



CANADIAN
WILDLIFE HEALTH
COOPERATIVE

Considerations for planning future wild bird avian influenza surveillance in Canada

An Opinion Paper Prepared by the Canadian
Wildlife Health Cooperative

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**CREATING A WORLD
THAT IS SAFE AND SUSTAINABLE
FOR WILDLIFE AND SOCIETY**



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Context for the report

This report is a ‘think-piece’; a piece of writing meant to be thought-provoking that consists chiefly of background material and personal opinion and analysis. The Canadian Wildlife Health Cooperative (CWHC) undertook this exercise after the outbreak of highly pathogenic avian influenza (HPAI) in British Columbia and during the incursion of HPAI into Ontario. It was in response to the lack of a distinct national strategy with which to guide the future direction, design and use of data based on surveillance, surveys or investigation of avian influenza (AI) in wild birds in Canada or elsewhere. After a decade of Canada’s Interagency Wild Bird Influenza Survey, we felt it an appropriate time to reflect on past experience and provoke discussion about the next decade of a wild bird AI program.

The report’s contents are the opinion of the authors and are not meant to represent the opinions of other agencies or individuals involved in wild bird AI surveillance in Canada or elsewhere.



Overview of wild bird avian influenza

Summary

Wild birds, particularly waterfowl, play an important role in influenza ecology. They can harbour and shed both low pathogenicity avian influenza (LPAI) and high pathogenicity avian influenza (HPAI); however, there is a gap in understanding the exposure pathways that link wild birds and poultry. Better understanding of wild bird ecology and pathogen traffic at the wildlife-agriculture interface may help direct future surveillance and biosecurity planning.

Wild birds as sources of AI

Influenza A viruses have been isolated from many species, including people, domestic mammals (e.g. pigs, horses, mink, felids), wild mammals (e.g. marine mammals), a variety of domestic birds and over 100 species of wild birds (Olsen et al, 2006). It has now been well established that wild birds carry a wide range of LPAI subtypes and that they perpetuate LPAI (Hoye et al, 2010). Isolation rates for LPAI viruses average about 11% for ducks and geese and around 2% for other species (Alexander, 2007), but vary around these averages with country, species, age and season. LPAI is usually isolated from apparently healthy wild birds during surveillance programs, but HPAI has occasionally been detected after mortality incidents. Ducks, geese, and swans (Anseriformes) and gulls, terns, and waders (Charadriiformes) constitute the major natural LPAI virus reservoirs (Olsen et al, 2006) and the species in which the greatest variety of virus subtypes has been detected (Olson et al, 2014). Extensive surveillance studies of wild ducks have revealed LPAI virus prevalence peaks in the Northern Hemisphere in early fall, particularly in juvenile birds on southward migrations. In North America, the prevalence falls from as high as ~60% in ducks sampled close to the breeding areas in early fall, to 0.4 to 2% at the wintering grounds in the southern U.S.A., and ~0.25% on return to the breeding grounds in spring (Olsen et al, 2006). Experience with the Canadian wild bird program suggests that detection of AI is greater in live ducks (~30% tested positive) compared with other species of birds (~5% tested positive) (note: all live bird sampling occurred in the late summer and fall; however, when birds found dead were tested, LPAI was only detected in 3%) (Parmley et al, 2009). This may reflect the different seasons of sample collection as well as the species of birds tested rather than a true difference in ability to detect viruses.

HPAI, although much less frequently found in wild birds, has occasionally been associated with wild bird mortality (Anseriformes and raptors) in Asia, Europe and North America. It has also been found in birds dying of other causes (ex. aspergillosis in waterfowl in Washington in 2014) and in asymptomatic birds. Whereas it is believed that wild bird migrations play a role in distributing LPAI sub-types, the role of avian migration in moving HPAI remains debated as conflicting information on the impacts of HPAI on bird survival and migratory abilities remain unresolved (Olsen et al, 2006). Krauss et al (2007), on one hand, concluded that “the available evidence does not support the perpetuation of {HPAI} H5N1 influenza in migratory birds and suggests that the introduction of {HPAI} Asian H5N1 to the Americas by migratory birds is likely to be a rare event”. Keawcharoen et al (2008), on the other hand, concluded that “some wild duck species, particularly mallards, can potentially be long-distance vectors of highly pathogenic avian influenza virus (H5N1).” The H5 viruses detected in North America in 2014-15 seem to behave differently than Asian



and European H5, emphasizing the need to be cautious when extrapolating findings in AI viruses across locations and wild bird species as well as the importance of further understanding the influence of virus genetics/subtypes on their spread and impacts.

Behaviour and ecology are thought to be determinants of the prevalence and persistence of LPAI in wild birds and, thus, can inform which species to target in surveillance programs. For example, dabbling ducks may have greater exposure to the virus in the aquatic environment (thought critical in waterfowl transmission). Long term data (approx. 20 years) from North America suggest that shorebirds had a higher frequency of influenza A virus isolation during their northern migration, while ducks had higher virus isolation frequencies during their southern migration and shorebirds yielded a broader range of subtypes but less frequently were positive compared to ducks (Krauss et al, 2004). Birds that aggregate during migrations or breeding may have greater opportunities for exposure through concentration of fecal contamination which may present ample amounts of virus in their environment. There is evidence that influenza remains viable in surface water and aquatic sediments for extended periods, allowing shorelines to be important avenues for virus traffic (Wilking et al, 2009), and making dabbling ducks more likely to be exposed than diving ducks. Birds that feed or live in and around agriculture settings may be important in bridging wild and domestic populations.

Wild birds as mechanisms of spread of AI to poultry

As was seen in the 2014-15 North American HPAI outbreak, when the mechanism of spread is not firmly established, evidence of shared viral lineage in wild and domestic birds is usually used to support claims that wild birds are spreading the virus. There have been some cases where HPAI was seen first in a country in wild birds before being detected in domestic poultry, but there are also many cases where the reverse is true. The contribution of poultry and/or wild bird movement in the spread of HPAI remains controversial, in part due to challenges in quantifying and tracing these movements (Wilking et al, 2009). As discussed in more detail below, biases created through opportunistic sampling that has not been strategically selected to reflect high risk poultry areas further complicates the ability to link temporal and geographic patterns of wild bird AI with patterns of cases in poultry.

The risk of AI outbreaks in poultry is partially dependent on the probability of contact between domestic poultry and viral contaminated wild bird feces; however, surveillance programs often do not target this interface. Burns et al (2012) noted: "Because detection of AIV, particularly H5 and H7 strains, in wild birds on or near poultry farms could result in implementation of disease control actions on poultry farms, surveillance of wild birds in Canada is functionally restricted to areas that are distant from commercial poultry farms. These areas have different habitat and human activity patterns than commercial poultry farms; therefore, sampling of wild birds off-farm may not reflect the species distribution on poultry farms and species that are most likely to have contact with poultry might be insufficiently represented to estimate their potential to transmit AIV." The focus of most wild bird AI surveillance programs on Anseriformes and Charadriiformes limits the extent of data available about the occurrence of AI in other bird species. This gap may be important given that Burns et al (2012) found approximately 68 species of birds around commercial poultry farms in British Columbia and Ontario. Understanding the exposure or mixing of these species with waterfowl and their AI infection status may be a next step in AI ecological research. In order to be able to do this



work, cooperation and trust with many partners will be required as it is still unclear what the repercussions will be if a wild bird tests positive for HPAI on a poultry farm.

The disconnect between understanding wild bird ecology, behaviour and disease has resulted in debate about how AI infections might affect the ability of a wild bird to continue on its migration, or its potential to stray from its migratory path or shed virus. Feare (2010) for example, noted that all H5N1 outbreaks in wild birds in the early 2000's occurred in the summer when birds were moulting and only travelling locally rather than over long distances. After reviewing several international outbreaks, Feare (2010) concluded that wild bird HPAI outbreaks were linked to periods of physiological stress (moulting, cold weather) and periods of bird aggregation; however, given the demands of migration, if an HPAI was causing illness, it is plausible that affected birds die en route and are not found by geographically and temporally limited surveillance programs. It is difficult to test the assumption that birds will carry and shed HPAI on their migration without the ability to follow the course of infection in individual birds as they migrate and because of the biases in sample collection in most wild bird surveys.

