

# A Study on the Space-Time Dynamic of Global Avian Influenza and Relationship with Bird Migration

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## Abstract

In the past 100 years, the outbreak of avian influenza all over the world is periodic, and it is more and more frequent and harmful, which is thought to be related with deterioration of ecological environment. In recent 3 years, the outbreak of avian influenza is seasonal, it mainly breaks out from the end of fall to the beginning of winter and from end of winter to the beginning of spring, because at this time, the climate and temperature change fiercely, which is a possible inductive factor of avian influenza. By mapping the places where avian influenza broke out before 2000 and after 2003, we found that global avian influenza mainly distributed in the arc zone of West Europe, Mediterranean Sea, West Asia, Southeast Asia and Latin America, where the interaction of sea and land is intense, and fowls and water birds inhabit densely. It is demonstrated that the avian influenza virus exists in the water body like sea, lakes and swamps, and the chemicals discharged by human activities are the possible causes of avian influenza virus variation. By comparing the global space-time distribution of avian influenza with the flyway of migratory bird, we found that eight flyways are the main zones where avian influenza broke out frequently, so it can be concluded that bird migration is an important approach to spread the avian influenza all over the world.

**Keywords:** Avian influenza, Periodicity, Seasonal fluctuation, Spatial distribution, Bird migration

## 1. Introduction

Avian influenza is short for the epidemic influenza, which breaks out in fowls. It is a high infectious disease caused by the subtype of influenza A virus and is defined as list A infectious disease by the Office International Des Epizooties (Gao and Su, 1999). Avian influenza first broke out in Italy, after that, it broke out in Spain in 1918, which led to the death of 21 million people. In 1955, it was formally named avian influenza (Xue, 2003). Since 2003, a total of 250 million fowls died of avian influenza (including ones that were killed), 265 people were infected with avian influenza virus and 109 people died. The direct economic loss of the world caused by avian influenza is over 250 billion dollars. The avian influenza has aroused the attention of government and academic world in every country because it not only impedes the development of world economy, but also endangers people's health (Gao and Wang, 2006).

At present, the study on avian influenza mainly focuses on the field of animal husbandry and veterinary science, including toxicity detection, diagnosis of avian influenza in livestock and fowls, research and development of antiviral medicine, spread approaches, as well as establishment of plans and countermeasures for emergency etc. (Guo, 2004). For example, some scholars thought that avian influenza is caused by the pathogens that can be filtrated (Liao and Song, 2004); investigation carried out in the United States revealed the host of avian influenza and its main spread approaches (Pomeroy, 1982); some scholars put forward countermeasures for avian influenza (Oxford and Lambkin, 2006) In China, study on animal husbandry and veterinary science is unprecedented (Cui and Li, 2005; Chen, et al, 2004), such as the research and development of vaccines for avian influenza (Liu et al, 2005) and the analysis on the influence of avian influenza on animal husbandry (Chen and Li, 2005). However, avian influenza is a natural focus disease, its outbreak must be related with the geological environment, and has specific and dynamic space-time characteristics. Recently, analysis on the influence of temperature variation on avian influenza was carried out (Cui and Wang, 2005), and the space-time distribution of high pathogenic avian influenza has been studied (Fang, et al, 2005). But their study only focused on the special region of Chinese mainland, and paid no attention to the global situations of avian influenza.

In this study, we collected the avian influenza information of the world through the internet, including the time when avian influenza broke out, the place where avian influenza broke out, as well as the number of fowls killed, and the number of people who were infected with avian influenza; further more, we collected the relating environmental information, such as the climate variation, environment pollution and bird migration. We integrated these data and established a dynamic database, which exhibits the space-time distribution of avian influenza, and analyzed the relationship between avian influenza and bird migration.

