STUDIES ON THE EPIDEMIOLOGY OF CLASSICAL SWINE FEVER IN THE REPUBLIC OF KOREA

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DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Signed.....

Sunoh Che

ABSTRACT

Classical swine fever (CSF) is a serious and highly infectious viral disease of domestic pigs and wild boar, which is caused by a single stranded RNA pestivirus. A study was undertaken to further understand the disease in pigs in the Republic of Korea. This study was designed to describe the history of outbreaks and risk factors for the disease in the Republic of Korea and to conduct a risk assessment for the introduction of CSF into Jeju Island, which is currently free from the disease.

The pig industry has an important role in the Republic of Korea due to the preference by Koreans for the consumption of meat from freshly killed pigs. Historical data, collected as part of active disease surveillance, were examined to determine the seroprevalence of antibodies and antigen to CSF. Only 0.03% (95% CI: 0.03 – 0.04) of samples tested from 2004 to 2010 were positive for CSF antigen. There was no significant difference in the prevalence between years. In contrast the average seroprevalence (antibody) for this period was 89.25% (95% CI: 89.20 – 89.29). The level of antibody in piglets was lower than in older pigs, most likely due to maternal antibody interference. There were no consistent differences in the prevalence from samples collected from different provinces or cities. It is suggested that these inconsistencies arose from differences in the efficacy of vaccine due to

variation in the cold chain, method of vaccination and cross-reactions from other pathogens.

After the declaration that the Republic of Korea was a CSF-free country in December 2001, the disease was again reported in 2002. It was hypothesised that the disease was reintroduced through indirect means from other countries and subsequently 72 outbreaks originated from one infected breeding farm. This finding highlights the importance of biosecurity on farms. Subsequently sporadic cases of CSF have been reported and may indicate spread through wild boars.

Four major factors were identified in the risk assessment for the introduction of CSF into the free area of Jeju Island: the prevalence of CSF on the mainland; the smuggling of pork into Jeju; the heat treatment of swill; and the rate of transmission between farms.

It is concluded that CSF will only be eradicated from the Republic of Korea if there is full cooperation between the government and the livestock industry. However, the disease has the potential to reenter via pork smuggled from infected neighbouring countries or through the inadequate treatment of swill. Since the eradication of CSF is the ultimate goal of the Republic of Korea, it is recommended that material be developed to improve the education of farmers about the disease, and a cost benefit analysis is undertaken to evaluate the benefit in stopping the vaccination of pigs.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The epidemiological aspects of classical swine fever **(**CSF) in the Republic of Korea (ROK) are described in this thesis. Accordingly, this literature review is set out to give an introduction to the general and specific topics covered. To do this it starts with an overview of the background and history of CSF, and then describes major developments in research into the distribution of the disease during the last century. Finally, it focuses on the disease, examining its epidemiology, clinical signs and pathology, control and eradication programs, risk factors for its spread and the various laboratory techniques that are used to diagnose the disease.

1.2 History of CSF

Classical swine fever is a highly contagious viral disease of worldwide importance and one of the World Organization for Animal Health (Office International des Epizooties - OIE) listed diseases. It is a serious and highly infectious viral disease of domestic pigs and wild boar (Paton and Greiser-Wilke, 2003).

Historically, peracute, acute, chronic, or prenatal forms of CSF were attributed to distinct levels of virus virulence. However, characterization of strain virulence is

difficult since the same isolate can induce different signs depending on the pigs' age, breeding, health status, and immune status (Le Poiter *et al.*, 2006). The disease is also known as Hog Cholera (HC) in the USA and Swine Fever (SF) or "European" swine fever in Europe, and needs to be differentiated from African Swine Fever (ASF) which is caused by an icosahedral double stranded DNA virus, the sole member of the new genus Asfivirus in the family Asfarviridae (Dahle and Liess, 1992; Dixon *et al.*, 2008).

Classical Swine Fever was first reported in the 1830's in the midwest of the USA (Moennig *et al.*, 1990; Moennig, 2000), although anecdotally it was seen in the state of Ohio as early as 1833 (Dahle and Liess, 1992; Moennig and Greiser-Wilke, 2008). The origin of the disease was reviewed by Hanson (1957) who stated that the disease originated in Europe and was introduced into the USA through the importation of new breeds of pigs (Edwards *et al.*, 2000). However, this was refuted by European authorities (Dahle and Liess, 1992), and consequently the real origin/source of the virus remains uncertain.

Transmission of the disease was demonstrated experimentally through the use of bacteria-free filtrates indicating the viral nature of the disease in 1903 (de Schweinitz and Dorset, 1903).

Milestones in the control of the disease involved the use of immunization by simultaneous inoculation of antiserum and virulent virus in 1907 (Niles 1910); the

application of crystal violet inactivated vaccine in 1934 (McBryde and Cole, 1936); the use of attenuated live virus vaccines from 1951 (Cole *et al.*, 1962); and, most recently, the development of subunit 'marker' vaccines (Rijn *et al.*, 1996). Meanwhile, significant advances in the laboratory diagnosis of infection have been made with the recognition of its relationship to bovine viral diarrhoea virus (Darbyshire, 1960), the application of fluorescent antibody techniques to detect antigen (Mengeling *et al.*, 1963), the use of ELISA for serology (Have, 1984), the development and application of monoclonal antibodies to the virus (Wensvoort *et al.*, 1986) and the use of molecular technology for epidemiological investigations (Lowings *et al.*, 1994) and diagnosis of infections (Edwards *et al.*, 2000).

The disease has, at some point of time, been distributed throughout the world including North and South America, Europe, Asia and Africa (Figure 1.1). However, several countries, including Australia, Canada, New Zealand, USA, and some European Union (EU) countries have succeeded in eradicating it (Moennig, 2000). Eradication was successfully implemented in Australia in 1963, Canada in 1964, USA in 1977, and France, Greece, Luxembourg, Netherlands, Portugal, Spain, and the UK at the end of 1989 (Dahle and Liess, 1992). Furthermore in 1990, Italy the last member state of EU vaccinating ceased this practice, and since then it has been free from CSF (Saatkamp *et al.*, 2000).

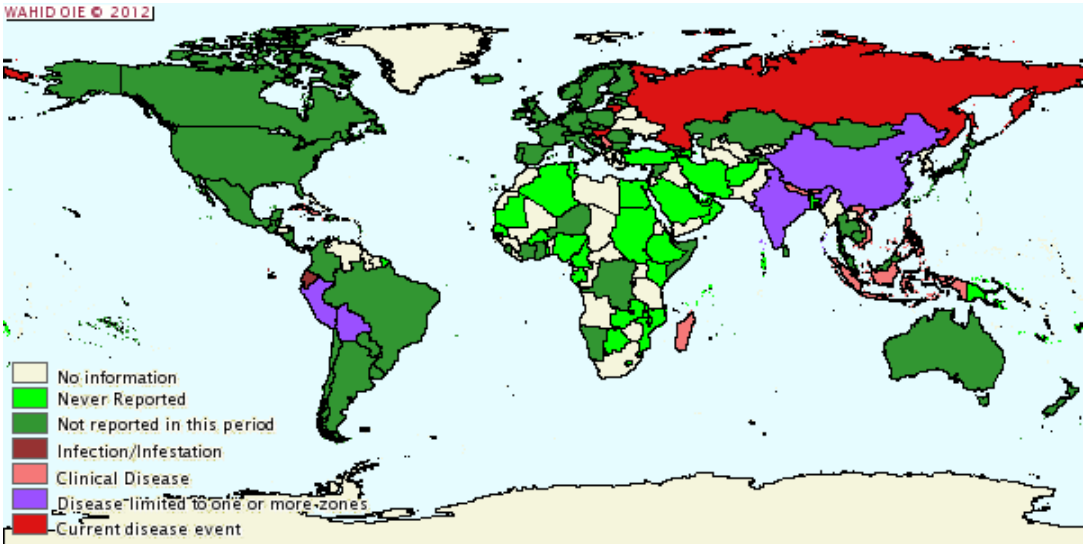

Figure 1.1 Distribution of CSF (period Jan-Jun 2011)

Source: (OIE, 2011)

1.3 Aetiology of CSF

The CSF virus (CSFV) is a small (40-60 nm) enveloped ribonucleic acid (RNA) virus with a single stranded RNA genome with positive polarity (Collett *et al.*, 1989; Moennig, 1992; Paton and Greiser-Wilke, 2003; Moennig and Greiser-Wilke, 2008). The virus belongs to the pestivirus genus of the *Flaviviridae* family (Wengler, 1991) and it is related to the bovine viral diarrhoea (BVD) virus and the border disease (BD) virus of sheep (Moennig, 2000). The genomic sequence of approximately 12,300 bases is known and infectious complementary deoxyribonucleic acids (cDNAs) have been produced in several laboratories (Meyers *et al.*, 1996).

The CSFV is relatively stable for an RNA virus (Vanderhallen *et al.*, 1999), but is antigenically and genetically diverse. Antigenic variability among CSFV isolates can be characterized using monoclonal antibodies (Edwards *et al.*, 1991) and the genetic variability evaluated by genomic sequencing (Le Poiter *et al.*, 2006). For example, two panels of monoclonal antibodies, directed against E2 and Erns glycoproteins defined 21 antigenic virus types (Kosmidou *et al.*, 1995). Genetic characterization of new CSFV isolates has become standardized in terms of the genomic fragment sequenced, the algorithms used in constructing phylogenetic trees, and the classification of the genetic groups. Three regions of the viral genome are usually evaluated: the 3' end of the polymerase gene (NS5B), 150 nucleotides of the 5'NTR, and 190 nucleotides of the gene encoding E2. The E2 glycoprotein is most commonly used for genetic typing because abundant sequence data are available (Le Poiter *et al.*, 2006).

Genotyping of the 190 nucleotide region of B/C domains of E2 has divided CSFVs into three major genetic groups (Groups 1 to 3) (Lowings *et al.*, 1996), each with three or four subgroups: 1.1, 1.2, 1.3; 2.1, 2.2, 2.3; 3.1, 3.2, 3.3, and 3.4 (Paton *et al.*, 2000). The phylogenic analyses undertaken during the last decade have demonstrated a link between genotype and geographical origin (Bartak and Greiser-Wilke, 2000). Therefore, providing that a representative selection of viruses has been typed, it becomes possible to identify the possible origins for new outbreaks occurring in previously uninfected areas (Greiser-Wilke *et al.*, 2007). Group 1 comprises most of the historical strains, including the vaccine strains. Group 2 contains most of the

current strains, of which infections have increased since the 1980s and Group 3 contains most of the strains distributed in separate geographical regions (Paton *et al.*, 2000).

Most viruses isolated from outbreaks in Western Europe in the 1990s belonged to Group 2. The situation is more complex in Central and Eastern Europe where isolates usually belong to Groups 2.2 or 2.3. Group 1 isolates are present in South America (Frias-Lepoureau and Greiser-Wilke, 2002). In Europe and Asia, field viruses have tended to switch from genotypes of groups 1 and 3 to that of group 2 in recent years (Cha *et al.*, 2007).

Since the virus mutates relatively slowly (Vanderhallen *et al.*, 1999), isolates obtained from sequential outbreaks are almost identical and this enables secondary cases to be distinguished from new introductions (Paton and Greiser-Wilke, 2003). The state of knowledge with regard to the current worldwide distribution of the ten major CSFV subtypes is shown in Figure 1.2.

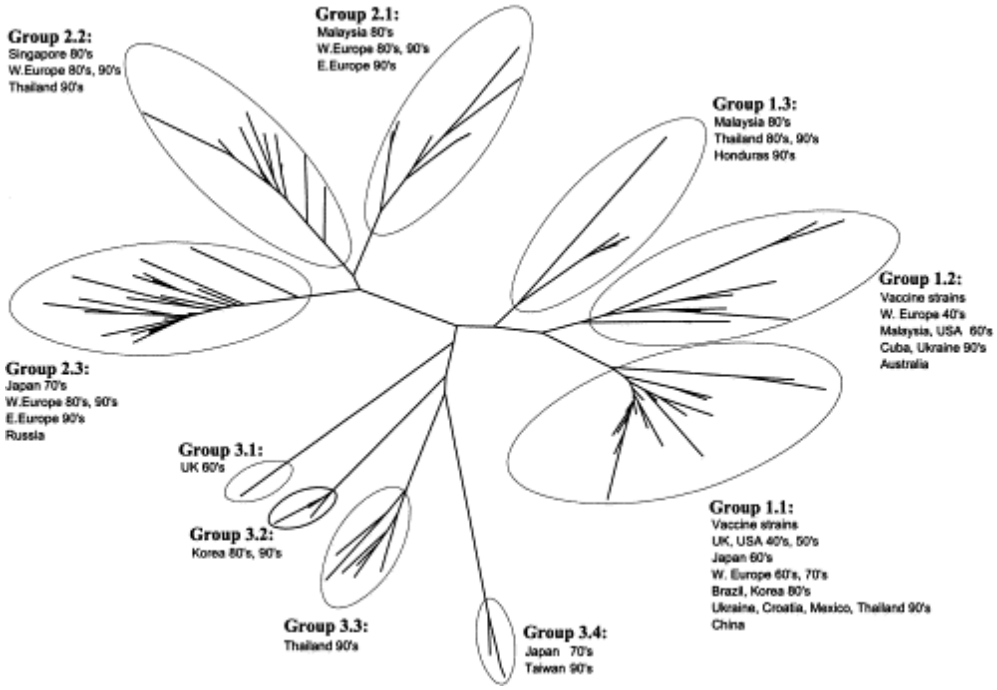

Figure 1.2 The extent of CSF virus diversity as revealed by a phylogenetic tree obtained with 190 nt of E2 sequence data from 100 CSF viruses

Source (Paton *et al.*, 2000)

1.4 Epidemiology

1.4.1 Host Species

Pestiviruses are not strictly host-species specific and can infect not only domestic but also wild animals (Vilcek and Nettleton, 2006). Wild boar are found in many countries and are known reservoirs for a number of viruses, bacteria and parasites that are transmissible to both domestic animals and humans (Meng *et al.*, 2009). Infection with CSFV occurs under natural conditions in both domestic pigs and wild boars (*Sus scrofa*) (Kern *et al.*, 1999). This is important as infection of wild pigs with CSFV

may complicate the success of an eradication program (Vilcek and Nettleton, 2006). The virus can be experimentally transmitted to probably all ruminants, but with certainty to goats, sheep, calves and deer (Dahle *et al.*, 1987).

One study conducted in 11 species of wild and domesticated animals showed that, following experimental challenge, no antibody to CSFV could be detected in wild mice (*Mus* spp.), cottontail rabbits (*Sylvilagus sylvilagus*), sparrows (*Passer* spp.), wild rats (*Rattus* spp.), raccoons (*Procyon lotor*), or pigeons (*Columba livia*). In contrast significant antibody production was detected in peccaries (*Tayassu tajacu*), calves, goats, sheep and deer (species not specified) (Loan and Storm, 1968).

Pestiviruses are able to cross the species barrier (Moennig, 1990). Many studies have shown that BVDV can naturally infect pigs, sheep, goats and a wide range of wild ruminants (Snowdon and French, 1968; Doyle and Heuschele, 1983; Dahle *et al.*, 1987) (Table 1.1). In a survey conducted in pigs in Northern Germany, 15-20% of all breeding pigs were found to be seropositive to BVDV (Liess *et al.*, 1974). Such cross-species transmission can be important when interpreting the results from a sero-surveillance study.

Table 1.1 Genetic typing of pestiviruses isolated from species other than domesticated pigs, cattle, sheep and goats

Source (Vilcek and Nettleton, 2006)

Animal	***Origin***	***Species/genotype/ genogroup***	***References***
Boar (*Sus scrofa*)	Austria	CSFV 2.1	(Hofmann and Bossy, 1998)
	Austria, Germany, Italy, Czech Republic	CSFV 2.2	(Biagetti *et al.*, 2001),(Fritzemeier *et al.*, 2000) (Bartak and Greiser-Wilke, 2000)
	Germany, Italy, Czech Republic, Slovakia	CSFV 2.3	(Bartak and Greiser-Wilke, 2000) (Biagetti *et al.*, 2001) (Lowings *et al.*, 1999) (Stadejek *et al.*, 1997)
Buffalo (*Syncerus caffer*)	Germany (zoo)	BVDV-1	(Becher *et al.*, 1997)
Eland (*Tragelaphus oryx*)	Zimbabwe	BVDV-1	(Vilcek *et al.*, 2000)
Canadian bison (*Bison bison bison*)	Canada	BVDV-1a, BVDV-1b	(Deregt *et al.*, 2005)
Alpaca (*Lama pacos*)	UK, USA	BVDV-1b	(Foster *et al.*, 2005) (Goyal *et al.*, 2002)
Pudu (*Pudu puda*)	Chile	BVDV-1b	(Pizarro-Lucero *et al.*, 2005)
Bongo (*Tragelaphus euryceros*)	Germany (zoo)	BVDV-1b	(Becher *et al.*, 1999)
Deer (unspecified)	New Zealand	BVDV-1c	(Becher *et al.*, 1999)

Table 1.1. (Continued)

Animal	Origin	Species/genotype/ genogroup	References
Roe deer (*Capreolus capreolus*)	Germany	BVDV-1d	(Becher *et al.*, 1999)
Mouse deer (*Tragulus javanicus*)	Denmark	BVDV-1f	(Grøndahl *et al.*, 2003)
Deer (unspecified)	Great Britain	BVDV-1j	(Becher *et al.*, 1997; Becher *et al.*, 1999) (Vilcek *et al.*, 2004)
Giraffe (*Girafa camelopardalis*)	Kenya	Giraffe genotype	(Becher *et al.*, 1997; Becher *et al.*, 1999; Becher *et al.*, 2003) (Harasawa *et al.*, 2000) (Avalos-Ramirez *et al.*, 2001)
Reindeer (*Rangifer tarandus*)	Germany (zoo)	BDV-2	(Avalos-Ramirez *et al.*, 2001) (Becher *et al.*, 1999; Becher *et al.*, 2003)
European bison (*Bison bonasus*)	Germany (zoo)	BDV-2	(Becher *et al.*, 1999) (Becher *et al.*, 2003)
Chamois (*Rupicapra pyrenaica pyrenaica*)	Andorra	BDV-4	(Arnal *et al.*, 2004)
Pronghorn antelope (*Antilocapra americana*)	USA	Pronghorn genotype	(Vilcek *et al.*, 2005)

1.4.2 Incubation period

The incubation period for CSF is generally between 3 and 10 days (Moennig and Greiser-Wilke, 2008). Under field conditions, clinical signs may only become evident in a piggery 2 to 4 weeks after virus introduction, or even later (Laevens *et al.*, 1999). The severity of clinical signs mainly depends on the age of the animals and the virulence of the virus, and in older breeding pigs the course of the infection is often mild or subclinical (Moennig *et al.*, 2003).

Pigs infected *in utero* are often persistently infected carriers, whether or not they are healthy at birth (Maclachlan and Scott, 2004). Pigs exposed postnatally are infective between 5 and 29 days post-infection (pi), however with chronic infections this infective stage can last for over 30 days (Mengeling *et al.*, 1963; Dahle and Liess, 1992).

1.4.3 Survival of the Agent

1.4.3.1 Survival in the environment

The CSFV, like many enveloped viruses, may be regarded as moderately fragile. It shows a short but variable survival time in the environment, depending on the physical conditions present, but importantly may remain viable for prolonged periods in favourable circumstances, for example, in stored meat (Edwards, 2000). The durability of the virus is affected by many physical and chemical variables, including temperature, humidity, pH, presence of organic matter, and exposure to various chemicals (Edwards, 2000). The stability of CSFV in the environment is of particular

importance, since experience has shown that many outbreaks of the disease may be caused by vector-mediated spread of the virus (Moennig, 1992).

The virus may survive for long periods in manure, and experimental studies have suggested that the virus survives longer in solid manure than in liquid manure (Have, 1984). Survival time in various types of water has been reported to vary from 6 to 24 days at 20°C (Pagnini *et al.*, 1984).

The virulence of the strains circulating in the field and the measures applied to control the disease determine, to a large extent, the course of an epidemic. Outbreaks of disease caused by highly virulent strains are easily recognised by the sudden onset of high mortality and morbidity. In contrast, epidemics caused by low virulent strains are characterised by indistinct signs of disease, slow spread of virus through the herd and the comparatively important role of the 'carrier sow syndrome'. The latter phenomenon may result in the birth of healthy looking, but persistently infected, immune-tolerant piglets. This, and the occurrence of chronic infections, is largely responsible for the perpetuation of the virus in the pig population (Terpstra, 1987).

The infectivity of CSFV can be inactivated by elevated temperatures e.g. 10 min at 60°C, or by ultraviolet radiation (Kubin, 1967). Due to the virus's lipid envelope, detergents and lipid solvents inactivate the virus with ease (McKissick and Gustafson, 1967). The inactivation rate of CSFV has been shown to be inversely related to the storage temperature. The average half-life for the virus has been shown to be between

2 and 4 days at 5°C, but only 1 to 3 hr at 30°C (Weesendorp *et al.*, 2008). Significant differences have been observed in the survival of virus in faeces kept at different temperatures, however not with virus in urine (Weesendorp *et al.*, 2008). Survival times at temperatures above 100°C are less than 1 min (Downing *et al.*, 1977). In contrast inactivation occurred in 1 min at 90°C, 2 min at 80°C, and 5 min at 70°C (Rehman, 1987). At lower temperatures, the virus is reasonably stable (depending on the suspending medium) which facilitates handling in the laboratory and shipment of diagnostic samples. In general, diagnostic samples should be kept cool (4°C wherever possible) although short periods at room temperature is considered not too deleterious (Edwards, 2000).

The CSFV is generally stable at neutral to slightly alkaline pH in the range 5–10, but is rapidly inactivated at pH 3 or below, and above pH 10 (Kubin, 1967). A sharp pH peak for virus survival in defibrinated blood has been demonstrated at pH 5.2 (Chapin *et al.*, 1939; Edwards, 2000).

Thermal inactivation curves may be derived for the virus at different temperatures but may vary with the virus strain (Kubin, 1967; Depner *et al.*, 1992). The half life of virus is dependent upon both temperature and pH (Table 1.2), with the effect of pH (below 4.0) being much more marked at 4°C than at 21°C (Depner *et al.*, 1992). In aerosols the virus remains infective for at least 30 min with a half-life ranging from 4.5 to 15 minutes (Weesendorp *et al.*, 2008).

Table 1.2The influence of pH and temperature on the half life (hours) of classical swine fever virus

Source (Depner *et al.*, 1992)

Temperature	pH 3.0	pH 3.5	pH 4.0	pH 7.0
4°C	70 (25-118)	174 (156-197)	260 (224-299)	na
21°C	5 (5-6)	5(4-5)	11 (10-14)	50(24-77)
37°C	na	na	0.7	7

(na : value not determined)

The virus can be inactivated by organic solvents, such as ether or chloroform, detergents, deoxycholate, or saponin (Moennig, 1992) and a wide range of chemicals, including chlorine-based disinfectants, detergents, phenolics, quaternary ammonium compounds, and aldehydes (formaldehyde, glutaraldehyde) (Liess and Schurian, 1973; Russell and Hugo, 1987). The virus can also be killed by pasteurisation or by thorough cooking. Treatment of virus-contaminated meat for 30 min at 65°C or 1 min at 71°C has been shown to render it non-infective (Keast and Helwig, 1966; McKercher *et al.*, 1978; Stewart *et al.*, 1979). Blood contaminated at 10^5 TCID50/ml can be inactivated at temperatures of 66°C for 60 min, 68°C for 45 min, or 69°C for 30 min (Edwards, 2000).