The role of wild birds will undoubtedly vary with epidemiological circumstances. For example, poultry movements have clearly been linked to the spread of HPAI H5N1 in Southeast Asia (Feare, 2010). Differences in virulence, effects on infected hosts, housing and biosecurity practices, and environmental conditions will cause complexities that may result in different routes of transmission at different times and locations. Kilpatrick et al (2006) integrated data on phylogenetic relationships of virus isolates, migratory bird movements, and trade in poultry and wild birds to describe possible pathways for 52 individual introduction events. Their analysis suggested that 9 of 21 of H5N1 introductions to countries in Asia were most likely through poultry, and 3 of 21 were most likely through migrating birds; but 20/23 countries in Europe were more likely exposed through migratory birds, while 3/8 introductions in Africa could partly be linked to wild bird movement. The validity of this analysis has not been confirmed but they do emphasize that circumstances may affect the role of wild birds as sources and spreaders of HPAI. The epidemiological, climatological and agricultural differences between tropical versus temperate climates, northern versus southern countries, and extensive versus intensive agriculture regions can limit confidence in extrapolations of findings from one area to another.

Structure of the Canadian Interagency Program

Summary

A national program of testing dead birds for AI currently exists across Canada and is supplemented with limited live bird testing. The CWHC helps to coordinate and deliver the program, including reporting and archiving results. Known as the Interagency Wild Bird Influenza Survey, it is the only ongoing wild bird surveillance program that operates across Canada and involves all provinces and territories. The goals and objectives have evolved over time with changing knowledge and changing epidemiological situations.



Structure, Roles and Responsibilities of the Program

The Interagency Wild Bird Influenza Survey is undertaken by the governments of Canada and of Canada's provinces and territories, and is coordinated on behalf of government agencies by the CWHC. It is part of national and global efforts to detect AI viruses that could threaten the agricultural sector and human health.

Nationally, the CWHC works with the Canadian Food Inspection Agency (CFIA), the Public Health Agency of Canada (PHAC) and Canadian Wildlife Service (CWS) of Environment Canada (EC) to develop and deliver a harmonized Canadian program. Primary funding is derived from the CFIA and PHAC with the former also providing confirmatory testing and having overall program obligations. Each of the federal partners assists in AIV and survey communications. Significant in-kind support is provided by CWS, primarily in the form of sample collection, in particular limited live-bird sampling and research and dead bird collection in British Columbia. At the national level the CWHC provides program development, information management, communications and reporting as well as expert advice.

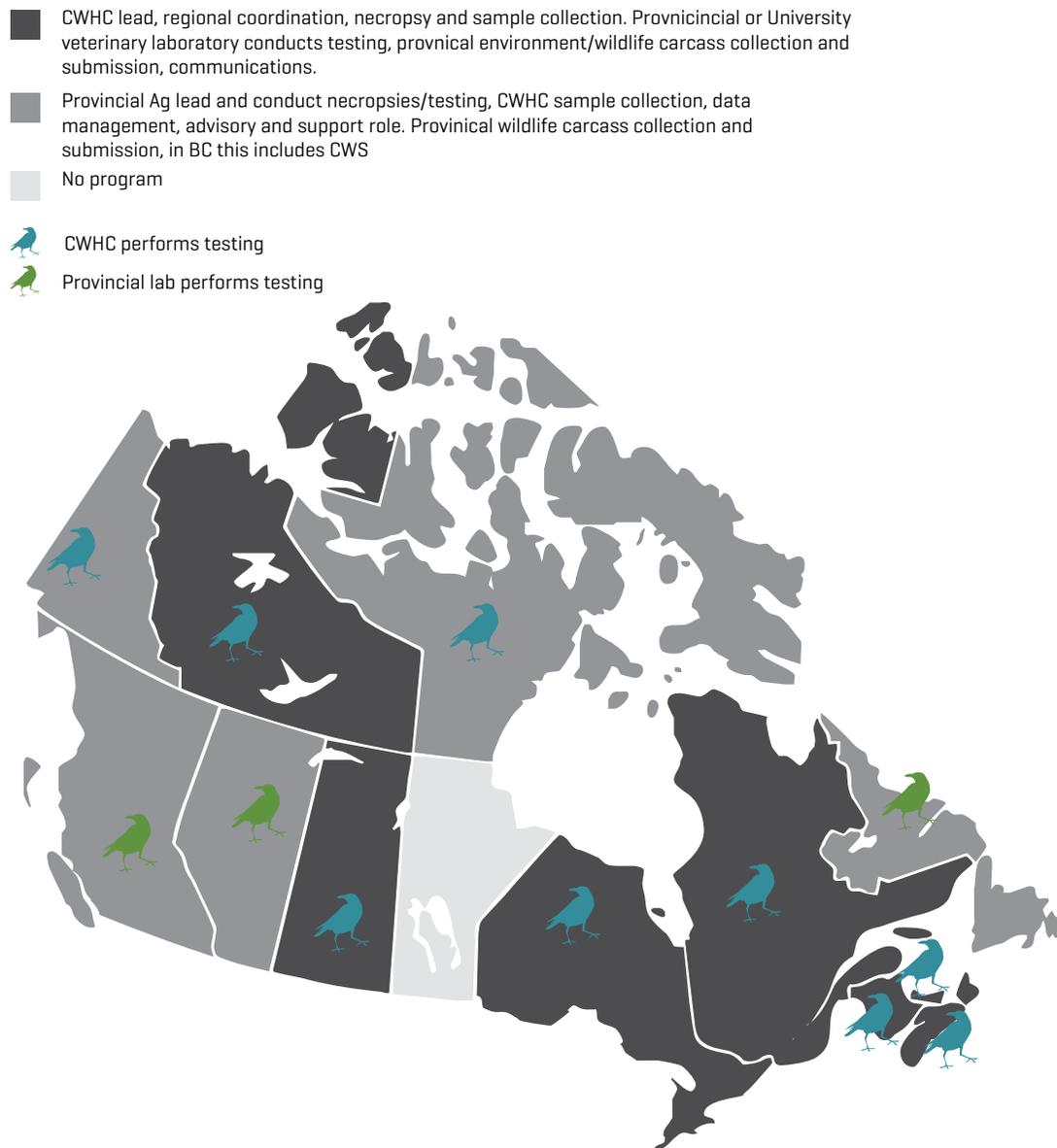
Provincial and Territorial governments take primary responsibility for organizing the detection of dead wild birds and their conveyance to participating veterinary diagnostic laboratories. Each will do what can be done within its program to obtain dead ducks, other water-associated birds, raptors or clusters of dead birds for the Survey. Birds are screened for avian influenza virus by real time reverse transcriptase PCR for the M1 gene. All matrix protein gene-positive samples are tested by PCR for H5 and H7 viruses and any samples positive by these tests are sent to the National Centre for Foreign Animal Diseases (NCFAD) for further characterisation.

The extent to which the activities of the Survey are deferred to a CWHC regional centre for diagnostic testing varies by jurisdiction (See Fig. 1). Procedures and the scale of activity differs among provinces and territories, as does the involvement of CWHC diagnostic centres in testing birds, the detection of dead wild birds and their conveyance to participating veterinary diagnostic laboratories. In some jurisdictions, notably, BC, AB, MB and NL, lab examination and testing is conducted by the provincial agricultural department/ministry, with the CWHC providing a supporting role. In the remaining provincial/territorial jurisdictions the CWHC has a lead role in coordinating among provincial partners, performing lab examinations and obtaining samples. All initial testing is done at a provincial/university diagnostic laboratory. The CWHC collects data and reports findings to the CFIA and public as soon as results are available and, when dealing with HPAI, after confirmation and reporting by the CFIA.

Funding support differs among provinces and territories. Generally those departments responsible for wildlife provide in-kind support in the collection and submission of dead birds. Provincial agricultural departments may provide in-kind testing support and in some cases, for instance in Saskatchewan and Ontario, direct support to the CWHC regional centre in support of the program.



Figure 1 – Summary of wild bird avian influenza surveillance partners and activities by jurisdiction.



The scale of the Survey has significantly changed in the 10 years since its inception. The peak of the program was in the calendar years 2006 and 2007, when greater than 6,000 dead birds were examined and the number of samples collected from live birds exceeded 17,000. The total budget in that period was approximately \$3.5M. Interest and available resources have waned subsequent to this time with an annual budget (including in-kind) of approximately \$600K for the last several years and an almost exclusive focus on dead bird surveillance. In 2014, 1,545 dead birds were examined as part of the survey and 1,324 live birds were tested via independent research programs and collaborations. Appendix 1 puts this sampling effort in context with other countries.



Evolving goals and objectives

Canada's Interagency Wild Bird Influenza Survey was initiated in the spring of 2005, partly in response to the outbreak of HPAI (H7N3) in the poultry in southwestern British Columbia in 2004. The original survey was to focus on the collection of samples from live wild birds with the following objectives:

- Making an inventory/archive of influenza A viruses that occur in wild birds, in Canada
- Characterising these viruses sufficiently to determine if wild birds were a transmission route for influenza A viruses that are pathogenic for people or domestic animals
- Monitoring wild bird populations for the presence of influenza A viruses of national or international concern
- Establishing field, laboratory and coordinative capacity needed in Canada to carry out influenza A virus surveillance in wild birds
- Complimenting surveillance efforts being conducted by the United States

The scope and objectives of the program were expanded in late 2005 in response to the range expansion of highly pathogenic H5N1 from Southeast Asia into Europe and Africa and concern that this virus may be transported by wild birds to North America. As the European experience had shown that highly pathogenic viruses were more likely to be found in dead birds, the survey was expanded to include dead bird surveillance as a means of early detection for this particular virus.

