Introduction to mathematical modelling of avian influenza in livestock

Julien Arino

April 2023

AI characteristics

Modelling AI

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REVIEW ARTICLE

Avian influenza viruses in poultry products: a review

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Table 1. *Summary of data available in the literature on the presence of HPAI viruses in poultry commodities*

Commodity	Species	Strain	Experimental (E) or natural (N) infection	Infecting dose (EID_{50} log_{10})	Titres (log_{10} EID_{50}/g) detected in commodity
Meat	Chickens	A/duck/Anyang/AVL-1/01 (H5N1)		6/0.1 ml	5.3 to 5.5
		A/chicken/Pennsylvania/1370/1983 (H5N2)	E	6/0.1 ml	2.2 to 3.2
		A/tern/South Africa/61 (H5N3)		7/0.1 ml	>4
	Turkeys	A/turkey/Italy/4580/99 (H7N1)	E	7/0.1 ml	4.38
	Ducks	A/duck/Anyang/AVL-1/01 (H5N1)	E and N	6/0.1 ml	3 to 4
		A/goose/Vietnam/3/2005 (H5N1)	E	6/0.1 ml	3
		A/Vietnam/1203/2004, A/ThailandPB/6231/2004, A/crow/Thailand/2004, A/Egret/HK/757.2/2002 (H5N1)	E	5/0.1 ml	4 to 6 (2-week-old birds) 2 to 4 (5-week-old birds)
		A/egret/HK/757.2/2002 (H5N1)	E	8/0.1 ml	7
		A/chicken/Yamaguchi/7/2004 (H5N1) A/duck/Vietnam/12/2007 (H5N1)	E	7/0.1 ml	1.5
Eggs	Turkeys	A/turkey/Ontario/7732/66 (H5N9)	N	Not reported	Not reported
		H5N2 (Virginia/1985)	E	Not reported	Not reported
	Chickens	H5N2 (Virginia/1985)	N	Not reported	Not reported
	Ducks and geese	H5N1 (strain not reported)	N	Not reported	Not reported
	Quail	H5N1 (strain not reported)	N	Not reported	4.6 to 6.2
Feathers	Chickens, turkeys, quail, guinea fowl	A/chicken/Yamaguchi/7/2004, A/chicken/Miyazaki/K11/2007, A/chicken/Hong Kong/220/1997	E	5.8 to 6.2/0.1 ml	Not investigated
	Ducks	A/chicken/Yamaguchi/7/2004, A/chicken/Miyazaki/K11/2007	E	8/0.1 ml	Not investigated
	Turkeys	H5N1 (strain not reported)	N	Not available	Not investigated
Liver	Ducks	A/chicken/Vietnam/12/2005 (H5N1)	E	7/0.1 ml	Not reported
Blood	Chickens	A/tern/South Africa/61 (H5N3)	E	7/0.1 ml	4
		A/chicken/Pennsylvania/1370/1983 (H5N2)		6/0.1 ml	Not reported
	Pigeons, geese	A/turkey/Ontario/7732/66 (H5N9)	E	8/0.5 ml	Not recovered
	Turkeys	A/turkey/Italy/4580/99 (H7N1)	E	6/0.1 ml	1 to 5.8
		A/turkey/Ontario/7732/66 (H5N9)		8.7/0.5 ml	2.7 to 3.7
	Ducks	A/chicken/Vietnam/12/2005 (H5N1)	E	7/0.1 ml	Not reported
		A/turkey/Ontario/7732/66 (H5N9)	E	8/0.5 ml	Not recovered
Skin	Ducks	A/chicken/Yamaguchi/7/2004,	E	8/0.1 ml	2.5 to 4.4
	Geese	A/chicken/Yamaguchi/7/2004	E	8/0.1 ml	3.5
		A/chicken/Miyazaki/K11/2007	E		4.5

Table 2. *Summary of data available in literature on the presence of LPAI viruses in poultry commodities*