1.4.3.2 Survival in live animals

Infected pigs that are shedding large amounts of virus in their saliva, as well as lesser amounts in urine, faeces, ocular and nasal secretions, are a potent source of infection for other pigs. Importantly pigs start to shed virus several days prior to the development of clinical signs (Van Oirschot, 2004). Piglets born to carrier sows can shed large quantities of the virus for months without showing clinical signs or developing an immune response (Terpstra, 1991). There is ample field evidence to indicate that the major route of transmission of CSFV is directly from pig to pig (Terpstra, 1988; Edwards, 2000).

1.4.3.3 Survival in animal products and animal by-products

Classical swine fever virus is relatively stable in moist excretions and fresh meat products, including ham and salami type sausages (Savi *et al.*, 1965). The virus has been reported to survive for more than 4 years in frozen pork (Edgar *et al.*, 1949), while in chilled fresh pork it can survive for up to 85 days (Birch, 1917; Doyle, 1933; Edwards, 2000). However, the virus is readily inactivated by heat, detergents, lipid solvents, proteases and common disinfectants (Stewart *et al.*, 1979; McKercher *et al.*, 1987).

Pig intestines used for the production of natural sausage casings may carry CSFV, therefore feeding pigs human food waste (swill) may result in the spread of virus to CSF-free animals (Wijnker *et al.*, 2008).

1.4.4 Forms of CSFV

Although the different forms of CSF (peracute, acute, chronic, or prenatal) have been attributed to distinct levels of virus virulence, virulence is difficult to define because clinical signs also depend on pig age, breed, health status, and immune status (Depner *et al.*, 1997; Floegel-Niesmann *et al.*, 2003; Moennig *et al.*, 2003). Although the course of infection with CSFV is often subclinical, the virus can cross the placenta of pregnant sows, thereby infecting foetuses during all stages of development (Moennig *et al.*, 2003). In addition, the outcome of infection depends on the virulence of the virus strain and the gestation stage of the sows. Infection of sows early in pregnancy may result in abortions, stillbirths, mummifications and malformations. Infection between 50 and 70 days of gestation can lead to the birth of persistently viraemic piglets, which are clinically normal and survive for several months (Moennig *et al.*, 2003). Sows infected with low virulent strains of CSFV 40 days after mating have been shown to have litters with higher prenatal mortality (Van Oirschot and Terpstra, 1977). In contrast litters infected 65 days after mating had more postnatal deaths. For this latter group three sows produced completely infected litters, whereas another five produced litters with some non-infected piglets. Twelve piglets recovered from the infection and the percentage of piglets recovering increased with the stage of pregnancy at which the infection took place. Twenty-three piglets developed a persistent infection. Consequently the later sows are infected during pregnancy, the more non-infected piglets are born. On the other hand, the earlier infection occurred

during pregnancy, the more persistent infections were produced (Van Oirschot and Terpstra, 1977).

1.4.5 Risk Factors

Imported contaminated pig products have frequently resulted in the introduction of CSFV into previously disease-free regions (Paton and Greiser-Wilke, 2003). Feeding of untreated swill (kitchen waste) that contains infected pork is a major source of primary outbreaks in regions previously free from CSF (Sharpe *et al.*, 2001; Moennig and Greiser-Wilke, 2008). Consequently swill feeding has been officially banned in almost all CSF-free countries; however often awareness of the risk factors and knowledge of the legislation are not sufficient to prevent an outbreak as some farmers continue to illegally feed swill (Fritzemeier *et al.*, 2000). Consequently European countries are increasingly tightening restrictions on swill-feeding (Paton and Greiser-Wilke, 2003).

Other important factors for the transmission of the virus from infected pigs include contact with wild boar, and poor management and biosecurity practices, including a lack of suitable hygienic measures allowing exposure to contaminated fomites. Epidemiological investigations and virus typing has provided strong evidence that infected wild boars have been the source of numerous outbreaks in Europe (Fritzemeier *et al.*, 2000). The spread of the disease is facilitated by the movement of virus excreting pigs. The purchase of weaner pigs from different breeding farms or

from markets carries a high risk of introducing the virus into susceptible populations (Beals *et al.*, 1970).

Semen from infected boars has also been shown to be significant in the spread of CSF (Elbers *et al.*, 1999; Floegel *et al.*, 2000; Stegeman *et al.*, 2000). If it occurs, airborne transmission of virus is probably only over short distances and mainly within a holding. However, there have been concerns that surrounding farms could be at risk from airborne spread during depopulation of affected premises (Laevens *et al.*, 2000; Elbers *et al.*, 2001b). Indirect transmission may occur via people, wild animals and inanimate objects, but the exact mechanisms whereby the virus spreads between neighbouring farms are poorly defined (Laevens *et al.*, 2001; Elbers *et al.*, 2001a; Elbers *et al.*, 2001b).

As well as infection with CSFV, pigs can also be infected with the ruminant pestiviruses, BVDV and BDV. The presence of cattle on the same premises and a high density of sheep and/or goat herds within 3 km of the pigs have been identified as risk factors associated with a BVDV-seropositive breeding pigs. In addition, serological cross-reactions occur between the pestiviruses, providing potentially protective immunity, but also leading to confusion in the interpretation of the results from diagnostic tests (Loeffen *et al.*, 2009).

In the Netherlands, five factors have been identified that can be associated with the introduction of CSFV into pig herds (Elbers *et al.*, 2001b):

1) Presence of other animal species on the premises besides pigs;
2) Visitors entering pig units without wearing protective clothing and footwear provided by the farm;
3) Drivers of trucks used for transporting pigs wearing their own boots rather than boots provided by the farm;
4) A moderate herd size (500-1000 animals) and a very large herd size (> 7000 animals) compared with a small herd size (< 500 animals);
5) Aerosols generated during high-pressure cleaning which can be dispersed at least 250 metres by wind.

1.5 Disease

1.5.1 Clinical signs

The clinical signs of CSF vary with the strain of virus, the age of pig affected and the immune status of the pigs (Moennig *et al.*, 2003). More virulent strains cause acute disease; less virulent strains can result in a high percentage of chronic, mild or asymptomatic infections (Dahle and Liess, 1992; Kaden *et al.*, 2005).

The diagnosis of CSF based only on clinical signs is often difficult as the signs may vary considerably (Moennig and Plagemann, 1992; Depner *et al.*, 1997; Van Oirschot, 2003). Anorexia, fever, conjunctivitis, constipation, diarrhoea, hyperaemia of the skin, posterior paresis, convulsions, and purplish discoloration of the abdomen, snout, ears and medial sides of the legs have all been observed in infected pigs (Ruiz-Fons *et*

al., 2008). The typical haemorrhages of the skin associated with the disease are usually observed during the second and third week after infection until death (Moennig *et al.*, 2003).

The virulence of a CSFV isolate is difficult to determine on a rational basis (Mittelholzer *et al.*, 2000). However, acute, chronic and prenatal forms of CSF occur. The acute form is most often seen in piglets up to the age of 12 weeks. A constant finding is pyrexia, usually higher than 40°C; however often in adults the temperature does not exceed 39.5°C. Anorexia, lethargy, conjunctivitis, enlarged and discoloured lymph nodes, respiratory signs and constipation followed by diarrhoea are the initial signs of CSF. Animals may display incoordination, weakness of the hind limbs and convulsions. The main clinical signs of the different CSF forms are summarised in Table 1.3.

Table 1.3 Clinical signs of the different forms of Classical Swine Fever

Source (Bulu, 2011)

Infection time	Virulence	Form of CSF	Clinical signs	References
Postnatal	High	Peracute	Characterized by a rapid course without typical clinical signs for CSF followed by sudden death A high morbidity and death within 5 days post infection Young pigs may be found dead without any prior sign of illness especially at the beginning of an outbreak. Death within 24-48 hours preceded by lethargy. Mortality can reach 100%	AHP 2010; Dunne 1973; Everett *et al*. 2009; Fuchs 1968; Pig disease information centre 1996
		Acute	Fever (39.5–42°C)	AusVetPlan 2009; Moennig and Greiser-Wilke 2008
			Initial signs are anorexia, lethargy, huddling together, conjunctivitis, respiratory symptoms, and constipation followed by diarrhoea	AusVetPlan 2009; CFSPH 2009; Moennig and Greiser-Wilke 2008
			Incoordination, stiff gait, inability or unwillingness to stand, convulsions	AusVetPlan 2009
			Hyperaemia or cyanosis of extremities, particularly ears and snout	
			Death occurs 2-3 weeks after infection	Moennig 2000

Infection time	Virulence	Form of CSF	Clinical signs	References
			Laboured breathing, coughing	AusVetPlan 2009
			Abortion, mummifications, stillbirth and foetal abnormalities	
			Case fatality rate up to 100%	
			Dysentery or diarrhoea, conjunctivitis, nasal discharge, and vomiting	
			Neutralizing antibodies against CSFV become detectable 2–3 weeks post infection.	Moennig and Greiser-Wilke 2008
			Severe leucopaenia	AusVetPlan 2009
	Moderate	Chronic	Fever (> 40.5°C), which may fluctuate irregularly	
			Animals usually survive for 2 to 4 months before death	Moennig 2000; Moennig and Greiser-Wilke 2008
			Pneumonia, coughing	AusVetPlan 2009
			Lower case fatality rate than the acute form	
			Antibodies may be temporarily detected in serum samples, as the immune system begins to produce antibodies	Moennig 2000; Moennig and Greiser-Wilke 2008
Prenatal	Low	Subacute	Infection during early pregnancy may result in abortions and stillbirths, mummifications and malformations	Moennig *et al*. 2003; Moennig and Greiser-Wilke 2008

Infection time	Virulence	Form of CSF	Clinical signs	References
			Infection of sows from about 50 to 70 days of pregnancy may lead to the birth of persistently viraemic piglets, which may be clinically normal at birth and survive for several months.	Moennig and Greiser-Wilke 2008
			After birth, piglets usually show poor growth (‘runt’), wasting, or occasionally a congenital tremor.	
			Death occurs 2-11 months after infection	Van Oirschot 1999

1.5.2 Prevalence of CSF

Many studies have reported on the prevalence of CSF in different countries in both wild and domestic pigs. In the Netherlands, a survey on wild boar found that 11 of 116 (9%) wild boars were seropositive for CSFV (Stegeman *et al.*, 2000), while in France 80 of 12,025 (0.7%) wild boars tested from 1991 to 1998 were shown to be seropositive (Albina *et al.*, 2000). Additionally, in France during two outbreaks of CSF from 2002 and 2003, of the 3337 samples from wild boar tested 188/2525 (7·45%) were positive on the ELISA, 65/152 (42·8%) were positive to the virus neutralization test (VNT), 70/1707 (4·1%) were positive to a PCR, and 15/84 (17·9%) had virus isolated from them (Pol *et al.*, 2008). A summary of the prevalence reported in various studies for CSF is presented in Table 1.4 (Bulu, 2011).

Table 1.4 Prevalence of CSF reported in various countries

Country	Type of pig	Number of samples tested (% positive)	References
Croatia	wild boars	259 (46.7%) 44 (36.6%)	(Roic *et al.*, 2006; Zupancic *et al.*, 2002)
Switzerland	wild boars	1,294 (14.0%)	(Schnyder *et al.*, 2002)
Germany (The federal states Sachsen-Anhalt and Brandenburg)	wild boars	659 (5.0%)	(Oslage *et al.*, 1994)
Netherlands	domestic pigs wild boars	135,000 (64.0%) 116 (9.0%)	(de Smit *et al.*, 2000a; Stegeman *et al.*, 2000)
France	Wild boars	12,025 (0.7%)	(Albina *et al.*, 2000)

1.5.3 Pathology

Once the disease develops, pathological changes visible on post mortem examination are observed most often in the lymph nodes, spleen and kidneys of acute cases. The lymph nodes become swollen, oedematous and haemorrhagic. Haemorrhages in the kidney may vary in size from hardly visible petechiae to ecchymotic haemorrhages, and frequently occur on the surface of the cortex resulting in the characteristic "turkey kidney" pathological lesion, but are less common in the medullary pyramids and hilus. Kidney parenchyma may display a yellowish brown colour. Petechiae can also be observed in the urinary bladder, larynx, epiglottis and heart, and may be widespread over the serosa of the abdomen and chest (Van Oirschot, 1999).

A non-purulent encephalitis is often also present (Gruber *et al.*, 1995). Infarctions of the spleen are considered to be pathognomonic for CSF, however they are rarely observed. These infarcts are a result of a disrupted blood flow to certain areas resulting from the occlusion of blood capillaries by thrombi (Sato *et al.*, 2000). In the spleen severe atrophy of the splenic corpuscles, swollen reticular cells in the mantle zone and follicular necrosis (which is a typical lesion of CSF) are observed on histology. In pigs with persistent CSF, the most common lesions are severe atrophy of the thymus and depletion of the lymphocytes and germinal follicles in the peripheral lymphoid organs (Sato *et al.*, 2000).

1.5.4 Disease Transmission

With respect to agent (viral) factors, virulence and mutation are important factors for disease transmission (Risatti *et al*. 2005). In addition, an association may exist between virulence and antigenicity, where strains that are antigenically related to BVDV appear to be less virulent. Infection with highly virulent CSFV strains generally leads to death of infected animals, whereas isolates of moderate to low virulence induce a prolonged chronic disease (Van Oirschot, 1999).

In terms of host factors, the transmission of CSF is enhanced by many factors including: movement of virus excreting pigs within a population, population density, presence of susceptible and reservoir hosts, age structure of the population, and iatrogenic factors (Dahle and Liess, 1992). Persistent infections are the most important mechanisms by which the disease perpetuates in the domestic pig population (Liess, 1984). Persistent infections are commonly established during gestation at a time when the immune response of the foetus is not capable of eliminating the virus. The optimal time for the establishment of persistent viraemia depends on the maturation of the foetal immune system (Moennig, 1990).

Transmission of the virus can occur via direct and indirect routes including contaminated fomites (Karsten *et al.*, 2005). With respect to spread via vehicles, trucks play a major role in the transmission of CSFV (Ribbens *et al.*, 2004). For example in the Netherlands it was estimated that approximately 39 herds were

infected before the first measures of an eradication campaign came into force (Elbers *et al.*, 1999). Transportation of weaners from different breeding farms to fattening farms has been identified as a significant risk factor for the spread of disease. Such transportation, often over long distances, may result in a large number of non-traceable contacts (Terpstra, 1991).

Acute, chronic or congenital infection can occur (Dahle and Liess, 1992). Congenital infections, in which the piglets are born `healthy', from an epidemiological point of view, are the most dangerous. These piglets may shed large quantities of virus for months without showing signs of disease or developing an antibody response (Van Oirschot and Terpstra, 1977). The main route of infection in field cases is via the oro-nasal route (Moennig, 2000), by either direct or indirect contact with infected pigs or through contaminated feed, e.g. swill. In areas with a high density of pigs, virus spreads easily between neighbouring pig holdings (Terpstra, 1988; Fritzemeier *et al.*, 2000).

The ability of the virus to persist in uncooked pork and processed pork that has not been heated to high temperatures for long periods – months when kept at cool temperatures and years if frozen – is of great importance for virus transmission over long distances and between continents (Mather *et al.*, 2011).

Farmers, veterinarians, inseminators and castrators potentially could also transmit CSF through the use of contaminated instruments. Use of hypodermic needles on

more than one pig or more than one farm is also a very important method of spread. The disease can also spread when vaccinating teams use the same bottle of vaccine on different farms (AusVetPlan, 2009).

Disease transmission via the semen of infected boars may also occur (Elbers *et al.*, 1999; Risatti *et al.*, 2005). Tabanids are potential mechanical vectors of CSFV (Krinsky, 1976), however the virus is not transmitted biologically by any arthropod vectors, but it may be spread mechanically by arthropods as well as through scavengers such as dogs or wild birds (AusVetPlan, 2009). Feral pigs (wild boar) can be infected by the virus, and it is therefore necessary to minimize contact between feral and domestic pigs by ensuring secure boundary fencing (Weesendorp *et al.*, 2008; AusVetPlan, 2009).

Transmission of CSFV is most commonly via the oro-nasal route, with primary virus replication in the tonsils. From the tonsils, it spreads to the regional lymph nodes, then via the peripheral blood to bone marrow, visceral lymph nodes, and lymphoid structures associated with the small intestine and spleen. The spread of virus within the pig is usually complete in less than 6 days (Le Poiter *et al.*, 2006).

1.6 Diagnosis

The CSF epidemics in Europe have shown that early recognition of CSF and prompt elimination of CSFV-infected animals are paramount in the control of the disease (Le Poiter *et al.*, 2006). The longer CSF remains undetected, the greater the opportunity for the virus to spread (Elbers *et al.*, 1999).

1.6.1 Clinical diagnosis

It is difficult to make a clinical diagnosis of CSF, especially in older pigs (Paton and Greiser-Wilke, 2003), because of the presence of viral strains with only moderate virulence (Williams and Matthews, 1988; Koenen *et al.*, 1996). This increases the danger of delayed detection of primary cases, as was experienced in England in 2000 (Paton, 2002). Although the diagnosis of CSF can be based on clinical and pathological findings (Edwards *et al.*, 2000), the clinical signs are often not pathognomonic for the disease (Le Poiter *et al.*, 2006). The disease often has an incubation period of some weeks, requiring several cycles of amplification before it becomes clinically apparent (Paton and Greiser-Wilke, 2003). Furthermore the recent emergence of porcine dermatitis and nephropathy syndrome also complicates the diagnosis, since it can have a similar clinical appearance to CSF. Therefore, confirmation of disease has to be supported by laboratory investigations (Edwards *et al.*, 2000), even for secondary cases during large outbreaks (Paton and Greiser-Wilke, 2003).

1.6.2 Laboratory Tests

Laboratory tests are used to confirm the diagnosis of CSF and either detect viral antigen or antibody to the virus (Le Poiter *et al.*, 2006).

1.6.2.1 Detection of CSFV

Virus isolation (VI) is still the most sensitive and specific method for virus detection (Le Poiter *et al.*, 2006). Virus may be isolated from tissue homogenates, serum, plasma, buffy coat, and whole blood collected in heparin or EDTA (Terpstra, 2000). It is critical that all cells, media, and reagents have been previously determined to be free of pestiviruses or antibodies against pestiviruses (Le Poiter *et al.*, 2006). Although VI is the reference method in most CSFV eradication programs, it is labour intensive, time consuming, and incompatible with the rapid response required to prevent further spread of virus (Le Poiter *et al.*, 2006).

A fluorescent antibody test (FAT) using polyclonal antibody is widely adopted in laboratories for the detection and identification of antigen in cryostat sections (de Smit *et al.*, 2000b). In contrast monoclonal antibodies are used in only a few countries, mainly for specialist purposes rather than for routine disease investigations (Edwards *et al.*, 2000).

Different types of enzyme-linked immunosorbent assay (ELISA) techniques (competitive, blocking, indirect) and kits are used for the diagnosis of infection (Edwards *et al.*, 2000). The fluorescent antibody virus neutralization (FAVN) test and the neutralization peroxidase-linked assay (NPLA) have limited use because of the need for cell culture facilities (Edwards *et al.*, 2000). A PCR has been used to determine the relatedness between Colombian isolates from different geographical regions, and genetic sequences of the glycoprotein E2 and the 5_UTR of CSFV (Sabogal *et al.*, 2006). Moreover, a multiplex reverse transcription polymerase chain reaction (RT-PCR) assay has also been used for the rapid and differential diagnosis of CSF from other pestiviruses (de Arce *et al.*, 2005). Reverse transcription polymerase chain reaction (RT-PCR) has been used for the differentiation of CSFV from ruminant pestiviruses (Canal *et al.*, 1996).

1.6.2.2 Detection of antibodies against CSFV

Serology is routinely used for the diagnosis of CSF and also for surveillance. Serology is the method of choice for surveillance in an apparently disease-free area or for ensuring that there are no residual foci of infection during an eradication program (Pearson, 1992).

Antibodies are first detectable 2 to 3 weeks after infection, persist in surviving animals for the duration of their life (Moennig and Greiser-Wilke, 2008) and are a

good indicator that infection with CSFV has been present in a pig herd. The most commonly used tests for antibody detection are virus neutralization tests (VNT) and ELISAs. The VNT is regarded as the "gold standard" but it is labour intensive and time consuming, as it relies on cell culture technology (Dahle *et al.*, 1993).

Three ELISA test procedures have been described for detecting antibody to CSFV: an indirect ELISA (Moennig *et al.*, 1990; Edwards *et al.*, 2000); a blocking ELISA (Leforban *et al.*, 1990); and a competitive ELISA (Clavijo *et al.*, 2001). The sensitivity and specificity of the ELISAs have been reported to be greater than the FAVN test and the NPLA (Leforban *et al.*, 1990; Moennig *et al.*, 1990). All ELISAs offer the advantage that a result can be obtained within 24 hours. However imperfect tests can lead to misclassification of the disease status of pigs (Greiner and Gardner, 2000), and details of the sensitivity (Se) and specificity (Sp) of the ELISAs is summarised in Table 1.5 (Bulu, 2011).

Table 1.5 Sensitivity and specificity of ELISAs used to detect CSF

Type of ELISA	Sensitivity	Specificity	References
Indirect ELISA	99%[a]; 98.3%[b];	99%[a]; 99.6%[b];	a. (Colijn *et al.*, 1997)
Ceditest ELISA for CSFV-Ab using monoclonal antibody	96.1%[c]; 98%[e]	94.8%[c]; >99%[d,e]	b. (Moser *et al.*, 1996)
ELISA using glycosylated E2			c.(Sung *et al.*, 2011)
			d. (Moormann *et al.*, 2000)
			e. (Loeffen *et al.*, 2009)
Blocking ELISA	96.9% (cut off value 50%) [f]	97.8%' (cut off value 50%) [f]	f. (Beaudeau *et al.*, 2001)
	96.9% (cut off value 30%)[f]	97.3% (cut off value 30%) [f]	g. (Ruiz-Fons *et al.*, 2006)
	95.2%–98.9%[g]	97.8%–99.5%[g]	h. (Zupancic *et al.*, 2002)
	97.5%[h]	99.5%[h]	
Competitive ELISA	86%[i]	100%[i]	i. (Clavijo *et al.*, 2001)

1.6.3 Differential diagnosis of CSF

In the field CSF is often suspected initially on clinical signs and gross pathological lesions (Greiser-Wilke *et al.*, 2007). However many clinical signs are not exclusively associated with CSF and the signs can vary with the strain of virus, age and health status of the pigs (Greiser-Wilke *et al.*, 2007) and presence of concurrent infections (AusVetPlan, 2009). Diseases with similar clinical signs to CSF which should be included in a differential diagnostic list include: Porcine Circovirus type 2, African

Swine Fever, erysipelas, infection with *Haemophilus parasuis*, *Streptococcus suis*, Menangle virus or porcine myocarditis virus, *Actinobacillus pleuropneumonia*, Pasteurellosis, BVD, salt poisoning (water deprivation), Aujeszky's disease, salmonellosis and viral encephalomyelitis (Andries and Pensaert, 1980; Gard *et al.*, 2007; AusVetPlan, 2009; Balatinec *et al.*, 2010; Bulu, 2011; Asai *et al.*, 2010).