Since 2005 the focus of the survey has shifted from the original emphasis on live bird surveillance to a focus on dead bird surveillance. Concurrent live bird and dead bird surveillance was conducted for the first 6 years of the program with live bird studies becoming almost exclusively reliant on the support of the United States Department of Agriculture (USDA) and US Geological Survey (USGS). This aspect of the program was discontinued in 2012 due to lack of resources. An informal and small-scale live bird program has been continued since that time due to the in-kind contributions of CWS, CFIA (testing) and the CWHC.

A 2009 publication listed Canada's interagency wild bird influenza survey's purposes as follows (Parmley et al, 2009):

Live bird surveys:

1. Develop an inventory of influenza A viruses occurring in wild birds in Canada and measure the year-to-year variation in virus detection and strains
2. Characterise influenza A viruses isolated from Canadian wild birds
3. Survey Canadian wild bird populations for the presence of particular influenza A viruses that are of national and international concern (e.g. H5 and H7 subtypes)
4. Establish an archive of influenza A viruses from wild birds in Canada
5. Use the survey to enhance networks established for disease management



6. Determine if foreign strains of avian influenza are carried to the Americas by trans-Atlantic migrant wild birds
7. Complement and extend avian influenza surveillance carried out by the USA and Mexico

Dead bird surveys:

1. Dead bird surveillance shared the goals above but included enhancing detection of HPAI strains in Canada.

The 2013-14 operational plan for Canada's Interagency Survey stated that the purpose of the survey was: "primarily to be vigilant for highly-pathogenic strains of influenza A viruses that may cause mortality in wild birds and to a lesser extent to provide information on the forms of influenza A in circulation among wild birds each summer, including H5 and H7 variants of potential importance to poultry". The CFIA press release for the 2013-14 plan stated: "If the survey were to detect a virus of concern in wild birds in a location close to a poultry flock, the CFIA would alert producers in the area and conduct heightened surveillance in domestic poultry". Thus, the wild bird survey seemed to be intended to provide both an early warning as well as research role.

The 2014-15 wild bird avian influenza survey had four main objectives:

1. To provide vigilance for highly pathogenic AI virus strains
2. To assess whether or not AI viruses had caused the death of the birds
3. To monitor year-to-year variation in AI viruses present in wild birds
4. To support provincial outbreak response

The objectives of the enhanced activities in response to the outbreak in British Columbia were as follows:

1. To determine if the same strain of virus found in commercial birds was present in wild birds
2. To determine if highly pathogenic strains were present in wild birds or their environments after the outbreak in the commercial poultry
3. To enhance preparedness for surveillance in the Spring 2015 migration

The diversity, extent and variation in goals and objectives reflected changing knowledge and funding but has resulted in variations in expectations of the program within and between Survey partners and stakeholders.

Plans accompanying these objectives originally aimed for testing 3000 birds per year. Later operational plans recognized that the available resources did not allow this target to be met. These plans outlined the general goals, provided guidance on viral sample collection and submission, and general testing procedures but they did not specify target species, locations or sample sizes required to meet the intended goals or purpose. This lack of detail reflected the reliance on opportunistic sample and in-kind support to deliver the Survey.



While other AI surveillance efforts exist in Canada, such as the Canadian Notifiable Avian Influenza Surveillance System (a government, industry, farmer program) or the FluWatch (which monitors for human cases of influenza), there is no other organized program for wild bird AI surveillance in Canada other than the Interagency Wild Bird Influenza Survey.

What are the intended outcomes of wild bird AI surveys or surveillance?

Summary

It can be argued that there are 3 general categories of outcomes that have informed the design and implementation of AI surveillance around the world:

1. Meeting obligations based on statutes and international agreements
2. Providing early warning of the incursion of HPAI
3. Improving the scientific understanding of AI ecology

A common motivation for early warning is rapid and early detection of an agro-economic and to a lesser extent public health risk in order to inspire actions that would prevent exposure or spread of a highly pathogenic strain in domestic poultry and/or people. The effectiveness of this early warning function has not been evaluated. Low sample sizes, challenges in obtaining representative samples and untargeted sampling results in a low probability of detection AI in wild birds. Little work has been done to undertake surveillance that can forecast risk in a reliable manner in advance of finding a virus or to classify changing vulnerability of specific geographic locations.

Obligations

Canada faces many binding and non-binding obligations and responsibilities with respect to wildlife health. These include international obligations such as those found pursuant to the World Organization for Animal Health's (OIE) *Terrestrial Animal Health Code* as well as domestic responsibilities including those deriving from the *Health of Animals Act*. Together with obligations originating from international treaties such as the World Trade Organization (WTO) and the North American Free Trade Agreement (NAFTA) these responsibilities include measures to support economic opportunities and trade while ensuring a safe and secure Canada.

Safety and Security

Canada is obligated to report diseases causing significant morbidity or mortality in domestic and wild animals. In Canada this includes HPAI and LPAI H5 and H7 viruses, which are considered a reportable disease under the *Health*



of Animals Act as well as the OIE *Terrestrial Animal Code*. These responsibilities are designed to prevent, contain, and eradicate reportable diseases of significance to public health and/or Canadian well-being. Surveillance for wildlife diseases, such as AI, is an essential component for reporting animal disease threats accurately and is expected by OIE members, trade partners, industry, and the Canadian public.

Chapter 10.4 of the OIE *Terrestrial Code* states: “Infection with influenza A viruses of high pathogenicity in birds other than poultry, including wild birds, should be notified according to Article 1.1.3. However, a Member Country should not impose bans on the trade in poultry commodities in response to such a notification, or other information on the presence of any influenza A virus in birds other than poultry, including wild birds”. The Code notes that “no Member Country can declare itself free from influenza A in wild birds”. The Code does recommend targeting poultry at specific risk, recognizing that contact with wild birds is a determinant of risk. Understanding contact between wild birds and poultry, therefore, seems an important part of national AI surveillance. To meet OIE requirements laid out in the *Terrestrial Code*, wild bird programs should be able to detect HPAI in wild birds as well as inform domestic poultry risk assessment based on wild-domestic bird interactions.

Due diligence and supporting economic activities

Investment in AI surveillance helps to establish that an entity has acted reasonably in their decision-making, therefore avoiding or minimizing liability while providing context for the impacts of their decisions. Investment in wild bird AI surveillance can help to ensure that impacts to trade and the economy are minimized. For instance, ongoing surveillance can serve as a defense against trade restrictions, including those under NAFTA, and be used to minimize the impact of adopted sanitary and phytosanitary measures under WHO International Health Regulations and WTO regulations.

Additional international responsibilities exist under the Security and Prosperity Partnership of North America (North American Plan for avian and pandemic influenza), which includes wild bird surveillance to provide early warning for potential or real threats that may exist in the wild bird population. The partnership suggests that wild bird surveillance should be conducted at least annually and should include active and passive methodologies as well as live and dead bird sampling. The CFIA plays a key part in upholding all of these obligations, as reflected in their mission/mandate of:

- Protecting Canada’s livestock resources;
- Mitigating risks associated with animal diseases; and
- Supporting the health of Canada’s animal resources and preserving confidence in the safety of said animals and animal products



Goals and objectives – international examples

Hoye et al's 2010 review of 191 published reports found 4 main foci for wild bird surveillance: (1) early detection of HPAI; (2) detailing the ecology and epidemiology of LPAI; (3) studying viral evolution within wild birds; and (4) multi-pathogen studies in wild birds. Early warning was a ubiquitous motivator for wild bird AI surveillance across nations and programs. The majority of programs used wild birds as early warning sentinels of risk to domestic poultry and indirectly to people

The USDA system, for example, aims to detect any HPAI viruses in migratory birds regardless of the source. Their system also seeks to increase knowledge regarding LPAI viruses and the general health of wild birds (Deliberto et al, 2009). The primary objective of the USGS 2009 Plan was to provide for the early detection of H5N1 HPAI if it was introduced by migratory birds to the United States or U.S. Territories and Freely-Associated States, as stated in the initial charge of their Interagency Strategic Plan. A secondary objective was the detection of H5 and H7 subtypes of avian influenza viruses in wild birds. Detecting wild bird infection by any of the circulating LPAI viruses was a tertiary objective. Outputs from their program were intended to provide information for scientific study that can provide insight into the modes and mechanisms of the spread of influenza viruses in general, which may have application in understanding the potential role of wild birds in the spread of HPAI viruses.

