Fish farming and the risk of spread of avian influenza

by Prof C J Feare
Email: feare_wildwings@msn.com

Wild Wings
BIRD MANAGEMENT

March 2006

PDF copies of this report are available at:
http://www.birdlife.org/action/science/species/avian_flu/index.html

Contents

Fish farming and the risk of spread of avian influenza

1 Background

In south-east Asia, in many parts of which HPAI H5N1 avian influenza is now endemic, spread of the virus between poultry flocks, locally, regionally and across international borders, is attributable to movements of poultry, poultry products and poultry residues. An important feature in the development of the current outbreak appears to have been the association, on farms and in markets, of different kinds of poultry, especially chickens and ducks, the two most numerous categories. Domestic ducks can, at least after experimental infection in the laboratory, sometimes carry the virus asymptomatically (Sturm-Ramirez *et al.* 2005) but there is only limited evidence that wild ducks can do so. In Russia, four live ducks were claimed to be positive but the neuraminidase was not identified, while in two others the pathogenicity of the H5N1 was not determined (OIE 2005). In China, Chen *et al.* (2006) undertook routine surveillance of wild waterfowl during the 2002-3, 2003-4 and 2004-5 winters and out of 12,865 samples of cloacal and faecal samples found six (0.047%) samples from apparently healthy migratory ducks positive for HPAI H5N1, all in 2004-2005 and all at Poyang Lake, Jianxi province. Unfortunately, the species of duck, kind of sample obtained, method of capture if caught and method of determining health status are not given. Despite the sampling of wild birds on a huge scale in Europe, and also in north and East Africa, no apparently healthy wild birds positive for H5N1 have so far been found.

In addition to fulfilling their role as poultry, domestic ducks frequently take on a pest management role by being released into harvested paddy fields to eat waste grain, weed seeds, snails and other pests. Duck flocks are moved over surprising distances to perform this function, sometimes over hundreds of km (FAO 2005). Duck flocks are also frequently led to nearby ponds and lakes during the day, and taken back to the homestead at night where they mix with the remainder of the backyard poultry flock (FAO 2005). There is thus a degree of association between avian influenza outbreaks and wetlands in many parts of south-east Asia and this has led to suspicions (in some circles claimed certainty) that wild waterbirds have been responsible for the spread of the virus.

In 2005, HPAI H5N1 spread away from its heartland in south-east Asia north-westwards to northern China, Mongolia, Kazakhstan, southern Russia, and more recently into eastern Europe. In early 2006, this expansion of range has continued into more central parts of Europe and the Middle East, together with Africa and India. Movements and migration of wild birds have been widely blamed for this range extension of the virus (e.g. FAO 2005a) but the evidence remains entirely circumstantial, resting on the deaths of wild birds from which H5N1 has been isolated, and the occurrence of a few of these and of poultry deaths during migration periods and on known migration routes. The proximity of these outbreaks to water bodies has led wild waterbirds to be blamed for virus introduction, e.g. the OIE report on the deaths of poultry (ducks and geese) in Kazakhstan stated that the birds had contracted the virus through contact with wildfowl on open reservoirs.

The occurrences of outbreaks of HPAI H5N1 in Romania, Turkey and Croatia in October 2005 have all been close to wetlands. This, together with their timing, has implicated the migration of wild waterbirds from southern Siberia in bringing the virus to eastern Europe. However, the deaths of mute swans *Cygnus olor* in the two outbreaks in Croatia both occurred at fish farms (OIE reports). The outbreak in Turkey was close to Lake Manyas (=Lake Kus) that supports a declining fishery, mainly carp (Karafistan & Arik-Colacoglu 2005). Romania also supports a wide range of inland fisheries, in man-made reservoirs, fish farms and ponds, and in natural water bodies including fresh water lakes, wetlands and in the flood plain of the Danube Delta (Eurofish 2000), where most of the AI outbreaks occurred. At each of the Croatian fish farms, 15 swans died out of much larger flocks that arrived around 19 October. By chance, one of these swans had been ringed ay Lake Balatan, Hungary (where there had been no recorded outbreaks of H5N1) on 9 September, and it was seen again at the same site 13 days later, still apparently healthy. This bird was seen, identified from its neck ring, among the flock of 1500 swans that arrived at Grudnjak fish farm, Orahovica, Croatia, on 19 October, but was subsequently found dead; it is not clear from the ring recovery report or from the OIE virus notification report when the bird was found dead, but it may have been on the same day. The bird was subsequently found to have HPAI H5N1. These events suggested that the bird could have become infected with the virus in Croatia. In autumn 2004, Paul Tout (pers. comm.) saw piles of chicken waste, including dead birds, dumped next to fish farms at Varazdin, NE Croatia, where they were left to weather and leach into the ponds as fertiliser. In Serbia, manufactured poultry manure fertilisers are added to fish ponds; they are believed to be imported but their origin is not known at present (Marko Sciban, pers. comm.).Vladimir Savic, a Croatian scientist involved with control of the outbreak, on the other hand, said that some of the swans showed symptoms on the day of arrival and, as other waterfowl on the fish pond were unaffected, he thought the swans must have become affected before their arrival (information in email from Martin Gilbert). The association of some wild bird deaths with proximity to fish farms led to this search for information on fish farming practices that could be involved in AI transmission.