Commodity	Species	Strain	Natural (N) or experimental (E) infection	Infecting dose (EID_{50} log_{10})	Titres (log_{10} EID_{50}/g
Meat	Chickens	A/chicken/aq-Y-55/01 (H9N2);	E	7/0.1 ml	1.6 to 2
		A/chicken/aq-Y-135/01(H9N2)	E	7/0.1 ml	1.6 to 2
	Turkeys	A/turkey/Italy/3675/99 (H7N1)	E	6/0.1 ml	
		A/turkey/Virginia/159512/2002 (H7N2)	E	6/0.1 ml	No infectious virus detected
		A/chicken/New York/21586–8/99 (H7N2)	E	6/0.1 ml	
	Ducks	No data available			
Eggs	Turkeys	A/turkey/California/meleagrium/64; A/turkey/California/5142/66	E	2.25/0.2 ml	No infectious virus detected
	Chickens	A/chicken/Alabama/7395/75 (H4N8)	N	Not reported	No infectious virus detected
	Ducks and geese	Not available			
Feathers	Avian species	Not available			
Liver	Avian species	Not available			
Blood	Chickens	A/chicken/aq-Y-55/01 (H9N2)	E (co infection with *S. aureus*)	6/0.1 ml	Not reported
		A/chicken/Beijing/2/97 (H9N2)		6/0.1 ml	
	Turkeys	A/turkey/Italy/3675/99 (H7N1)	E	6/0.1 ml	<1
	Ducks	No data available			

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Natural history of highly pathogenic avian influenza H5N1