The AI program in the United Kingdom has aimed to ensure the early detection of H5N1 HPAI and to identify the risk of introduction of HPAI and LPAI into domestic poultry. This goal was shared in Europe. For example, in Denmark and Greenland, surveillance is aimed at detecting viruses of both HPAI subtypes H5 and H7 as well as LPAI viruses (Hjulsager et al, 2012).

Early warning as a goal

The North American plan for animal and pandemic influenza¹ states: " Effective wild bird surveillance provides an early warning system for potential or real threats that may exist in the wild bird population....Advance warning would enable the poultry sector to adopt enhanced biosecurity measures and allow poultry surveillance programs to be targeted to those populations or compartments at increased risk".

Early warning systems are timely surveillance systems that collect information on epidemic-prone diseases in order to trigger prompt interventions. Whereas most surveillance systems are intended to detect and measure disease outbreaks as they occur, early warning systems aim to alert the relevant authorities in advance to implement effective measures to reduce adverse health outcomes during and after the event (Ebi and Schmier, 2005). At their very basic, early warning systems are information systems designed to facilitate decision making to enable actions to mitigate the impacts of an impending hazard.

1 <http://www.phe.gov/Preparedness/international/Documents/napapi.pdf>



There are 5 key requirements for effective early warning: (1) the warning system must be able to detect the risk signal earlier than by monitoring the population of concern for the adverse effects that are to be avoided or mitigated; (2) there must be timely communication of early warning signals to inspire action soon enough to avoid or mitigate negative impacts; (3) there must be capacity to verify the signals to avoid unnecessary response, (4) there must be capacity to assess the risk associated with the early warning signal (WHO, 2014), and (5) there must be adequate infrastructure, including the political will, to undertake the design, implementation and sustainability of the system.

Early warning requires all parts of the system to work. Common areas of failure include the following: (i) the risk signal is inaccurate; (ii) there may be a failure to communicate warning information in sufficient time or in an understandable or interpretable fashion; (iii) the response to the signal may not be appropriate due to missing ancillary information or problems in incorporating or applying the information into decision making (NAS, 2001); and/or (iv) the linkage between the early warning signal and the risk to the population of concern or need for action is not well established.

Sentinel species are often used for early warning. Sentinel wildlife are a group of wild animals under observation that provide signals of risk to other members of the group, other groups and/or other species. In the case of AI, wild birds provide risk signals for domestic poultry and, indirectly, for public health. Sentinels can give early insights into the capacity of a hazard, such as AI virus, to be a threat. For example, early warnings on the emergence of an HPAI sub-type in wild bird surveillance gives warning of a sub-type capable of causing significant morbidity and/or mortality. Sentinels can also give an indication on the threat accessibility. In the case of an infectious agent, this may involve information that indicates that populations of concern are potentially exposed to a circulating threat. Challenges exist for wild bird AI in that the scale and location of sampling can be too far removed from domestic populations of concern to provide precise descriptions of the locations and timing of viral presence.

Sentinels can give an indication of systems susceptibility. For example, situating a sentinel species within the environment of species of concern may give insights into biosecurity. The use of immunocompromised mice in rodent research facilities to detect incursions of a pathogen is an example. The latter function cannot be part of wild bird AI surveillance as mixing wild and domestic birds on purpose is not recommended nor is it known if the wild birds would manifest signs of infection before domestic birds due to variation in pathogenicity with host species and viral subtype.

Little evidence exists to evaluate the value of animal sentinels or to specify the standard criteria for selection of a sentinel species, however, general features of a potential sentinel species are known. Table 1 lists generic features of sentinel animals and relates them to wild bird AI surveillance. This table suggests there are limits to the value of wild birds as sentinels for AI risk to domestic poultry or public health; however, as wild birds are the reservoir for this virus, there continues to be interest in tracking the variety, abundance and distribution of AI virus in these species.



Table 1. Generic features of sentinel animals and reflections on those features as they relate to avian influenza surveillance of wild birds in Canada.

General sentinel attribute	Attribute in wild birds in Canada
The population needs to be under observation.	Populations are not systematically or intensively sampled for AI. Either opportunistic collection of dead birds or time and space limited surveys of sub-populations are the backbone of wild bird AI surveillance. Neither provides for representative or repeatable population surveys, but the ongoing surveillance does allow for regular observation.
The sentinels should be in the same environment as the population of concern to establish that the presence of the hazard in the sentinel animals is a signal of exposure risk for the population of concern.	Strategic allocation of sampling effort has not emphasized locations where wild birds intersect with domestic birds on a small scale, requiring extrapolation of risk signals derived from a location distant to the populations of concern.
The sentinels need to produce a measureable and meaningful signal.	A number of well-established tests are available for AI virus detection and characterisation. The results are generally accepted within the scientific community (especially PCR) although not all tests are validated for wildlife. There are greater challenges in using those diagnostic signals to predict population effects or risks.
The sentinels should reveal a warning before impacts are realized in the population of concern.	While there is evidence that wild birds can be reservoirs of various AI virus types and that these types can sometimes be detected in wild birds before in domestic birds, delays in testing, variation in clinical presentation, the reliance on opportunistic sampling and the inadequacy of wild bird isolates alone to inspire management actions reduces the willingness and ability to quickly respond to the early warning signal.
Their signals should create a warning.	Thresholds for wild bird findings that inspire specific actions that would reduce on-farm risk have not been identified. Specific actions have not been defined for detection of AI in wild birds in Canada.



The sentinel populations should be able to cope with the sampling plan.

Birds targeted for AI surveillance are abundant and are not thought to be harmed by the program.

Does early warning work?

When examining the role of wild bird surveillance for Asian H5N1, Feare (2010) concluded that surveillance of apparently healthy wild birds had not provided early warning to the poultry industry but searching and examining dead birds was able to demonstrate the environmental presence of the virus, although not its source. When Halliday et al (2007) applied their framework for selecting a sentinel species, wild birds did not fare well in their example of developing a HPAI H5N1 surveillance program. Positive attributes of wild birds included the following: (i) they can serve as a source for the virus; (ii) they have a measureable response when infected; and (iii), there are highly specific diagnostic tests. Negative attributes were as follows: (i) the response to H5N1 can be variable. This combined with a low prevalence limits the sensitivity of wild birds as sentinels; (ii) wild birds are less accessible than domestic sentinels and the associated cost of capture or accessing samples plus logistic challenges limits the sample size; and (iii) they may live remote from the populations of concern. These comments reflect experience with H5N1 Eurasian strain. They may not be equally applicable to other strains circulating in North America or elsewhere.

Some authors have concluded that active surveillance of live or hunter killed birds have failed to show early warning for certain HPAI (mostly H5N1) but these samples have greatly expanded our understanding of the geographic, temporal and host variables related to variation in LPAI strains (Feare 2010, Wilking et al, 2009). Feare (2010) concluded that dead bird surveillance has been able to indicate the environmental presence of HPAI in areas where it is both endemic and new to poultry production regions. However, there are exceptions to these generalizations. For example, HPAI H5N1 has been found in live, apparently healthy birds or birds dying for something other than influenza and there are many instances where HPAI was found in poultry before wild birds, such as the recent outbreak in British Columbia.

One of the challenges of an early warning system is to find the disease soon after it emerges and is still at low prevalence. Wilking et al (2009) reviewed German experience with wild bird surveillance for H5N1 HPAI and concluded that, under their circumstances, 318 birds would need to be tested daily in order to find H5N1 HPAI at or above a 1% prevalence. This represented a 4-fold increase in the existing sampling effort in Germany in 2007; a sample size of over 116,000 birds/year. The sampling efforts achieved for HPAI in Germany in the early 2000's were unable to either rule in or rule out the presence of HPAI in wild birds (Wilking et al, 2009). These authors recommended risk-based sampling that made use of geographic, ornithological and veterinary information to select locations, species and times to target specific animals for sampling as a means to reduce sample size and increase the probability of detection HPAI in wild birds.

The literature on the effectiveness of early warning to change people's behaviour in the face of an infectious disease risk is sparse. Implicit in early warning for AI is the assumption that farmers will alter their biosecurity



practices to reduce risk of transmission to domestic birds from wildlife based on knowledge about which sub-types of AI are circulating in wildlife. We are unaware of any studies that validated this assumption and showed that effective biosecurity changes accompany wild bird AI findings.