1.7 Control and Eradication of CSF

1.7.1 Control measures

Classical Swine Fever is classified as a notifiable disease in most countries. The strategy for the prevention, control and/or eradication of the disease in domestic pigs differs between countries and can be summarized as follows (Edwards *et al.*, 2000):

1. In countries previously free from CSF, a non-vaccination policy combined with a total stamping-out, in the case of disease outbreaks, and eventual preventive slaughter of pigs in suspect and in-contact farms, is applied as necessary. Serological surveillance is undertaken in the domestic pig population. The surveillance system and number of samples collected depends on the prevalence of CSF, the wild boar population and the epidemiological situation of neighbouring countries.
2. In countries where the disease is endemic, control is generally based on vaccination. In some countries, the decision to use vaccination depends on the

ownership or on the size of the farms. Programs of vaccination can vary as can the type of vaccines used in different countries. In some countries (e.g. Russia), it is recommended to vaccinate 3-week-old piglets, whereas in others (e.g. Bulgaria, Romania) pigs are not vaccinated until 10-12 weeks of age.

3. Legislation should be in place to prohibit the importation of pigs from infected countries.
4. Quarantine measures and restrictions on the movements of pigs need to be employed within infected countries to control the spread of the disease.
5. Other precautions include slaughter of infected herds (although this may not be possible due to financial restrictions), and establishment of protection (approximately 3 km radius) and surveillance zones (approximately 10 km radius) around infected farms to control the spread of the disease.
6. Swill feeding needs to be regulated.

Control and prevention strategies, specifically in relation to sanitary and medical prophylaxis, and responses to outbreaks have been outlined by the OIE (2010). The OIE has suggested the following strategies:

1. Effective communication between veterinary authorities, veterinary practitioners and pig farmers should be established.
2. The disease reporting system should be effective and the policy for the importation of live pigs, and fresh and cured pig meat should be strictly implemented.
3. Pigs should be quarantined before admission into a herd.

4. Waste food or swill should be banned from being fed to pigs or if it is fed it must be properly sterilised.
5. Efficient control of rendering plants should be established.
6. Structured serological surveillance should be undertaken that is targeted at breeding sows and boars.
7. An appropriate pig identification and recording system should be implemented.

In areas where CSF is endemic, vaccination with modified live virus strains is recommended (Van Oirschot, 2003; Suradhat *et al.*, 2007). In contrast, in countries which are free of disease, or where eradication is in progress, vaccination is normally prohibited (Van Oirschot, 2003).

To eradicate CSF from a pig population, the transmission needs to be reduced to such an extent that the virus cannot maintain itself in the population. This might be obtained by control measures including slaughtering infected herds, culling of herds at risk, vaccination, improved hygiene measures and movement restrictions (Moennig, 2000). The most important control measures are the culling of infected herds, prohibition of transport, the tracing and testing of infectious contacts, and the implementation of hygienic measures and surveillance in the affected area (Klinkenberg *et al.*, 2003). The control policy depends upon the incidence and prevalence of the infection in both the domestic and wild pig populations. In countries where CSF is endemic in domestic pigs it is common practice to adopt systematic vaccination campaigns (Moennig, 2000; Van Oirschot, 2003),

accompanied by routine diagnostic procedures and control measures (Van Oirschot, 2003) to minimise serious losses of pigs from the disease (Moennig, 2000). Vaccination overcomes some of the ethical dilemmas arising from large-scale culling of pigs during an outbreak (Klinkenberg *et al.*, 2003).

Control of animal-to-animal transmission of disease agents is a key concept in infectious disease epidemiology. To reduce disease transmission movement controls are needed to be strictly implemented and subject to legislation (Fevre *et al.*, 2006).

1.7.2 Vaccination

Vaccination against CSF has a long history, leading to the development in the 1960s of a number of highly effective live attenuated vaccines. Prophylactic vaccination is still carried out in many parts of the world (Paton and Greiser-Wilke, 2003). The disease can be effectively controlled by vaccination with the live C-strain vaccine (Kortekaas *et al.*, 2011), and pigs can be protected against infection for at least 10 months following oral vaccination with 'C-strain' live virus vaccine (Kaden and Lange, 2001).

Oral vaccination of wild boar may contribute to lowering the incidence of CSF, and consequently diminishing the threat of the introduction of virus to domestic herds. Disease-free countries should not vaccinate pigs but they should be aware of the disease and have a rapid response plan to counter any incursions. Once CSF is

introduced into areas with a high pig density, an emergency vaccination program should be immediately instituted, to be of maximal benefit (Van Oirschot, 2003).

Recently marker vaccines have been developed to enable the differentiation of immunity induced from natural infection and that induced by vaccination (Vannier *et al.*, 2007). The primary stimulus for these studies has been the desire to develop emergency vaccines to augment or replace stamping out policies and thereby reduce the amount of slaughtering needed to control CSF when the disease enters previously free regions (Paton and Greiser-Wilke, 2003).

1.8 **Study aims**

The aim of this study is to analyze and interpret the existing data of the epidemiology of CSF in the Republic of Korea (ROK). The history of the disease is examined and in particular disease surveillance results from the past 10 years are investigated in detail. As part of this study a risk assessment was undertaken for the introduction of CSF to Jeju Island. The information obtained from this thesis will contribute to a greater understanding of CSF in this region and provide information to support decision-making by Korean government officials and the industry about the best method of controlling and potentially eradicating the disease in the ROK.

CHAPTER 2: MATERIALS AND METHODS

2.1 Study design

Existing historical data were collected for this project. Data used in this study were sourced from the Korea Animal Information System (KAHIS). Permission to use this data was obtained from the National Veterinary Research and Quarantine Service (NVRQS) Epidemiology Division in Dec 2010. The data were used to analyse previous outbreaks of CSF, further the knowledge on the epidemiology of the disease and to undertake a risk assessment to examine the probability of CSF transmission to a free area (Jeju Island).

It is hypothesized that the illegal movement of pig meat from CSF affected areas is responsible for the transmission of the virus. The hypothesis is evaluated in Chapter 5.

This study was designed to develop recommendations for the government and the livestock industries to enable planning of suitable control and eradication programs for CSF.

2.2 Data Collection

Historical data were collected from KAHIS for the period 2004 to 2010. These data include information about the pig farms, detailed disease outbreak reports, vaccination records and the antigen and antibody seroprevalence.

2.3 Laboratory methods

Sera were tested at the laboratory using commercially available ELISA kits. The procedures recommended by the manufacturers were followed for these tests (see Chapter Four).

2.4 Data management

Data were entered or transferred into Excel 2007. Subsequently the data were exported to the statistical package SPSS version 17.0 for statistical analysis.

2.5 Data Analyses

In the serological study (Chapter Four), the seroprevalence was compared between pigs sampled during different years, and from different provinces and types of pigs. Odds ratios (OR) and their 95% confidence intervals were calculated using Woolf's method (Kahn and Sempos, 1989). The seroprevalence and their 95% confidence intervals (95% CI) were calculated using the exact binomial method (Ross, 2003).

2.6 Geographical Information System

A Geographical Information System (GIS) is a set of computer tools that allows people to work with data that are tied to a particular location (Price, 2010). Geographical information systems are now used for a multitude of purposes, including surveillance and monitoring of diseases and the analysis of disease policy and planning (Martin *et al.*, 2007). The yearly outbreaks of CSF were analyzed using GIS in Chapter Four.

2.7 Risk assessment

A quantitative risk assessment was applied in this study in order to estimate the probability of transmission of CSF from mainland Korea to Jeju Island. The risk assessment process followed was based on OIE guidelines. The computer package, PopTools, is an add-in to Excel which can be used to analyse populations and to simulate stochastic processes. It was used in this study for risk analysis (Hood, 2010) (see Chapter Five).

CHAPTER 3: PIG HUSBANDRY AND MANAGEMENT

3.1 Introduction

The Republic of Korea (ROK) is located on the southern portion of the Korean Peninsula and is neighbored by North Korea to the north, China to the west and Japan to the east (Figure 3.1). The only country with a land border to ROK is North Korea, with a 238 km border running along the demilitarized zone (DMZ). The ROK is mostly surrounded by water and has 2,413 km of coastline along three seas. Its territory covers a total area of 99,392 square kilometres and has a human population of approximately 48 million (Anon, 2011).

Figure 3.1 Map showing the location of the Republic of Korea

Source (Ksiom, 2008)

The ROK is divided into 8 provinces, 1 special autonomous province, 6 metropolitan cities, and 1 special city. These are further subdivided into smaller entities, including cities, counties, towns and villages (Figure 3.2).

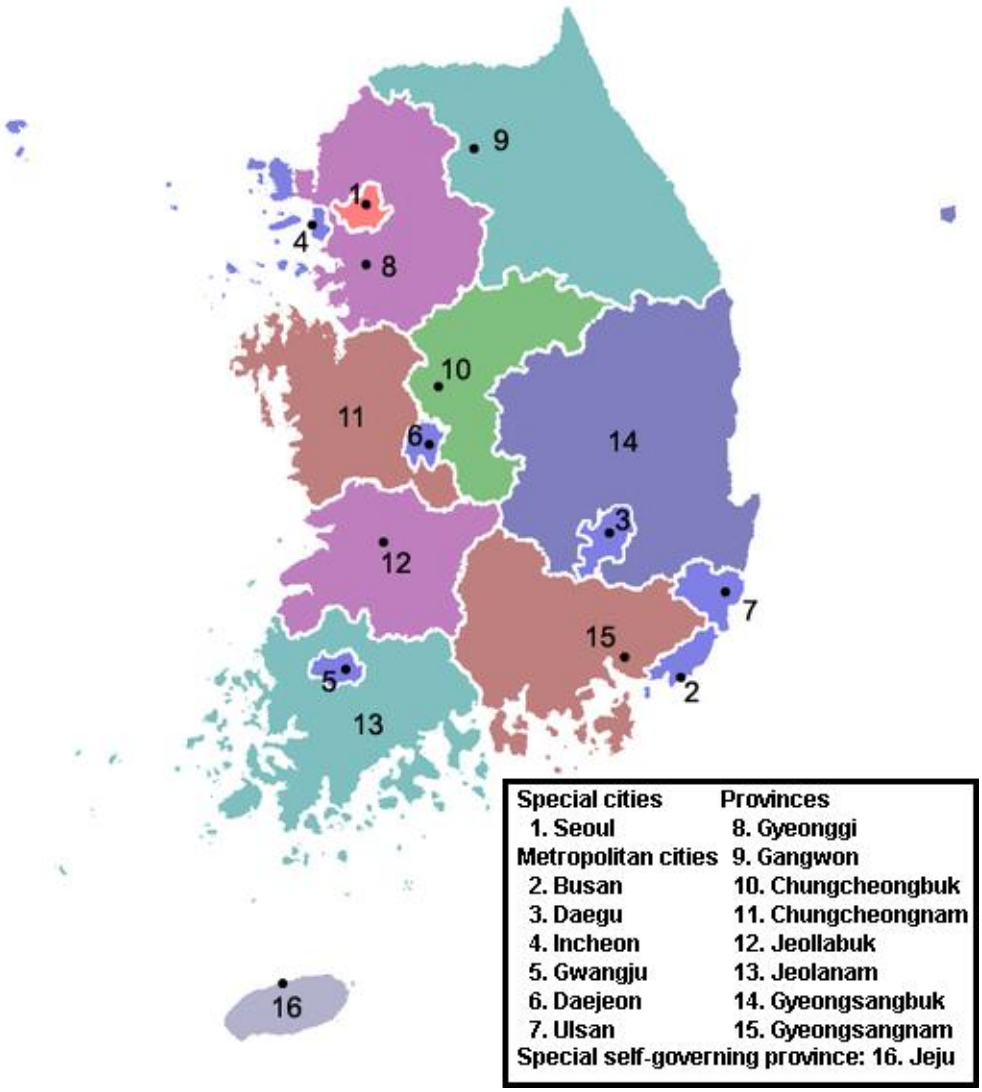

Figure 3.2 The ROK administrative map

Source (Hijmans, 2011)

Agriculture makes up 3% of the GDP (Gross Domestic Product) with agricultural exports generating USD 2.135 billion in 2010. In value these agricultural exports represent 0.84% of all exports. In contrast the value of the agricultural imports was

USD 10.616 billion in 2010 representing 4.73% of all imports (FAO, 2011).

In Table 3.1 the agricultural, livestock and pork production for the period 2004 to 2008 is displayed. Livestock production made up 35.3% of all agricultural production in 2009 and of this pork represented 30% (MIFAFF, 2011).

Table 3.1 Agricultural production in 2009

Source (MIFAFF, 2011)

Year	Agriculture (million USD)	Livestock (million USD)	Pork (million USD)	Livestock/ Agriculture (%)	Pork/ Livestock (%)
2004	36,155.5	10,839.9	3,666.8	30.0	33.8
2005	35,088.9	11,776.2	3,758.6	33.5	31.9
2006	35,232.4	11,676.3	3,609.3	33.1	30.9
2007	34,685.0	11,277.3	3,319.7	32.5	29.4
2008	38,469.8	13,592.9	4,085.3	35.3	30.1

Meat production in ROK from 2001 to 2010 is summarised in Table 3.2 (Statistics Korea, 2011). In 2010 pork made up 55.12% of all meat produced followed by

chicken meat 31.45% and beef 13.42%.

Table 3.2 Annual meat production (tonnes) in the ROK

Source (Statistics Korea, 2011)

Year	Beef	Pork	Chicken meat
2001	163,000	733,000	267,000
2002	147,000	785,000	291,000
2003	142,000	783,000	286,000
2004	145,000	749,000	288,000
2005	152,000	702,000	301,000
2006	158,000	677,000	349,000
2007	171,000	706,000	380,000
2008	174,000	709,000	377,000
2009	198,000	722,000	409,000
2010	186,000	764,000	436,000

The consumption of beef, pork and chicken meat per capita is shown in Table 3.3 (Statistics Korea, 2011). In 2010 49.74% of meat consumed was pork followed by

chicken (27.57%) and beef (22.68%). Consequently from the results summarised in Tables 3.2 and 3.3, pork is the major meat in ROK.

Table 3.3 Per capita (kg) meat consumption in ROK

Source (Statistics Korea, 2011)

Year	Beef	Pork	Chicken meat	Total
2001	8.1	16.9	7.3	32.3
2002	8.5	17.0	8.0	33.5
2003	8.1	17.4	7.9	33.4
2004	6.8	17.9	6.6	31.3
2005	6.7	17.8	7.5	32.0
2006	6.8	18.1	8.1	33.0
2007	7.6	19.2	8.6	35.4
2008	7.5	19.1	9.0	35.6
2009	8.1	19.1	9.6	36.8
2010	8.8	19.3	10.7	38.8

The domestic production and amount of pork imported are summarised in Table 3.4. The amount of pork imported each year increased over the six year period.

Table 3.4 Domestic production of pork and amount imported

Source (Statistics Korea, 2011)

Year	Domestic Production (A) 1,000 tonnes	Imported (B) 1,000 tonnes	Total amount (C) 1,000 tonnes	Proportion (A/C) %
2003	782.6	60.8	843.4	92.8
2004	747.7	108.8	856.5	87.3
2005	701.5	173.6	875.1	80.2
2006	677.4	210.5	887.9	76.3
2007	709.6	248.2	957.8	74.1
2008	716.2	214.4	930.6	77.0

The ROK imports pork from the U.S.A., Chile, Canada and European Union countries (Table 3.5).

Table 3.5 Amount of pork (tonnes) imported from countries into ROK

Source (MIFAFF, 2011)

Year	Total import	U.S.A	Canada	Chile	France	Austria	Belgium	Netherlands
2005	173,598	38,665	20,183	25,357	18,270	9,228	16,887	9,481
2006	210,462	60,862	26,060	22,348	18,245	10,971	18,539	10,746
2007	248,343	70,384	29,505	31,898	21,540	14,002	16,830	13,502
2008	214,378	72,320	28,476	19,472	17,274	16,387	14,212	11,386
2009	190,780	74,821	26,266	36,302	14,207	12,839	10,600	11,272
2010	179,510	51,008	17,742	29,862	13,852	13,354	13,277	13,154

The ROK exports pig meat to Russia, the Philippines, Thailand, and several other countries (KMTA, 2008). In Table 3.6 the volume of pork exported from the ROK is summarised (Huh *et al.*, 2011).

Table 3.6 Amount of pork (1000 tonnes) exported from ROK

(Huh *et al.*, 2011)

Year	Export
2005	14.7
2006	12.2
2007	12.6
2008	10.4
2009	12.5

According to statistics from the Korean Meat Traders Association (KMTA), the ROK exported 12,612 tonnes of pig meat in 2007 valued at 25.6 million USD. In Table 3.7 the destination, amount and value of the exported pig products are recorded (KMTA, 2008). The exported pig products included fat, skin, liver, ears, and tongue as these parts are rarely consumed within Korea. The price of the exported pork varied from

USD 0.9/kg to $2.1/kg (KMTA, 2010).

Table 3.7 Volume of pork exported in 2007 from the ROK

Source (KMTA, 2008)

Destination country	Volume (tonnes)	1,000 USD
China	56.3	754.3
Japan	27.6	212.7
Philippines	4,695.3	3,167.9
Russia	4,530.2	19,216.0
Thailand	2,253.4	1,595.3
Mongolia	24.2	18.9
Hong Kong	617	209.4
Vietnam	317.5	130.6
Indonesia	2.9	12.3
Other countries	87.7	301.7
Total	**12,612.1**	**25,619.1**

3.2 Breed of pigs in the ROK

It is believed that Korean native pigs were introduced to Korea from north China approximately 2,000 years ago (Kim and Choi, 2002). Since 1910, the Korean native pigs have been crossed with European pig breeds, such as the Berkshire, to improve their productivity (Kim *et al.*, 2005). Yorkshire, Landrace, Hampshire and Duroc pigs were imported for cross breeding from 1950. Many of the pig farms in the ROK cross breed between three or four different breeds (NIAS, 2002).

3.3 The pig population in the Republic of Korea

The increased demand for pork and the government policy which encouraged specialized farms has resulted in an increase in the size of piggeries. Although the number of pigs has increased annually, the number of pig farms has decreased (Jeong *et al.*, 2010). This structural change and concentration of pig production with intensive production has raised concerns about the increased risk of large-scale disease losses (Niemi *et al.*, 2008). Changes in the pig population from December 2000 to March 2011 are displayed in Table 3.7 (KOSIS, 2011).

The number of pig farms has declined steadily over time (Table 3.8). This is particularly evident with small-scale pig farms with less than 20 pigs which have reduced in number from over 10,000 to less than 1,200 herds over a 10 year period.

Outbreaks of foot and mouth disease (FMD) between November 2010 and March 2011 had a significant impact on the pig industry with approximately one-third of the total population culled in order to contain the spread of this disease (Ban and Francom, 2011).

In Figure 3.3 the relationship between the number of households and pigs is summarised and in Figure 3.4 the density of pigs in the different provinces is displayed. Pigs are clustered in the provinces of Gyeonggi and Chungchung.

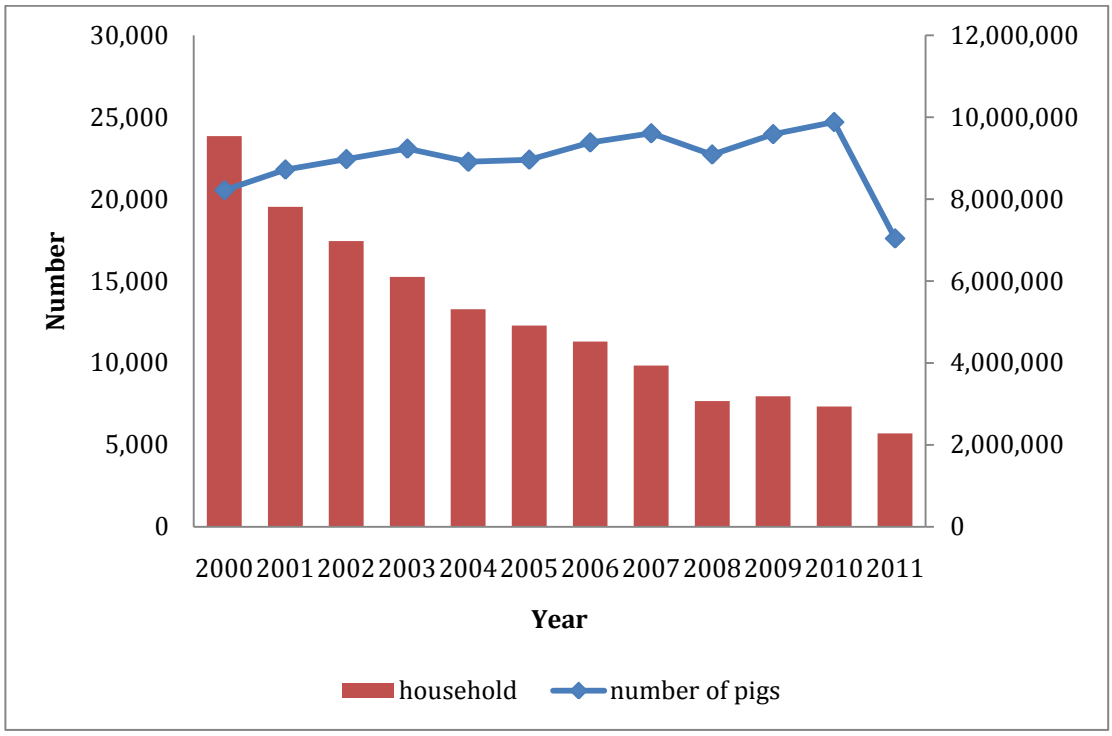

Figure 3.3 Number of pigs and pig farms in ROK

Source (Statistics Korea, 2011)

Table 3.8 Size of pig population

Source (KOSIS, 2011)

		Number of pigs in different sized herds								
Year	Total number of pigs	1 - 19	20 - 49	50 - 99	100 - 299	300 - 499	500 - 999	1,000 - 4,999	5,000 - 9,999	> 10,000
2000	8,214,369	43,143	53,302	102,901	579,371	637,312	1,855,068	3,819,868	629,293	494,111
2001	8,719,851	34,848	41,566	106,170	457,187	548,613	1,701,293	4,511,772	689,957	628,445
2002	8,974,403	26,621	30,778	99,508	396,418	499,732	1,536,765	4,902,290	807,462	674,829
2003	9,230,677	21,316	23,795	74,723	332,982	430,302	1,642,026	5,057,413	870,827	777,293
2004	8,908,456	19,276	25,619	57,504	339,120	353,307	1,402,434	5,018,593	852,493	840,110
2005	8,961,505	17,758	28,028	45,430	293,273	342,874	1,257,740	5,184,769	883,407	908,226
2006	9,382,039	17,043	18,455	47,489	306,904	338,847	1,150,600	5,406,129	1,104,654	991,918
2007	9,605,831	10,377	20,337	25,878	297,456	252,455	1,111,039	5,616,165	1,132,986	1,139,138
2008	9,087,434	8,397	10,312	25,578	82,933	186,953	1,078,525	5,329,107	1,213,158	1,152,471
2009	9,584,903	8,811	13,856	19,582	89,752	177,679	985,758	5,750,734	1,252,558	1,286,173
2010	9,880,632	6,915	11,448	17,877	83,528	128,059	902,524	5,843,485	1,413,491	1,473,305
2011	7,036,116	6,261	12,761	14,224	76,731	124,432	680,294	4,216,083	980,289	925,041

Table 3.9 Number of piggeries

Source (KOSIS, 2011)

