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Model pathways and data requirements for microbial risk assessment of major animal production types in Europe

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MODEL PATHWAYS AND DATA REQUIREMENTS FOR MICROBIAL RISK ASSESSMENT OF MAJOR ANIMAL PRODUCTION TYPES IN EUROPE

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Preface

MED-VET-NET aims to develop a network of excellence for the integration of veterinary, medical and food scientists, in the field of food safety, at the European Level, in order to improve research on the prevention and control of zoonoses, including food-borne diseases. The Network will also take into account the public health concerns of consumers and other stakeholders throughout the food chain. Med-Vet-Net comprises 16 partners across Europe and over 300 scientists. The institutes involved consist of eight veterinary, seven public health institutes and one learned society from 10 European countries. All partner institutes have national reference laboratory-based responsibilities for the prevention and control of zoonoses. The Network officially commenced on 1 September 2004. It is funded for five years at a cost of €14.4 million (£10 million) by the European Union (EU) 6th Framework Programme, within the 'Quality and Safety of Food' Priority Area. More information can be found on the website www.medvetnet.org.

The intended audience for this review is primarily scientists within MED-VET-NET or other interested scientists. The executive summary addresses decision makers, both food safety risk managers but also those responsible for research funding and veterinary and public health surveillance.

This report results from the activities in Work Package 14. In addition to the authors of this report, the following colleagues participated in meetings and made an active contribution to discussions and generation of concepts: Lüppo Ellerbroek (BfR, Berlin, Germany), Eric Evers (RIVM, Bilthoven, The Netherlands), Bruno Gonzalez Zorn (UCN, Madrid, Spain), Matthias Greiner (DFVF, Copenhagen, Denmark), Arie Havelaar (RIVM, Bilthoven, The Netherlands), Hans Houe (RVAU, Copenhagen, Denmark), Béla Nagy (VMRI, Budapest, Hunagry) and Maria Nöremark (SVA, Uppsala, Sweden).

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Preface

1. Introduction

The stage in the food production chain where multiplication of the pathogen takes place is key to any risk analysis. After all, there will be no human health problem without massive multiplication of a pathogen in one or more stages of the production chain. Often, multiplication of the pathogen occurs mainly or even exclusively in live animals. In live animals, not only multiplication of the pathogen within an animal has to be taken into account, but also transmission of the pathogen from one animal to the next. In primary production, the complexity of many non-linear processes, numerous possible interactions, a variety of management procedures, production forms and traditions all play a role in the establishment and spread of food borne pathogens. These positive feedback loops makes on-farm risk assessment non-trivial and considerably different from traditional risk assessment

This report is meant to give a brief overview and evaluation of major animal production types in Europe for which pre-harvest risk assessments are either available or needed.
The animal production types that are discussed in this report are broiler production, table-egg production, turkey production, ducks and geese production, pig production, dairy cattle production, beef cattle production, sheep production, and fish production. We cannot be comprehensive and describe all possible model pathways in all major production types in all possible levels of detail, so we restrict ourselves to one pathway per major production type. The species specific model pathways either focus on the entire pre-harvest phase in broad terms or a specific setting, phase or event during pre-harvest.

Each chapter describes a major animal production in Europe and provides an introduction to the specific animal-production type, the variations that can be found (e.g. conventional, free-range), the production processes involved, description of management, etc. This is followed by a decription of a selected model pathway that can be based on an existing model or a conceptual model framework. For the selected model, the data requirements are listed and some conclusions and recommendations are made. One of these suggested model pathways could form the basis of a research-grant proposal that would allow our consortium to put our gained insight into action.

2. Broiler production

2.1 Introduction

For the purpose of animal health requirements, poultry is defined as comprising fowl, turkeys, guinea fowl, ducks, geese, quails, pigeons, pheasants, partridges and ratites *(Ratitae),* reared or kept in captivity for breeding, production of meat or eggs for consumption, or for re-stocking supplies of game (EU, 1990). The production of chickens represents the majority of the poultry production. In the World, the number of chickens involved in commercial production can be estimated to be $20x10^9$ broilers and $180x10^6$ breeding birds. Most of this production is concentrated in few countries, with USA representing 24%, China 18.5% and the EU 14% of the World production (EC, 2000). Within Europe, France, the United Kingdom and Spain are the major producers of broilers (Table 1). With the adhesion of the ten New Member States on the first of May 2004, the poultry production in European Union increased by approximately 18% (EC, 2005).