The deaths in early 2006 of small numbers of wildfowl, mostly mute swans that appear to be particularly prone to infection, scattered over a wide area of eastern and central Europe and the Middle East, suggests that infected birds can carry the virus across international borders. However, these movements were not along a migratory flyway and were not during a migration season; they appeared to represent dispersal of birds away from extreme cold in the Black Sea area, in parts of which H5N1 infection in poultry had been widespread for several months. All reported cases of H5N1 infection have been of sick or dead birds. The relative roles of dispersal of infected birds and acquisition of infection close to sites where they died are unknown.

The main wild birds deaths from HPAI H5N1 in Asia occurred at Lake Qinghai in China and Lake Ehrel in Mongolia. Lake Qinghai has become a tourist destination on account of its birds and is also a centre for research on its geomorphology and sediments. According to a travel website (http://www.chinavista.com/travel/qinghai/part2.html) it is "teeming with carp" and Foggin (2000) reported the presence of a state-owned fish factory on the south shore of the lake, and large trawlers operating on the lake. During the 20th century water levels have decreased leading to the formation of islands and also the isolation of small lakes around the periphery of the main lake (Wikipedia 2005). In the late 1980s and early 1990s the agricultural potential of the Lake Qinghai area was being recognised and local people were being encouraged to settle and cultivate crops. Some of these crops and their by-products supported a rapidly growing livestock industry. Poultry were one of the main sectors, with ducks and fish as minor ones (Tacon 1990). Fish farming was being encouraged, both in the lake and in surrounding reservoirs, supported by local fish feed manufacturing facilities (Edwards 1991). Features of the developing fish farming industry included manuring of ponds, supplementary feeds using kitchen waste, movements of fish between reservoirs and the lake, use of feather meal and poultry by-product meal in manufactured feeds and, importantly, import of feather meal from other Chinese provinces (Tacon 1990).

Even less appears to be known about Lake Ehrel and its uses, bird or fish populations. An unconfirmed report mentioned hunting at the lake, using decoy ducks imported from China, but the experiences of a recent WCS expedition to the area doubted the validity of this.

2 Associations between fish farming and poultry

In addition to the enormous expansion of poultry rearing in south-east Asia over the past two decades, there has also been a big increase in aquaculture (Little & Satapornvanit 1995, Little & Edwards 2003). In many parts of south-east Asia there are strong associations between poultry and fish farming. Some of these are formalised in "Integrated fish farming" (IFF) or "Integrated agriculture-aquaculture" (IAA) techniques, although links between small-scale poultry production and small-scale fish-rearing appear commonplace and sometimes based on traditional practices, some of which, e.g. in China, have been traced back 1700 years (FAO 2001). IFF and IAA systems work best in "warm water" fisheries, at temperatures of 25-32°C but can also be successful seasonally where summer temperatures approximate these levels (Little & Edwards 2003). Trials of similar techniques were undertaken in Hungary and Germany before and after the Second World War (FAO 2003, Woynarovich 1979).

These integrated systems make use of the products of animal farming, and sometimes arable crops, as foods and fertilisers for fish farms, thereby increasing the yields of fish and at the same time using farm wastes in ways that avoid pollution. In addition, in some systems poultry (chickens and ducks, but possibly other poultry species as well) and pigs are reared in cages above fish ponds, so that excreta and spilled food drop directly into the ponds, and duck flocks are often moved to fish ponds by day to remove snails and other unwanted invertebrates while at the same time fertilising the ponds with their droppings. In other systems the use of fish ponds is rotated between fish and crop production, and in others rice fields can be flooded for fish rearing between rice crops. Clearly, many kinds of fish-poultry integration have arisen to cater for local needs, but the practices are widespread (Little & Edwards 2005). Duck-fish systems appear to be favoured since ducks fit more easily into aquaculture facilities, performing both vegetation and pest management as well as fertilisation roles, with minimum requirement of special facilities and expenditure. This applies in both warm water systems (Little & Edwards 2005), and in the seasonal systems in eastern Europe (Woynarovich 1979).