		Number of herds with different numbers of pigs								
Year	Total number of pig herds	1 - 19	20 - 49	50 - 99	100 - 299	300 - 499	500 - 999	1,000 - 4,999	5,000 - 9,999	Over 10,000
2000	23,841	10,765	1,611	1,498	3,366	1,628	2,633	2,211	94	35
2001	19,531	7,904	1,239	1,426	2,444	1,415	2,370	2,588	102	43
2002	17,437	6,698	955	1,212	2,217	1,275	2,135	2,776	122	47
2003	15,242	5,485	760	960	1,775	1,103	2,231	2,746	130	52
2004	13,268	4,373	793	738	1,686	892	1,918	2,682	128	58
2005	12,290	3,808	877	619	1,452	876	1,707	2,755	133	63
2006	11,309	3,147	601	612	1,433	849	1,579	2,858	165	65
2007	9,832	2,059	656	342	1,502	631	1,494	2,905	169	74
2008	7,681	1,684	316	349	462	504	1,423	2,687	182	74
2009	7,962	1,878	453	279	433	444	1,330	2,880	185	80
2010	7,347	1,447	401	262	427	337	1,225	2,943	216	89
2011	5,705	1,159	423	193	400	321	920	2,084	147	58

Table 3.10 Number of pigs and herd size in different provinces

Source (KOSIS, 2011)

				Chapter 4: Number of pigs in different sized herds						
Province	Number of pigs	1 - 19	20 - 49	50 - 99	100 - 299	300 - 499	500 - 999	1,000 - 4,999	5,000 -9,999	> 10,000
Seoul	36	0	36	0	0	0	0	0	0	0
Busan	6,240	15	345	200	730	1,150	2,150	1,650	0	0
Daegu	22,735	28	0	0	503	310	0	21,894	0	0
Incheon	8,867	31	167	0	645	2,394	4,400	1,230	0	0
Gwangju	6,133	83	0	0	0	0	650	5,400	0	0
Daejeon	225	80	0	145	0	0	0	0	0	0
Ulsan	37,457	8	0	0	110	915	1,842	11,472	0	23,110
Gyeonggi	448,728	225	1,952	880	7,046	6,914	53,529	316,292	61,890	0
Gangwon	145,152	190	0	1,626	3,429	9,495	9,053	102,759	6,100	12,500
Chungcheongbuk	233,679	238	680	1,929	724	10,862	31,926	122,569	54,098	10,653
Chungcheongnam	1,552,125	758	1,547	1,505	10,731	39,433	132,266	911,414	230,213	224,258
Jeollabuk	1,155,201	425	552	1,960	7,319	2,289	145,000	598,447	176,374	222,835
Jeollanam	848,036	2,282	2,093	1,584	33,979	13,811	87,599	501,388	111,738	93,562
Gyeongsangbuk	946,288	271	2,720	3,250	3,579	8,127	77,114	575,501	152,778	122,948
Gyeongsangnam	1,137,004	1,360	2,611	257	5,715	16,935	96,686	676,338	149,718	187,384
Jeju	488,210	267	58	888	2,221	11,797	38,079	369,729	37,380	27,791
Total	7,036,116	6,261	12,761	14,224	76,731	124,432	680,294	4,216,083	980,289	925,041

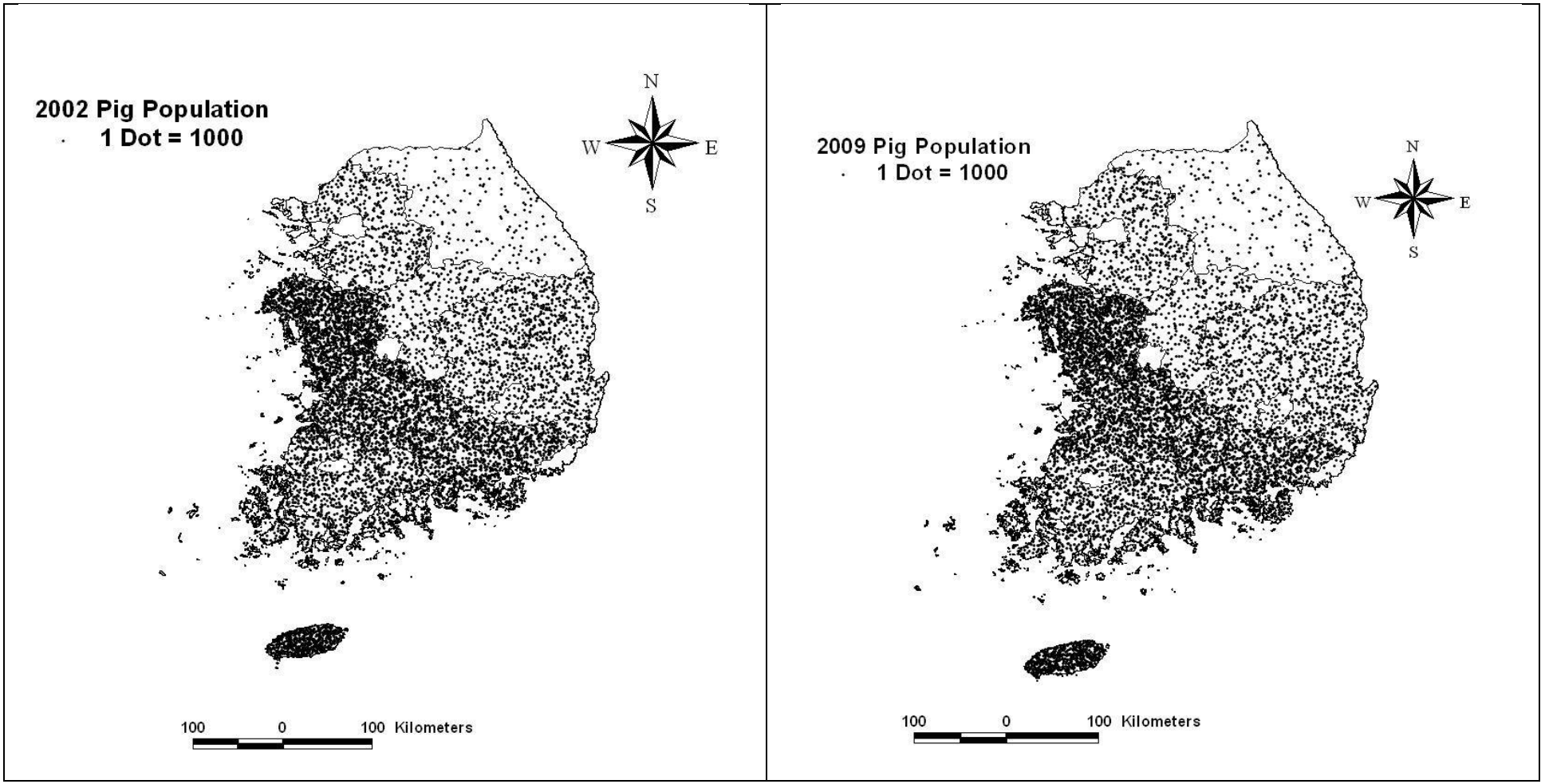

Figure 3.4 The pig density in different provinces in 2002 and 2009.

Source (Statistics Korea, 2011) **One dot represents 1,000 pigs**

3.4 Pig husbandry

Previously in the ROK, pigs were generally raised as a side enterprise on a farm (Korea development institute, 1975). This accounted for the many small herds previously found in the country. However raising of pigs was expanded by the provision of special government assistance for the building and expansion of commercial pig farms (Korea development institute, 1975). Pig farm sizes have been increasing due to modernisation of agriculture, and high use of inputs such as capital and labour (Kim, 2007)

Pork producers in the ROK can be subdivided into two broad categories: private commercial enterprises which are often inter-twined with other commercial primary production practices; and large commercial enterprises that are often vertically integrated with feed mills and/or processing plant.

Most pig producers utilize an intensive continual sow management system where matings, farrowings and weanings are done on a weekly basis (Jang *et al.*, 2009).

3.5 Pig breeding

Korea has 122 pig breeding companies. Great-Grand Parent (GGP) companies breed pigs including Landrace, Yorkshire and Duroc. They then provide these pigs to Grand Parent (GP) companies. Some pig farms have both GGP and GP stock. These companies

produce F1 pigs and then sell them to other pig farms (Jeong *et al.*, 2010). The number of GP and GGP companies in June 2010 is summarised in Table 3.11.

Table 3.11 Number of grandparent and great grandparent pig farms

Source (Jeong *et al.*, 2010)

Type	Breeding farms (GGP)	Breeding farms (GP)	Pig farms (GGP+GP)	Total
Number of farms	20	41	61	122
Number of animals	7,186	21,466	37,379	66,031

Korea imports GGP stock from countries including the USA, Canada and Denmark (Jeong *et al.*, 2010).

The use of artificial insemination was adopted in the ROK in 1994 and has, in large herds, replaced natural mating (Yi *et al.*, 2004). The number of AI centres has consequently increased from 5 in 1994 to 50 in 2009 (Jeong *et al.*, 2010).

Table 3.12 Number of artificial insemination centres in the ROK

Source (Jeong *et al.*, 2010)

Province	1994	1998	2004	2006	2008	2009
Gyeonggi	2	9	7	8	8	8
Gangwon	0	2	2	2	2	2
Chungcheongbuk	0	2	6	5	4	4
Chungcheongnam	2	9	13	13	16	16
Jeollabuk	0	5	5	6	7	7
Jeollanam	0	2	3	4	4	4
Gyeongsangbuk	1	4	6	7	4	4
Gyeongsangnam	0	8	6	6	5	5
Jeju	0	4	2	2	2	2
Total	**5**	**45**	**50**	**53**	**52**	**52**

Female breeding stock are either purchased from a seed stock producer or are reared on-farm. Boars are purchased from seed stock suppliers.

3.6 The pig and pork distribution system

According to surveys undertaken by the KMTA in 2006, 59% of pigs were sold to meat processing companies through a contract between the companies and the farms. Another

22% of pigs were sold through cooperatives, 11% were sold to wholesalers at a market and 8% of pigs were sold through brokers visiting farms (Kim *et al.*, 2006). The distribution system for pigs and pork is intertwined and is summarised in Figure 3.5.

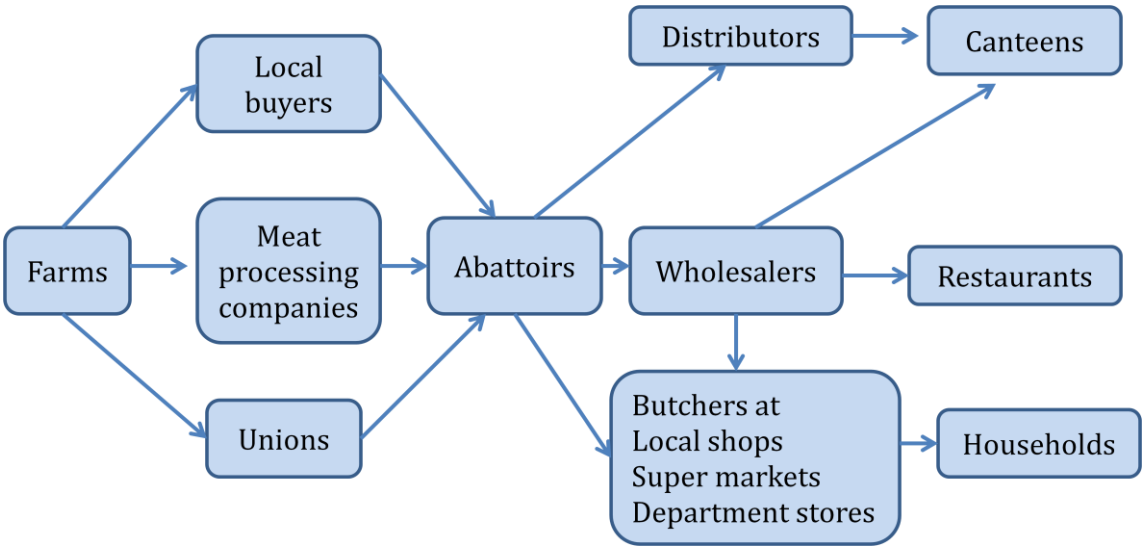

Figure 3.5 The pig and pork distribution system in the ROK

3. 7 Pig slaughterhouses and processing plants

In 2010 there were 87 slaughter houses for pigs distributed throughout the country (Table 3.13) (Livestock product safety division, 2011). Small-sized abattoirs have been reported to have financial difficulties, with a debt ratio estimated at 800% and are operating at 59% capacity. The Government has announced a plan to merge and acquire slaughterhouses due to these problems so that the number will reduce to 36 in 2015 (MIFAFF, 2011).

Table 3.13 The distribution of slaughter houses for pigs in the ROK

Province	Number of slaughterhouses
Seoul	1
Busan	1
Daegu	3
Incheon	3
Gwangju	2
Daejeon	1
Ulsan	2
Gyeonggi	12
Gangwon	8
Chungcheongbuk	11
Chungcheongnam	7
Jeollabuk	10
Jeollanam	9
Gyeongsangbuk	10
Gyeongsangnam	9
Jeju	1

3.8 Movement of Pigs

Pig movement depends on the pig farming system adopted. Intensive pig farms breed, farrow, grow out and sell their own pigs. Some companies have specialized sites with sows on one site, weaners on another and growers and finishing pigs on another or alternatively there may be a combination of these. Consequently pigs move to different properties prior to slaughter. Pigs are usually transported early in the morning for slaughter the same day.

The Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF) of the ROK announced that it would establish a "nationwide hog farm management system" that would enable comprehensive farm-to-slaughter management of pigs to improve the farming environment and to help prevent the spread of pig diseases from 2010. According to Article 34 of the Livestock Industry Act (Act no. 10310, May 2010), a livestock market shall be established and managed by a livestock cooperative (National assembly of the Republic of Korea, 2010). However a survey in 2005 reported that pigs were not traded in this market with only cattle trading done at the livestock markets in the ROK (Kim *et al.*, 2006).

Each of the ROK's pig farms has been issued with a unique five-digit livestock business registration code. The disease status of each farm is fed into the KAHIS run by the National Veterinary Research and Quarantine Service (NVRQS). A system has been

established that includes comprehensive data on the disease status of farms, provision of vaccines, antibody test results and the imposition of fines if the owners are negligent.

3.9 Slaughter of pigs

According to Article 7 of the Processing of Livestock Products Act (Act No. 6192, Jan 21, 2000), pigs shall be slaughtered at a licensed slaughter house (National Assembly of the Republic of Korea, 2008). However there are exceptions to this article. Pigs for academic research or the owner's home consumption do not need to go to a slaughter-house. In 2010 178 pigs were killed for academic research and 865 were killed for the owner's consumption (Livestock product safety division, 2011).

Most pigs are sold for slaughter between a live weight of 105 and 125 kg at approximately 24 weeks of age (Lee, 2005). In Table 3.14 the number of pigs slaughtered in 2010 at abattoirs is summarised (Livestock product safety division, 2011).

Table 3.14 Distribution of pigs slaughtered in 2010

Source (Livestock product safety division, 2011)

Province	Slaughtered pigs(head)
Seoul	156,657
Busan	10,509
Daegu	250,115
Incheon	301,034
Gwangju	228,100
Daejeon	149,577
Ulsan	154,437
Gyeonggi	2,804,235
Gangwon	743,531
Chungcheongbuk	2,358,969
Chungcheongnam	1,474,988
Jeollabuk	1,457,021
Jeollanam	810,232
Gyeongsangbuk	1,196,802
Gyeongsangnam	1,812,071
Jeju	721,101
Total	**14,629,379**

3. 10 Animal feeds

Assorted feeds are made from grain imported from countries including USA, Canada, China and Australia. There are 60 animal feed production companies in ROK and 98 factories. The factories produced 16.7 million tonnes of animal feed of which 32.5% was pig feed in year 2010 (Jeong *et al.*, 2010).

3.11 Veterinary drugs

In the ROK there are 44 licensed veterinary drug suppliers employing 1,516 people and with drug sales of USD 588.2 million (Jeong *et al.*, 2010).

3.12 Marketing of pork and its consumption

People buy meat from a range of shops including department stores, super market chains, agricultural cooperative stores and butchers. In 2009, the number of shops selling pork to consumers was 48,362 (Jeong *et al.*, 2010).

The majority of pigs are sold for pork. Traditionally, Korean prefers pork belly. Grilled pork belly serves with vegetables. There is a seasonal increase in the demand for pork belly during summer due to the occurrence of the summer holidays. In Table 3.15 the retail price of pork cuts is outlined (Choi, 2009).

Table 3.15 Retail price of pork

Source (Choi, 2009)

Retail cut	Retail price (USD/kg)
Belly	18.1
Shoulder loin	16.2
Ribs	10.1
Picnic	9.3
Ham	6.2
Tender loin	8.7
Loin	7.6

Canteens at school only sell domestic pork with 44% of this frozen and the remainder chilled. In Figure 3.6 the distribution of domestic and imported pork to restaurants is summarised (Choi, 2009).

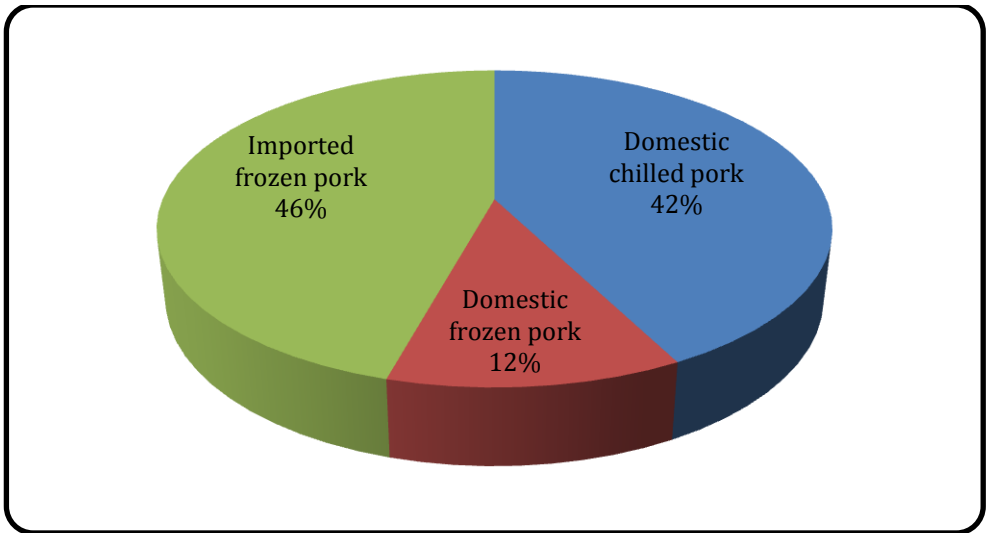

Figure 3.6 Percentage of pork used at restaurants

Domestic chilled pork is preferred by butchers. In Figure 3.7 the preference between domestic and imported pork is displayed.

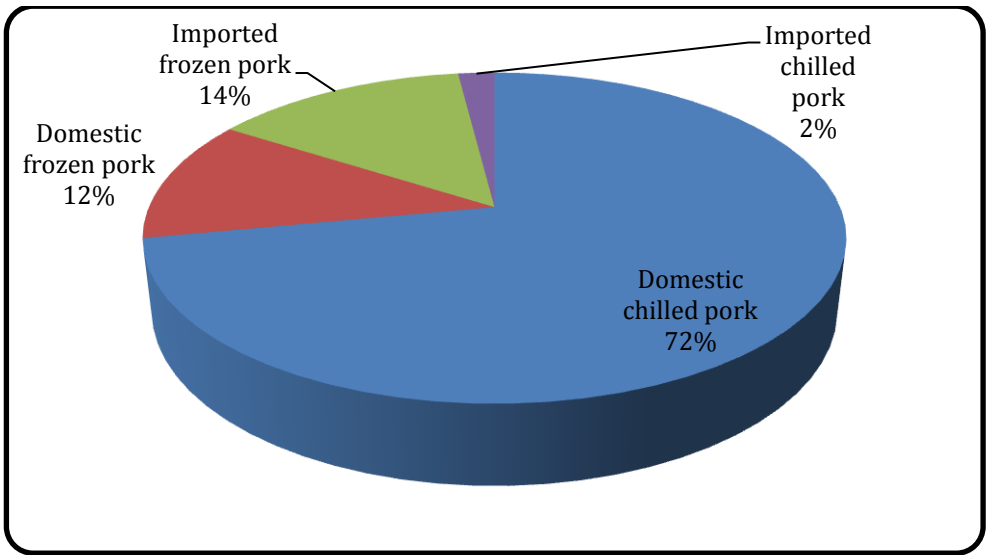

Figure 3.7 Percentage of pork sold at butchers

According to a survey in 2008 (Choi, 2009), consumers considered that the cut (source) of the pig meat, the meat's freshness and its country of origin were important features influencing their purchases (Table 3.16). Table 3.16 concluded that Korean preferred domestic fresh pork belly.

Table 3.16 Considerations for pork purchases

Source (Choi, 2009)

Considerations of consumers influencing purchasing behaviors	Percentage (%)
Parts of pigs	30
Freshness	24
Country of origin	14
Price	11
Safety	7
Amount of fat	6
Hygiene of store	5
Brand of pork	3

3.13 Discussion

In this chapter the pork industry in the ROK was described. Although the contribution of agriculture to the Korean economy is low, the pork industry is important because of a preference of Koreans for the consumption of locally produced pork. In the ROK more pork is consumed than other meats.

The number of pigs in the ROK has increased each year. In contrast the number of pig farms has declined steadily, especially the number of small-scale pig farms. This situation is due to the modernization of agriculture in Korea. Pig farmers have noticed that running large scale farms are more economical. It was the economics of scale. This change has likely increased overall productivity of the pig industry. Pork producers are divided into two groups: private farms and large commercial enterprises. Breeding companies provide pigs to these farms and raised pigs are sold to processing companies or meat cooperatives. From here the meat is on-sold to distributors such as supermarkets and butchers and eventually is purchased by consumers. Pork belly has reputation traditionally in Korea. Consumers prefer domestic chilled pork and pork belly and consequently these cuts have the highest price of the carcass.

Pork production accounted for 30% of all livestock production and 77% of this was from domestic production with only 23% imported in 2008. The higher domestic consumption is due to the preference for chilled pork by consumers. Although a large amount of pork is imported (248,343 tonnes in 2007), only a small volume of pig

products was exported (12,612 tonnes). There is the potential to increase exports to other Asian countries, especially due to the preference of people from this region to eat pig meat. Many countries only import meat from disease free countries and thus a disease free status for CSF in the ROK has the potential to allow the growth of the pig industry and to foster an export industry.

The ROK has a policy of stamping out major animal diseases such as FMD and CSF. In the case of disease outbreaks, many animals can be slaughtered resulting in insufficient animals to supply domestic demands. Due to the complicated world meat market, it is not easy to quickly import meat in the event of a disease outbreak.

The economic impact of an exotic disease outbreak on the national pig industry has the potential to be enormous (Clavijo *et al.*, 2001). The total financial impact of the outbreaks of CSF in the Netherlands in 1997 was estimated at US $ 2.3 billion (Artois *et al.*, 2002). Consequently it is important to maintain disease freedom in free-countries and in countries such as the ROK to regain disease freedom. This would allow for the potential to export pork products to other Asian and south-east Asian countries.

In the next chapter the serological results for the period 2004 to 2010 are analysed. Outbreaks of CSF during the period from 2002 to 2010 will also be studied and discussed.

