.

Short-term plans:

- 1) Collate missing data from the Sandwich tern colonies in the Wadden Sea and neighboring countries (environmental data, presence of heterospecifics, updated numbers on birds (breeding, dead, chicks)).
- 2) Analyze data to address different hypothesis regarding the factors affecting the spread and scale of the outbreak. There are many important knowledge gaps that need to be addressed, such as the impact of environmental factors, age differences in survival, transmission mechanism and routes (e.g. the role of ducks and geese) and foremost the effectiveness of different management strategies.
- 3) Explore and mobilize funds to better prepare for the next years. The considerable impact of the outbreak on the Sandwich tern colony is likely to affect their AEWA status which may lead to further funding

opportunities (also: ‘Capaflu’ consortium is seeking funding from the EU and is looking for collaborators).

Intermediate plans:

- 4) Establish a monitoring, research and (as far as possible) management protocol for the next breeding season that will ensure a coordinated approach.
- 5) Strengthen the birdflu network and reach out to experts from more disciplines and international partners, especially those working in veterinary science and virology. In the Netherlands, there is a multidisciplinary group dedicated to the bird flu issue, which could be a good starting point for the network to create an active network of exchange.
- 6) Develop experimental designs to test possible future mitigation measures, but caution should be taken when dealing with infected birds.
- 7) Highlight the importance of testing wild dead birds (at high political levels), to check for new HPAI strains, and the development of immunity (screening for antibodies) in the population.

Long-term:

- 8) Create an online platform to exchange information on bird flu outbreaks in Sandwich terns (and maybe other species) and new knowledge about Sandwich terns that may be relevant in this context.
- 9) Determine the effects of the outbreak on the flyway scale, making use of the results from the total counts along the East Atlantic flyway in January 2023.
- 10) Provide support for the improvement of color-ringing programs to be able to analyze survival of Sandwich terns at the European level.
Improve counts and ring reading in the wintering grounds.
- 11) Study the long-term impact of bird flu infection in immune birds to better understand population consequences of such outbreaks
- 12) Establish working groups to prepare management plans for governments and managers.

The CWSS, in collaboration with partners, is planning to organize another birdflu workshop, in person, before the next breeding season. Concrete suggestions for objectives to be addressed at the workshop are welcome.