Table 2.1. Production of poultry (Eurostat, 2005). Includes the total carcass weigh of poultry whose meat is declared for human consumption. Covers mainly the production of *gallinaceae*, including broilers.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
EU (15 countries)	-	7774	8182	8358	8636.4	8823	9148	8939	9381.5	9382	-	-
Euro-zone	-	5758	5943	6154	6362.3	6521	6843	6649.4	7032.5	7343	-	-
BLEU	204	236	270	297	315	346	325.2	295.81	290.8	320.5	-	-
Czech Republic	-	-	-	-	-	-	-	-	218.7	222.1	-	-
Denmark	172	185	184	182	185	194	205	205	218	219	205	213
Germany	615.4	639.2	663.9	692.8	733.52	789.7	825.8	922.64	985.65	1025	1076.8	1155
Greece	170.8	171.8	161	176.4	172.84	149	153.7	163.79	162.59	164	169.15	165.6
Spain	824.6	972.8	1008	954.1	998	999.1	1199	1124.5	1304.8	1331	1335.6	1310
France	1875	1991	2219	2230	2275.2	2324	2403	2242.9	2268.8	2145	2015.3	1975
Ireland	90	100	112	118	124	119	124	121	121	121	-	-
Italy	1086	1092	1098	1117	1137	1148	1131	1080	1134	1169	1097	1128
Latvia	-	-	-	-	-	-	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-	-	-	-	33	-	-
Malta	-	-	-	-	-	-	-	-	-	6.9	7.4	-
Netherlands	575	587	610	650	671	674	704	695	717	705	485	-
Austria	101.5	101.9	98.57	98.08	103.75	107.2	103.5	105.9	108.4	109.9	112.1	114.1
Poland	-	-	-	-	-	-	-	-	-	-	851	-
Portugal	216	235	231	245	267	298	287	293	317	311	270	-
Finland	-	39.44	42.8	49.44	52.8	61.2	66.4	64.4	75.7	82.6	83.7	87
Sweden	-	75.23	79.8	82.33	89.73	87.93	94.14	99.149	105.83	110.6	105.66	-
United Kingdom	1292	1348	1404	1466	1511.6	1526	1527	1525.9	1571.9	1544	1573.5	1574

(-) Not availabe

Different production types, either extensive or intensive systems, are described: label rouge, freedom food, extensive indoor, free range, traditional free range and free range total freedom (EU, 2000).

2.2 Description of the production types

The different production systems can be broadly categorized into extensive or intensive production. Intensive production systems imply indoor production with large flock sizes, big output and a large number of hens per m^2. Moreover, the majority of the processes are automated. The production takes place on litter systems, and regulations (Sweden and Switzerland) or recommendations (Germany and UK) for proper standard broiler production are available (EU, 2000). Figure 1 summarizes the broiler production in intensive systems.