There is evidence that societal learning can affect the final size of disease outbreaks, justifying investment in early warning systems (Drake et al, 2006; Rubine et al, 2009). However, studies of the drivers of biosecurity practices on farms are few and sometimes surprising. For example, a survey of cattle farmers in the United Kingdom (UK) post-bovine spongiform encephalopathy and post-foot and mouth disease outbreaks found that “despite the heavy toll animal disease has taken on the agricultural economy, most study participants were dismissive of the many measures associated with bio-security,” often blaming external factors for disease problems (Heffernana et al, 2008). Conversely, Dutch swine farmers “valued biosecurity measures as a more effective strategy than animal health programs” (Valeeva et al, 2011). UK poultry farmers, showed an inverse relationship between their willingness to adopt a biosecurity measure against zoonotic infections that did not limit production and its estimated cost (Fraser et al, 2010). A Quebec study found that the effects of interventions that improved biosecurity (in this case video monitoring of staff) could be short lived (Racicot et al, 2012). Following an H5N1 outbreak in the UK, one study found that farmer claims about the best ways to protect flocks against disease were influenced by the structure of the industry and farmer knowledge and belief systems about purity and dirt, health and hygiene (Nerlich et al, 2009).

Disease ecological research as a goal

The past decade of surveillance has greatly expanded our understanding of AI ecology and epidemiology. Laboratory-based research has provided key insights into host- or strain-specific pathogenesis, the timescales of infection, and the routes of virus shedding. Experimental work and examination of carcasses have revealed significant information on the course of infection, the extent of viral shedding and the relative importance of cloacal versus oropharyngeal shedding (Feare, 2010). Major gaps still exist in our knowledge on the ecology and epidemiology of LPAI and HPAI in wild birds. “Although wild birds are the recognized source and reservoir for all subtypes of avian influenza viruses (AIV), the complex interaction among these diverse host and virus populations has not received adequate attention” (Stallknecht and Brown, 2007). Few efforts have been directed to linking ornithological information and exposure pathway analysis to allow ready translation of the laboratory evidence to management outcomes (Yasué et al, 2006). Not enough research has focused on understanding exposure and transmission systems at the wild bird-domestic bird interface, making it difficult to target specific settings, species or circumstances for focused sampling and surveillance (Bevins et al, 2014) or to attribute sources of spread or exposure. This limitation was evident in the 2014-15 North American HPAI outbreaks wherein several agencies assumed waterfowl were moving HPAI through migratory flyways across and within North America. Genetic evidence indicated that the some HPAI sub-types contained a mixture of Eurasian and North American wild bird virus lineages, suggesting that they were likely the product of viral mixing in wild birds, probably in the western Arctic during the summer months. The fall southward migration of waterfowl could have brought these new viral variants into southern British Columbia and the northwestern USA. In early March, H5N2 virus was identified in a turkey flock in Minnesota and since then, there have been subsequent identifications in domestic poultry in other states and provinces including Missouri,



Arkansas, Kansas, Iowa, North and South Dakota, Wisconsin and Ontario. Various agency statements and news reports highlighted the fact that these were the first identifications of these viruses in the Mississippi Flyway. The use of the flyway as a geographic identifier put the blame, by implication, on wild birds as the source of the virus and many commentators made this connection. It is reasonable to believe that these strains of HPAI arrived in the Pacific Northwest and in the Midwest after being transported south with migrating waterfowl in the fall. However, waterfowl typically do not stop and overwinter in the areas in the Midwest where the virus was initially found in turkeys. They continue their southward migration to their overwintering grounds. Furthermore, while there is some straying between flyways, connections tend to occur when birds aggregate in the northern nesting areas or where flyways intersect at their southern terminus; not mid-continent (although straying does occur). Prematurely concluding that waterfowl were the mechanisms of continental transport of the virus and introduction into domestic populations could limit investigation of alternative anthropogenic sources.

The implication of waterfowl as the primary source of introduction of novel strains in domestic poultry has good support in Asia where reducing exposure to wild birds has been a critical factor in preventing spillover into poultry (Pandit et al, 2013). Given that the production settings, wild species and environmental conditions are significantly different between Asia and North America and within North America, generalization of this conclusion, while precautionary in nature, should not preclude investigation of transmission pathways in Canada.

Section 2: Assessment of success on reaching goals

Summary

Systematic evaluations of the impact, reliability, representativeness, cost:benefit, or utility of wild bird avian influenza surveillance could not be found in the peer reviewed literature. Key informants in Canada and the USA noted that past surveys have greatly increased our knowledge of the virus and increased awareness of the need to incorporate wild bird information when planning biosecurity or surveillance.

Program evaluation or review

Published reviews

Our rapid literature review found no published reports of systematic and comprehensive evaluations for wild bird avian influenza programs. This finding is consistent with Vrbova et al (2010) whose systematic literature review found no comprehensive evaluation of emerging zoonotic disease surveillance systems and only 4 assessments of the usefulness of such programs. Published assessments of avian disease surveillance programs focus mainly on experiences with West Nile virus surveillance. Papers we found that included the words “assessment” or “evaluation” and “avian influenza” tended to focus on evaluations of testing protocols or diagnostic methods. There is, therefore, no ability to make evidence-based recommendations based on published literature.



Qualitative assessment done for this report

In recognition of the absence of systematic evaluations, the CWHC undertook interviews of key informants within who have had a role in avian influenza surveillance, research and control as well as surveyed directors of each of the CWHC regional centres and participating provincial diagnostic laboratories. We also surveyed opinions of critical personnel involved in the wild bird enhanced program that was launched in south western BC in the winter of 2014. The goal was to identify main themes or insights on the impacts, opportunities and challenges facing wild bird AI surveys or surveillance.

Comments from key informants

Theme 1: Much has been learned about AI ecology but knowledge gaps remain

Key informants in Canada noted that we have learned a lot about AI ecology and the role of wild birds due to past surveys and research. Interviewees noted that the lack of trade restrictions upon the detection of EA/AM H5N8 and H5N2 in wild birds likely reflected desensitization of poultry trading partners of findings in wild birds, because they have been consistently studying and reporting findings in wild birds for 9 years. They recognized the need for more research on how wild birds, domestic poultry and people get infected and on the drivers of viral reassortment.

Theme 2: Inability to point to specific impacts on AI risk or policy, but there was recognition that there have been some effects on programs and practices

Personnel interviewed at the Environment Canada, the Wildlife Conservation Society, USDA and USGS were unaware of any policy changes resulting directly from of AI surveillance in wild birds. They were unable, like many experts, to answer the question about what data would trigger action or propose a way this might happen.

Canadian interviewees noted that the Interagency Survey helped to develop and support a network of laboratories across Canada. Recent shifts away from live bird surveys may have eroded some of the networks with other agencies and field personnel, but engagement with labs and the poultry industry remains good. In addition, experience with AI has formed important bridges with the wildlife diseases community and has resulted in more regular and systematic consideration of wildlife in the national animal health program. Given that there are a variety of important wildlife-agriculture issues (e.g. Tuberculosis, Brucellosis, Chronic Wasting Disease), how much of this change we can attribute to AI is speculative.

During our interviews, we learned that the USDA modified biosecurity recommendations on farms to eliminate use of untreated surface water for poultry, to make poultry houses bird proof, and to discourage waterfowl from becoming resident on property ponds. The USDA Biosecurity for the Birds Campaign now includes information on wild bird surveillance and provides information on how hunters and farmers can protect themselves from exposure to infected wild birds. USDA key informants further noted that there is growing recognition by the US poultry industry that wild bird surveillance could serve as an early warning



system for poultry. For example, many industry veterinarians requested in 2014 that the USDA develop a plan to conduct surveillance for H5N8 and its reassortments in all flyways. Given that the biosecurity in European and North American poultry farms is high already, understanding the impacts and benefits of incremental changes based on knowledge of wild bird AI status seems warranted.

The USDA suggested that their previous efforts are now being used to design wild bird surveillance for the recent HPAI introduction; and that work on environmental determinants of AI (Farnsworth et al. 2012) and wild bird surveillance (Bevins et al. 2014) were used to design their enhanced Pacific Flyway surveillance effort as well as the ones being developed for the other flyways.

For all of the changes discussed above, it was not possible to determine what proportion of the changes were due to the outputs of national wild bird surveillance activities *per se* or the combined growing international knowledge derived from research and surveys from around the world.

Comments from diagnostic centres in Canada

Theme 1: Reliance on opportunistic sampling

The focus on opportunistic sampling has limited the ability of diagnostic centres to design regional programs with specific sample sizes, locations or species to target. Capacity to expand the program to increase the number, locations or diversity of dead birds (through active solicitation and field collection) or to include live birds has been limited by available resources. In some regions, the lack of resources or willing partners to transport dead birds to the lab reduces the scope of annual sampling efforts. These issues create delays in detecting dead birds and can affect timeliness of the program.

Some regions are able to make extra efforts to overcome the geographic bias associated with dead animal surveillance. For example, in Ontario and Saskatchewan, provincial ministries are already providing funds or are in discussions with local CWHC regions to develop this additional capacity. The CFIA was able to supplement capacity in British Columbia during the 2014-15 outbreak that increased acquisition of dead bird samples. Such efforts rely on support outside annual investment in the Interagency Survey and are not being uniformly developed across jurisdictions.