## 2. Dynamic analysis of the outbreak time of avian influenza all over the world

### 2.1 The periodicity of global avian influenza in the past 100 years

In this paper, we collected a total of 2454 items of information about the avian influenza from 1950 to April 2006. We made a statistical analysis on these information and figure out the number of countries in which the avian influenza broke out in the recent 50 years (Figure 1). As we can see from Figure 1 that there are four stages when the avian influenza broke out frequently, i.e. 1957-1966, 1975-1985, 1991-1999, and 2003-now. Around 1960, avian influenza broke out in six countries and regions, they are Hong Kong in 1957, Scotland in 1959, England in 1963, and Canada in 1966; from 1975-1985, avian influenza broke out in six countries, they are Australia in 1976, Scotland and German in 1979, United States in 1983, Ireland in 1984, and Australia in 1985; in 1990s, avian influenza broke out in ten countries and regions, they are England in 1991, Australia in 1992, Mexico in 1994, Australia, Mexico and Pakistan in 1995, and Hong Kong, Italy, Australia in 1997; from 2003 to now, the outbreak of avian influenza is much more frequent than before, in 2003, it broke out in United States, Holland, German, and Korea, in 2004, it spread to 9 countries, and the number of countries in which avian influenza broke out in 2005 and 2006 are 16 and 34 respectively.

We can see from the outbreak situation of avian influenza in the recent 50 years that the global avian influenza exhibits three characteristics: the first, the outbreak of avian influenza is periodic, there are four stages when the avian influenza broke out frequently, that is around 1960s, around 1980, the early 1990s and early years of 21 century; the second, the outbreak of avian influenza is more and more frequent, from 1960s to 1980s, the period of avian influenza was 20 years, and in 1980s, it decreased to 10 years, in 1990s, it became 5 years, after 2003, avian influenza broke out every year, and the situation seems becoming worse and worse; the third, avian influenza is spread to more and more countries and regions, in 1960s, it only broke out in a few countries or regions, and in 1980s, it broke out in several countries, since 2003, the number of countries and regions in which avian influenza broke out began to grow significantly, and up to April 2004, it had spread to 54 countries of five continents, and became a global problem that endangers the animal husbandry and public health.

We made a statistical analysis on the global diseases that endanger people's health and life in recent 50 years, and classified them into traditional disease, modern disease and infectious disease according to the cause of disease. Traditional disease is brought by the underdevelopment of economy, and is decreasing with the development of social economy; modern disease is caused by the abuse of technology, bad life style and non-sustainable development, and it is more and more serious; the infectious disease is usually caused by various complex factors, and it usually breaks out periodically. Avian influenza is an infectious disease that breaks out periodically and has the modern characteristics, because since 1990s, avian influenza broke out more frequently and was spread to more and more countries and regions. Climate variation, environment pollution, and style of animal husbandry are the possible causes of avian influenza.

### 2.2 Seasonal change of avian influenza all over the world since 2003

Since 2003, avian influenza has become a common threat to health in worldwide range. We collected the reports about epidemic situation of avian influenza from February 2003 to April 2006, analyzed these data by month and educed the situation of avian influenza within a year, including the number of countries in which avian influenza broke out, the number of people infected with avian influenza, the number of people died, and the number of poultry died or killed. Three parameters of were used to draw a statistical figure about the situation of avian influenza within a year (Figure 2).

We can see from Figure 2 that the outbreak of global avian influenza is seasonal in recent four years, mainly from the end of autumn to the beginning of winter (October to November), and from the end of winter to the beginning of spring (February to April), further more, it exhibits the trend of changing from "single-peak pattern" to "double-peak pattern". The stage of February to April in 2003 is the first fastigium of avian influenza, during that time, avian influenza broke out in four countries or regions, 87 people were infected, two people died, and the situation in Holland was more serious than the other three countries. The stage of January to April in 2004 is the second fastigium of avian influenza, during that time, avian influenza broke out in nine countries, 37 people were infected, and 24 people died. The stage of January to April in 2005 is the third fastigium of avian influenza, in January, eleven people were infected and three people died, from March to April, avian influenza broke out in five countries, 32 people were infected and two people died. The October to November of 2005 and the January to March of 2006 is the "double-peak" stage, in October 2005, avian influenza broke out in ten countries, twelve people were infected, and four people died, in November 2005, avian influenza broke out in nine countries, 18 people were infected, and nine people died; in January 2006, avian influenza broke out in four countries, 28 people were infected, and eight people died, in February, avian influenza broke out in 26 countries, thirteen people were infected, and seven people died, in March, avian influenza broke out in nine countries, three people were infected and two people died.