The increase in poultry production in south-east Asia has been achieved through intensification at both the village and the industrial levels. In addition to the use of manure as a fertiliser for fish ponds, manure is also used to fertilise field crops and fruit orchards (Little & Edwards 2005). Recent developments of IFF/IAA have encouraged farmers at the village level to recycle their waste products locally but Little & Edwards (2005) note that, in north-east Thailand in particular, improved road links have enabled poultry products to be dispersed more widely. This poses a risk for the dissemination of AI virus since it is in village/backyard enterprises, where there is minimal or no biosecurity, that AI viruses are most likely to circulate (FAO 2005b). However, while industrial poultry production systems generally have higher levels of biosecurity and have had lower incidences of AI outbreaks, there have recently been many H5N1 outbreaks in large industrial systems in south-east Asia, Siberia, Europe and Africa.

The following table shows the variety of ways in which poultry and poultry products are used in fish farming, and how widespread these practices are. This list should not be considered to be exhaustive; it is based on information from Erman (1968), Sinha (1979), Woynarovich (1979). Engle & Skladany (1992), Little & Satapornvanit (1995), FAO (2001, 2003, 2005a), Little & Edwards 2005), Marko Sciban (pers. comm..), Paul Tout (pers. comm.).

Activity	**Countries where used**
Poultry-fish (caged over ponds)	India, Thailand
Poultry manure used as fertiliser in fish ponds	India, Indonesia, Thailand, Bangladesh, Vietnam, USA, Serbia, Croatia
Poultry/cattle manure used as fertiliser	India
Dried poultry manure in fish feed	USA
Duck-fish (share ponds)	India, Nepal, Taiwan, Hong Kong, Vietnam, Philippines, Indonesia, Russia, Hungary, Germany, Czech Republic, Poland
Poultry products – egg	India, USA
Poultry products – feather meal	USA,
Poultry by-product meal (bone/blood?)	USA

While manure from a range of farm animals is used to fertilise fish ponds, reflecting the animals kept on smallholdings, several studies have highlighted the supremacy of poultry manure in increasing fish yields (Bannerjee et al. 1979, Natarajan & Varghese 1980, Engle & Skladany 1992, Little & Satapornvanit 1995). This stems from poultry manure being regarded as a "complete" fertiliser with characteristics of both organic and inorganic fertilisers, which can be used without resort to the addition of supplementary chemicals (FAO 2003). Traditionally, poultry manure has come from flocks on the homestead, but recent desires for increased yields has led to an increase in the use of off-farm manures, e.g. from intensive feedlots (Little & Satapornvanit 1995). This trend will increase the extent of movement of poultry manures, with potential implications for the spread of AI among farms. The discovery that such manures were being used in Serbia in 2005-6 illustrates this risk.

Manures perform several functions in fish ponds. Some components are eaten directly by fish. Manures are also used to increase the production of phytoplankton and zooplankton as food for fish, and also to increase the amount of aquatic vegetation available for grazing fish. The addition of poultry manures is thus valuable for fish reared in monocultures, e.g. carp, or in polycultures where fish of different trophic strata are produced together.

The above table shows that duck-fish systems appear to be the most widespread. Their popularity stems from the low maintenance needed for ducks, their utilisation of snails, tadpoles and weed seeds that could compete for fish food, their turning over of bottom soils and silt allowing aeration, aeration of surface waters while swimming, and fertilisation of the water through their droppings. Duck meat is a popular food in south-east Asia. Ducks are, however, considered to be a high risk factor in the epidemiology of AI (Gilbert & Slingenbergh 2004, Gilbert *et al.* 2005, Hulse-Post *et al.* 2005).

Engle & Skladany (1992) mention the sale of chicken manure in Thailand, and also the production of feather meal, blood meal and poultry litter meal. This suggests that several poultry by-products are marketed in Thailand but the extent of this industry is not reported in their paper. This further suggests that the information in the table above is incomplete, since in the papers cited the use of feather meal was not mentioned in south-east Asian countries. The increase in road transport facilities in Thailand (Little & Edwards 2005) will facilitate greater movements of poultry and poultry products.