Theme 2: Delays in testing

There are pragmatic impediments to timely wild bird surveillance related to the logistics of collecting samples and the challenges of maintaining the pathogen as a priority in inter-epidemic periods. Sample collection is affected by bird movements, accessibility and availability of sampling crews or submissions to the lab.

There has been variation across the country between labs on the perceived importance of testing between outbreaks. In some regions risk perceptions and resource constraints combine to affect testing practices. For example, in some jurisdictions, laboratories “batch” samples to reduce costs, creating delays in testing. Resource limitations and the desire to establish cause of death in birds can also cause further delays in examining and testing birds.

Respondents suggested ways to streamline the survey such as creating shared inclusion criteria for dead bird



surveillance that could help triage and prioritize testing. An example given was the elimination of testing wild birds that had been held in captivity for prolonged times. Understanding geographic vulnerability could also assist in triage and prioritization of testing. Live bird surveillance, especially in regions with significant poultry operations, could be implemented with focus on identifying viral traffic in high risk areas.

Theme 3: Communications

Communications require ongoing effort, and in some areas awareness about the importance of the survey and the need to retain vigilance in dead bird collection, timely submission and prompt testing has been diminished. The communication of program objectives and development has been a challenge as has the reporting of confirmatory results from the CFIA back to regional labs and/or CWHC regional offices. A renewed focus on communication is necessary to ensure vigilance and improve timeliness of reporting.

Theme 3: Value for investment

Overall the program was thought to work well and at a relatively low cost. Sample numbers of birds found dead and tested have remained stable in recent years and a cause of death has been determined for each dead bird submitted. Data entry standards and information management issues present at the beginning of the Survey were largely resolved 7-8 years ago.

Review of experience obtained in wild bird surveillance in the British Columbia 2014-15 outbreak

In early May 2015, members of the BC Interagency Wild Bird Mortality team, the BC Animal Health Centre and the CWHC met to discuss and reflect on the ability to respond to, enhance activity and manage wild bird surveillance in response to the HPAI in the Fraser Valley. The purpose was to identify strengths and challenges in trying to ensure a reliable understanding of the wild bird AI situation during and after the outbreak.

Members of the Interagency Wild Bird Mortality team come from the Ministry of Agriculture (BC Animal Health Centre), Ministry of Forests, Lands and Natural Resources Operations (FLNRO) and the Canadian Wildlife Service. This pre-existing team has jurisdiction to collect, handle and test wild birds in the province. The former provides diagnostic services, the latter provides logistical support in collecting dead birds and maintains a database of collections and results, and the FLNRO representative provides liaison with the provincial wildlife community and context for assessing diagnostic results. The Program is intended to address surveillance needs for AI, West Nile virus and other wild bird mortality events. Program outputs are shared with the CWHC who also provides coordination, liaison and communication support to the group. The Interagency team develops an annual plan and investigative protocol. An example can be found at: http://www.env.gov.bc.ca/wld/documents/wldhealth/AI_1pager2014.pdf

Theme 1: Communication

- Strengths
 - The Interagency Wild Bird Mortality team has been in existence for several years, over which time team members have built trust and shared understanding that facilitates ongoing communications



and shared decision making. The pre-established relationship and protocols reduce confusion on priorities and activities and ensures coordination in messaging and communications. The CWHC's pre-existing working relations with this team assisted in information flow and coordination of communications.

- A local emergency laboratory database assisted in timely entry of laboratory results and communication within the BC Animal Health Centre and to the CFIA, but did limit data sharing with other partners including the CWS and CWHC.
- Challenges
 - The lack of a pre-established communications plan resulted in gaps in public messaging that delayed requests for public vigilance and reporting of dead birds and outreach to the hunter community to bolster submissions of birds for testing.
 - The lack of an agreed communication plan and contingencies for unavailable personnel caused delays and some misunderstandings of activities and outcomes.
 - Reporting and sharing of data back from national partners was seen as a significant impediment to ensuring all partners had an equitable and shared understanding of the situation during the outbreak.
 - True early warning in BC is likely to come from findings from Washington State and Alaska, but no regular or formal mechanisms for collaboration and information sharing existed prior to the outbreak. This gap remains post-outbreak.
 - Lack of capacity for wildlife surveillance, diagnostics and epidemiology within the CFIA was felt to create some challenges in communicating priorities on activities and needs for information/sample sharing.

Theme 2: Pre-planning

- Strengths
 - Existing protocols and a history of local collaborations allowed rapid deployment of an enhanced wild bird program, created mechanisms for public reporting that were immediately available as well as established local decision making roles.
 - The cross-agency characteristic of the Interagency Wild Bird Mortality team created a social network that allowed for quick access to suitably trained surge capacity as well as to connect with a diversity of groups to allow for communication with stakeholders who could report dead birds. It also allowed local partners and team member to take advantage of capacity to exploit the outbreak to develop and assess novel means for surveillance.
- Challenges
 - This disease crosses many jurisdictions, yet there was a lack of clarity and direction on roles,



responsibilities and actions on an operational and tactical level for each of the program partner or individuals. While there is a Foreign Animal Disease Emergency Support (FADES) plan for avian influenza in British Columbia, wildlife does not feature prominently and the details are insufficient for operational or tactical planning. This gap created confusion on roles and responsibilities for the wild bird portions of the response, including issues of communication, information and sample control, and management and resource use.

- There are no “hard targets” for wild bird surveillance. This can lead to inconsistencies in expectations for goals for wild bird AI activities and lack of clarity on what can be and needs to be accomplished within financial constraints, and how those needs vary in the pre-, inter- and post-outbreak periods. The lack of a pre-existing operational plan that specifies detailed roles and responsibilities resulted in challenges in making decisions on survey designs and allocation of resources. The lack of guidance on optimum tools, targets and strategies for wild bird surveillance or on how to best share, assess and use data exists across Canada, creating the opportunity for variation in the operational goals and prioritization of activities, species and locations for surveillance across Canada and between jurisdictions.

Theme 3: Capacity

- Strengths
 - The combination of CFIA contributions and pre-existing professional social networks allowed for rapid access to surge capacity needed to supplement the Interagency Wild Bird Mortality team’s ability to collect samples.
 - The team could compensate for the lack of a pre-existing surge capacity plan or budget because of their pre-existing relationships and personal contacts. This allowed for recruitment of an external contractor concurrent with CFIA activities to secure funds.
- Challenges
 - While the local experts believed their activities resulted in a representative view of HPAI in the Fraser Valley, lack of capacity to collect many dead wild birds beyond this geographic region or to test more hunter killed and live birds that were travelling into or out of this area limited confidence in the ability to wild bird roles in the HPAI outbreak beyond the Fraser Valley.
 - Despite efforts to encourage more reporting of dead birds and to actively search for hunter killed birds or dead birds stored at other facilities, the sample size of birds available for examination seemed to reach a cap. Whether this reflected the lack of sufficient public profile of the team and its 1-800 reporting line or reflected the biological reality of relying of passive surveillance is unknown.
 - Lack of resources required pre-outbreak surveillance to be done in batches. This in part reflected the goal of establishing cause of death but also reflected lack of capacity in partnering agencies such as the Canadian Wildlife Service which received significant cuts to its operating budget- restricting time



for collection, submission and management of dead bird recovery.

Wild Bird AI surveillance in 2015 and beyond

Summary

Our overview of existing opinion and experience suggest there are four key areas for consideration when examining future program activities for wild bird AI surveillance, surveys or research:

1. There is a need for program evaluation. Understanding if the information being generated is having the desired effects on human behaviours that can influence poultry exposure probabilities or affect the vulnerability of poultry operations is critical for evidence based program development.
2. There is a desire to improve the timeliness and forecasting ability of information generated by an AI program so that poultry operations can be better prepared in advance of an outbreak. Given inherent delays in acquiring, testing and confirming the AI status of a wild bird, it may be time to include monitoring variables that could affect the vulnerability (susceptibility and exposure) of poultry operations to contaminated wild bird feces.
3. To support vulnerability assessment and to maximize the efficient use of limited resources to cover a vast number of wild birds over all of Canada, risk-based surveillance that targets vulnerable and higher risk locations should be explored.
4. An up-to-date and explicit strategy that outlines roles, responsibilities, and expectations for the governance, objectives and conduct of national wild bird AI programs is needed.

Program evaluation

The lack of program evaluation prevents evidence-based program planning and assessment. Program evaluation is a systematic way to improve and account for actions by involving procedures that are useful, feasible, and accurate (Milstein et al, 1999). Evaluation includes a needs assessment that reviews and establishes the goals of the program to assist in planning; a process evaluation to see how the program is operating; and an outcome evaluation to determine if the program has had its desired effect.