The seasonal outbreak of avian influenza within a year is related with the following three factors: the first, the survival and proliferation of virus need cool environment, according to the experiment on virus survival, virus will live longer if temperature is low, at zero centigrade, avian influenza virus can survive over 30 days, so it is easier for virus to infect animals or people; on the contrary, virus will live much shorter if temperature is relatively high, for example, if the temperature is over 22 centigrade, virus can only survive four days, so there is little chance for it to infect animals or people. The second, the fastigium of avian influenza usually emerges when the season changes or temperature fluctuates greatly. In the Northern hemisphere, the time of October to December is just at the end of autumn and the beginning of winter, and the time of February to April is just at the end of winter and beginning of spring, at this time, temperature fluctuates greatly, and epidemic influenza prevails easily, so temperature change is an important factor to induce the outbreak of avian influenza. The third, bird migration is an important factor to spread avian influenza to different regions of the world, at the end of autumn and beginning of winter every year, migratory birds migrate from the north to the south, which will bring the avian influenza virus of the water area in high latitude regions to the south, while at the end of winter and beginning of spring, migratory birds migrate from the south to the north, which will bring the avian influenza virus of water area in low latitude regions to the north.

### **3. Analysis on the space-time distribution of avian influenza all over the world**

Being affected by bird migration, trade of livestock and fowls and flow of people, the distribution of avian influenza is very complex, and there is no agreement on the distribution of original places of avian influenza at the present time. In this paper, we discussed the distribution law of avian influenza at two stages and paid special attention to discovering the original places of avian influenza and its distribution law.

#### *3.1 Distribution of avian influenza before 2000*

It has been more than 130 years since avian influenza broke out for the first time. We collected 24 items of record about the avian influenza all over the world from 1878 to 2000 and drew a figure about space-time distribution of avian influenza using the Arc View of GIS software. Before 2000, there are ten countries and regions, including England, Ireland, German, Spain, Italy, Pakistan, Hong Kong of China, Australia, Mexico and United States, in which avian influenza broke out, and these countries distribute on the arc zone from the North Sea, Mediterranean Sea, via Persian Gulf, Arabian Sea, South China Sea, Banda Sea, across the Pacific Ocean, to Gulf of Mexico. In Australia (four times) and Hong Kong of China (three times), avian influenza broke out more frequent than any other countries. In Spain and Hong Kong of China, the number of people who died is the largest. In accordance with geography, the arc zone is a region where the sea and land interact frequently, islands take up the larger percent of land, and the seas in this region are usually inland sea. Further more, the arc zone is the main channel of global transportation by sea, and the main habitable region for water birds and fowls, so it is affected by human activities to a great extent.

#### *3.2 Distribution of avian influenza after 2003*

We collected 2430 items of information about the avian influenza all over the world from February 2003 to April 2006, of the 45 countries and regions involved, Holland and Hong Kong of China are regions where avian influenza broke out firstly, and Vietnam is the country in which the epidemic situation was more serious than any other countries, because during this stage, avian influenza broke out 1023 times in 325 places in Vietnam, 93 people were infected, and 42 people died. In this paper, we paid more attention to the macro-distribution of avian influenza, so we incorporated the small countries, which border each other as one and separated the regions, which are far from each other in one country. Using the GIS software, we established a space database and property database in Arc View, and drew the figure of global distribution of avian influenza at the present time (Figure 3).