3 Movements of fish

With the intensification and diversification of fish farming in Europe, especially towards polyculture using fishes of different trophic strata, new fish species were introduced. Sinha (1976) reported that in addition to China and India, polyculture became especially popular in Israel and Russia. Some of the species used in polyculture are of Asian origin, e.g. in Russia white amur *Ctenopharyngodon idellus*, silver carp *Hypophthalmichthys molitrix* and bighead *Aristichthys nobilis* were imported on a large scale to the European and central parts of the then USSR in the 1960s (Erman 1968). I have not discovered whether such imports continue now or whether these species are reared locally. However, Andrej Bibiè (Ministry of Environment and Spatial Planning, Slovenia, by email) informed me of a message from the Slovenian Anglers' Association saying that young fish had been introduced into a pond by the Mura river (border between Slovenia and Croatia). Information on the barrels in which the fish were transported showed that these fish originated from breeding ponds in the Daruvar area of Croatia, where AI-infected swans had died earlier. Water from the breeding ponds was introduced into the Mura ponds along with the young fish. The source of this information is: http://www.ribiska-zveza.si/si/index.php?option=content&task=view&id=196

4 Waterbirds involved in the main H5N1 die-offs

There have been reports from Russia of wild ducks being found dead in areas where outbreaks have occurred in poultry but collection, identification and examination of such birds has not been well-organised (OIE 2005), with the result that no reliable information is available on the species affected.

The species mainly involved in the better-reported major die-offs at Lake Qinghai in north-west China, Lakes Ehrel and Hovsgol in Mongolia, and in Croatia and Romania, have been mute and whooper swans *Cygnus cygnus*, bar-headed geese *Anser indicus*, ruddy shelducks *Tadorna ferruginea*, great black-headed *Larus icthyaetus* and brown-headed gulls *Larus brunneicapilla* and great cormorants *Phalacrocorax carbo*. At Lake Qinghai and in Croatia, and possibly in Romania and Mongolia, the birds appeared to have died soon after their arrival. Apart from at Lake Qinghai, where mortality apparently continued for up to two months, outbreaks in wild birds have been short-lived and only a proportion (usually small) of the birds have died. At all of these sites where large numbers of dead birds have been found, they have all been found at the same site without any sign of scatter around the local area; this suggests that death has occurred quickly in these cases. Furthermore, healthy birds that have been sampled at some of these sites (Quighai, Ehrel and Croatia) have all been found to be negative for H5N1. These observations could indicate that birds either travelled with the virus on migration and died of the virus's effects shortly after arrival at their destination, or that the birds contracted the virus close to the destination and died soon afterwards. It is interesting to note that Stuart Baker (1921) stated that bar-headed geese leave their wintering grounds in India earlier than other birds, with most having departed by the end of February, and they arrive on their breeding grounds as soon as ice on the lakes melts, in March. If this is correct, the bar-headed geese that died at Lake Qinghai must have been in that area for several weeks before the outbreak occurred there (disease first detected 4 May 2005 - OIE 2005a).

In early 2006, mute swans in particular have shown a different pattern of infection. Birds have died in parts of eastern, central and into western Europe, usually as single birds or in small numbers, and the deaths have been generally widely scattered. Small numbers of other species have also been found

dead, including tufted duck *Aythia fuligula*, pochard *Aythya ferina*, mallard *Anas platyrhynchus*, goosander *Mergus merganser*, smew *Mergus albellus* and unspecified wild ducks, Canada goose *Branta canadensis*, red-breasted goose *Branta fuficollis* and unspecified wild geese, whooper swan, cormorant, grey heron *Ardea cinerea*, gull (unspecified) buzzard (unspecified), goshawk *Accipiter gentilis*, kestrel *Falco tinnunculus*, and grouse (unspecified),.
The birds involved have different feeding strategies. Mute swans and whooper swans feed in shallow water (< 1 m) by dipping or up-ending, taking vegetation (leaves, stems, roots, stolons) from the bottom or sometimes floating, and they also graze nearby vegetation and take seeds on land (Cramp & Simmons 1977). Bar-headed, Canada and red-breasted geese feed mainly on land by grazing vegetation close to water, and in winter bar-headed geese in India feed mainly at night (Stuart Baker 1921) and also take grain, tubers, vegetables and seaweed; they sometimes feed on water (del Hoyo *et al*. 1992). Ruddy shelducks are omnivorous, taking plant material, seeds, insects, crustaceans and molluscs, and occasionally other animals including fish and frogs (Cramp & Simmons 1977). Tufted duck and pochard feed by diving for underwater vegetation and invertebrates, while mallard feed in shallower water from the surface and by up-ending. Great black-headed and brown-headed gulls are similarly omnivorous and are additionally scavengers (del Hoyo *et al*. 1996), as can be buzzards and kestrels. Great cormorants, goosander and smew are piscivores, taking a wide variety of fish, especially from the bottom, and grey herons are also piscivores but also scavenge (Cramp & Simmons 1977). Grouse are herbivorous and in winter sometimes forage in farmland.