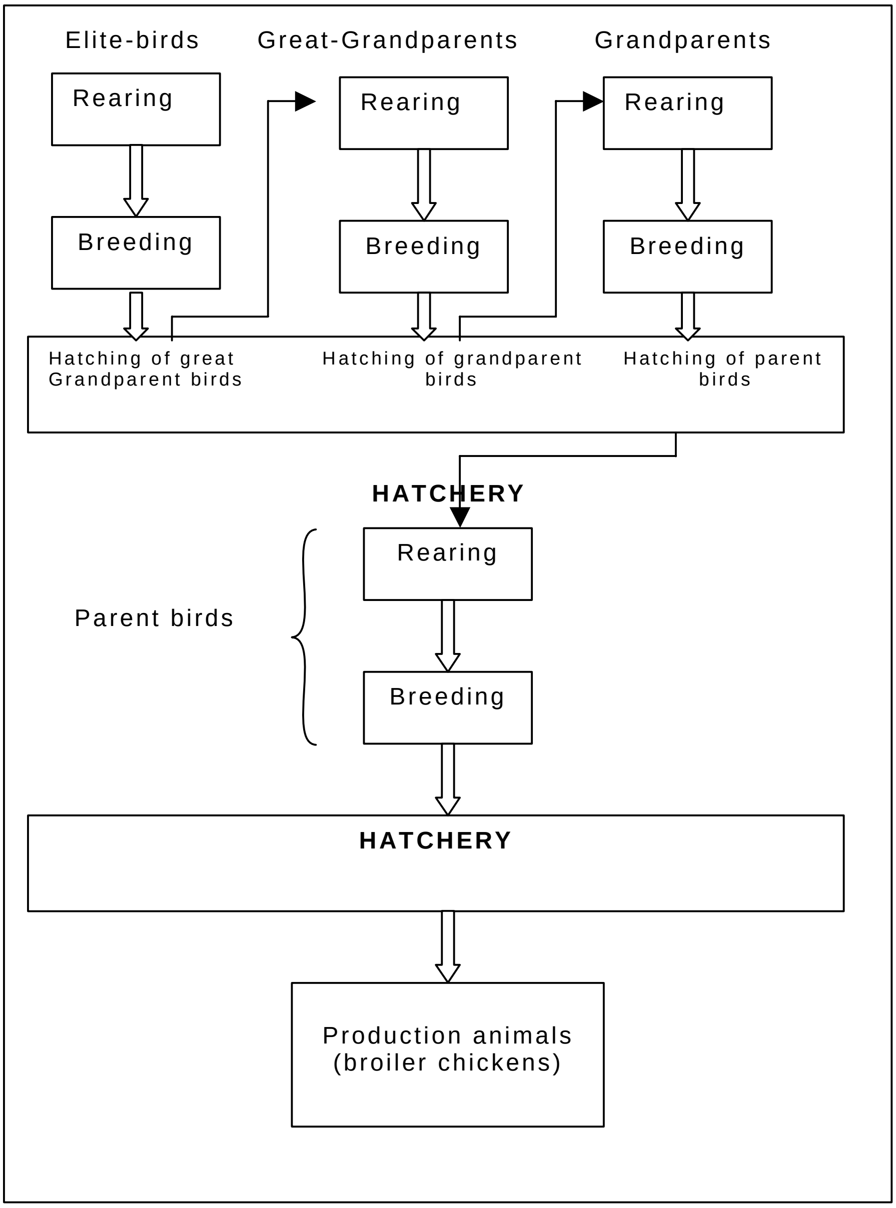

Figure 2.1. Overview of the broiler breeder production (Flensburg, 2001)

The extensive systems typically consider different animal-welfare parameters. Broilers with outside access have a lower stocking density and immediate access to fresh air. Nevertheless, the animals that are kept outdoors have a greater risk of exposure to infectious agents, through the contact with wildlife or insect vectors.

This chapter will focus on the intensive production systems of. The broiler breeder production includes a number of closed lines: a population of elite-birds, the great-grandparent stock, the grandparent stock, parent birds and production animals (boiler chickens). Table 2 shows the production parameters for broiler in European countries.

Table 2.2. Range of broiler production parameters in European countries (EU, 2000)

Parameter	Typical reported ranges
Slaughter weigh (g)	1440 - 2310
Slaughter age (days)	36 - >50
Stocking density	
(No./m^2)	11 - 25.4
(Kg/ m^2)	22.5 – 42.5
Mortality (%)	4.1 - 7.1

The number of broiler producer companies is limited in a worldwide basis (Flensburg, 2001). Consequently, the same company distributes grandparents and parent flocks to the EU, Central and Eastern Europe, Middle East, Africa, Australia and Japan (Flensburg, 2001).

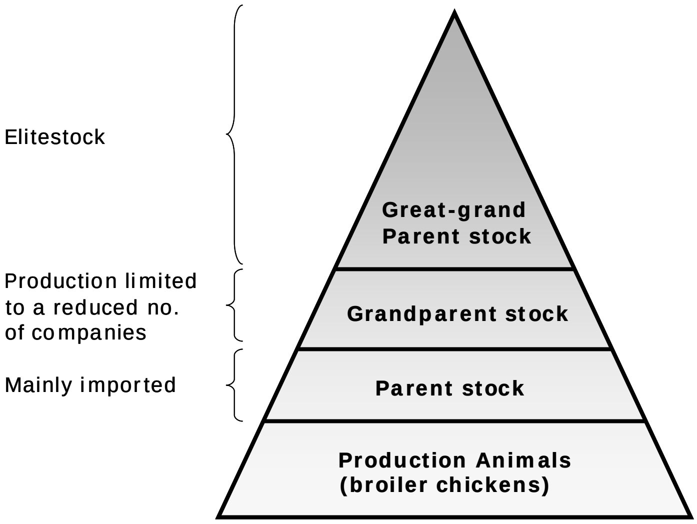

Figure 2.2 The pyramidal structure of broiler chicken production (adapted from Flensburg, 2001).

2.3 Overview of recent risk assessments of the broiler production chain

In the pre-harvest broiler production chain there are essentially two pathogens that at present pose a significant problem to human health: Salmonella and Campylobacter. Especially *S. Enteritidis*, *S. Typhimurium*, *C. jejuni*, and to a minor extent *C. coli,* are at present important food borne pathogens. Potentially, other pathogenic bacteria, such as pathogenic *E. coli* (especially VTEC), could also constitute a future threat to human health.