As we can see from Figure 3 that, except South Africa, Nigeria, and Niger, global avian influenza after 2003 mainly distributes at the triangle region from West Europe to Southeast Asia. If United States and Columbia are added, the distribution of avian influenza after 2003 is similar to the distribution of avian influenza before 2000. That is, it mainly distributes at the arc region approximately from West Europe (including Greece, Holland, Poland, German, France, England etc.), via Mediterranean Sea to countries of West Asia (including Turkey, Iraq, Afghanistan, Iran, Pakistan, India etc.), then via Indo-China Peninsula (including Vietnam and Cambodia), to Southeast Asia (including Hong Kong of China, Taiwan of China, Philippine, Indonesia and Malaysia), and then across Pacific Ocean to Latin America (including Mexico, United States, Colombia). That triangle region includes the following sea areas: North sea, Baltic sea, Gulf of Bothnia, Bay of Biscay, Mediterranean Sea, Adriatic Sea, Black sea, Caspian Sea, Red sea, Persian Gulf, Arabian sea, Bay of Bengal, Gulf of Thailand, South China sea, Java sea, Malacca Strait, Caribbean Sea, Gulf of Mexico, Great Lakes, Hudson Bay. Global water birds and fowls mainly inhabit in the triangle region described above, in which nine countries are the main places where avian influenza broke out frequently and are the "disaster areas" of the world. The numbers of people infected and died are shown in table 1.

Besides, we summed up the number of places where avian influenza broke out and the number of fowls died or killed in some countries from January 2005 to April 2006 (Table 2). We can see from table 2 that in 2005, avian influenza mainly broke out in Asian area, and influenced the animal husbandry of Vietnam, Thailand, Indonesia, Japan, China, and Turkey to a great extent. Since 2006, avian influenza began to spread to Europe and Africa, and influenced France, German, Italy, Rumania, Nigeria and Egypt etc. Avian influenza broke out in fourteen countries of Europe and four countries of Africa, further more; cat was infected with avian influenza in German.

### 3.3 Analysis on the causes of the global distribution of avian influenza

The factors that influence the distribution of avian influenza are complex. Distribution of sea and land, the ecological environment, host animals, and the flyway of migratory bird are factors that have close relationship with the distribution of avian influenza. It is demonstrated by the global distribution of avian influenza that the “original places” mainly distribute at the region where water and land interact mutually, including the countries and regions where there are many islands, archipelago, lakes, and swamps. It can be explained in the following three aspects: the first, the cool and moist water area is fit for the survival of avian influenza virus, so the probability of the outbreak of avian influenza is increased (Glass, et al 2000); secondly, water bird and fowls are the host and carrier of avian influenza virus, they inhabit at the places where water and land interact such as sea, island, lake and swamp, the dejection of birds is not only the origin of virus but also the culture medium for virus to proliferate, avian influenza virus can easily be isolated from the water polluted by bird dejection without condensation (Constandinos, 2003); the third, the direct discharge (or after elementary decontamination) of industrial waste water and life sewage make the pollution in sea, lake and swamp be more and more serious. The zone from Mediterranean Sea to the South China Sea of and Java Sea of Indonesia is the most severely polluted area, the biochemical reaction and variation of a large number of pathogens and poisonous chemicals in water may be the factors to induce avian influenza virus.

Basing on the above cognizance, we classified the avian influenza virus into “primary type” and “spread type”. And we speculate that the zone from England and Holland of West Europe, via Italy and Spain beside the Mediterranean Sea to West Asia, then via Indo-China Peninsula and Southeast Asia to Indonesia archipelago, and then across the Pacific Ocean to Latin America, is the original place of avian influenza, in which avian influenza is mainly of “primary type” (including cross infection within area), and the virus may be formed by the variation of pathogens (mechanism is till unclear). The avian influenza in regions like the inland of China, Russia, Africa continent (such as Niger), in which there is a lack of water, may be of “spread type” introduced by the bird migration. It has been proved by the investigation in ten places of Chinese mainland, although more proofs are still needed. Hence, the essential measures to prevent global avian influenza are strengthening the monitoring on ecological environment, eliminating epidemic influenza pathogens and prevention and cure of water pollution.