CHAPTER 4: A RETROSPECTIVE STUDY FOR CLASSICAL SWINE FEVER IN THE REPUBLIC OF KOREA

4.1 Introduction

The first reported outbreaks of CSF in ROK date back to 1908 (Kim *et al.*, 1967). Since that time sporadic outbreaks have been reported throughout the nation, with epidemics recorded in the years of 1948 and 1983 (Bae, 1988). In an effort to rid the country of CSF, a nationwide, three-staged eradication campaign was initiated in 1996. The first stage consisted of the wide-spread use of vaccination and culling of infected animals to reduce the number of outbreaks; the second stage consisted of mandatory nationwide vaccination and testing to bring the disease under control; and the final stage consisted of a complete vaccination ban, so that the country could be declared free from CSF. Vaccination was conducted throughout mainland South Korea with the purpose of achieving 100% compliance. No vaccination was adopted in the Jeju Islands as this region has been free from disease since 1999 (Kim *et al.*, 2008).

As a result of the campaign, the number of cases of CSF decreased until no cases were reported in 2000 and 2001. On the basis of this situation, the South Korean authorities decided to ban all vaccination against CSF on December 1, 2001, and notified the OIE that South Korea had achieved all the OIE requirements to declare the country free from CSF (Wee *et al.*, 2005). However, in 2002 11 farms were confirmed infected and every

year since then cases of CSF have been reported. It was hypothesised that the outbreaks in 2002 originated from virus introduced to farms through workers from China. This was supported by the finding that the type of virus isolated (2.1) was different to that previously found in the ROK (3.2) (Cha *et al.*, 2007). Presently, CSF is endemic at a low level and vaccination, using conventional, attenuated CSFV vaccine, is enforced (Wee *et al.*, 2005).

In this chapter the results from a retrospective study of CSF in the ROK are presented.

4.2 Materials and Methods

4.2.1 Data collection

Serological data reported in this chapter were collected from the Korean Animal Health Integrated System (KAHIS) run by the National Veterinary Research and Quarantine Service (NVRQS) in the ROK.

4.2.2 Diagnostic Assay

After serum samples were collected, the sera were diluted 1:20. Samples were analysed for reactivity against CSFV antigen by using a commercially available ELISA kit (Jeno Biotech Inc., Chuncheon, Korea). The assay was performed according to the manufacturer's instructions. The optical density (OD) of the positive control was ≥0.5 and the OD of the negative control was 0.3. To validate the ELISA result, the values of a

corrected positive control (CPC) was ≤0.3 (CPC = mean OD of positive control-mean OD of negative control). The ELISA results were analysed by calculating the sample to positive ratio (S/P ratio) of a sample using the following formula, S/P ratio = (OD of sample – OD of NC) ÷ CPC. Based on the S/P ratio, a value greater than or equal to 0.14 was considered positive and < 0.14 was considered negative.

4.3 Results

4.3.1 Overall Seroprevalence

The seroprevalence based on the detection of antigen was less than 1% in each year between 2004 and 2010 (Table 4.1). The lowest seroprevalence was in 2005 when only two pigs were seropositive. Compared to 2005, the years 2004, 2006, 2007 and 2008 had significantly higher level of disease (all OR did not include the value 1 in the 95% CI). Only year 2010 was not significantly different to 2005. Overall there was no significant difference between all of the years (χ^2 = 1.25, df 1, 6, P = 0.26).

Table 4.1 Results of antigen test on sera collected from 2004 to 2010

Year	Number of positives	Total number tested	Percent Positive (95% CI)	OR (95% CI)
2004	83	25,726	0.32 (0.26, 0.40)	96.36 (23.70, 391.77)
2005	2	59,542	0.00 (0.00, 0.01)	1.0
2006	31	66,141	0.05 (0.03, 0.07)	13.96 (3.34, 58.33)
2007	10	65,312	0.02 (0.01, 0.03)	4.56 (1.00, 20.81)
2008	12	67,544	0.02 (0.01, 0.03)	5.29 (1.18, 23.64)
2009	28	125,348	0.02 (0.01, 0.03)	6.65 (1.58, 27.92)
2010	8	109,897	0.01 (0.00, 0.01)	2.17 (0.46, 10.21)
Total	174	519,510	0.03 (0.03, 0.04)	

In Table 4.2 the serological results based on the presence of antibody to CSF are summarised. This table includes the results of all provinces including Jeju Island. The lowest seroprevalence was in 2008 (84.64%) and the highest in 2006 (91.94%). All years had a significantly higher seroprevalence when compared with 2008 (all OR 95% CI did not include the value one).

Table 4.2 Results of antibody test from 2004 to 2010

Year	Number of positives	Total number tested	Percent Positive (95% CI)	OR (95% CI)
2004	70,099	82,268	85.21 (84.97, 85.45)	1.05 (1.02, 1.07)
2005	188,115	210,731	89.27 (89.14, 89.40)	0.95 (0.93, 0.96)
2006	222,796	242,324	91.94 (91.83, 92.05)	2.07 (2.03, 2.11)
2007	224,204	248,994	90.04 (89.93, 90.16)	1.64 (1.61, 1.67)
2008	229,771	271,464	84.64 (84.51, 84.78)	1.0
2009	323,465	360,779	89.66 (89.56, 89.76)	1.57 (1.55, 1.60)
2010	302,733	332,700	90.99 (90.90, 91.09)	1.83 (1.80, 1.86)
Total	1,561,183	1,749,260	89.25 (89.20, 89.29)	

The seroprevalence (antibody) in different cities and provinces were compared between years (Tables 4.3 to 4.9). In 2004 no samples were collected from animals in the cities of Daejeon and Ulsan (Table 4.3). The lowest prevalence in this year was in Jeollabuk province (94.3%). All other cities or provinces, except for Seoul, had significantly higher seroprevalences than Jeollabuk Province.

For the years 2005 - 2007 and 2009 - 2010 Gwangju had the lowest antibody seroprevalence and all other cities/provinces were compared to this city.

Table 4.3 Antibody seroprevalence in sera originating from different regions in 2004

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	790	756	95.70 (94.04, 97.00)	1.33 (0.93, 1.90)
Busan	542	528	97.42 (95.70, 98.58)	2.26 (1.32, 3.88)
Daegu	813	803	98.77 (97.75, 99.41)	4.82 (2.56, 9.05)
Incheon	2,271	2,199	96.83 (96.02, 97.51)	1.83 (1.42, 2.36)
Gwangju	405	393	97.04 (94.88, 98.46)	1.96 (1.10, 3.52)
Gyeonggi	9,139	8,886	97.23 (96.87, 97.56)	2.11 (1.80, 2.46)
Gangwon	3,615	3,494	96.65 (96.01, 97.22)	1.73 (1.41, 2.12)
Chungcheongbuk	2,875	2,820	98.09 (97.52, 98.56)	3.08 (2.32, 4.08)
Chungcheongnam	10,568	10,096	95.53 (95.12, 95.92)	1.28 (1.13, 1.46)
Jeollanam	7,337	7,124	97.10 (96.69, 97.47)	2.01 (1.70, 2.37)
Gyeongsangbuk	6,226	5,972	95.92 (95.40, 96.40)	1.41 (1.21, 1.65)
Gyeongsangnam	7,382	7,197	97.49 (97.11, 97.84)	2.33 (1.96, 2.77)
Jeollabuk	8,357	7,884	94.34 (93.82, 94.83)	1

The antibody seroprevalence in different provinces in 2005 are summarised in Table 4.4. All regions, other than Busan and Daegu, had a significantly higher seroprevalence than Gwangju.

Table 4.4 Antibody seroprevalence in sera originating from different regions in 2005

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	796	766	96.23 (94.66, 97.44)	1.99 (1.28, 3.09)
Busan	1,025	965	94.15 (92.53, 95.50)	1.25 (0.88, 1.79)
Daegu	2,147	2,022	94.18 (93.10, 95.13)	1.26 (0.93, 1.71)
Incheon	6,925	6,633	95.78 (95.28, 96.24)	1.77 (1.35, 2.32)
Daejeon	304	303	99.67 (98.18, 99.99)	23.62(3.27, 170.84)
Ulsan	1,645	1,574	95.68 (94.59, 96.61)	1.73 (1.23, 2.43)
Gyeonggi	35,276	33,678	95.47 (95.25, 95.68)	1.64 (1.28, 2.11)
Gangwon	12,492	12,059	96.53 (96.20, 96.85)	2.17 (1.67, 2.82)
Chungcheongbuk	10,554	10,029	95.03 (94.59, 95.43)	1.49 (1.15, 1.93)
Chungcheongnam	23,511	22,240	94.59 (94.30, 94.88)	1.36 (1.06, 1.75)
Jellabuk	17,343	16,577	95.58 (95.27, 95.88)	1.69 (1.31, 2.18)
Jeollanam	18,965	17,875	94.25 (93.91, 94.58)	1.28 (0.99, 1.65)
Gyeongsangbuk	24,158	23,032	95.34 (95.07, 95.60)	1.59 (1.24, 2.05)
Gyeongsangnam	22,105	20,910	94.59 (94.29, 94.89)	1.36 (1.06, 1.75)
Gwangju	954	885	92.77 (90.94, 94.33)	1

The antibody seroprevalence in different provinces in 2006 is tabulated in Table 4.5. All regions other than Chungcheongnam province had significantly higher seroprevalences than Gwangju.

Table 4.5 Antibody seroprevalence in sera originating from different regions in 2006

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	3,206	3,057	95.35 (94.57, 96.06)	1.85 (1.40, 2.43)
Busan	1,101	1,039	94.37 (92.84, 95.66)	1.51 (1.08, 2.11)
Daegu	2,800	2,682	95.79 (94.97, 96.50)	2.05 (1.54, 2.73)
Incheon	7,530	7,221	95.90 (95.42, 96.33)	2.10 (1.64, 2.69)
Daejeon	401	390	97.26 (95.14, 98.62)	3.19 (1.69, 6.04)
Ulsan	2,115	1,992	94.18 (93.10, 95.14)	1.46 (1.10, 1.94)
Gyeonggi	45,594	43,399	95.19 (94.99, 95.38)	1.78 (1.42, 2.23)
angwon	16,289	15,721	96.51 (96.22, 96.79)	2.49 (1.97, 3.15)
Chungcheongbuk	15,982	15,389	96.29 (95.98, 96.58)	2.34 (1.85, 2.95)
Chungcheongnam	26,663	24,813	93.06 (92.75, 93.36)	1.21 (0.97, 1.51)
Jellabuk	22,562	20,899	92.63 (92.28, 92.97)	1.13 (0.90, 1.42)
Jellanam	23,780	22,614	95.10 (94.81, 95.37)	1.75 (1.39, 2.19)
Gyeongsangbuk	29,351	27,943	95.20 (94.95, 95.44)	1.79 (1.43, 2.24)
Gyeongsangnam	25,851	24,512	4.82 (94.54, 95.09)	1.65 (1.31, 2.07)
Gwangju	1,053	966	91.74 (89.91, 93.33)	1

The antibody seroprevalence in different provinces in 2007 is summarised in Table 4.6. Other than the city of Daejeon all regions had a significantly higher seroprevalence than Gwangju city (all 95% CI for odds ratios did not include the value 1.0).

Table 4.6 Antibody seroprevalence in sera originating from different regions in 2007

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	3,530	3,358	95.13 (94.36, 95.81)	3.11 (2.51, 3.86)
Busan	1,041	1,013	97.31 (96.14, 98.21)	5.76 (3.84, 8.64)
Daegu	2,800	2,786	99.50 (99.16, 99.73)	31.71(18.35,54.78)
Incheon	7,967	7,380	92.63 (92.04, 93.20)	2.00 (1.68, 2.38)
Daegjeon	308	273	88.64 (84.55, 91.96)	1.24 (0.85, 1.82)
Ulsan	1,939	1,878	96.85 (95.98, 97.59)	4.91 (3.64, 6.60)
Gyeonggi	45,614	42,908	94.07 (93.85, 94.28)	2.53 (2.16, 2.96)
Gangwon	15,979	15,215	95.22 (94.88, 95.54)	3.17 (2.68, 3.76)
Chungcheongbuk	18,259	17,155	93.95 (93.60, 94.30)	2.48 (2.10, 2.92)
Chungcheongnam	27,730	25,954	93.60 (93.30, 93.88)	2.33 (1.98, 2.73)
Jeollabuk	26,564	25,061	94.34 (94.06, 94.62)	2.66 (2.26, 3.12)
Jeollanam	23,009	21,973	95.50 (95.22, 95.76)	3.38 (2.87, 3.98)
Gyeongsangbuk	27,245	25,884	95.00 (94.74, 95.26)	3.03 (2.58, 3.56)
Gyeongsangnam	23,689	22,052	93.09 (92.76, 93.41)	2.15 (1.83, 2.52)
Gwangju	1,397	1,205	86.26 (84.34, 88.02)	1

The antibody seroprevalence in different provinces for 2008 is tabulated in Table 4.7. All other regions had a significantly higher seroprevalence compared to Daejeon city in 2008.

Table 4.7 Antibody seroprevalence in pigs originating from different regions in 2008

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	4,030	3,836	95.19 (94.48, 95.83)	2.49 (1.78, 3.50)
Busan	787	754	95.81 (94.16, 97.10)	2.88 (1.81, 4.58)
Daegu	2,846	2,833	99.54 (99.22, 99.76)	27.46(14.70,51.32)
Incheon	8,110	7,612	93.86 (93.31, 94.37)	1.93 (1.40, 2.65)
Gwangju	1,288	1,187	92.16 (90.55, 93.57)	1.48 (1.03, 2.14)
Ulsan	2,102	1,938	92.20 (90.97, 93.31)	1.49 (1.05, 2.10)
Gyeonggi	48,857	46,406	94.98 (94.79, 95.18)	2.39 (1.75, 3.25)
Gangwon	16,766	16,154	96.35 (96.05, 96.63)	3.33 (2.42, 4.57)
Chungcheongbuk	18,993	18,132	95.47 (95.16, 95.76)	2.65 (1.94, 3.63)
Chungcheongnam	27,641	26,008	94.09 (93.81, 94.37)	2.01 (1.47, 2.74)
Jeollabuk	24,432	23,464	96.04 (95.79, 96.28)	3.05 (2.23, 4.18)
Jeollanam	23,186	22,205	95.77 (95.50, 96.02)	2.85 (2.09, 3.90)
Gyeongsangbuk	27,404	26,206	95.63 (95.38, 95.87)	2.76 (2.02, 3.77)
Gyeongsangnam	24,775	23,449	94.65 (94.36, 94.92)	2.23 (1.63, 3.04)
Daejeon	411	365	88.81(85.35,91.69)	1

The antibody seroprevalence in different provinces in 2009 is summarised in Table 4.8. In 2009, Busan, Gyeonggi, Gangwon, Chungcheongnam, Jeollanam, Gyeongsangbuk provinces had significantly higher seroprevalences than Gwangju city.

Table 4.8 Antibody seroprevalence of pigs originating from different regions in 2009

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	2,184	2,038	93.32 (92.19, 94.33)	1.00 (0.73, 1.36)
Busan	1,068	1,051	98.41 (97.46, 99.07)	4.43 (2.57, 7.64)
Daegu	996	941	94.48 (92.87, 95.81)	1.23 (0.84, 1.79)
Incheon	8,063	7,556	93.71 (93.16, 94.23)	1.07 (0.81, 1.41)
Daejeon	477	446	93.50 (90.90, 95.54)	1.03 (0.66, 1.61)
Ulsan	1,419	1,342	94.57 (93.26, 95.69)	1.25 (0.88, 1.770
Gyeonggi	78,310	75,094	95.89 (95.75, 96.03)	1.67 (1.29, 2.18)
Gangwon	17,996	17,297	96.12 (95.82, 96.39)	1.77 (1.35, 2.32)
Chungcheongbuk	18,464	17,494	94.75 (94.41, 95.06)	1.29 (0.99, 1.69)
Chungcheongnam	55,459	53,056	95.67 (95.49, 95.84)	1.58 (1.22, 2.06)
Jellabuk	37,987	35,994	94.75 (94.52, 94.98)	1.29 (0.99, 1.69)
Jellanam	31,830	30,285	95.15 (94.90, 95.38)	1.41 (1.08, 1.83)
Gyeongsangbuk	38,277	36,457	95.25 (95.03, 95.46)	1.44 (1.10, 1.87)
Gyeongsangnam	36,482	34,586	94.80 (94.57, 95.03)	1.31 (1.00, 1.70)
Gwangju	912	851	93.31 (91.49, 94.85)	1.00

The antibody seroprevalence in different provinces in 2010 is summarised in Table 4.9. All regions, other than Busan, had significantly higher seroprevalences than Gwangju city.

Table 4.9 Antibody seroprevalence in pigs originating from different regions in 2010

Region	Number of animals	Test positive	Seroprevalence (95% CI)	OR (95% CI)
Seoul	1,500	1,449	96.60 (95.55, 97.46)	2.19 (1.46, 3.29)
Busan	923	877	95.02 (93.41, 96.33)	1.47 (0.97, 2.23)
Daegu	1,032	999	96.80 (95.54, 97.79)	2.33 (1.48, 3.68)
Incheon	6,240	5,998	96.12 (95.61, 96.59)	1.91 (1.38, 2.64)
Daejeon	344	341	99.13 (97.47, 99.82)	8.76 (2.71, 28.35)
Ulsan	1,624	1,550	95.44 (94.31, 96.41)	1.61 (1.11, 2.35)
Gyeonggi	72,656	70,110	96.49 (96.36, 96.63)	2.12 (1.57, 2.86)
Gangwon	19,843	19,316	97.34 (97.11, 97.56)	2.82 (2.07, 3.85)
Chungcheongbuk	21,945	21,086	96.08 (95.82, 96.34)	1.89 (1.39, 2.56)
Chungcheongnam	49,037	47,290	96.43 (96.27, 96.60)	2.09 (1.54, 2.82)
Jeollabuk	24,743	23,695	95.76 (95.51, 96.01)	1.74 (1.29, 2.36)
Jeollanam	35,060	34,067	97.16 (96.99, 97.34)	2.64 (1.95, 3.58)
Gyeongsangbuk	34,820	33,347	95.76 (95.55, 95.98)	1.74(1.29, 2.36)
Gyeongsangnam	35,879	34,095	95.02 (94.80, 95.25)	1.47 (1.09, 1.99)
Gwangju	657	610	92.85 (90.60, 94.70)	1.0

In Table 4.10 the seroprevalence of pigs from Jeju Island are summarised for the period 2004 to 2010. The seroprevalence ranged from 0% in 2009 to 13% in 2006.

Table 4.10 Distribution of antibody titre in sera originating from pigs from Jeju Island

Year	Number of animals positive	Number of animals	Seroprevalence (95% CI)
2004	69	2,360	2.92 (2.28, 3.69)
2005	1,406	1,824	11.89 (11.31, 12.49)
2006	830	6,402	12.96 (12.15, 13.81)
2007	554	10,386	5.33 (4.91, 5.78)
2008	981	29,618	3.31 (3.11, 3.52)
2009	0	20,056	0.00 (0.00, 0.02)
2010	127	17,030	0.75 (0.62, 0.89)

In Tables 4.11 to 4.17 the antigen seroprevalence is tabulated for different classes/types of pigs in the years 2004 to 2010, respectively.

Every year the total antigenic seroprevalence was less than 1%. Antigen to CSF was detected in piglets in the years 2004, 2006, 2007, 2008, 2009. Piglets had a significantly higher prevalence than other pigs.

Table 4.11 Distribution of antigen in different types of pigs in 2004

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	6,259	16	0.26 (0.15, 0.41)	0.79 (0.46, 1.35)
Gilts	1,965	0	0.00 (0.00, 0.19)	n/a
Finishers	16,379	55	0.34 (0.25, 0.44)	1.04 (0.73, 1.46)
Boars	445	0	0.00 (0.00, 0.83)	n/a
Piglets	678	12	1.77 (0.92, 3.07)	5.57 (3.02, 10.25)
Total	**25,726**	**83**	**0.32 (0.26, 0.40)**	1

Table 4.12 Distribution of antigen in different types of pigs in 2005

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	16,114	0	0.00 (0.00, 0.02)	n/a
Gilts	5,667	0	0.00 (0.00, 0.07)	n/a
Finishers	36,812	2	0.01 (0.00, 0.02)	1.61 (0.22, 11.48)
Boars	556	0	0.00 (0.00, 0.66)	n/a
Piglets	393	0	0.00 (0.00, 0.93)	n/a
Total	**59,542**	**2**	**0.00 (0.00, 0.01)**	1

Table 4.13 Distribution of antigen in different types of pigs in 2006

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	12,572	0	0.00 (0.00, 0.03)	n/a
Gilts	6,602	0	0.00 (0.00, 0.06)	n/a
Finishers	45,377	29	0.06 (0.04, 0.09)	1.36 (0.82, 2.26)
Boars	956	0	0.00 (0.00, 0.39)	n/a
Piglets	634	2	0.32 (0.04, 1.13)	6.74 (1.61, 28.26)
Total	**66,141**	**31**	**0.05 (0.03, 0.07)**	1

Table 4.14 Distribution of antigen in different types of pigs in 2007

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	9,360	0	0.00 (0.00, 0.04)	n/a
Gilts	6,365	0	0.00 (0.00, 0.06)	n/a
Finishers	48,287	0	0.00 (0.00, 0.01)	n/a
Boars	649	0	0.00 (0.00, 0.57)	n/a
Piglets	651	10	1.54 (0.74, 2.81)	101.87 (42.26, 245.61)
Total	**65,312**	**10**	**0.02 (0.01, 0.03)**	1

Table 4.15 Distribution of antigen in different types of pigs in 2008

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	8,442	0	0.00 (0.00, 0.04)	n/a
Gilts	8,973	0	0.00 (0.00, 0.04)	n/a
Finishers	48,632	4	0.01 (0.00, 0.02)	0.46 (0.14, 1.43)
Boars	1,058	0	0.00 (0.00, 0.35)	n/a
Piglets	439	8	1.82 (0.79, 3.56)	104.46 (42.49, 256.83)
Total	**67,544**	**12**	**0.02 (0.01, 0.03)**	1

Table 4.16 Distribution of antigen in different types of pigs in 2009

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	11,759	0	0.00 (0.00, 0.03)	n/a
Gilts	10,848	0	0.00 (0.00, 0.03)	n/a
Finishers	95,446	12	0.01 (0.01, 0.02)	0.56 (0.29, 1.11)
Boars	2,844	0	0.00 (0.00, 0.13)	n/a
Piglets	4,451	16	0.36 (0.21, 0.58)	16.15 (8.73, 29.87)
Total	**125,348**	**28**	**0.02 (0.01, 0.03)**	1

Table 4.17 Distribution of antigen in different types of pigs in 2010

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95%CI)	OR (95% CI)
Sows	11,406	2	0.02 (0.00, 0.06)	2.41 (0.51, 11.35)
Gilts	6,767	0	0.00 (0.00, 0.05)	n/a
Finishers	89,368	6	0.01 (0.00, 0.01)	0.92 (0.32, 2.66)
Boars	1,172	0	0.00 (0.00, 0.31)	n/a
Piglets	1,184	0	0.00 (0.00, 0.31)	n/a
Total	**109,897**	**8**	**0.00 (0.00, 0.01)**	1

In Tables 4.18 to 4.24 the antibody seroprevalence is tabulated for different classes/types of pigs in the years 2004 to 2010, respectively. Every year the percentage of pigs seropositive was higher than 80%.