We were struck in this review by the challenge of determining the link between program goals, outputs and outcomes. Historically, it appears that increasing knowledge of AI ecology in wild birds was a major outcome but the desired goal was early warning. A needs assessment with industry and decision makers may help to determine which outcomes are desired in the future and the outputs required to meet these expectations. Understanding how these expectations will vary in inter-, pre- and post-outbreak scenarios is important not only to ensure a consistent cross-



Canada approach but also to maintain interest and activity between outbreaks. Early warning surveillance requires consistent inter-epidemic activity that does not wane in interest or capacity between epidemic events. Outcome evaluation may require research to establish if/how program outputs affect biosecurity planning and practices and to determine which outputs would influence risk reduction behaviours.

Timeliness and forecasting

A number of authors advocate for risk-based wild bird surveillance as a way to increase the forecasting value of wild bird information (e.g. Hoyer et al, 2010; Wilking et al, 2009; Snow et al, 2007). Recommendations on how best to identify risk varied across publications with some authors emphasizing high risk times and places where wild birds aggregate and are more likely to be shedding; others emphasizing geographic proximity to domestic birds and still others focusing on landscape features such as water bodies in the vicinity of poultry agriculture as means to select sampling locations, times and species more likely to provide reliable risk forecasting.

Wagner et al (2001) nominated four main ways to improve the timeliness of early warning surveillance, three of which are relevant to AI. First, more complete sampling can be undertaken to improve the quality of the warning signal. In this case, expanding the sample size, species diversity and geographic distribution of wild birds samples may help in the detection of a relatively rare event such as a new AI sub-type. Unfortunately, the opportunistic nature of the Interagency Survey and limits of typical budgets and infrastructure reduce capacity to increase sampling effort or geographic distribution. Sample sizes needed to detect target prevalence will vary with seasonal changes in expected true prevalence and whether the desire is to describe common LPAI or detect rare sub-types. A single sample size could not be spread across species, season or location because prevalence can be expected to vary with each of these variables.

An alternative strategy to simply increasing sample size is to refine the search area and prioritize species based on their known proximity to and interactions with poultry farms, as well as their known history as sources of AI sub-types. Burns et al (2012) attempted to identify high priority species for BC and Ontario using such criteria. Such an approach would reduce geographic representativeness and constrain a full view of AI ecology, but could allow for focused efforts around high risk circumstances. Planning such a program would need to balance the frequency of contact between wild birds (or their feces) and the likelihood of the targeted species being infected. Guberti and Newman (2007) recommended daily to weekly sampling in important bird habitats to increase the likelihood of early detection of HPAI H5N1. Furthermore, they recommend restricting samples to dead or sick birds, given the experience in finding HPAI in association with mortality/morbidity events. For live bird surveillance, they recommended restricting sampling to areas near poultry farms, and focusing on waterfowl aggregations of more than 1,200 birds. It is important to note that Guberti and Newman's (2007) recommendations have not been validated as methods to more completely characterise the AI risk or facilitate more timely detection in a North American setting or with other sub-types. Before adopting a risk-based approach, a detailed consideration of the implications and actions associated with finding AI on or near a poultry operation in wild birds or their environment must be undertaken.

The second strategy is to add additional signals to the early warning system. Current Canadian efforts focus



almost exclusively on dead bird surveillance with one geographically and temporally constrained live bird sample collection per year. Additional signals of viral presence in birds would require expanding the system as described above. Alternative means to determine the presence of the virus in environments of concern could focus on testing other environmental media frequented by waterfowl. Feces-contaminated water is a well-established route of infection for wild birds. AI has been isolated from feces, lakes and ponds. Fresh fecal samples have been used as the basis of national AI surveillance systems and surveys elsewhere (eg. Kang et al, 2010; Ofula et al, 2013). Fecal sampling may provide less information on the hosts involved (unless supplemented with DNA testing to identify the host) and may yield lower prevalence estimates, but it is considered by some to be an efficient approach to identifying circulating viruses and eliminates the need to capture birds, reduces staff training needs and eases needs for permits for sampling wildlife (Stallknecht et al, 2012). Other studies have shown the capacity to detect AI virus in water, even under warm conditions with low densities of waterfowl (Henaux et al, 2012; Burns et al, 2012). The inclusion of ornithological data, particularly on animal movements and wild bird interactions with poultry, may help identify areas with increased risk of spillover of virus into the domestic bird population (Yasué et al, 2006). Remote sensing technology has been nominated as means to identify water bodies, including flooded areas, that might be suitable habitat for wild ducks and/or places where environmental contamination with AI virus may be greater. Virus survival outside of a bird is affected by environmental characteristics and persistence of AI virus in aquatic ecosystems is a key in wild bird infection dynamics. Remotely-sensed information on the presence and suitability of water for waterfowl and AI virus may allow for more rapid detection of high risk areas and deployment of survey resources to areas more likely to harbour infected birds (Tran et al, 2010). While all of these data sources could yield additional data to increase the timeliness of response to an AI threat, their suitability for forecasting risk and inspiring action awaits validation.

The challenge with adding in new data sources is that, while they may detect risk signals early, the certainty people have in their predictive power is lower. We can state that an epidemic in poultry or even the finding of an index farm/case is not early warning, but it would inspire immediate action. Conversely, remote sensing data, or environmental sampling would give much earlier warning, but its likelihood of inspiring immediate action in the absence of effects in poultry would likely be low. We found no papers describing the resulting actions based on environment or remote sensing signals. While economic constraints may force risk managers to focus on a smaller number of sources of risk information, a multi-stage approach would allow resources to be gradually ramped up with more precise selection of high risk areas as forecast certainty increases.

The third strategy to improve the timeliness of early warning is to optimize detection thresholds. For some AI tests, such as mRT-PCR, sensitivity can be changed by altering positive detection thresholds. Shifting to syndromic surveillance is unlikely to be useful for LPAI (and some HPAI) due to the lack of clinical symptoms in infected birds, and may yield too many false positives if used alone for HPAI.

Vulnerability surveillance

There are two main ways to improve the risk forecasting value of wild bird data within the reality of resource and logistic constraints. One is to increase the likelihood of early detection of HPAI in wild birds. The second approach



is to focus on poultry operations and identify factors that make them more vulnerable to exposure and disease. The poultry industry wants advanced warning of an incursion of a HPAI strain in time enough to act. Global experience suggests that there is not a consistent pattern of whether or not HPAI will be detected in wild birds before domestic poultry or that the wild birds that do test positive are the source of a domestic outbreak (as opposed to being spill-back hosts or sharing an exposure source with domestic birds). Wild bird surveillance alone is inadequate to reveal which locations are most vulnerable to exposure.

Vulnerability is composed of the likelihood of exposure to a hazard and the susceptibility to harm from that exposure. There is a growing body of work emerging from concerns over bioterrorism, emergency response, climate change and emerging infections that addresses questions of how to determine which populations are most vulnerable to an epidemic spreading through a network, and which carry the highest risk of causing a major outbreak if they are the source of the infection. Becker (2003) recognized the lack of vulnerability assessment work in veterinary medicine and recommended increased attention be placed by the veterinary profession on vulnerability assessment to better protect agriculture and public health.

As illustrated above, there has not been sufficient work conducted on the mechanisms of introduction of HPAI into poultry barns nor on the use of epidemic intelligence to characterise the risk/vulnerability setting of a region/farm in order to motivate changes in biosecurity practices in advance of detecting an infected wild or domestic bird. Forecasting a risk (as opposed to detecting it early) requires an intelligence approach that provides awareness of the changing epidemiological situation by tracking not just disease outcomes but also vulnerabilities of populations of concern. Sawford et al (2011) proposed an intelligence system for detection of emerging zoonoses under low resource settings. In that paper, they outlined the features of a system that could allow for ongoing situational awareness. Their work highlights the need to expand surveillance from only tracking disease outcomes to also tracking the population of concern, as well as the need for contextual information affecting susceptibility or exposure along with the capacity for ongoing trends assessment. Further work would be required before an AI epidemic intelligence program could be launched. Table 2 proposes, for discussion, possible elements of a wild bird AI intelligence program. The thresholds for action (e.g. what remotely sensed changes in water systems would trigger deployment of resources to search for viruses) and the balance between the desire for early warning and implications of finding certain AI sub-types would need to be discussed and balanced. However, with growing interest in the use of techniques other than direct bird sampling, regulatory agencies are advised to proactively consider how alternative early warning or environmental sampling techniques can be used, interpreted and communicated.