Risk assessments of the broiler production chain that include a dynamic description of pathogen growth in live animals have been published recently (Table 3).

Table 2.3. Relevant risk assessments of the broiler production chain that take the on-farm multiplication stage of pathogens into account.

study	year of publication	study characteristics
Chriel *et al.*	1999	Pathogen(s) considered: *Salmonella Typhimurium.* Data used: Danish Poultry Council database. Model: Generalised Linear Mixed Model. Main result: Broiler flocks with Salmonella infected parent stocks have increased risk of Salmonella infection. Description: This study presents a state-of the-art statistical analysis of the risk factors for Salmonella infection based on ante-mortem data from the Danish Poultry Council. The model is purely statistical, i.e. no dynamical transmission model is used.
Hartnett *et al.*	2001	Pathogen(s) considered: *Campylobacter* spp. Data used: Published data on Campylobacter prevalence in the UK, and expert opinions on a variety of parameters such as transmission and contact rates, flock size, age at exposure, etcetera. Model: Two-stage within flock transmission model. Main result: Probability that a random bird is positive at slaughter is approximately 50%, with the age at first exposure being an important determinant of prevalence at slaughter. Description: In this study a two-stage transmission model is constructed. The first stage describes the spread of Campylobacter in a small cluster of birds by means of a stochastic chain-binomial model. The second stage describes epidemic transmission of Campylobacter through the remainder of a flock by means of deterministic Ordinary Differential Equations (ODEs). Critical parameter values are largely based on expert studies.
Ranta and Maijala	2002	Pathogen(s) considered: *Salmonella* spp. Data used: Finnish National Control Programme. Model: A stochastic model is presented for both horizontal and vertical transmission of Salmonella in different types of broiler flocks (i.e. grandparent, parent, broiler). The model is used to obtain estimates of key epidemiological parameters such as (vertical and horizontal) transmission parameters, cross contamination levels) as well as test sensitivity. Main result: The model analysis yields estimates for the parameters mentioned above. The model predict the 1999 broiler flock prevalence to lie in the range 1%-17%. On the basis of the model estimates and prediction of broiler prevalence, the model suggests that intervention (i.e. slaughter of positive breeder flock) would results in a broiler flock prevalence of 1%-6%. Description: This model structure is inspired by the structure of the data from the Finnish control programme. As a result, within-flock prevalence is not modelled dynamically, but is constant over time. Flock prevalences are estimated with a Bayesian approach using Markov Chain Monte Carlo (MCMC) techniques. Programming tool: WinBugs.

Rose *et al.*	2003	Pathogen(s) considered: *Salmonella* spp. Data used: survey data from 85+60 broiler flocks in France. Model: The model(s) is (are) described very concisely, making it difficult to follow the precise methodology. It appears that the data of the survey of the 85 broiler flocks are analysed using logistic regressions. The various analyses are then combined to produce an overall measure for the 'risk of Salmonella contamination before placement of chicks'. Main result: Using the results from the analyses mentioned above, it is estimated that the overall measure of Salmonella risk has an estimated sensitivity and specificity of 98% and 64%, respectively. Description: This study gives a lot of raw background data of the surveys that may be helpful in future risk analyses. However, methodologies deficiencies may limit the scope and validity of the results. The model is purely statistical, i.e. no dynamical model for the spread of Salmonella is considered. This may further limit the generality of the results, as well as the model's applicability to other regions.
Maijala *et al.*	2005	Pathogen(s) considered: *Salmonella* spp. Data used: The Finnish Salmonella Control Programme, national statistics, industry data, and expert solicitation. Model: The complete model is made up of three separate modules describing the primary production, the secondary production, and the production phase. The focus is on the impact of the Finnish Salmonella Control Programme. Main result: The model predicted that 0.21% (0.05%-0.48%) of domestically produced broiler meat would be Salmonella positive. Based on this prediction, the effectiveness of control measures such as heat treatment of meat, and removal of detected positive flocks are estimated. Description: This study gives a complete farm-to-fork risk analysis of Salmonella infections in broilers. The on-farm module relies heavily on the study of Ranta and Maijala (2002) mentioned above.
Katsma *et al.*	2005	Pathogen(s) considered: *Campylobacter* spp. Data used: Within-flock data: Longitudinal data on development of Campylobacter prevalence in small experimental broiler flocks. Between-flock data: A Dutch one-year study of Salmonella prevalence on 10 broiler farms with 2 to 7 houses per farm. The sudy was carried out in 1999-2000. Model: The within-herd prevalence of Campylobacter in two small experimental populations is fitted to a generalized logistic growth curve by means of least squares. Subsequently, the fitted curve is used to derive a deterministic curve for Campylobacter prevalence in large commercial flocks. Between flock transmission levels were estimated using a chain-binomial-like model. Three infection routes are considered: from a previous flock in the same house, from a flock in the same farm, or from the outside. Main result: The estimated prevalence of infected flocks (~40%) lies within the range observed in the Netherlands. Description: This study is comparable in approach to the study of Hartnett *et al.* (2001). In comparison with the study of Hartnett, however, the description of the with-flock transmission is based on a simpler model, while the analysis and modelling of between-flock transmission is more sophisticated.