Table 4.18 Distribution of antibody titre in different types of pigs in 2004

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	11,747	10,995	93. 60 (93.14, 94.03)	2.54 (2.35, 2.74)
Breeders	2,645	2,049	77.47 (75.83, 79.05)	0.60 (0.54, 0.66)
Finishers	66,308	56,122	84.64 (84.36, 84.91)	0.96 (0.93, 0.98)
Boars	749	720	96.13 (94.49, 97.39)	4.31 (2.97, 6.25)
Piglets	819	213	26.01 (23.03, 29.16)	0.06 (0.05, 0.07)
Total	**82,268**	**70,099**	**85.21 (84.96, 85.45)**	**1**

Table 4.19 Distribution of antibody titre in different types of pigs in 2005

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	34,428	30,745	89.30 (88.97, 89.63)	1.00 (0.97, 1.04)
Breeders	9,982	9,353	93.70 (93.20, 94.17)	1.79 (1.65, 1.94)
Finishers	163,645	146,045	89.25 (89.09, 89.39)	1.00 (0.98, 1.02)
Boars	1,460	1,373	94.04 (92.70, 95.20)	1.90 (1.53, 2.36)
Piglets	1,216	599	49.26 (46.41, 52.11)	0.12 (0.10, 0.13)
Total	**210,731**	**188,115**	**89.27 (89.14, 89.40)**	**1**

Table 4.20 Distribution of antibody titre in different types of pigs in 2006

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	31,282	29,192	93.32 (93.04, 93.59)	1.22 (1.17, 1.28)
Breeders	10,081	9,664	95.86 (95.46, 96.24)	2.03 (1.84, 2.24)
Finishers	198,623	181,754	91.51 (91.38, 91.63)	0.94 (0.92, 0.96)
Boars	1,359	1,318	96.98 (95.93, 97.83)	2.82 (2.06, 3.85)
Piglets	979	868	88.66 (86.51, 90.58)	0.69 (0.56, 0.84)
Total	**242,324**	**222,796**	**91.94 (91.83, 92.05)**	**1**

Table 4.21 Distribution of antibody titre in different types of pigs in 2007

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	24,212	22,651	93.55 (93.24, 93.86)	1.60 (1.52, 1.69)
Breeders	8,894	8,336	93.73 (93.22, 94.23)	1.65 (1.51, 1.80)
Finishers	213,575	191,110	89.48 (89.35, 89.61)	0.94 (0.92, 0.96)
Boars	1,072	1,028	95.90 (94.71, 97.08)	2.58 (1.91, 3.49)
Piglets	1,241	1,079	86.95 (85.07, 88.82)	0.74 (0.62, 0.87)
Total	**248,994**	**224,204**	**90.04 (89.93, 90.16)**	**1**

Table 4.22 Distribution of antibody titre in different type of pigs in 2008

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	19,711	17,648	89.53 (89.10, 89.96)	1.55 (1.48, 1.63)
Breeders	15,137	11,173	73.81 (73.10, 74.51)	0.51 (0.49, 0.53)
Finishers	234,797	199,695	85.05 (84.91, 85.19)	1.03 (1.02, 1.05)
Boars	1,281	1,033	80.64 (78.37, 82.77)	0.76 (0.66, 0.87)
Piglets	538	222	41.26 (37.07, 45.56)	0.13 (0.11, 0.15)
Total	**271,464**	**229,771**	**84.64 (84.51, 84.78)**	**1**

Table 4.23 Distribution of antibody titre in different types of pigs in 2009

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	25,584	24,124	94.29 (94.01, 94.58)	1.91 (1.81, 2.01)
Breeders	14,893	13,183	88.52 (88.01, 89.03)	0.89 (0.84, 0.94)
Finishers	313,534	282,117	89.98 (89.87, 90.08)	1.04 (1.02, 1.05)
Boars	2,974	2,871	96.54 (95.88, 97.19)	3.22 (2.64, 3.91)
Piglets	3,794	1,170	30.84 (29.37, 32.31)	0.05 (0.05, 0.06)
Total	**360,779**	**323,465**	**89.66 (89.56, 89.76)**	**1**

Table 4.24 Distribution of antibody titre in different types of pigs in 2010

Type of pigs	Number of animals tested	Number of animals positive	Seroprevalence (95% CI)	OR (95% CI)
Sows	30,747	29,350	95.46 (95.22, 95.69)	2.08 (1.97, 2.20)
Breeders	10,229	9,022	88.20 (87.56, 88.820	0.74 (0.70, 0.79)
Finishers	289,358	262,371	90.67 (90.57, 90.78)	0.96 (0.95, 0.98)
Boars	1,299	1,240	95.46 (94.18, 96.52)	2.08 (1.60, 2.70)
Piglets	1,067	750	70.29 (67.45, 73.02)	0.23 (0.21 (0.27)
Total	332,700	302,733	90.99 (90.89, 91.09)	1

In Table 4.25 the antigen seroprevalence is summarised for samples collected from Jeju Island from 2004 to 2010. No antigen was detected in any of the pigs tested.

Table 4.25 Antigenic seroprevalence in pigs originating from Jeju Island (2004 – 2010)

Year	Number of animals tested	Test positive	Seroprevalence (95% CI)
2004	736	0	0.00 (0.00, 0.50)
2005	2,557	0	0.00 (0.00, 0.14)
2006	4,062	0	0.00 (0.00, 0.09)
2007	3,590	0	0.00 (0.00, 0.10)
2008	5,794	0	0.00 (0.00, 0.06)
2009	7,604	0	0.00 (0.00, 0.05)
2010	4,956	0	0.00 (0.00, 0.00)
Total	**29,299**	**0**	**0.00(0.11, 0.01)**

Antibody titre in pigs from Jeju Island are tabulated in Table 4.26. The seroprevalence peaked in 2005 and 2006, and then decreased. This peak is due to the illegal use of contaminated animal feed from mainland Korea.

Table 4.26 Seroprevalence of antibody in pigs originating from Jeju Island

Year	Number of animals	Test positive	Seroprevalence (95% CI)	OR
2004	2,360	69	2.92 (2.28, 3.69)	0.71 (0.56, 0.90)
2005	11,824	1,406	11.89 (11.31, 12.49)	3.19 (2.99, 3.39)
2006	6402	830	12.96 (12.15, 13.81)	3.52 (3.25, 3.81)
2007	10386	554	5.33 (4.91, 5.78)	1.33 (1.21, 1.46)
2008	29618	981	3.31 (3.11, 3.52)	0.81 (0.75, 0.87)
2009	20056	0	0.00 (0.00, 0.02)	-
2010	17030	127	0.75 (0.62, 0.89)	0.18 (0.14, 0.21)
Total	**97,676**	**3,967**	**4.06 (3.94, 4.19)**	**1**

4.3.2 CSF outbreak in Korea

The total number of outbreaks of CSF in pigs reported during the eight year period from 2002 to 2009 is displayed in Figure 4.1. Most outbreaks (72) occurred in Gyeonggi Province, followed by Jeollabuk Province (32) and Gyeongsangnam Province (20). Seven other provinces had some cases and 6 regions had no outbreaks, including Jeju Island.

In Table 4.27 the number of outbreaks per year is tabulated. There were no report of CSF from 2000 and 2001.There were 13 cases of CSF in three provinces in 2002. It was believed that the most likely introduction of virus into these farms was associated with direct or indirect contact of pigs with foreign workers and/or farm owners who had returned from China where an outbreak was occurring (Park *et al.*, 2006b). In 2003 72 cases of CSF were reported. The source of infection in 2003 was a breeding farm. Virus entered this breeding farm through the introduction of breeder pigs from contracted farms which were located in areas that had been affected by the CSF epidemic in 2002 (Park *et al.*, 2006a).

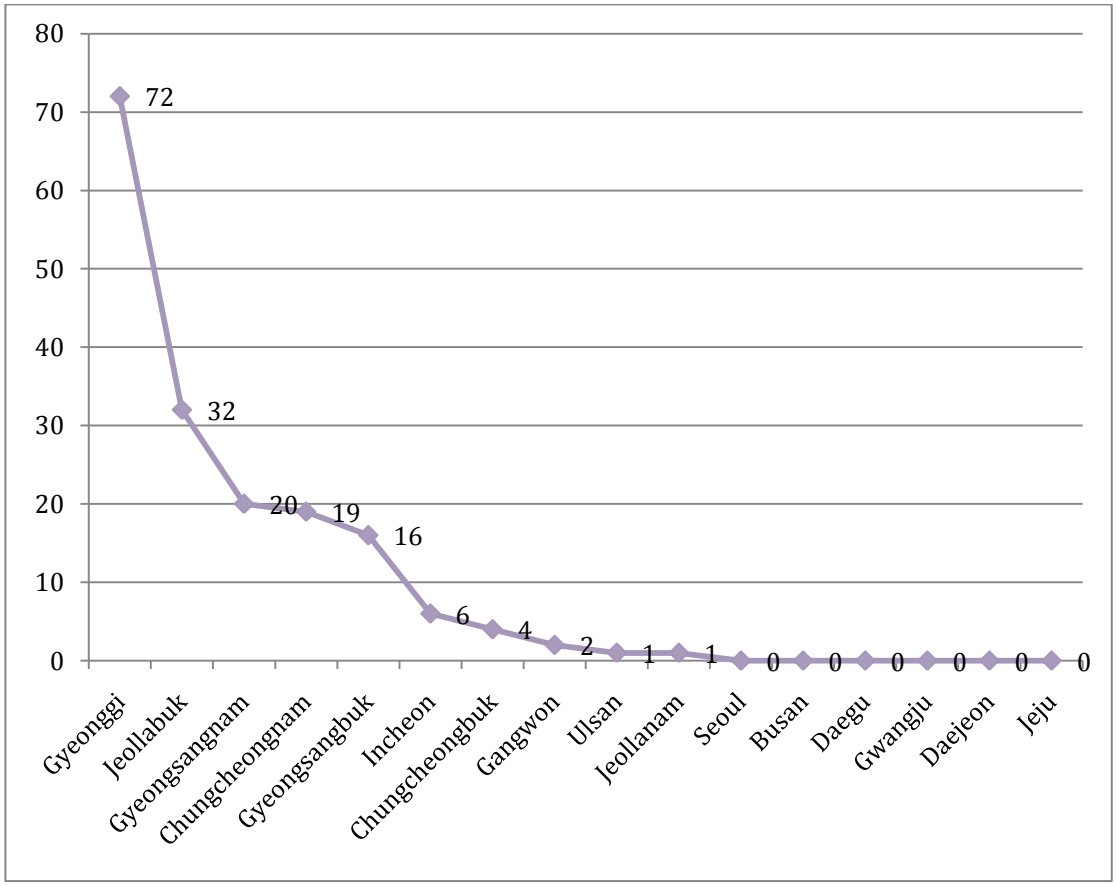

Figure 4.1 The total number of outbreaks of CSF in different provinces of the ROK from 2002 to 2009

Table 4.27 The number of CSF outbreaks per year

Year	Number of outbreaks	Number of diseased pigs	Number of dead pigs
2000	0	0	0
2001	0	0	0
2002	13	1,089	152
2003	72	5,866	1,890
2004	9	781	240
2005	5	811	808
2006	2	1,074	815
2007	5	58	18
2008	7	99	83
2009	2	316	47
2010	0	0	0

In Figures 4.2 to 4.9 the number of outbreaks and their location is plotted along with the incidence risk (per 10^6 pigs) for the period 2002 to 2009.

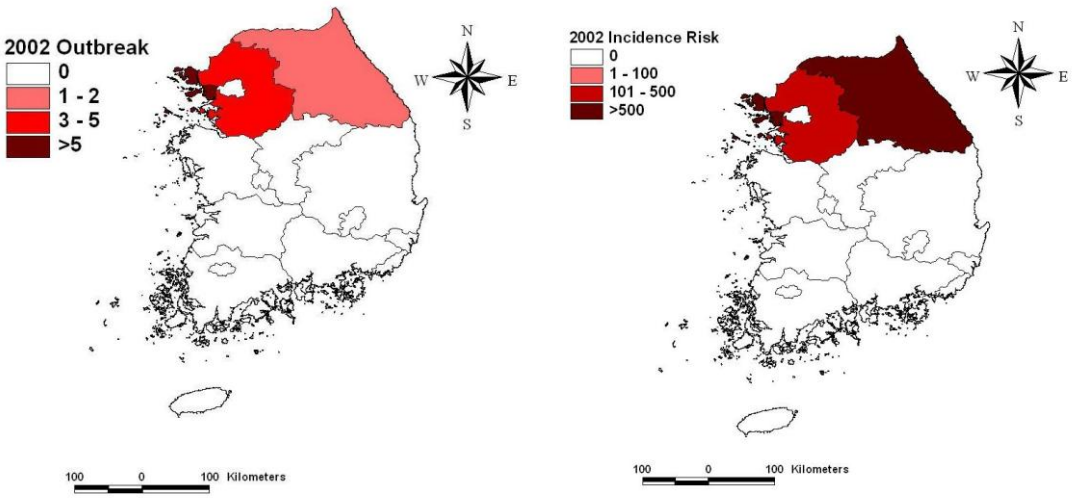

Figure 4.2 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2002

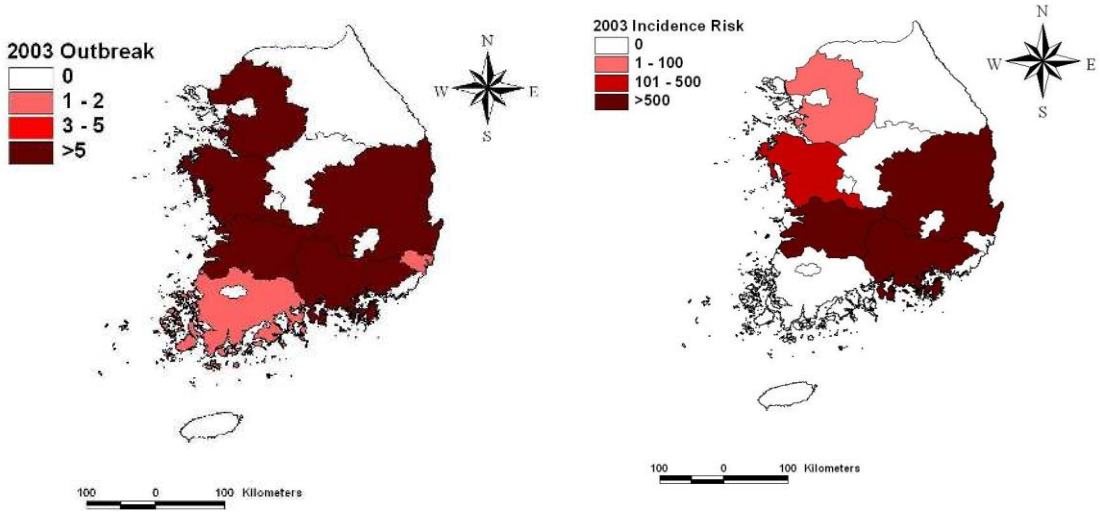

Figure 4.3 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2003

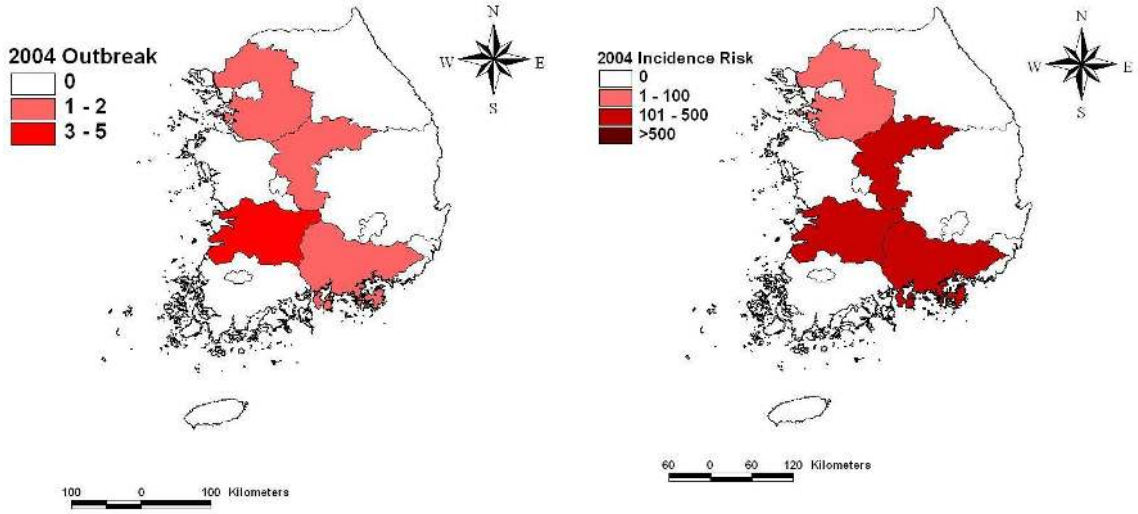

Figure 4.4 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2004

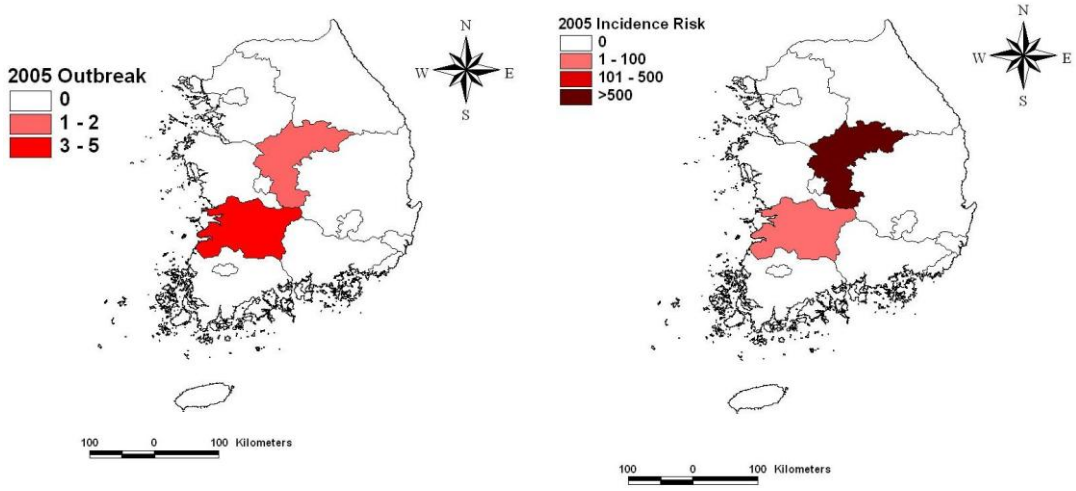

Figure 4.5 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2005

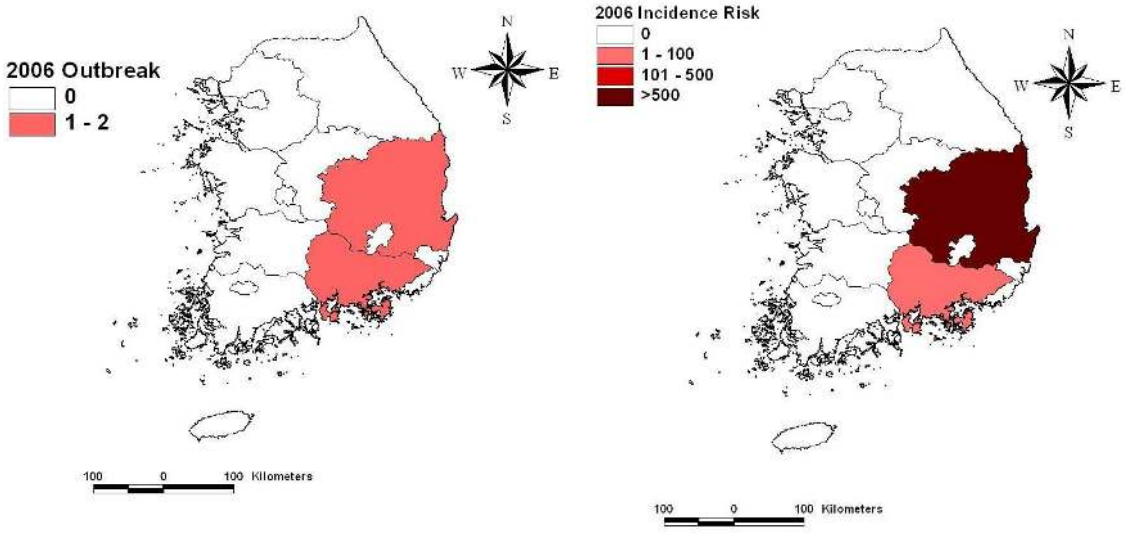

Figure 4.6 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2006

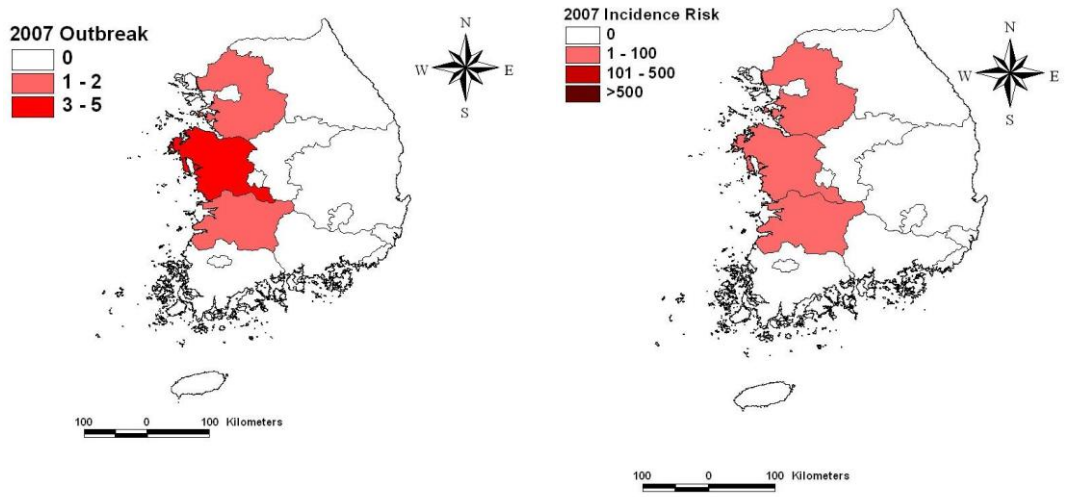

Figure 4.7 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2007

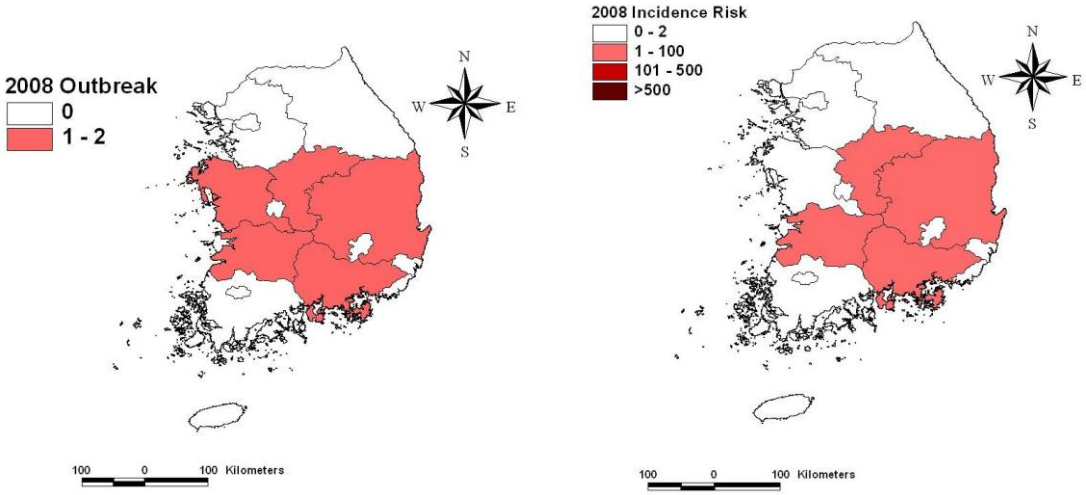

Figure 4.8 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2008

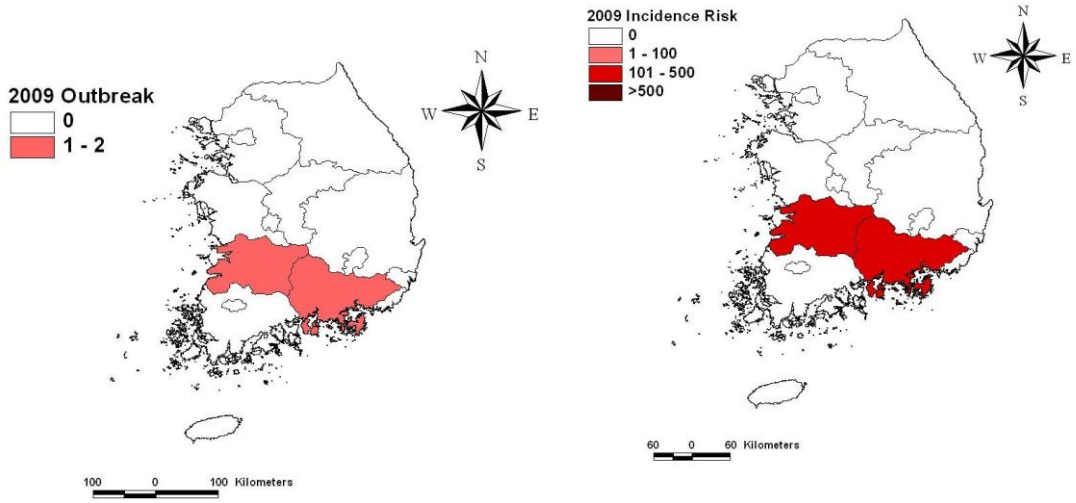

Figure 4.9 The location and number of outbreaks of CSF and the incidence risk per 1,000,000 pigs per year in 2009

4.3.3 Virus isolates from the Republic of Korea

The types of virus isolated from the ROK during the period 1988 to 2003 are summarised in Table 4.28 (Cha *et al.*, 2007). The viruses isolated before 2000 were type 3 and the reference strains, whereas the virus isolated after 2002 were genetic type 2 (Park *et al.*, 2006b). Based on the combined analysis of epidemiological data and genetic typing in 2006, the transmission routes of classical swine fever virus were found to be the movement of vehicles (60%) and persons (10%), neighborhood spread (20%) and unknown (10%) (Park *et al.*, 2006a).