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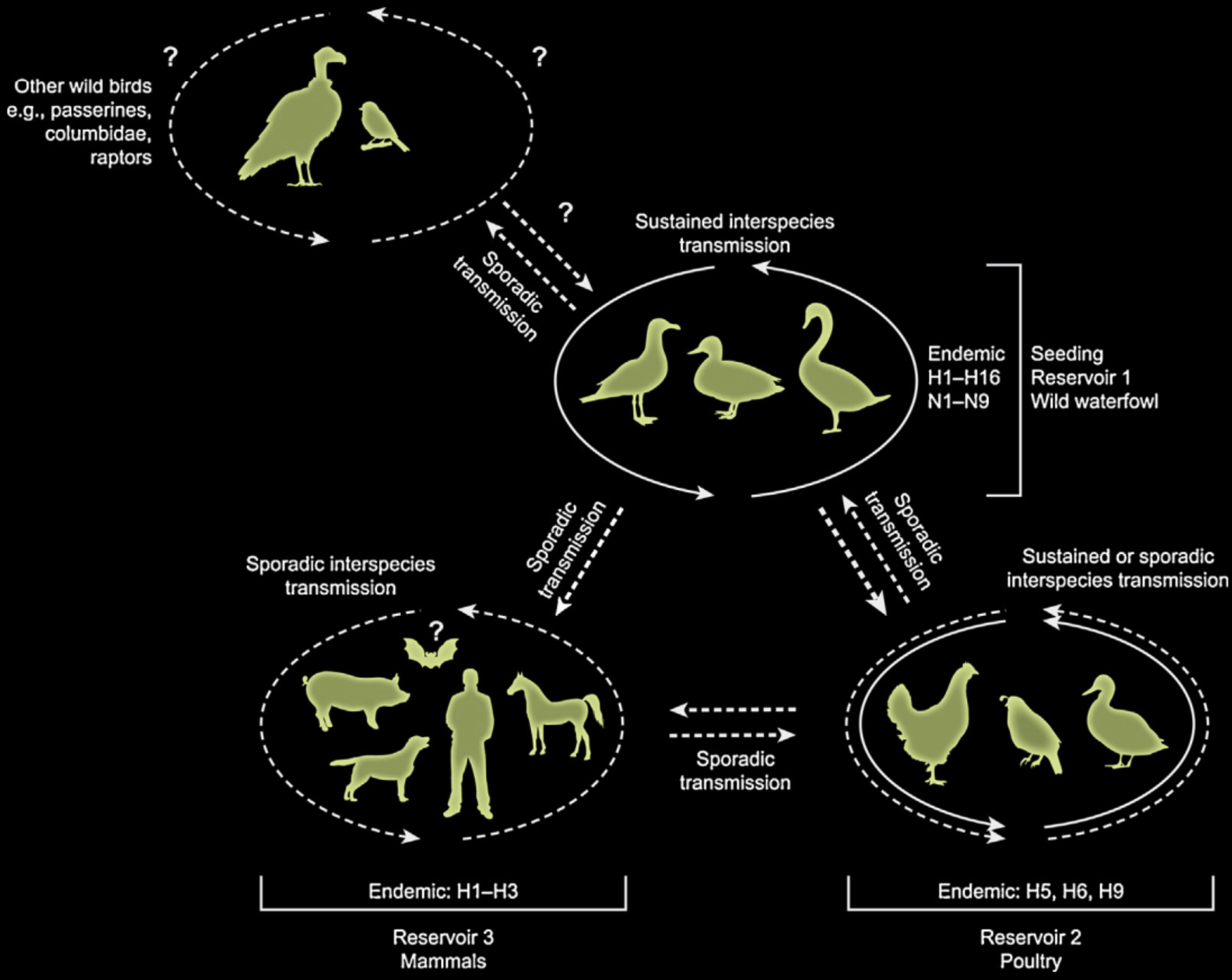
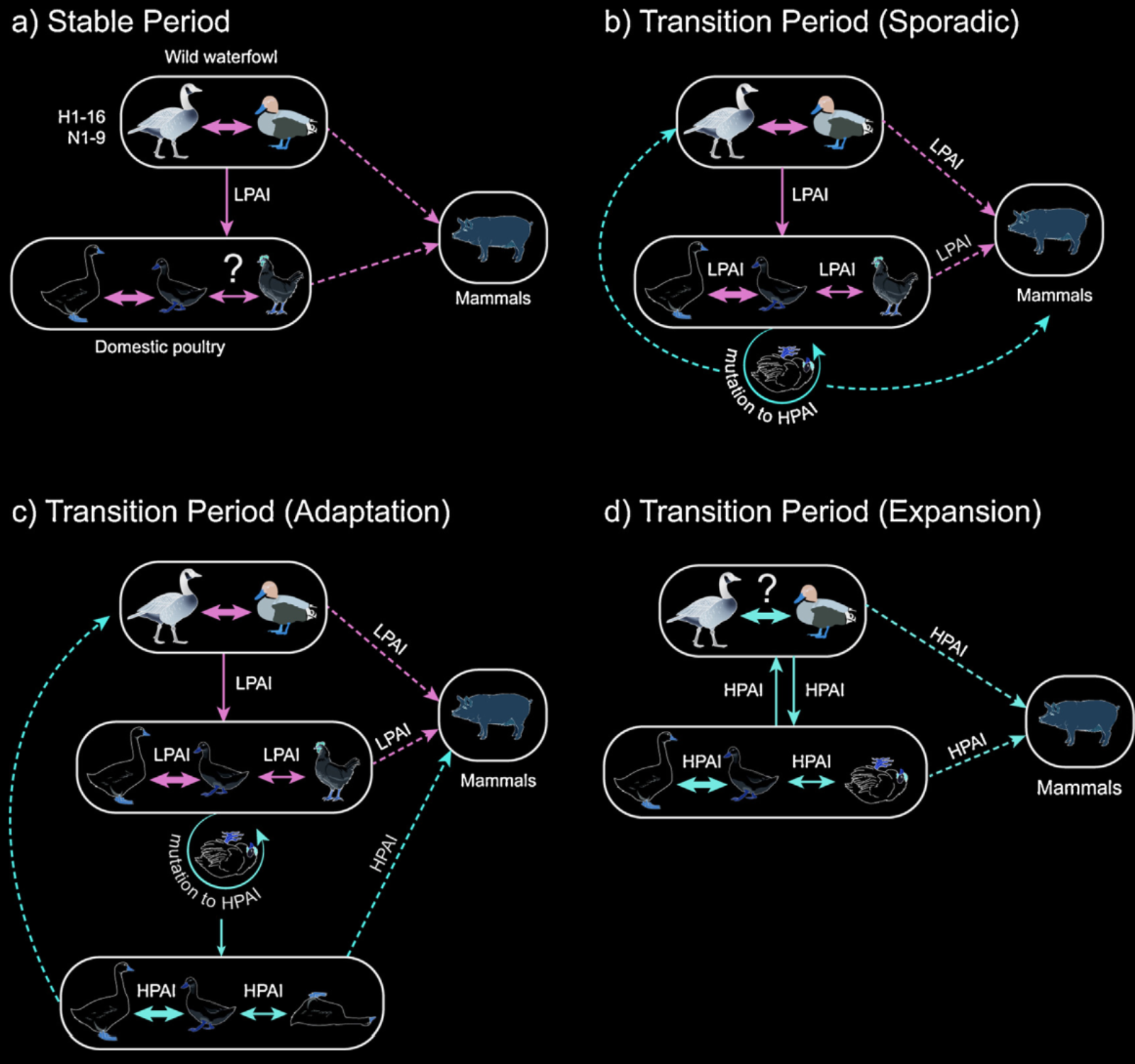