2.4 Description of selected model pathway

The production of broilers is strictly hierarchical in structure (Fig. 2). A small number of flocks, comprising the top level of the production pyramid, delivers all the eggs to the hatchers. The parent stock hens are moved into the egg-laying units when they are 16 weeks old and are replaced with new hens after a production period of approximately 40 weeks.

In the hatcheries, the eggs from different parent stocks are often mixed and in the hatchers. As a result, a flock of chickens delivered from the hatchery to a producer may contain offspring from more than one parent stocks (Chriél *et al*., 1999).

Uninfected flocks can become infected via vertical transmission (i.e. infected before hatching, resulting in exposure of a cohort via horizontal transmission following hatching), via contaminated feed, or via environmental sources (i.e. carryover infection from previously infected flocks).

The pre-harvest model should describe, quantitatively, the changes in prevalence and numbers that occur within each step, attributable to specific factors. The inputs to the model include the results of sampling on the different levels of the chain, both feaces of living birds and environmental samples of the hatcheries (Ranta and Maijala, 2002). The frequency of sampling varies according to the programmes adopted in the different European countries. The estimation of the prevalence and quantity of an infectious agent can involve taking into account various epidemiological and farm management factors that may influence these parameters (FAO/WHO, 2002).

The prevalence of an infectious agent in the first components of the breeder production chain - great-grandparents, grandparents and parent flocks - will determine the prevalence in the last generations of broilers. The vertical transmission can be modelled as a single occurrence resulting from the infection at the previous production level (Ranta and Maijala, 2002).

2.5 Data requirements

Quantitative modelling of the pre-harvest pathway requires quantitative information. Data can be collected from a number of sources, which include national surveillance data, epidemiological surveys, industrial surveys, research publications, unpublished research work and government reports. The data sources are not limited to the presented ones (FAO/WHO, 2002). Data requirements for pre-harvest modelling in broiler production are presented in Table 2.4.

2.6 Conclusions and recommendations

The aim of the broiler production model is to estimate the prevalence of an infectious agent in broiler flocks through the production chain, taking in account all the epidemiological and farm management factors that influence this parameter. The broiler flock prevalence is directly related to the probability of human illness related to the consumption of broilers (FAO/ WHO, 2002).

The different intervention methods integrated in a risk reduction strategy have different effects on the flock prevalence of a given agent. These measures can be broadly divided in methods to prevent vertical transmission, prevent horizontal transmission and increase the resistance of hens. The adopted measures and their effects should be taken into account in the pre-harvest chain model.

Table 2.4. Data requirements for pre-harvest modelling in broiler production

Main routes	Data requirements
Vertical transmission	Flock prevalence and within-flock prevalence in breeding flocks, separated by breed; Transmission rate at hatcheries;
Transmission from rearing phase to production phase	Flock prevalence and within-flock prevalence in rearing flocks, separated by breed, that includes information on sample size, test methods, etc; Testing scheme applied (i.e. test and destroy) ; Sensitivity of the scheme applied;
On-farm perpetuation (carry over infection from previously infected flocks)	Prevalence and within-flock prevalence of previous flock, that includes sensitivity of the testing scheme applied; Distribution patterns of infected flocks within holdings, regarding housing type; Cleaning and disinfection scheme, efficacy of it depending on housing system; Elimination of potential reservoirs (e.g. rodents); Management factors, depending on housing system;
Horizontal introduction of new infection	Feed supply; requirement for heat treatment; efficacy of control measures; Bio-security measures; Water supply and control; Other management issues;
Additional factors	Protective measures improving health status of birds, i.e. vaccination Data on the dynamics of within-flock transmission of the agent, depending on the housing type

2.7 References

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3. Layer production

3.1 Introduction

The commercial production of poultry is very diverse. There are two main food production systems: Poultry meat (carcasses and processed products) and eggs for consumption (table eggs) and further processing (egg products). Different genetic lines of birds are used for meat and egg producing flocks of chickens. There are also different genetic lines of birds for conventional and free-range or organic production systems. An overview on the population of laying hens in the European Union is given in Table 3.1.