Table 4.28 Geographical origin and collection year of classical swine fever viruses

Province	strain	Isolation year	Genotype
Chungnam	88030	1988	3.2
Chungnam	88015	1988	3.2
Gyeonggi	96939	1996	3.2
Gyeonggi	96940	1996	3.2
Gyeonggi	97009	1997	3.2
Jeonbuk	97347	1997	3.2
Jeju	JJ9811	1998	3.2
Chungnam	NS9811	1998	3.2
Gyeonggi	YI9908	1999	3.2
Incheon	IC2002	2002	2.1
Ganwon	CW2002	2002	2.1
Gyeonggi	KH2002N1	2002	2.1
Gyeonggi	KH2002N2	2002	2.1
Gyeonggi	SW03	2003	2.1
Gyeonggi	PC03	2003	2.1
Gyeonggi	KHJ03	2003	2.1
Chungnam	OSH03	2003	2.1
Jeonbuk	LJU03	2003	2.1
Jeonbuk	KYH03	2003	2.1
Jeonbuk	KSB03	2003	2.1
Jeonbuk	KKY03	2003	2.1
Jeonbuk	SCS03	2003	2.1
Gyeongnam	LBG03	2003	2.1
Gyeongnam	HA2003	2003	2.1
Not known	LOM (vaccine)	-	1.1

4.4 Discussion

In this chapter the results for testing samples for CSF for the period 2004 to 2010 are reported. The number of samples collected for testing for antigen varied from 25,726 in 2004 to 109,897 in 2010. The number of samples positive for CSF antigen was less than 0.1% in all years of sampling. The average antigen seroprevalence was only 0.03% (95%CI: 0.03 - 0.04) and there were no significant differences between years. These findings indicate that no major country-wide epidemics of CSF occurred during the study period.

A very large number of blood samples were tested for the presence of antibody to CSF. In 2004 82,268 samples were tested and this increased to 302,733 in 2010. A high seroprevalence (positive antibody titre) (higher than 84%) was found in every year of sampling. The overall seroprevalence in the ROK was 89.25% (95% CI: 89.20 - 89.29%). This result highlights the success of vaccination policy in the ROK as vaccinated pigs have developed serological immunity.

The increase in the number of samples tested for antigen and antibody was due to an increase in the budget allocated to facilitate the eradication of CSF. Each year local and central governments provided CSF vaccine to pig farmers to prevent the spread of CSF. The high adoption of vaccination accounts for the high antibody seroprevalence detected in this study. This level is indicative of protection against infection and is likely to be the main reason few outbreaks were reported over the study period.

The seroprevalence varied between different cities and provinces. It is likely that geographical differences were due to differences in the efficacy of the vaccine probably associated with the cold chain process (Morilla Gonzalez *et al.*, 2002), or through variation in the method of selecting animals for sampling. Cross reactions induced by other pathogens, including other pesti viruses, could also vary between locations (Suradhat *et al.*, 2007).

The antigen and antibody seroprevalences were different in different types (ages) of pigs. The higher seroprevalence in piglets is likely to be associated with transfer of maternal antibody (Morilla Gonzalez *et al.*, 2002).

Outbreaks of CSF were reported from 2002 to 2009, after no outbreaks had been reported in 2000 and 2001 and the country was declared CSF free in December 2001. The outbreak in 2002 was believed to have been from the introduction of virus from outside the country. Subsequently the virus was distributed from an infected breeding farm. Subsequent sporadic CSF cases are likely to have arisen from circulating field virus. Indirect or direct contact of domestic pigs with infected wild boar could also be the cause of these sporadic outbreaks (Fritzemeier *et al.*, 2000; Ruiz-Fons *et al.*, 2008).

Swill feeding is another potentially important factor in the spread of CSF (Horst *et al.*, 1997). According to a survey in 2010 by NVRQS, 273 pig farms fed swill to pigs. This represents 3.7% of all pig farms (NVRQS, 2010). To inactivate the virus in swill during processing it is required to be maintained at a temperature of at least 100^{o}C for a

minimum of 30 minutes (Animal Feed Act of Korea). Lower temperatures or shorter durations are likely to result in a risk that the virus is not inactivated resulting in subsequent outbreaks.

Farmer awareness and education programmes and other publicity campaigns are one of the most critical, but sometimes neglected, aspects of preparedness planning for emergency diseases (Geering *et al.*, 1999). However in the ROK there is a lack of communication between the public and private sector. Suitable educational material should be developed for farmers in the ROK. Similarly, material should also be produced for the general public to minimise risky practices such as the illegal importation of pork products.

The number of farmers on Jeju Island is small and there is a close relationship between the farmers and the public sector. Many pig owners know the importance of animal disease control and the importance of retaining disease free status. Furthermore it is difficult to bring animals or animal products from outside (either from the mainland or internationally) to the island. This would explain the low antigenic prevalence on Jeju Island reported in this study.

In countries with an intensive pig industry and a high wild boar density, CSF can have a significant impact on the agricultural industry including forestry (Kaden and Lange, 2004). During the epidemic of CSF in Europe from 1997 to 1998, the direct and indirect losses were estimated at €2.2 billion, excluding losses caused by CSF in the wild boar of

the forests (Terpstra and Smit, 2000). It is likely that in the ROK wild boar play a role in the circulation and survival of the CSFV.

In the following chapter the results from a risk assessment for CSF on Jeju Island are described using the risk factors for CSF described in this chapter.

CHAPTER 5: RISK ASSESSMENT FOR JEJU ISLAND - A CLASSICAL SWINE FEVER FREE REGION

5.1 Introduction

Jeju Island lies to the south of mainland Korea and is the only special autonomous province of the Republic of Korea. It is located 154km from Mokpo city, 255.1km from Tsushima of Japan and 548km from Shanghai, China. Jeju's total area is 1,848km^2 and its weather is subtropical. The total human population was 565,519 in 2007 (Jeju special self-governing province, 2007).

In 2005 there were 278 households involved in the farming of 394,905 pigs in Jeju (Korea National Statistical Office, 2007). The economy of pig farming in Jeju is closely related to tourism, as pork is one of the local delicacies that helps attracts tourists to the island. Both domestic tourists from mainland Korea and international tourists from China and Japan, visit the pork restaurants on the island and it has been estimated that the Jeju pig industry in 2010 was worth over 300 million USD (KSA, 2011). Jeju exported 5,000 tonnes of pork to Japan and Asia in 2010 worth approximately 19 million USD (KSA, 2011).

Jeju Island has been free from CSF since December 1999. An outbreak of CSF in Jeju would result in significant losses through the costs associated with the slaughter and disposal of affected animals and the compensation required. Furthermore loss of the CSF

free-status would result in a loss of markets which would also have a significant economic impact on the island.

There are direct flights and ships from mainland Korea and China to Jeju Island (Figure 5.1). Although these provide access to trading opportunities, they also increase the risk of entry of CSF into Jeju from these infected regions/countries. In this chapter the results from a risk assessment for CSF are reported and discussed to identify those routes of high potential risk for the introduction of disease.

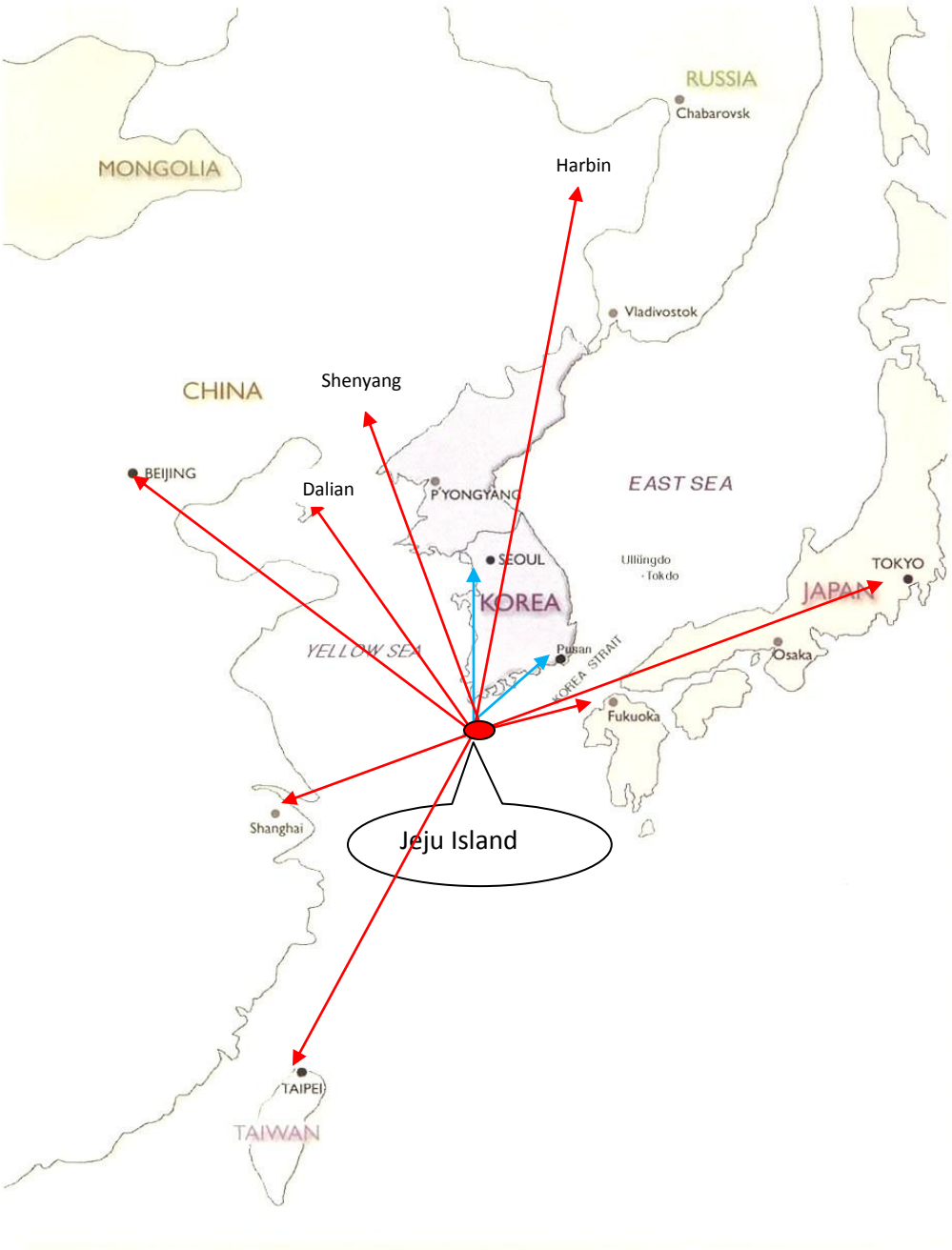

Figure 5.1 Sources of flights and ships to and from Jeju Island

5.2 Materials and Methods

5.2.1 Risk analysis

A risk is an event that may occur and when it does it results in a negative impact on the goals of an organization or country (Vose, 2008). Risk analysis consists of four components (hazard identification, risk assessment, risk management and risk communication) (OIE, 2010) (see Figure 5.2).

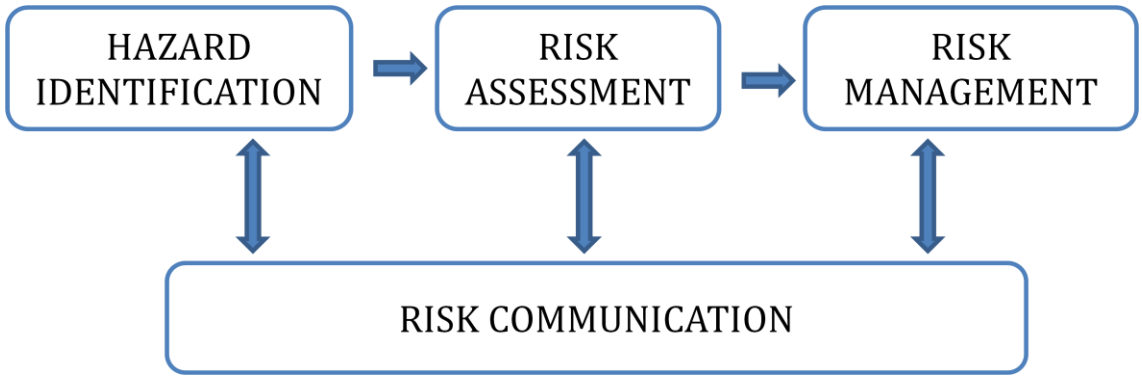

Figure 5.2 The four components of a risk analysis

In Figure 5.3 a flow-chart of a risk analysis for a disease, such as CSF, is displayed.

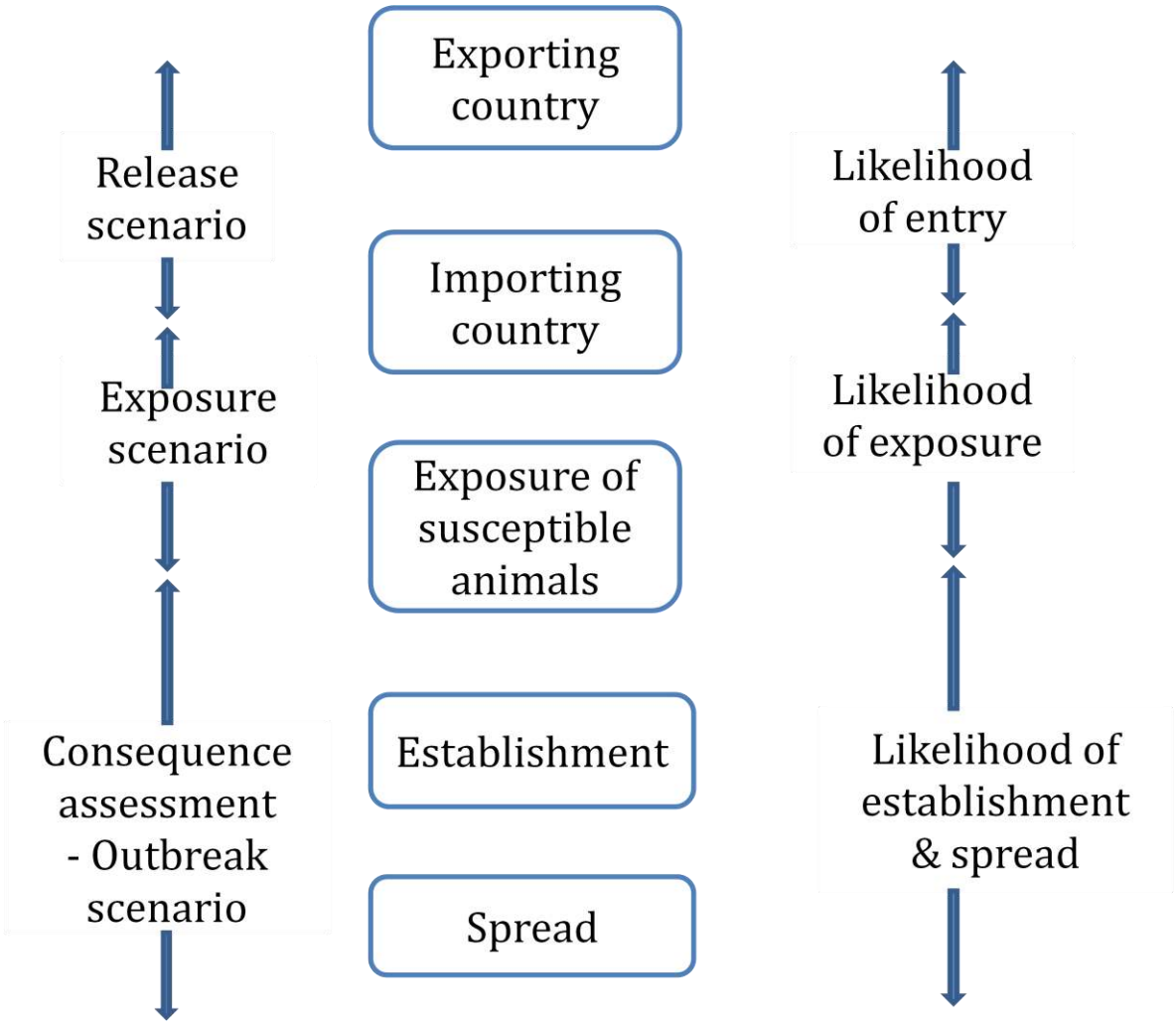

Figure 5.3 Risk assessment flowchart

5.2.2 Sensitivity analysis

To understand the influence of each input variable on the frequency of outbreaks, sensitivity analyses were conducted. The steps used to perform this sensitivity analysis were as follows: 1) Increase the value of one variable by a factor of 10; 2) Run the model 1,000 times to determine the mean number of years until an outbreak occurred; 3) Return

the variable to the initial value and increase the value of the next variable by a factor of 10 and repeat the process; 4) Compare all values to determine which variable has increased by the greatest multiple for a 10 fold increase in the initial value. This identifies the variables which are most sensitive to affecting the outcome of interest.

5.3 Risk assessment

5.3.1 Hazard identification

While Jeju Island is still free of CSF, its free status is threatened by the smuggling of live pigs or livestock products from China or mainland Korea. It is possible that CSF could be introduced to Jeju Island at any time through a number of ways. Therefore in this study the hazard was the introduction of CSF into Jeju Island.

5.3.1.1 Transportation to Jeju

Aeroplanes fly daily between Jeju and nine domestic airports on mainland Korea. Passenger and cargo ships also sail daily from six ports located in four provinces of the ROK (Table 5.1). There are also daily international flights from Jeju to Japan, China and Taiwan (KAC, 2011).

Table 5.1 Commercial transport between Jeju and mainland Korea

Source (KAC, 2011)

Province	Airport	Port
Seoul	Kimpo	-
Busan	Kimhae	Busan
Incheon	Incheon	Incheon
Daegu	Daegu	-
Gwangju	Gwangju	-
Ulsan	Ulsan	-
Gangwon	Wonju	-
Chungcheongbuk	Chungju	-
Jeollabuk	Gunsan	-
Jeollanam	-	Mokpo Wando Nokdong Janghung

5.3.1.2 CSF outbreaks in neighbouring countries

Japan and Taiwan were not considered as a risk in this study since both countries are free from CSF. Japan obtained CSF free country status from the OIE in 2007 (MAFF, 2007) and no CSF has been reported in Taiwan since 2009. In contrast, outbreaks were reported from provinces in China in 2010 (Table 5.2) (OIE, 2011). However, due to a lack of data from China, the risk assessment conducted did not include risk of introduction from this country.

Table 5.2 CSF outbreaks in China

Source (OIE, 2011)

Province	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anhui			2	3	3	2	4	3	2	1		
Fujian	4	8	7	6	4	5	6		1			
Gansu		2				1		1	1	1	2	
Guangdong	3	1	2	2	2	2		3			1	1
Guangxi	6	9	8	5	7	8	6	63	30	18	20	10
Guizhou	6	5	6	9	5	8	6	13	13	3	7	1
Heilongjiang	1					1	1					
Henan			1	1	1	1						
Hubei	2						5	2		1		
Hunan	1		1	1	1	1	1	1				1
Jiangxi									2		1	
Ningxia	3	2	3	3	1	2	1		1	2		
Qinghai		1		1				1				
Shaanxi	1	1	2	2	1	1	1	7		4	4	2
Xinjiang			2		1					3		3
Yunnan			3	4	3	4	4	2		3	3	
Zhejiang			1		1	1	2					
Total	**27**	**29**	**38**	**37**	**30**	**37**	**37**	**96**	**50**	**36**	**38**	**18**

5.3.2 Risk pathways

In this study the entry of CSF into Jeju Island was considered to be via seaports or airports. The probability of entry depends upon several pathways. Jeju Island has autonomous law that bans the importation of pigs and pig products from mainland Korea. Thus, the legal importation of pig and pig products was not considered as a risk; however, there is a risk due to smuggled pig products.

Between November 2004 and April 2005, antibodies to CSFV were detected in 34 pig farms on Jeju Island during the annual serological survey. The last occurrence of CSF occurred on a pig farm in 1998 and all the pigs on that farm were subsequently destroyed. Since that time, CSFV antigen- or antibody- positive pigs have not been permitted to enter the island from mainland Korea. It was concluded that the seropositives of 2004/2005 arose from the feeding of blood meal illegally obtained from mainland Korea (Kim *et al.*, 2008).

The main pathways for entry of virus from mainland Korea and China include the smuggling of: live pigs; raw pig meat; or livestock products. Heat processed pork products were not considered to be a risk in this study since the virus is inactivated during heat processing (Rehman, 1987). The entry of CSF can occur via any of these pathways, however due to a lack of data, only the highest risk pathway (smuggled live pork from mainland Korea and China) was analysed in the current model. This model used the Excel add-in Poptools for analysis and 1,000 iterations were undertaken. The values used for the Pert distributions were collected from the Korean National Statistics Office, KAHIS and from journal articles. Some data were estimated due to a lack of suitable reputable values.

5.3.3 Development of possible pathways for the introduction of CSF

The probability of entry of disease was calculated using a scenario tree approach and the possible outcomes are displayed in Figures 5.4 and 5.5.

As a release assessment, the following factors were considered.