## 4. Relationship between the space-time distribution of avian influenza in recent three years and flyway of migratory bird

Bird migration is an important approach to spread the avian influenza globally, which has been proved by research (Liu and Xiao, 2005; Li and Gu, 2006), so people now pay more attention to the relationship between bird migration and spread of avian influenza. Basing on the records about avian influenza in recent three years, we analyzed the relationship between the space-time distribution of avian influenza and flyway of migratory bird under the support of GIS, with the purpose of grasping the macro-law of avian influenza. Some scholars summed up the global flyways of migratory birds as eight routes, i.e. Atlantic Ocean, Black sea-Mediterranean Sea, East Africa-West Asia, Central Asia, Southeast Asia-Australia, America-Pacific Ocean, Mississippi River of North America, and Atlantic Ocean of America (Zhang and Yang, 1997). In this paper, the records about avian influenza in recent three years were grouped according to season and migratory route, and were compared with the flyway and direction of bird migration so as to reveal the relationship between the distribution of avian influenza and bird migration. The migration of bird is seasonal, usually, birds rise up seed in the north from May to September every year, and then they migrate to the south from October to November, and live through the winter in the south from December to February of next year, then fly back to the north. Owing to that there was little record about the avian influenza in South America, North America and Oceania, we just analyzed the avian influenza in the “World Island” of Asia, Europe, and Africa, and drew a figure about the relationship between the distribution of avian influenza and flyway of bird migratory by using Arc View. It is demonstrated that at least 8 flyways correspond with space-time distribution of avian influenza. This result will be propitious to the study on the space-time distribution of “spread type” avian influenza.

Figure 4 shows the three routes where the distribution of avian influenza corresponds with the flyway of bird migration at the end of autumn and the beginning of winter. The left one is the flyway of bird migration from Siberia to Mediterranean Sea, and avian influenza broke with the migration of bird: in July, 2005, avian influenza broke out in Russia, in August, it broke out in Kazakhstan, and then it spread to Croatia and Romania in October, and at last

broke out in Turkey in November. It is demonstrated that avian influenza spread from the north to the south when the bird migrate to south at the end of autumn and beginning of winter. The right one is the flyway of bird migration from Japanese Sea to Indonesia, along this route, avian influenza first broke in Korea in December 2003, then in Hong Kong and Vietnam in January 2004, and then spread to Indonesia in February. The middle one is the flyway of bird migration from east China to Indo-China Peninsula, avian influenza first broke out in Liaoning Province in October 2005, then in Guangxi and Fujian in December, at last spread to Laos and Thailand in January 2006. Figure 5 shows the five routes where the distribution of avian influenza corresponds with the flyway of bird migration at the end of autumn and beginning of winter. The left one is the flyway of bird migration from Gulf of Guinea to Black Sea, at the beginning of February in 2006, avian influenza broke out in Nigeria, then broke out in Niger at the end of February, after that, it spread to Egypt at the end of March, and Turkey and Iraq at the beginning of April, at last Azerbaijan at the middle of April. The right one is the flyway of bird migration from Mediterranean Sea to Northwest Europe; avian influenza first broke out in Bulgaria at the middle of February, then in Austria at the end of February, and spread to Denmark and Sweden at the beginning of March. The left three flyways are from Arabian Sea and Bay of Bengal to China and Mongolia. And we will discuss the relationship between the distribution of avian influenza in Chinese Mainland and bird migration in another paper.

### Conclusion

The first, in recent 100 years, the outbreak of avian influenza is periodic. Its period changed from 40 years to 10 years, so the outbreak frequency of avian influenza is becoming higher and higher. The outbreak of avian influenza is in accordance with the deterioration of ecological environment. In recent three years, the outbreak of avian influenza is seasonal within a year, mainly at the end of autumn and the beginning of winter, and at the end of winter and the beginning of spring, because at this time, season changes, and temperature fluctuates greatly.