Other wild birds
e.g., passerines,
columbidae,
raptors
?
?
?
Sporadic
transmission
Sustained interspecies
transmission
Endemic
H1–H16
N1–N9
Seeding
Reservoir 1
Wild waterfowl
Sporadic
transmission
Sporadic
transmission
Sporadic interspecies
transmission
Sustained or sporadic
interspecies transmission
?
Sporadic
transmission
Endemic: H1–H3
Endemic: H5, H6, H9
Reservoir 3
Mammals
Reservoir 2
Poultry


a) Stable Period
Wild waterfowl
H1-16
N1-9
LPAI
?
Domestic poultry
Mammals
b) Transition Period (Sporadic)
LPAI
LPAI
LPAI
LPAI
LPAI
Mammals
mutation to HPAI
c) Transition Period (Adaptation)
LPAI
LPAI
LPAI
LPAI
LPAI
Mammals
mutation to HPAI
HPAI
HPAI
HPAI
d) Transition Period (Expansion)
?
HPAI
HPAI
HPAI
HPAI
HPAI
Mammals

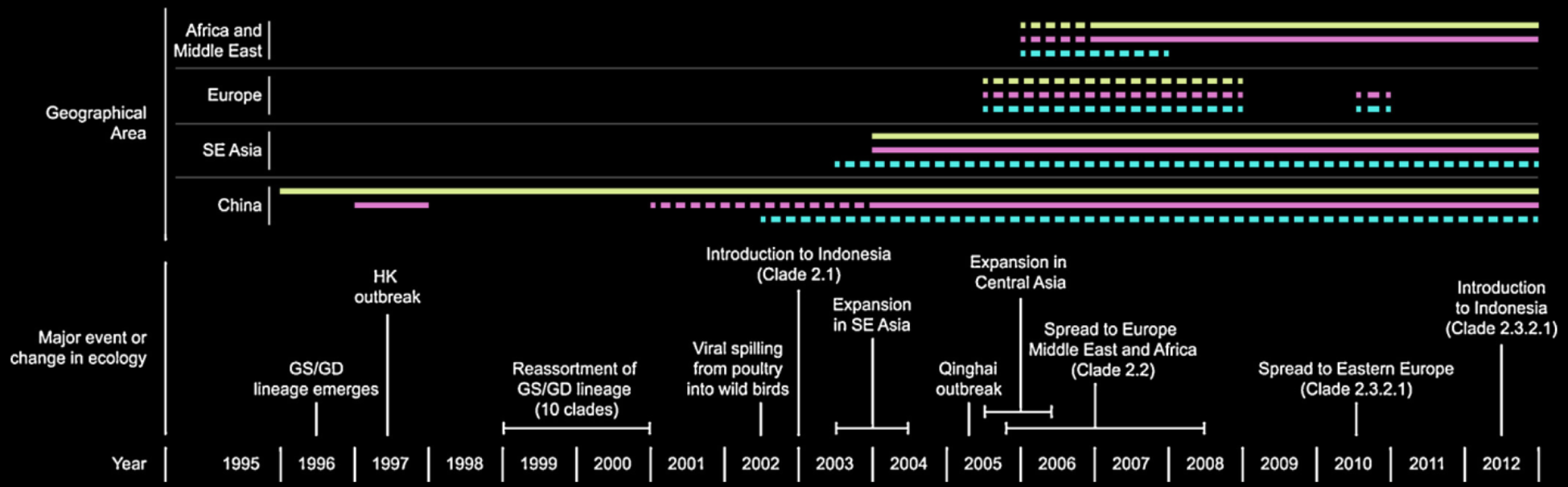


Fig. 3. Timeline of major events of goose/Guangdong-lineage H5N1 evolution. Shown are times of major changes in the evolution of highly pathogenic H5N1, goose/Guangdong-lineage. Expansion into different geographical areas is depicted, as is status in various hosts in different locations: solid lines depict stable interactions between virus and hosts and dashed lines depict transient interactions. Blue lines represent aquatic poultry hosts, green lines terrestrial poultry hosts, and red lines wild birds hosts. SE Asia – South East Asia, Gs/GD – goose/Guangdong, HK – Hong Kong.

Table 1
Reported highly pathogenic avian influenza isolates obtained from primary outbreaks in poultry[a] since 1959

	HPAI virus	Subtype	Approximate numbers of poultry involved
1	A/chicken/Scotland/59	H5N1	1 small farm
2	A/turkey/England/63	H7N3	29,000
3	A/turkey/Ontario/7732/66	H5N9	8,000
4	A/chicken/Victoria/76	H7N7	58,000
5	A/chicken/Germany/79	H7N7	1 chicken farm, 1 goose farm
6	A/turkey/England/199/79	H7N7	9,000
7	A/chicken/Pennsylvania/1370/83	H5N2	17,000,000
8	A/turkey/Ireland/1378/83	H5N8	307,000, mostly ducks
9	A/chicken/Victoria/85	H7N7	240,000
10	A/turkey/England/50–92/91	H5N1	8,000
11	A/chicken/Victoria/1/92	H7N3	18,000
12	A/chicken/Queensland/667-6/94	H7N3	22,000
13	A/chicken/Mexico/8623-607/94	H5N2	Unknown—millions?
14	A/chicken/Pakistan/447/94	H7N3	>6,000,000
15	A/chicken/NSW/97	H7N4	160,000
16	A/chicken/Hong Kong/97[b]	H5N1	3,000,000
17	A/chicken/Italy/330/97	H5N2	8,000
18	A/turkey/Italy/99	H7N1	14,000,000
19	A/chicken/Chile/2002	H7N3	~700,000
20	A/chicken/Netherlands/2003	H7N7	>25,000,000
21	A/chicken/Eurasia and Africa[c]/2003–2006	H5N1	Unknown—100s of millions
22	A/chicken/Texas/2004	H5N2	6,600
23	A/chicken/Canada-BC/2004	H7N3	16,000,000
24	A/ostrich/S. Africa/2004	H5N2	30,000

[a] Where outbreaks were extensive and infecting different types of poultry the first reported virus is listed.
[b] Probably early outbreak of 21.
[c] 19 Asian, 7 European and 5 African countries had reported outbreaks to May 2006.