- How many pig farms are present on mainland Korea?
- What is the probability of a CSF outbreak in Korea?
- How many pigs are there per farm?
- What is the prevalence of CSF on affected farms?
- What is the probability of detection during slaughter?
- What is the probability of CSFV being harbored in/on meat?
- What is the probability of frozen pig meat being smuggled to Jeju Island?

As an exposure assessment, the following factor was also considered.

- What is the probability of the detection of CSF infected pork during quarantine?

As a consequence assessment, the following factors were considered.

- What is the probability of CSF infected pork being distributed to pig farms?
- How many farms feed swill?

- What is the probability of insufficient heat treatment of swill?
- What is the probability of CSF transmission in farms?
- What is the probability of spread from the target (initial) farm to other farms?

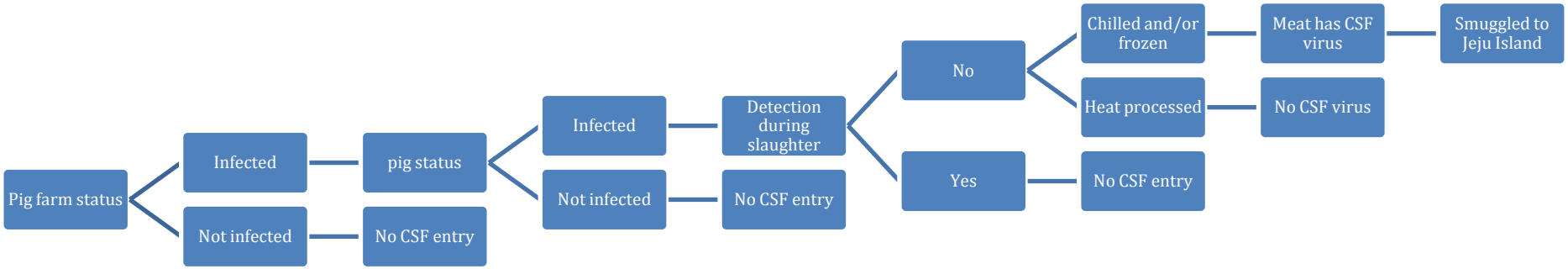

Figure 5.4 Risk pathways for release assessment

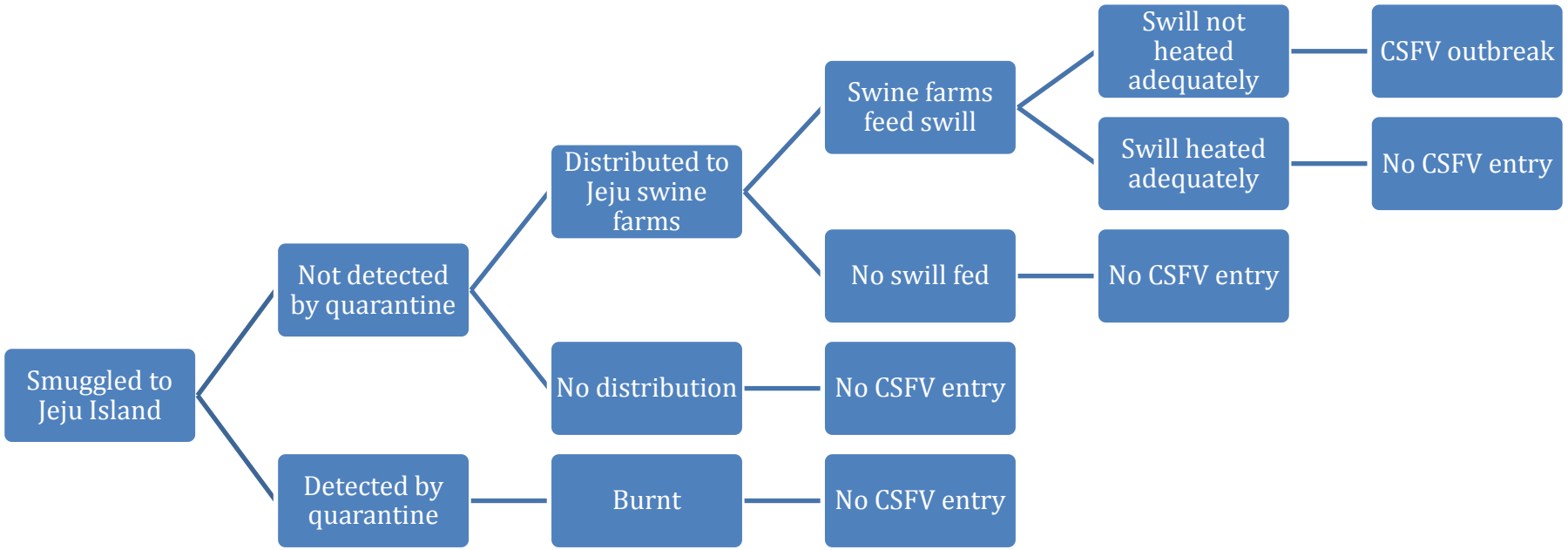

Figure 5.5 Risk pathways for exposure and consequence assessment

5.3.4 Summary of input parameters

In March 2011 the number of pig farms on mainland Korea was 5,400 (KOSIS, 2011). The number of outbreaks of CSF between 2000 and 2010 varied from 0 to 72 (KAHIS, 2011) and consequently in the analysis a minimum number of 0, a median value of 5, and a maximum value of 72 was used for the number of outbreaks on the mainland. The number of pigs per farm used in the analysis was set at a minimum of 50 for small-scale farms, 1,000 for medium-scale farms and 10,000 for large-scale farms.

The prevalence of CSF on infected farms was set at a minimum of 1%, with 8% most likely and a maximum of 20. The input variables for the proportion of carcasses harboring CSFV on the meat, the probability of frozen pig meat being smuggled, the proportion of smuggled meat detected during quarantine, the probability of smuggled meat being distributed to small-scale pig farms on Jeju Island, the number of pig farms feeding swill on Jeju Island, the proportion of farms that were swill feeding but not adequately heat treating the swill, the probability of transmission in these farms and the probability of spread to other farms are summarised in Table 5.3.

Table 5.3 Summary of the values used in the risk analysis

Inputs	Type of distribution	Minimum value	Most likely value	Maximum value
Number of pig farms on mainland Korea	Single value		5,400	
Number of CSF outbreaks on mainland Korea	Pert	0	5	72
Number of pigs per farms	Pert	50	1,000	10,000
Prevalence of CSF on infected farm	Pert	0.01	0.08	0.2
Detection during slaughter	Pert	0.01	0.5	0.9
Proportion of pigs harbouring CSFV in meat	Pert	0.01	0.4	0.8
Probability of smuggling frozen pig meat	Pert	0.01	0.1	0.3
Probability of detection during quarantine	Pert	0.01	0.5	0.9
Probability distributed to small-scale pig farms	Pert	0.01	0.3	0.7
Number of farms feeding swill	Pert	0.01	0.3	0.6
Proportion of farms with inadequate heat treatment of swill	Pert	0.1	0.3	0.6
Probability of transmission on the farm	Pert	0.1	0.5	0.9
Probability of spread from target farm to another farm	Pert	0.05	0.1	0.3

After 1,000 iterations in Poptools, the average number of years before an outbreak of CSF occurs on Jeju Island was calculated and the results are shown in Figure 5.6. It was simulated that the mean number of years until an outbreak occurred through smuggled pork was 1,862 years.

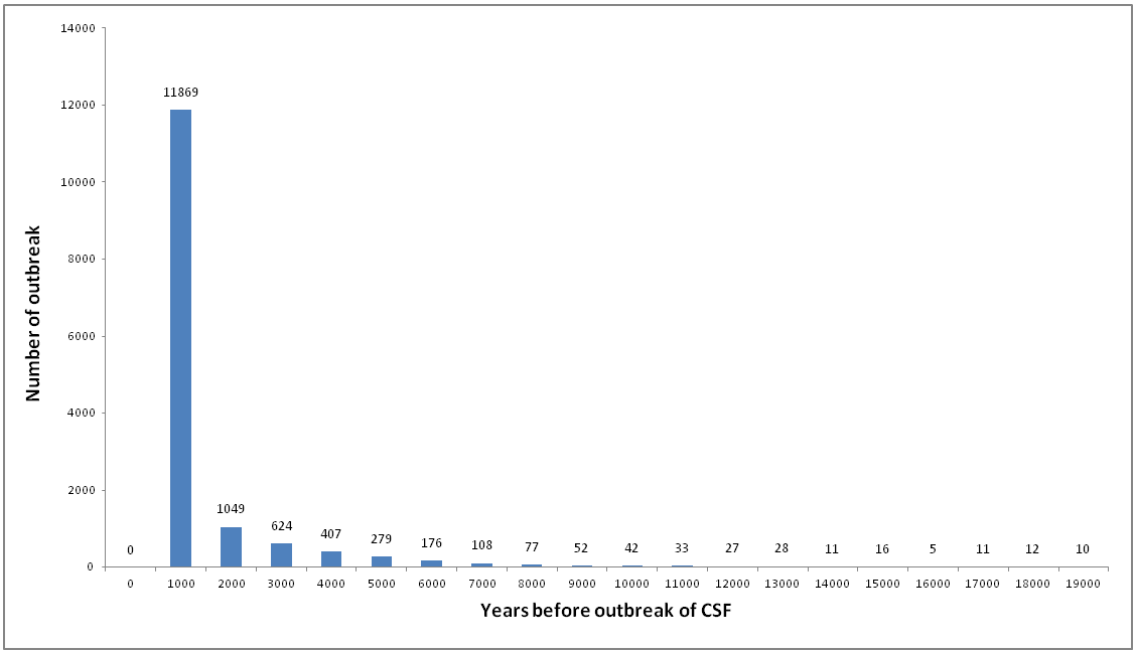

Figure 5.6 Average number of years before an outbreak of CSF

5.3.5 Sensitivity analysis for CSF

In Table 5.4 the results of the sensitivity analysis are displayed. The prevalence of CSF in infected farms, the probability of smuggling frozen pig meat and the probability of spread from a target farm to another farm and probability of ineffective heat treatment of swill had the largest impact on the number of years between outbreaks.

Table 5.4 Summary of sensitivity analysis for the introduction of CSF to Jeju Island

Parameters	Annual incidence	Magnitude of influence
Number of CSF outbreaks on mainland Korea	1,821	1.02
Prevalence of CSF on infected farms	1,540	1.21
Probability of detection during slaughter	1,838	1.01
Proportion of pigs harboring CSFV in meat	1,976	0.94
Probability of smuggling frozen pig meat	1,309	1.42
Probability of detection during quarantine	2,545	0.73
Probability of distribution to small scale pig farms	1,725	1.08
Number of farms feeding swill	1,833	1.02
Proportion of farms not effectively heat treating swill	1,526	1,22
Probability of transmission in an affected farm	1,780	1.05
Probability of spread from the target farm to another farm	1,403	1.33

5.4 Discussion

The risk assessments undertaken in this study were based on the release, exposure and consequence pathway which did not cover all the possible transmission pathways for CSF virus. The complete transmission pathway would include both direct and indirect pathways and would involve many factors including environmental factors, biological

factors. Unfortunately there were not enough available data to assess the complete risk pathway at the time of study. Further studies are required to estimate the likelihood of virus transmission to Jeju Island through all potential routes. However it is probable that the virus would most likely enter the island through contaminated meat products and hence this analysis considered this risk.

This study supports the hypothesis that CSF virus spreads by the illegal movement of pig meat. In this study the risk of CSFV entering into Jeju Island through contaminated smuggled pork was predicted at only once every 1,862 years. This value was sensitive to the prevalence of CSF, the probability of pork being smuggled, the probability of transmission between farms and the probability that the heat treatment of swill was ineffective. If the prevalence of CSF was increased 10 times then outbreaks were predicted to occur once every 1,540 years. When the probability of people smuggling pork was increased 10 times, outbreaks were predicted every 1,309 years. Similarly insufficient heat treatment of swill and increased spread between farms resulted in more outbreaks. Thus, increasing awareness of farmers about the disease and developing educational materials about improving farm biosecurity and minimizing disease transmission are important.

This study identified the factors that increased the risk of CSF entering a free area (Jeju Island), however the overall probability of an outbreak occurring was low. Irrespective of this value it is still considered that methods should be implemented to further reduce

this risk. The role of education of both farmers and the general public are central to risk mitigation procedures for CSF.

CHAPTER 6: GENERAL DISCUSSION

6.1 Introduction

Pigs play an important economic role in the ROK and are a major aspect of agricultural production. The number of pigs slaughtered each year in the ROK is high being nearly 15 million in 2010 (Livestock product safety division, 2011). There are two forms of pig farms in the ROK: private farms and large commercial enterprises. Although the number of pig farms has declined steadily over the past decade, during this time the total number of pigs in the ROK has actually increased. More pork is consumed by Koreans than any other meat with pork now representing almost half of all meat consumed. This increasing demand for pork products and the concurrent increase in the pig population has resulted in the development and expansion of the pig industry with potentially increasing market opportunities. However these opportunities may be restricted by the presence of diseases such as CSF.

Classical swine fever is a highly contagious viral disease that infects both domestic and wild pigs (Paton and Greiser-Wilke, 2003), and has high morbidity and mortality, especially in young animals (Moennig and Greiser-Wilke, 2008). Infection of pigs can result in an acute fatal disease with mortalities up to 100% in a susceptible population, however it similarly can result in a chronic form of disease which may be difficult to detect due to the mild signs associated with reduced productivity (Dahle and Liess,

1992). In the ROK, CSF was first reported in 1947. Wide use of vaccination and culling of infected animals and mandatory nationwide vaccination and testing were implemented since 1996. As a result of these campaigns the number of cases of CSF decreased until none were reported in 2000 and 2001. In 2001 the ROK achieved all of the OIE requirements to declare the country free from CSF (Wee *et al.*, 2005). However since 2002, when the disease was reintroduced, sporadic outbreaks have been reported. Therefore, this study was designed: to describe the pig industry in Korea; to determine the seroprevalence (antigen and antibody) of CSF; to identify risk factors associated with infection; and to conduct a risk analysis for the disease entering a free area (Jeju Island).

6.2 **Prevalence of CSF in the ROK.**

In this study the overall antibody seroprevalence of CSF in ROK from 2004 to 2010 was 89.25% (95% CI: 89.2 - 89.3%). In contrast the proportion of samples positive to CSFV antigen was only 0.03% (95%CI: 0.03 - 0.04). The high seroprevalence was a result of the widespread use of vaccine, and the low antigen level indicates the virus is not circulating widely in the pig population.

The seroprevalence varied between different cities and provinces. It is likely that this was associated with vaccine failures through inadequate cold-chain (Morilla Gonzalez *et al.*, 2002), biased sampling or cross reactions (Suradhat *et al.*, 2007).

Others have shown that the purchase of weaner pigs from different breeding farms or from markets increases the risk of introducing the virus into a susceptible population (Beals *et al.*, 1970). However an effective vaccine program should counteract this and a survey conducted in 2009 found that 61% of farmers checked the vaccine status of pigs prior to purchase (KSA, 2010).

6.3 Impact of CSF in the ROK

Classical swine fever results in both direct and indirect losses to pig producers. Direct losses include deaths and decreased production, productivity and reproduction in pigs and the additional expenses for the treatment, control or prevention of the disease. Indirect losses include losses from any trade bans or restrictions on the sale of products, additional costs through any biosecurity measures implemented and stresses and strains on the pig producers (Niemi *et al.*, 2008; Saatkamp *et al.*, 2000). The economic impact from outbreaks of CSF in the Netherlands in 1997 was estimated to be USD 2.3 billion (Artois *et al.*, 2002; Clavijo *et al.*, 2001). Economic evaluation of the impact of CSF has not been conducted in the ROK. Such an evaluation is required and is essential to ensure cost-effective treatment, control and prevention measures are implemented.

6.4 Modes and routes of transmission of CSFV

Knowing the modes and routes of transmission of CSFV are essential in developing effective control programs for CSF. Transmission of CSFV can be through direct contact with infected pigs or by ingestion of products from infected pigs (Karsten *et al.*, 2005; Paton and Greiser-Wilke, 2003; Stegeman *et al.*, 1999). Whereas, indirect transmission may occur via people, wild animals and inanimate objects, animal products and by-products (Paton and Greiser-Wilke, 2003), vectors, semen and embryos, vehicles and other contaminated materials (Elbers *et al.*, 1999; Moennig *et al.*, 2003). The virus is transmitted mainly by the oro–nasal route, through contact with mucous membranes or skin abrasions, insemination, or percutaneous blood transfer (e.g., reuse of needles, contaminated instruments) (Moennig and Greiser-Wilke, 2008). The movements of infected pigs, contaminated trucks, swill feeding, contaminated clothing and footwear of people have been suggested as the most common means for transmitting the virus between herds (Dahle and Liess, 1992; Terpstra, 1987). People can play an important role in the distribution of virus, in particular farmers, inseminators, pig handlers, and veterinarians. The outbreak in 2002 in the ROK most likely resulted from the inadvertent carriage of the virus by piggery workers who had visited an infected area in China. The role of farm biosecurity cannot be overemphasized and must play a major part in keeping this and other diseases out of piggeries, provinces and countries. The virus can also be distributed through airborne transmission (Laevens *et al.*, 1999; Terpstra, 1987) however this is not likely to lead to the introduction of virus into a country but would facilitate the spread of virus within a country.

The movement of pigs, which were incubating the disease or which were persistently infected, has been shown to be an important source of transmission of CSFV, particularly at the start of an outbreak (Elbers *et al.*, 1999). Swill feeding is also an important risk factor for CSF (Edwards, 2000). There is the potential for CSFV to be transmitted through the semen if collected from infected boars (de Smit *et al.*, 1999; Floegel *et al.*, 2000). The best strategy to prevent AI-transmitted diseases is to use boars from specific pathogen free herds (SPF), to monitor the animals and semen regularly for disease, and to maintain a donor herd of very high biosecurity (Maes *et al.*, 2008). The CSFV can also be transmitted from domestic pigs to wild pigs and vice versa (Boklund *et al.*, 2008). As wild pigs are present in the ROK, there is a need for further investigation in the role of these animals in sporadic outbreaks.

6.5 **Eradication and control of CSF**

Vaccination against CSF was developed in the 1960s (Terpstra, 1991) and there are now a number of highly effective live attenuated vaccines available (Paton and Greiser-Wilke, 2003). Vaccination is the most common means used for prevention and control of the disease in endemic areas (Suradhat *et al.*, 2007). Several conventional vaccines against CSF have been developed that claim to be safe and effective in inducing protection of pigs against clinical disease and reducing the shedding of CSFV. The disadvantage of this type of vaccine is that vaccinated animals cannot be differentiated through standard serological tests from animals that have recovered from natural

infection (Suradhat *et al.*, 2007). In contrast the E2 vaccine is a marker vaccine, allowing differentiation between naturally infected and vaccinated pigs (Suradhat *et al.*, 2007). This vaccine is based on the envelope glycoprotein E2 (Zijl *et al.*, 1991) and induces a neutralizing antibody response in pigs (Van Oirschot, 2003; van Rijn *et al.*, 1999). During an infection with field virus, antibodies are produced against all viral proteins, although they do not all neutralise the virus. Consequently detection of antibodies which are not directed against the E2 glycoprotein should be indicative of a serological response to natural infection with CSF (Suradhat *et al.*, 2007).

It is essential that farmers understand the benefits of vaccination before a vaccination program is likely to be successful. Therefore it is important that suitable educational material is developed and disseminated before a vaccination campaign is implemented. The FAO emphasized the role of farmer awareness and education programmes as well as other publicity campaigns on disease control (Geering *et al.*, 1999). Agricultural extension includes both public and private sector activities relating to technology transfer, education, attitude changes, human resource development, and dissemination and collection of information (Marsh and Pannell, 1999). However currently in the ROK there is a lack of interaction between the public and private sectors and a deficiency in suitable educational materials.

With respect to husbandry and management, good farming practices are required to minimize infection on farms. Farm managers need to be encouraged to adopt good husbandry and management practices including cleaning of pens, minimising the

feeding of swill and if it is fed to only feed properly treated swill and appropriate disposal of carcasses. It is essential to implement suitable biosecurity measures to minimise the transmission of CSF. In the ROK the livestock business registration system includes data on the disease status of farms, vaccination history and antibody test results. This system facilitates disease control.

Markets are ideal premises for the transmission of CSFV as livestock from many different sources are brought together for a short period of time, before moving to new premises or returning to their place of origin. Such premises pose particular problems for disease control, as they are potential sources for the dissemination of disease agents over wide geographical areas. In the ROK it is mandatory to produce a vaccination certificate during trading. However, only 61% of farmers checked the certificate, and further educational material is needed to increase this percentage.

Routine cleaning and disinfection of fomites should be implemented as part of the normal management procedures to prevent the transmission of CSFV onto farms (Owen, 1995). Pathogens can survive on premises, and in particular in those areas associated with the housing of new-born and young animals, pregnant females and suckling mothers (Fotheringham, 1995) and regular cleaning and disinfection of such areas can help reduce the environmental burden of pathogens.

Biosecurity is important in the daily management of pig herds to avoid infections and subsequent costs associated with disease (Fotheringham, 1995). Entry to and exit from

contaminated premises by animal health personnel, workers, owners, wildlife, insects, domestic animals and rodents presents a risk of disease spread which demands constant attention. The least expensive means of controlling and eliminating the risk of introducing pathogens involves maintaining constant biosecurity programs (Ford, 1995) In order to reduce the risk of introducing CSFV into farms, both small-holder and large scale farms need to increase their on-farm biosecurity. As CSFV can be transmitted by both indirect and direct contacts, and the risk of disease introduction is more likely to be influenced by aspects of management and husbandry, it is important for farms to develop, implement and practice good on-farm biosecurity. Biosecurity is essential in preventing contact between healthy non-infected animals from infected ones, and encompasses cleanliness, disinfection, reduction of exposure, management of personnel, and ensuring the tracing of animals (Thrusfield, 2005).

Public awareness and understanding the benefits of a control program is required. Control programs for CSF are not stand alone programs and require the involvement and consideration of factors which affect the public, farmers, government and other stakeholders. Farmers, for instance, need to be informed about the benefits of the control program and its process so that the program implemented is well understood, particularly given that any control program is both time consuming and requires significant effort by farmers. The Government, farmers, stakeholders and other parties should work together to ensure the successful control and eradication of CSF.

When there has been: no outbreak of CSF in domestic pigs during the preceding 12 months, no evidence of CSFV infection in domestic pigs during the preceding 12 months and no vaccination against CSF then the ROK can be declared a CSF free country (OIE, 2010).

6.6 Risk assessment of CSF in Jeju Island

A quantitative risk assessment was undertaken to identify factors likely to result in an outbreak of CSF on Jeju Island, which has been free from CSF since 1999. Although this study did not cover all potential risk factors it focused on those considered to be of significance. Wooldridge *et al.* (2006) studied the importance of smuggled meats as a source of virus and highlighted the role of this product (Wooldridge *et al.*, 2006). This study also revealed that smuggled meats have the potential to result in outbreaks on Jeju Island, albeit infrequently. Corso (1997) similarly examined the likelihood of introducing CSF to domestic pigs in USA (Corso, 1997). In that study the feeding of uncooked swill was found to be an important precursor for disease outbreaks.

6.7 Limitations of the study and the need for further studies

It is concluded from this study that the ROK will eradicate CSF in the near future. However there is a risk of the disease reentering a free-area or country through a range of pathways. A lack of accurate data for these pathways results in significant uncertainty in the values obtained for modeling the risk of disease entry. To validate the modeling it

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