The implications of these feeding methods are, assuming the most efficient mode of virus passage is in bird faeces:

1. The Anseriforms could contract viruses from particulate matter put into fish ponds (e.g. pelleted feed) or directly from untreated poultry droppings (including fresh duck droppings in duck-fish systems), by eating it or preening it off their feathers. They could also contract virus from grazing vegetation that had recently had an application of poultry manure fertiliser; this risk may be short-lived if the virus cannot survive desiccation.
2. The gulls might contract virus by settling on water that has been fertilised with poultry manure and preening it off their feathers, by eating any particulate matter, and from scavenging the remains of birds that had died of H5N1 (which could include poultry if waste were discarded in or near the ponds/lakes, as has been widely reported).
3. Piscivores could contract the virus through preening it off their feathers, or through eating fish that had infected material in their guts, or were themselves infected (if this is possible).

There are thus routes of virus passage for all the waterbirds that died at Qinghai, Erhel and in Romania and Croatia and other parts of Europe if infected material were being used as fish food, but we would not expect piscivores to become infected if poultry products were only applied to crops, unless there was sufficient run-off to contaminate the water. There have been no reports of domestic ducks being seen at Qinghai or Erhel.

5 Outbreaks in poultry

There have been outbreaks in poultry that have not been associated with outbreaks in wild birds. In south-east Asia, in 2005 there have been continued outbreaks in Thailand, Vietnam and Indonesia (OIE updates and other sources). In October/November 2005 China has seen a resurgence covering many of its provinces, including northern ones - the extent to which these relate to spread or to resurgence where the disease had been formerly overlooked or unreported is not known. Further outbreaks have also occurred in southern Russia, mainly in areas where there had been outbreaks in July/August, but in early 2006 extending into new areas.

In Europe, in October/November outbreaks in poultry occurred in Tula province, Russia, and in north-west Turkey, in the absence of deaths reported in wild birds. In Romania, outbreaks occurred in poultry along with wild bird deaths in Tulcea county, in the Danube delta, and also in poultry away from the wetlands. The Turkish and most Romanian outbreaks were close to water bodies, but the situation in Tula is unknown. Outbreaks continue to occur in Romania, both within the Danube Delta and in some other parts of the country, strongly suggesting local dispersal after the initial infection, similar to the pattern of outbreaks in summer in southern Russia. In early December 2005 we learned that poultry had been dying in villages close to Lake Sivash, NE Crimea, Ukraine; deaths of wild birds have subsequently been reported. Lake Sivash is a hyper-saline lagoon used for salt and mineral extraction but a search of sites on Google has not indicated fishing activity, although the lagoons are used for hunting. This area is important for breeding, migrating and wintering waterbirds, as is the Danube delta. By the end of the year, widespred and persistent infection in poultry appeared to be present in countries around the Black Sea. In February 2006 in eastern France, an outbreak at a turkey farm followed the discovery of an infected dead pochard in a nearby lake.

6 Implications for the dissemination of AI

6.1 South-east Asia

The integration of poultry and fish farming is clearly widespread in south-east Asia, and the practice is also adopted in Russia and some eastern and central European countries. Highly pathogenic avian influenza virus is shed in upper respiratory tract secretions and in the faeces of infected birds, and the use of poultry manures as fertiliser or food at fish farms poses the risk of maintaining virus circulation where integrated fish farming is practiced, and poses a risk to wild animals that use the ponds of becoming infected. Wherever poultry products are marketed, the risk of virus spread over larger geographical areas is greater as infected products may be distributed more widely. The increase in backyard fish farming and poultry production in south-east Asia has been accompanied by increases in industrialised intensive production in these areas (Little & Edwards 2003). This doubtless increases the need to find outlets for the waste products involved and may have spawned enterprises for the manufacture of products incorporating these wastes. The risk of spreading AI infections will be affected by treatment that ensures that virus is killed, or lack of it.