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Review

The history of avian influenza

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Year	Event
1878	First description of highly pathogenic avian influenza (HPAI) or fowl plague
1880	Differentiation of HPAI from fowl cholera
1901	Identification of HPAI as a virus
1901–1930s	Major outbreaks of HPAI throughout the world
1918	Major human pandemic
1931	First influenza virus isolated (swine)
1941	Recognition of hemagglutination by influenza viruses
1942	HPAI and Newcastle disease virus shown to agglutinate red blood cells and to be different serologically
1955	HPAI virus shown to be a type A influenza virus
1959	Isolation of a HPAI virus serologically different from the classical fowl plague virus in hemagglutination inhibition test
1970s	Intensive surveillance of influenza viruses in wild birds and recognition that wild birds harbor all identified subtypes of influenza viruses
1971	Classification of influenza viruses based on antigenic properties of the NP (type) and HA and NA (subtype) proteins and the species of origin
1977–1981	Recognition that the presence of multiple basic amino acids in the HA cleavage site correlates with tissue spread and virulence of AI strains
1978	Recognition that the 1957 (H2N2) and 1968 (H3N2) pandemic influenza viruses aroused by reassortment with AI viruses
1980	Classification of influenza viruses based on antigenic properties of the NP (type) and HA and NA (subtype) proteins regardless of the species of origin
1981	First International Symposium on Avian Influenza
1981	The name highly pathogenic avian influenza is proposed to substitute fowl plague
1999–2001	H9N2 virus transmission to humans
1997-present	HPAI H5N1 transmission to humans
2000s	H9N2 becomes endemic in Asia
2003-present	HPAI H5N1 spreads through Asia, Europe and Africa and becomes endemic in Asia

Important outbreaks of HPAI documented since 1959*

	HPAI virus	Subtype	Species affected	Approximately number of birds culled
1	A/chicken/Scotland/59	H5N1	Chicken	1 small farm
2	A/tern/South Africa/61	H5N3	Common tern	1300
3	A/turkey/England/63	H7N3	Turkey	29,000
4	A/turkey/Ontario/7732/66	H5N9	Turkey	8000
5	A/chicken/Victoria/76	H7N7	Chickens, ducks	58,000
6	A/chicken/Germany/79	H7N7	Chicken and goose	1chicken and 1 goose farm
7	A/turkey/England/199/79	H7N7	Turkey	9000
8	A/chicken/Pennsylvania/1370/83**	H5N2	Chicken turkey	17,000,000 chickens and turkeys
9	A/turkey/Ireland/1378/83	H5N8	Turkey	307,000, chickens, turkeys and mostly ducks
10	A/chicken/Victoria/85	H7N7	Chicken	240,000
11	A/turkey/England/50-92/91	H5N1	Turkey	8000
12	A/chicken/Victoria/1/92	H7N3	Chicken	18,000 broiler breeders, ducks
13	A/chicken/Queenland/667-6/94	H7N3	Chicken	22,000
14	A/chicken/Mexico/8623-607/94**	H5N2	Chicken	Millions?
15	A/chicken/Pakistan/447/94**	H7N3	Chicken	>6,000,000

16	A/chicken/NSW/97	H7N4	Chicken	160,000 chickens, emus
17	A/chicken/Hong Kong/97	H5N1	Chicken, duck	1,500,000 chickens and other domestic birds
18	A/chicken/Italy330/97	H5N2	Chicken	8000 chickens, turkeys, guinea-fowl, ducks, quail, pigeons, geese, pheasant
19	A/turkey/Italy/99**	H7N1	Turkey	14,000,000 chickens, turkeys, guinea-fowl, quail, ducks, pheasants, ostriches
20	A/chicken/Chile/02	H7N3	Chicken	700,000 chickens, turkeys
21	A/grey heron/Hong Kong/861.1/02	H5N1	Wild birds	Outbreak in wild birds; over 800,000 domestic birds were culled
22	A/chicken/Netherlands/03**	H7N7	Chicken	>34,000,000
23	A/chicken/Asia, Europe and Africa/03-07**	H5N1	Chicken, duck	100s of millions
24	A/chicken/Texas/04	H5N2	Chicken	6600
25	A/chicken/Canada/04**	H7N3	Chicken	16,000,000
26	A/ostrich/South Africa/04	H5N2	Ostrich	30,000
27	A/chicken/North Korea/05	H7N7	Chicken	219,000
28	A/turkey/England/07	H5N1	Turkey	160,000