The second, by mapping the places where avian influenza broke out before 2000 and after 2003, we found that global avian influenza mainly distributes in the arc zone from West Europe, via Mediterranean Sea to West Asia, and from Indo-China Peninsula and Southeast Asia, then across Pacific Ocean to Latin America, where sea and land interact intensely, climate is cool and moist, and fowl and water bird inhabit densely. The poisonous chemicals discharged by human activities and the pollution of water area are the factors that induce the variation of influenza virus.

The third, comparing the distribution of avian influenza with the flyway of bird migration, we found that eight flyways in the "world island" of Asia, Europe, and Africa correspond with distribution of avian influenza. So we conclude that bird migration is an important approach to spread the avian influenza globally.

The fourth, in recent years, the Vechta University of German developed software of Vet GIS, which is used to collect, analyze and manage the data about epidemic disease in animal husbandry. The software plays an important role in the monitoring of avian influenza in Italy from 1999 to 2000 (Munch, 2003). We suggest that China should establish GIS and network for monitoring natural focus disease as soon as possible, so as to monitor the space-time dynamic of epidemic disease, understand their space-time distribution, and reveal the relationship between epidemic disease and ecological environment, accordingly, it will provide a scientific information platform for us to face up with the large-scale outbreak of epidemic disease.

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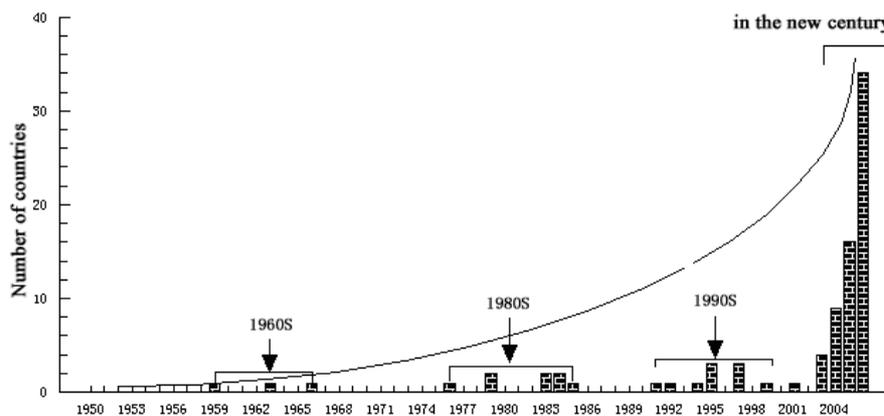