Table 3.1. Number of holdings of laying hens (1000 T)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
EU (15 countries)	-	359019	356185	341447	-	349221	351067	366531	366255	-	-	-
Belgium	12506	12277	12436	12300	13654	14270	14227	12452.4	12943.4	12160	11822.9	-
Czech Republic	12556	12029	12030	11833	12280	11902	-	-	-	-	-	-
Denmark	4222	5296	4297	4725	3993	3621	3680	3681	3732	3653	3701	-
Germany	50700	51700	50700	50636	50468	50188	50054	50348	49873	48569	45175	-
Estonia	-	-	-	-	-	-	-	-	-	-	-	-
Greece	15769	15473	15742	14681	-	14556	14469	14805	15220	14722	14425.2	-
Spain	45727	46698	48634	44351	48300	46717	46726	51419.4	52112.7	56345	57110.8	59166
France	67700	66500	66400	59657	59863	60073	60325	63600	63700	62400	62175	-
Ireland	3335	3145	3228	2873	2903	2632	2802	3516	3425	3529	3448	-
Italy	49314	48126	49506	47774	47523	51120	55696	63289	62195.4	59279	58710	-
Cyprus	-	-	-	-	-	1300	-	-	-	-	-	-
Latvia	2375.6	2093.5	2071.2	2264	2223	2066.4	2032.4	1980.5	2047.6	2277.5	-	-
Lithuania	-	-	-	-	4706.9	4258.4	3837.3	3500.4	3658.5	3637.6	3964.8	-
Luxembourg	63.444	60.451	55.618	61.419	40.127	43.01	46.53	48.75	62.739	53.592	-	-
Hungary	-	-	-	-	-	-	-	-	-	-	-	-
Malta	-	-	-	-	-	-	-	-	-	417.8	420	-
Netherlands	42234	40868	38162	39579	40077	41435	42461	42461	42726	-	-	-
Austria	6324	6477	5937	5752	6048	6025	5580	5215	5220	5333	5159.4	-
Poland	38967	41786	39766	45880	44612	43386	-	-	-	51759	45113	-
Portugal	8143	8696	8087	7747	6516	7226	7097	7548	8000	8065	8129	-
Slovenia	-	-	-	-	-	-	-	-	-	-	-	-
Slovakia	7308	7578	7625	7405	7258	6161	-	-	-	-	-	-
Finland	-	5561.2	5542.7	5229.6	4983.6	4767.5	3390	3329	3290	3248	3175	-
Sweden	5764	5918	6100.3	5708.5	5724.5	5361.7	5647.5	5669.7	5686.89	4731.8	4497.68	-
United Kingdom	43090	42223.5	41357	40372	41340	41161	38869	39148.4	42700.6	46256	45000	-
Bulgaria	9521	11632	10615	8957	8524	8896	-	-	-	-	-	-
Croatia	6321	6353	6449	6260	6089	-	-	-	-	-	-	-

(-) Not available

For a prevalence study, recently conducted in all Member States of the European Union, holdings of at least 1000 laying hens were selected. The updated figures for this study population are given in Table 3.2.

Table 3.2. Number of holdings of laying hens above 1000 heads, by heads present (Source: Baseline study on the prevalence of Salmonella in laying flocks of Gallus gallus in the EU. Technical specifications SANCO/34/2004 Rev3)

		NUMBER OF HOLDINGS BY NUMBER OF HEADS PRESENT					
Country	Year	1.000-2.999	3000-4.999	5.000-9.999	10.000-29.999	>=30.000	Total
Austria	2004	444	162	97	53	13	769
Belgium	2003	30	46	66	127	145	414
Cyprus	2003	5		5	14	4	28
Czech Republic			33			48	81
Denmark	2004	29	59	76	72	27	263
Estonia	2004	0	1	0	5	6	12
Finland	2002	348	135	125	63		671
France	2003	206	275	495	494	370	1840
Germany	2001	1174	356	325	332	232	2419
Greece	2004	34	48	88	121	61	352
Hungary	2004	207	57	73	62	65	464
Ireland	2000	60	30	50	30	10	180
Italy	2001	191	115	194	291	377	1168
Latria	2004	2			4	10	16
Lithuania	2004	1		1	1	14	17
Luxembourg	2003	3	3	1	1		8
Netherlands	2004	102	137	276	673	365	1553
Poland	2004	150	108	219	408	353	1238
Portugal	2000	20	20	30	60	90	220
Slovenia	2003	39	12	20		10	81
Slovak Republic	2004	5		4		27	36
Spain	2000	230	160	330	580	430	1730
Sweden	2003	59	40	78	95	31	303
United Kingdom	2002/03	277	178	305	294	148	1202
Malta							

In 2004, an overall production of 5.706.000 tons of usable eggs for human consumption was recorded in EU-15 (ZMP). The new Member States increased that amount by 19% to 6.776.000 tons of usable eggs for human consumption in EU-25. In 2004, on average the per capita consumption was 13,6 kg eggs in EU-25. In Germany, within the first six month of 2005, 26% of the eggs consumed were derived of barn flocks, 22% from conventional free-range flocks and 45% from caged flocks.