The risks of integrated fish farming in relation to outbreaks of avian influenza, especially human pandemics, were recognised over a decade ago (Scholtissek & Naylor 1988). Little & Edwards (2005) doubted that avian influenza pandemics were likely to be generated from IFF/IAA on the basis that pigs, that at their time of writing were regarded as necessary "mixing vessels" for the reassortment/recombination of poultry viruses, were rarely reared with both poultry and fish (except in Thailand?). However, this constraint has now been removed with the ability of the current HPAI H5N1 to pass directly from poultry to humans. FAO/OIE/WHO (2005) identified the use of poultry manure in fish farming as one of the risk factors in the spread of AI. In relation to other diseases, Garrett *et al.* (1997) considered the use of raw chicken manure in aquaculture to present risks of *Salmonella* and various parasites being transmitted to man. In response to these concerns, FAO (2004) recommended that the feeding to farmed fish of poultry manure/poultry litter, poultry meat, bone meal or feather meal, should be banned in countries affected by or at risk from avian influenza and where OIE or industry standards are not followed; where smallholder enterprises depend upon this system of pond fertilisation and people cannot afford expensive fish meals, there is little likelihood of any such bans being effective or practicable!

6.2 Europe

The UK does not use poultry products or wastes in fish feeds, in line with EU legislation which bans processed animal proteins (PAPs) from feed for all livestock, including farmed fish (R Smith, UK Food Standards Agency, pers. comm.).

The situation in central and eastern Europe is less clear but Gabor Nechay (pers. comm.) has found that in Hungary, Czech Republic, Germany, Italy, Germany, the Netherlands, and probably Croatia, pelleted feed for fish is manufactured in Europe and probably also imported from Israel, and Dr Nechay considers it doubtful that AI is likely to be spread through these. He points out, however, that Woynarowich (1991), in Hungary, and Schäperclaus (1949) in Germany described the merits of fresh manure with the recommendation that ducks be kept on ponds. Further, Gropp *et al.* (1976) recommended for German use that 75% of fish meal protein in feeds could be replaced by poultry by-product meal and hydrolysed feather meal. Further east, e.g. in the Danube delta, other foods may be used in the more traditional fish farming schemes used there, but Dr Nechay was unable to find much information. He thought that it was difficult to identify an alternative to wild birds as carriers of AI to Romania, but admitted that anything was possible, and mentioned a sack of dead poultry found at the Hungarian border; this had apparently been thrown from a goods train from Russia. He believes that biosecurity is poor, with many opportunities for contacts at ponds with wild birds, poultry, pigs and other animals, and that organic wastes are likely to be used as fertilisers in ponds and as animal feeds, but he has no certain knowledge of this.

In Romania, Cernescu (2005) believed that migrating birds had brought the HPAI H5N1 virus, but noted that an alternative could have been deliberate or accidental introduction by humans; he did not mention fish farming.

In Croatia, Jasmina Muzinic (via Richard Thomas) reported that poultry faeces are used as fertiliser on fields but not as fish food. Poultry manure is also used as fertiliser in fields in the UK (A Evans pers. comm.).

7 Outstanding questions

Many questions arise in relation to the risk of disseminating AI through IFF/IAA practices and through more intensive poultry and fish production.

- Is poultry waste from small poultry units always used locally or is it sometimes moved to other farms or dumped in watercourses or other water bodies? A popular media account from Vietnam suggests that it is, but is this widespread practice?
- Is product from large industrial units moved over long distances? With apparent increasing incidences of HPAI H5N1 in large commercial units, this could be a major risk.
- Is product from large industrial units incorporated in manufactured fish feeds? If so, does it undergo virus-killing treatment? Are manufactured fish feeds exported? Where? In particular do they get to Russia and eastern Europe? Does south-east Asian poultry residue become incorporated into pelleted fish feed, which wildfowl could eat?
- There is mention of feather meal production in south-east Asia (China and Thailand) but no mention of its use there. Is it used locally or is it exported?
- Do poultry wastes go into bone meal? Bone meal is used in other sectors, including agriculture and gardening - is south-east Asian bone meal imported into Europe? Does it undergo heat treatment?
- Do fish excrete AI virus? If so, to what extent are fish moved between regions/countries? South-east Asian fish species have been introduced into Europe - does this still occur? Do fish become

infected? Can piscivores contract the virus from gut contents of fish that have eaten infected feed? To what extent are young fish reared in Europe moved internationally?
- Is poultry waste from "wet markets" dumped in nearby watercourses or water bodies that could service fish farms?
- How long does virus survive when infected poultry manure is put into fish farms or spread on fields?
- Where are poultry for IFF systems obtained from?

8 Conclusions
The many types of integration between fish and poultry farming clearly present opportunities for the dissemination of AI viruses through poultry faeces. There is, however, no firm information that AI has been disseminated in this way, but this possible means of transmission should be considered when interpreting outbreaks of AI in wild and domestic birds at water bodies.