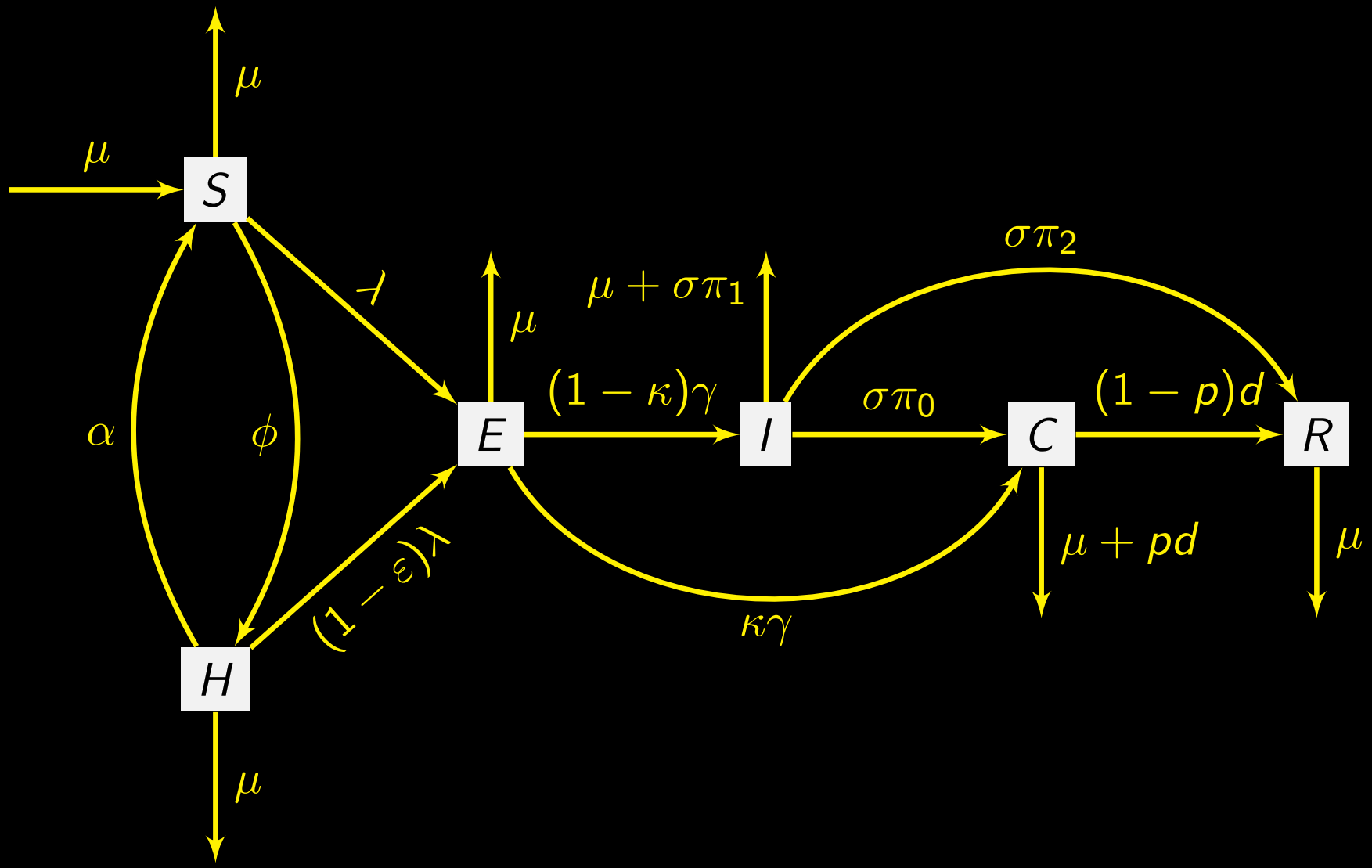
AI characteristics

Modelling AI

Mathematical modelling of AI

A lot more popular than FMD!

There are *many* mathematical models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