3.2 Description of production type

The structure of poultry production is “pyramidal”. Every stage engenders a consequent reproduction of the number of individuals of the following stage. Theoretically, very great-grandparent female (Elite) could be the origin of between 160,000 and 300,000 laying hens producing between 4.16×10^7 and 9.00×10^7 table eggs (EFSA, 2004). Laying hens are kept in two housing systems during their live. From one day old until about 18 weeks of age they are kept in rearing systems, after that date they are moved to the laying house. In principle there are three categories of systems for housing laying hens: conventional cage systems, furnished cage systems (also called enriched cage systems) and non-cage systems (also called alternative systems). The non-cage systems can be further distinguished to barn, free range conventional and free-range organic. The housing systems for hens differ in the possibilities to allow species specific behaviours to be carried out by each bird. Keeping birds outdoor presents a risk of exposure to a greater range of infectious agents compared to birds kept only indoor due, for example, to exposure to wildlife including insect vectors. The possible consequences of exposure, infection and transmission, are likely to be different depending upon whether the birds are kept indoors or out, and the specific management systems. Where housing and management systems are poor, infectious agents, mainly bacterial, may have favourable conditions to develop.

Faecal matter and infection of the oviduct during egg development are both recognised as ways in which egg shells or contents can become contaminated with *Salmonellae*. Faecal contamination of the external surfaces of egg shells can present a contamination hazard to other foods but can also lead to contamination of the shell contents if *Salmonellae* migrate through the shell and associated membranes, particularly when eggs are first laid or stored in conditions of high humidity. However, it is thought that egg contents are more commonly contaminated, particularly with *S*. Enteritidis, as a result of infected reproductive tissue during the *in vivo* stages of egg development.

3.3 Description of selected model pathway

3.3.1 Selected production phase or process

In the table egg production chain, the production phase of laying hens is the most crucial one to be considered. The selected approach models the frequency of contaminated eggs at the time of lay and the level of bacteria initially present in contaminated eggs.

The Risk assessment of Salmonella in eggs and broiler chickens, as published by WHO and FAO in 2002, was used as a basis of this description. There, the existing techniques and practices used to construct an exposure assessment of *S.* Enteritidis in eggs were explained and compared.

The production component of the *S.* Enteritidis exposure assessment produces an output consisting of a distribution of contaminated eggs at varying levels of contamination. This distribution describes the frequency of eggs that contain *S.* Enteritidis bacteria per unit time or per egg. The production module predicts that contaminated eggs are produced at a frequency of about 5×10^{-5} (1 in 20000) when flock prevalence is 25%.

Additional outputs might describe the fraction of *S.* Enteritidis contaminated eggs by geographic region, by flock type (e.g. battery or free range), or by other factors that distinguish egg production facilities (e.g. flock size). This is not addressed in the current RA model.

3.3.2 Justification of the selected pathway.

Council Directive 1999/74/EC provides that rearing of hens on un-enriched cages shall be prohibited from 1 January 2012. Recently, an Opinion of the Scientific Panel on Animal Health and Welfare on request from the Commission related to the welfare aspects of various systems of keeping laying hens was published (EFSA, 2005). There, the microbiological hazards affecting food safety by different production systems were addressed.

Keeping birds outdoors presents a risk of exposure to a greater range of infectious agents compared with birds kept only indoors due, for example, to exposure to wildlife including insect vectors. Probability of exposure will be influenced by management systems. The possible consequences of exposure, infection and transmission are likely to be different depending upon whether the birds are kept indoors or out, and the specific management systems. Flocks kept with outside access usually have a lower stocking density, and immediate access to fresh air. In contrast, birds kept indoors, especially in non-cage systems, are likely to have more frequent bird-to-bird contact due to a higher stocking density, plus an environment where pathogen density is likely to be increased. This is likely to lead to increased infection and transmission rates. Where housing and management conditions are poor, infectious agents, mainly bacterial, may have favourable conditions to develop and create chronic disorders for example respiratory problems.