The long distance transportation of poultry products for incorporation into fish feed, or already incorporated into exported fish feed, could provide opportunities for long distance spread of the virus. This assumes that the virus survives in such products but this has not, to my knowledge, been investigated.

Once AI virus gets into poultry, IFF/IAA could lead to local spread, both to other poultry and to wild birds. In this case we might expect an initial outbreak in an area, followed quickly by satellite outbreaks nearby. Although details are sketchy, this is what appears to have happened in southern Russia and now in Romania and Turkey. We cannot say that fish farming has been involved in these outbreaks, but investigations of the possibility would be welcome.

9 Acknowledgements
This review has been undertaken as part of ongoing advice to the RSPB. I am grateful to Andy Evans for arranging this, and to Andy and Tracey Cooke for providing some literature that would otherwise have been difficult to access. Gabor Nechay kindly investigated fish farming practices in central and eastern Europe and provided useful information, and Andrej Bibiè provided information on the movements of young fish in Slovenia. Richard Thomas has solicited information from a variety of sources and has kindly passed them on and Martin Gilbert passed on the email from Vladimir Savic concerning events in Croatia. Nicky Petkov, Marko Sciban and Paul Tout provided observation from Bulgaria, Serbia and Croatia respectively, and Ray Smith informed me of the restrictions on the use of animal products in the UK and EU.

10 References
Cernescu, C. 2006. Better safe than sorry: the human threat of avian influenza pandemic. http://www.virology.ro/engleza/PorcH5N1z.htm

Cramp, S & Simmons, K E L (eds). 1977. Birds of the western palearctic, Vol. 1. Oxford.

del Hoyo, J, Elliott, A & Sargatal, J (eds). 1992. Handbook of the birds of the world, Vol 1. Lynx Edicions, Barcelona.

del Hoyo, J, Elliott, A & Sargatal, J (eds). 1996. Handbook of the birds of the world, Vol 3. Lynx Edicions, Barcelona.

Edwards, D. 1991. Progress report on fish culture activities People's Republic of China. Field Document 10, FAO, Rome.

Engle, C R & Skladany, M. 1992. The economic benefit of chicken manure utilisation in fish production in Thailand. CRSP research reports 92-45. Pond dynamics/aquaculture collaborative research support program, USA. 8pp.

Erman, L A. 1968. Main methods of warm-water pond farming in the USSR. FAO first and second group fellowship study tours on inland fisheries research, management and fish culture in the Union of Soviet Socialist Republics, 15 July-15 August 1965 and 31 May-2 July 1966. FAO, Rome.

Eurofish. 2000. Romania. http://www.eurofish.dk/indexSub.php?id=296

FAO. 2001. Integrated agriculture-aquaculture. A primer. FAO Fisheries Technical paper No. 407. FAO, Rome. http://www.fao.org/docrep/005/y1187e/y1187e00.htm

FAO.2003. Recycling of animal wasted as a source of nutrients for freshwater fish culture within an integrated livestock system. http://www.fao.org/docrep/field/003/AC526E/AC526E01.htm

FAO 2004. Avian influenza - related issues. FAO Animal health special report.. http://www.fao.org/ag/aginfo/subjects/en/health/diseases-cards/avian-issues.html

FAO. 2005. A global strategy for the progressive control of highly pathogenic avian influenza (HPAI). www.fao.org/ag/againfo/resources/documents/empres/AI_globalstrategy.pdf

FAO. 2005a. FAOAIDEnews. Update on the avian influenza situation (as of 01/09/2005) – Issue No. 33. Potential risk of highly pathogenic avian influenza (HPAI) spreading through wild water bird migration. Avian influenza Technical Task Force, FAO, Rome & Bangkok.

FAO/OIE/WHO. 2005. FAO/OIE/WHO consultation on avian influenza and human health: risk reduction measures in producing, marketing, and living with animals in Asia. FAO, Rome.

FAO. 2005b. Update on the Avian Influenza situation – Issue no 29. Avian Influenza technical task force/ECTAD, Food and Agriculture Organisation, Rome & Bangkok, (report up to 12 April 2005). www.fao.org/docs/eims/upload/178770/AVIbull029.pdf

Foggin, J M. 2000. Biodiversity protection and the search for sustainablility in Tibetan Plateau grasslands (Qinghai, China). PhD Dissertation, Department of Biology, Arizona State University. www.plateauperspectives.org/foggin2000/dissertation/citation.htm

Gilbert, M & Slingenbergh, J. 2004. Highly pathogenic avian influenza in Thailand: an analysis of the distribution of outbreaks in the 2nd wave, identification of risk factors, and prospects for real-time monitoring. FAO - Findings resulting from a joint analysis by FAO and DLD, 2 – 7 November 2004 FAO Bangkok 26 November 2004.