Figure 1. Outbreak cycle of Avian Influenza in recent 60 years

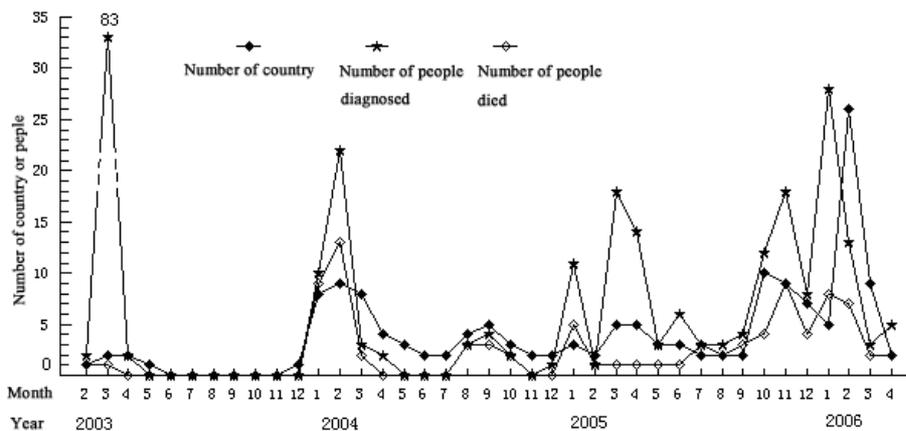


Figure 2. Statistical figure of avian Influenza from February 2003 to March 2006

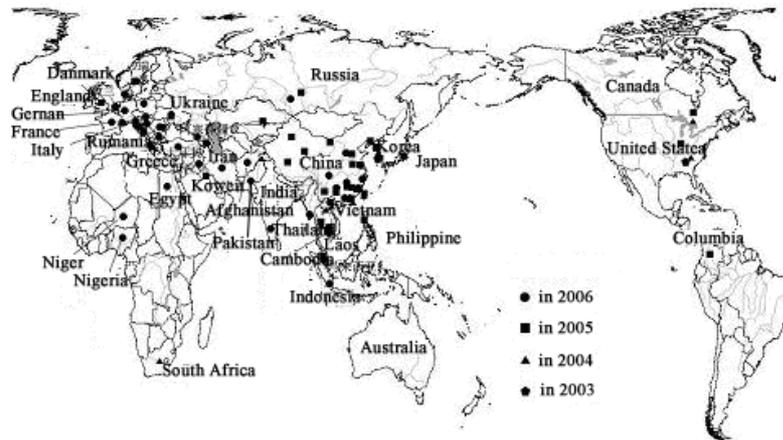


Figure 3. Distribution of Avian Influenza from February in 2003 to March in 2006



Figure 4. Flyway of bird migration and the distribution of avian influenza at the end of autumn and the beginning of winter



Figure 5. Flyway of bird migration and the distribution of avian influenza at the end of winter and the beginning of spring

Table 1. Number of people infected with avian influenza and died from 2003 to 2006.

Country/ Region	2003		2004		2005		2006		Total	
	Diagnosed	Dead								
Azerbaijan	0	0	0	0	0	0	7	5	7	5
Cambodia	0	0	0	0	4	4	2	2	6	6
China	0	0	0	0	8	5	8	6	16	12
Egypt	0	0	0	0	0	0	4	2	4	2
Indonesia	0	0	0	0	17	11	13	12	30	23
Iraq	0	0	0	0	0	0	2	2	2	2
Thailand	0	0	17	12	5	2	0	0	22	14
Turkey	0	0	0	0	0	0	12	4	12	4
Vietnam	3	3	29	20	61	19	0	0	93	42
Total	3	3	46	32	95	41	48	33	192	109

Data resources: Consultation Service Center of Hong Kong Special Administrative Region of the People's Republic of China, until April 12, 2006.

Table 2. Epidemic situation statistic of Avian Influenza in the world from 2005 to 2006

Number of poultry lost in 2005					Number of poultry lost from Jan. to Apr. in 2006				
Country	Places	Infected	Died	Killed	Country	Places	Infected	Died	Killed
Vietnam	385	333 356	303 160	716 726	Vietnam	258	-	30 990	416 272
S. Africa	125	-	-	26 454	Turkey	167	15 270	16 249	436 222
Thailand	113	45 580	54 013	376 350	China	15	32 800	32 800	316 700
Russia	53	-	-	121 287	Iraq	5	1 652	1 652	13 478
Indonesia	47	22 665	346 162	-	Ukraine	26	146 291	146 294	-
Japan	38	22	-	1336 965	Romania	15	473	233	386
Romania	37	1 563	1 336	25 733	France	3	10 502	401	11 300
China	32	45 796	42 204	742 348	Italy	12	2	17	-
Ukraine	30	2 077	2 101	23 589	Egypt	32	2 065	19 861	-
Turkey	2	2 900	2 900	13 190	Nigeria	17	54 056	49 681	26 819
Total	881	454 260	752 485	3228 657	Total	659	350 294	471 204	2533 331

Data resources: Consultation Service Center of Hong Kong Special Administrative Region of the People's Republic of China, until April 12, 2006. "-" means data are not available.