Regardless of whether or not an AI epidemic intelligence system is desired, there seems an obligation to better understand the wild bird-domestic bird interface. For example, to meet OIE requirements laid out in the Terrestrial Code, wild bird programs should be able to detect HPAI in wild birds as well as inform domestic poultry surveillance based on wild-domestic bird interactions. The nature of the required description is unclear. The 2015 North American situation, particularly the appearance of the HPAI in Minnesota at a time where wild waterfowl would be sparse in the winter environment, suggests we need a better understanding of how an AI virus can move from a wild bird, into the environment and into a barn in order to refine biosecurity plans.



Table 2: Hypothetical elements of a wild bird avian influenza (AI) intelligence system

	SPECTRUM OF WILD BIRD AI INTELLIGENCE			
	SAMPLE TARGETS			
	CONDUCTIVE ENVIRONMENT	VIRUS IN DETECTION	EXPOSURE POTENTIAL	DISEASE DETECTION
DATA/SAMPLE SOURCES	<ol style="list-style-type: none"> 1. Remote sensing of water conditions 2. Wild bird movements 3. Distribution of poultry 	<ol style="list-style-type: none"> 1. Water or sediments 2. Wild bird feces 3. Dead wild birds 4. Live wild birds 	<ol style="list-style-type: none"> 1. Wild bird movement or aggregation near poultry 2. Wild bird mortality on or near farms 3. Wild bird feces on farm 4. On-farm domestic bird surveillance 	<ol style="list-style-type: none"> 1. Dead or moribund wild birds 2. Dead or moribund domestic birds 3. Outbreaks of clinically compatible illness
ACTIONS	DEPLOY sampling resources strategically to areas conducive to AI presence and transmission. Make people AWARE so there is enhanced vigilance. Determine potentially VULNERABLE locations	Undertake RISK ANALYSIS for local conditions. Issue ALERTS to promote enhanced biosecurity at vulnerable locations	Issue ALERTS to promote disease containment and control and mount EARLY RESPONSE to restrict spread and eliminate risk to vulnerable populations	Mount RECOVERY and area CONTAINMENT actions

A National Wild Bird AI Strategy and Plan

A strategy outlines the desired goals and outcomes. Without it, it is not possible to identify the best tactics to achieve those outcomes. There have routinely been operational plans developed annually to guide participating organizations on the goals and methods of the Interagency Wild Bird Survey; however, variation in tactical decisions on how to triage and target sampling efforts suggest that there is not a shared understanding or agreement on the goals or targets for surveillance and how those may differ for inter-epidemic versus epidemic periods. In addition, there has been a lack of guidance and communication among participants in planning implementation of the program including information flow, performance expectations, or how to adapt to changing circumstances for communications or operations when key personnel depart. These limitations are not unique to Canada and they reflect the responsive and evolving nature of wild bird AI surveillance activities in the past. In many ways, it seems that the operational plans of many countries have been developed in response to fiscal and resource constraints rather than designed to achieve specific measurable targets. Reduction in interest and investment in modifying and assessing plans in between urgent events or outbreaks may have impeded the development and sharing of a plan that is useful to guide surveillance



operations under all epidemiological situations and ensure a shared vision of the desired outcomes in a manner that would allow local participants to adapt their resources to best address the specific program goals.

Resource limitations continue to inspire a search for ways to more efficiently conduct pathogen surveys. Hoyo et al (2010) for example, recommended standardized, hypothesis driven local surveys that are strategically compiled over a wider geographic area in order to maximize benefits of wild bird AI surveillance. Some of the methods discussed above for improvements in timeliness focus on the goal of improved early detection. However, care must be taken that such efficiencies do not compromise other goals, particularly those related to establishing the ecology and epidemiology of AI as such biased sampling approaches will not be representative of the true population infection status. For example, sampling birds further north may increase the probability of virus detection, but it would restrict sampling to one time in the birds life cycle when their stressors, age, proximity to agriculture and other variables that may affect viral prevalence, impacts and shedding will be different than at other times in their life course. A shared and standardized plan and strategy may reduce year-to-year and between-jurisdiction variations, as well as set out clear guidance on performance expectations for sampling, testing and communications.

What about the wild birds themselves?

The focus of this report has been on the use of data associated with wild birds as part of a surveillance program to protect agriculture and public health. Experience to date suggests that AI has not been a significant cause of mortality in wild birds (with limited examples of die-offs in HPAI-infected wild birds). Given that (i) ecological effects of infection in wildlife are often not realized through morbidity or mortality but rather through sub-clinical impacts on reproduction, predator avoidance, foraging success, or other population health determinants, (ii) avian influenza is recognized as a global disease that is regularly and possibly increasingly seen in susceptible wild and domestic hosts; and (iii) surveillance biases have precluded a robust assessment of the impacts of AI on wild birds under natural conditions, it seems reasonable to reflect on how wild bird AI surveillance and control may help protect wild birds as well.

Investment in understanding viral traffic may help better understand what proportion of wild bird infections are spill-over or spill-back cases and better protect either wild or domestic birds from exposure to novel sub-types. Understanding the role between wild bird stressors (especially those associated with human activity such as land use) may help identify policy decisions that are protective of wild birds while also reducing domestic bird risk. Engaging the wildlife health community and agencies in developing a comprehensive national wild bird AI strategy and operational plan is warranted as is developing plans that will allow resulting information to generate evidence that protects wildlife, agriculture and public health.



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Appendix 1. Overview of international wild bird influenza surveillance efforts

The following numbers were reported in research papers and are not necessarily representative of surveillance efforts across the entire country or geographic region.

Country/Region	Sample Size	Sample Type	Sampling Period	Surveillance Type	Species	Positives	% Positive
Australia	21858	Cloacal, fecal	2005-2008	Active – live sampling	Waterfowl, shorebirds, other	300	1.4
Bavaria	5864	Cloacal, tracheal, fecal, organs	Jul 2007-Dec 2008		12 orders	217	3.7
Caribbean region	324	Cloacal, Tracheal	2006-2009	Active – live sampling, hunter harvest	Waders, ducks, doves	0	0
Central Asia (Kazakhstan, Mongolia, Russia)	2604	Cloacal	2003-2009	Active – harvest, live capture	14 orders; mostly Anseriformes, Charadriiformes, Passeriformes	17	0.07
Denmark	11055	Oropharyngeal, cloacal, fecal	2007-2010	Passive – found dead; Active – live sampling, hunter harvest	11 orders – high percentage Anseriformes	536	4.8
Greenland	3555	Fecal	2007-2010	Active - fecal	6 orders	0	0
Egypt	7894	Cloacal	Sep 2003-Feb 2007	Active – live sampling, hunter harvest	Green-winged Teal, Northern Shoveler, Northern Pintail, 92 other species	745	9.4
Europe	24516	Cloacal	1998-2005			612	2.5
Georgia	5220	Tracheal, cloacal, fecal	2009-2011	Active – live sampling, hunter harvest	Anatidae, Charadriiformes, total 11 Orders	84	1.6



Country/Region	Sample Size	Sample Type	Sampling Period	Surveillance Type	Species	Positives	% Positive
Germany, Austria, Switzerland	778	Tracheal, cloacal	2006-2007 (Sep-Aug)	Passive – found dead, bycatch; Active – live sampling, hunter harvest	Swans, diving ducks, grebes, mergansers, other		
Great Britain	9960		2007-2009	Passive – found dead; Active – live sampling, hunter harvest Active - fecal			
Kenya	2630	Fecal	2008			12 (of 516 pooled samples)	
Mexico	1262	Cloacal, oropharyngeal	2007-2009	Active – hunter harvest	20 aquatic species	46	3.6
Mongolia	5831	Fecal	Jul 2009-Oct 2012 (May-Oct)		Anatidae, Laridae	80	
Norway	2417	Cloacal, tracheal	2005-2010 (Aug-Dec)	Active – hunter harvest	Dabbling ducks, gulls		15.5
Poland	366	Cloacal, oropharyngeal	2008-2010	Active – live sampling	Anseriformes, Charadriiformes, Gruiformes	14	3.8
Portugal	5691	Cloacal, oropharyngeal	2005-2009	Active – live sampling	13 orders	93	1.6
Russia (Asian region)	5678	Cloacal, fecal	2008	Active – live sampling, hunter harvest	18 orders	41	0.72
Slovakia	650	Cloacal, oropharyngeal	2008 (Apr, Jun, Jul)	Active – live sampling	Passeriformes, Falconiformes		13.6/17.5 (spring/fall)
South Korea	28214	Fecal	2003-2008	Active – fecal sampling	Anseriformes	225	0.8
Sweden	18645	Cloacal	2008-2009 (Mar-Dec)			2463	13.2
Switzerland	2106	Pharyngeal, cloacal	Sep 2006-Dec 2008	Active – live sampling, hunter harvest	13 orders	84	4
Taiwan	44786	Fecal	1998-2011	Active - fecal	Anatidae, shorebirds, Laridae, Ardeidae, other		1.1 (Anatidae)



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