Gilbert, M, Chaitaweesub, P, Parakamawongsa, T, Premashthira, S, Tiensis, T, Kalpravidh, W, Wagner, H & Slingenbergh, J. 2005. Free-grazing ducks and highly pathogenic avian influenza, Thailand. Emerging Infectious Diseases http://www.cdc.gov/ncidod/eid/vol12no02/05-0640.htm

Groop, J, Koops, H, Tiews, K, Beck, H. 1979. Replacement of fish meal in trout foods by other feedstuffs. In: Pillay, T V R & Dill, W A, *Advances in aquaculture. Papers presented at the FAO Technical Conference on Aquaculture, Kyoto, Japan, 26 May-2 June 1976*, pp. 596-601.

Hulse-Post, D J, Sturm-Ramirez, K M, Humberd, J, Seiler, P, Govorkova, E A, Krauss, S, Schlotissek, C, Puthavathana, P, Buranathai, C, Nguyen, T D, Long, H T, Naipospos, T S P, Chen, H, Ellis, T M, Guan, Y, Peiris, J S M & Webster, R G. 2005. Role of domestic ducks in the propagation of highly pathogenic H5N1 influenza viruses in Asia. Proceedings of the National Academy of Sciences, USA http://www.pnas.org/cgi/doi/10.1073/pnas.0504662102

Karafistan, A & Arik-Colacoglu, F. 2005. Physical, chemical and microbiological water quality of the Manyas Lake, Turkey. Mitigation and Adaptation Strategies for Global Change 10: 127-143.

Little, D C & Edwards, P. Integrated livestock-fish farming systems. Inland Water Resources and Aquaculture Service/Animal Production Service. FAO, Rome.

Little, D & Satapornvanit, K. 1995. Poultry and fish production – a framework for their integration in Asia. Second FAO electronic conference on tropical feeds. Livestock feed resources within integrated farming systems. www.aquafind.com/articles/poul.php

OIE. 2005. Mission to Russia to assess the avian influenza situation in wildlife and the national measures being taken to minimize the risk of international spread. OIE, Paris.

OIE. 2005a. Disease information. 27 May 2005, Vol. 18 - No. 21. http://www.oie.int/eng/info/hebdo/aIS_69.htm#Sec0

Schäperclaus. 1949. (I don't have details of this publication)

Scholtissek, C & Naylor, E. 1988. Fish farming and influenza pandemics. Nature 331: 215.

Sinha, V R P. 1979. New trends in fish farm management. In: Pillay, T V R & Dill, W A, *Advances in aquaculture. Papers presented at the FAO Technical Conference on Aquaculture, Kyoto, Japan, 26 May-2 June 1976,* pp. 123-126.

Stuart Baker, E C. 1921. Game-birds of India, Burma and Ceylon, Vol. 1. Bombay Natural History Society, Bombay.

Sturm-Ramirez, K M, Hulse-Post, D J, Govorkova, E A, Humberd, J, Seiler, P, Puthavathana, P, Buranathai, C, Nguyen, T D, Chaisingh, A, Long, H T, Naipospos, T S P, Chen, H, Ellis, T M, Guan, Y, Peiris, J S M & Webster, R G. 2005. Are Ducks Contributing to the Endemicity of Highly Pathogenic H5N1 Influenza Virus in Asia? Journal of Virology 79: 11269-11279.

Tacon, A G J. 1990. Fish feed formulation and production. A report prepared for the project Fisheris Development in Qinghai Province. FAO, Rome.

Wikipedia. 2005. http://en.wikipedia.org/wiki/Lake_Qinghai

Woynarovich, E. 1979. The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production. In: Pillay, T V R & Dill, W A, *Advances in aquaculture. Papers presented at the FAO Technical Conference on Aquaculture, Kyoto, Japan, 26 May-2 June 1976,* pp. 203-208.

Woynarowich, E. 1988. Adatok a halastavi szervestrágyázás tanulságos történetéhez. Halászat, 81 **:** 1. pp 14-16. [Data on the instructive history of manuring fish ponds]

Woynarovich, E. 1991. A halastótrágyázás gyakorlatáról. Halázat 84: 14-16. [Practice of manuring fish ponds].