In general, the level of bacterial eggshell contamination seems to be higher on eggs laid in furnished cages than in conventional cages. In alternative systems, this level is even higher and seems to be related mainly to a higher microbial load of the internal environment of the laying house. There is limited information on the proportion of eggs contaminated and the level of contamination, with zoonotic bacteria, related to the methods of production. Of these, *S.* Enteritidis dominated in eggs, raw egg materials and egg products, and can be present on the eggshell and in the yolk of eggs. In theory, the risk of contamination with Salmonella spp. and particularly with S. Enteritidis might be higher when eggs are produced in some non-cage systems, because of the greater exposure of layers and their eggs to environmental contamination. Keeping birds in systems other can conventional cages, especially in alternative systems, may increase the demand for egg washing practices, due to the probable higher numbers of dirty eggs. In the Opinion, among others, future research needs are addressed.

Changes and improvements in designs of systems should also be assessed in regard to the effects of egg quality on the microbial safety of eggs. Special attention should be given to biosecurity measures. Collection of monitoring data on the surveillance of zoonotic bacteria and especially Salmonella spp. should be improved including the origin and mode of production of eggs and egg products. Quantitative and qualitative studies should be conducted on the microbiology of eggs produced in different housing systems. The effects of such microbial load and types of bacteria on the processing technology and quality of further processed products should be studied.

Regulation 2003/99/EC requires Member States to implement a control programme on Salmonella in laying hens by the end of 2007. For setting the target for reduction, a one-year prevalence study was recently finalised which provides for estimates of the Salmonella prevalence in flocks of laying hens and detailed information on several possible risk factors, including housing systems in all Member States of the European Union.

The WHO / FAO risk assessment, finalised in 2002, emphasised that the analysis and conclusion presented in that document apply only to currently understood mechanisms and variables, as incorporated in previous exposure assessments. Therefore, caution should be applied in interpreting this report in the context of data that has become available since these models were completed.
In summary, there is a need to update the risk assessments and address specific issues related to table egg production in the European Union.

3.3.3 Description of the processes involved

Inputs to a production component include the prevalence of infected flocks; the frequency at which infected flocks produce contaminated eggs; the number of *S.* Enteritidis bacteria initially present at the time of lay (or soon thereafter); and possibly moulting practices. These data may be derived from several sources, including prevalence studies of *S.* Enteritidis in layer flocks, epidemiological studies on risk factors, transmission study results, industry demographic data, and experimental or survey data concerning the concentration of organisms in, or on, infected animals or their products. The availability of detailed epidemiological data provides better risk assessments. Increased details provide information that is more precise for decision-making based on risk assessments. For example, the proportion of all eggs in a country or region that are contaminated can be calculated from: (1) an estimate of the proportion of flocks containing *S.* Enteritidis-infected hens, and (2) the proportion of eggs laid by these flocks and which are contaminated. From the risk management perspective, information on the spatial and temporal clustering of infected flocks is important. This includes, whether some flocks produce contaminated eggs more frequently than others (i.e. spatial clustering), or if there were certain times when flocks produce more contaminated eggs (i.e. temporal clustering).

Many factors contribute to variability in the production of contaminated eggs. These include regional differences in flock prevalence (if egg marketing is regional) and flock age. Other factors, i.e. stage of infection in flock, season, control efforts by management may also modulate within-flock prevalence and egg contamination frequency. Moult status of flocks is a proven risk factor that can influence flock-to-flock variability in egg production and egg contamination frequency. Knowledge from epidemiological studies on the relative contribution of risk of infection from vertical, feed-borne or other environmental sources, and carry-over environmental contamination should be included in the model. The factors described should be re-analysed in the light of the different production systems.

The data from the Netherlands (Giessen et al., 1994) and the United States of America (Schlosser et al., 1999) suggest that the carry-over route may account for >80% of the risk of flock infection in countries where Salmonella is endemic. If true, the complete control of breeder flocks might be only be expected to achieve >=20% reduction in the prevalence of Salmonella infected flocks in such countries. To reduce the risk of *carry-over infection* for commercial flocks, it is thought that aggressive cleaning and disinfection must be completed after an infected flock is removed and before another flock is placed to begin a new production cycle. Cleaning and disinfection must also include a long term rodent control programme. The effectiveness of cleaning and disinfection in preventing re-infection of the subsequent flock was assumed to be 50%. Furthermore, it was assumed that carry-over infection was responsible for flocks becoming infected. Consequently, houses that were not effectively cleaned and disinfected resulted in infected flocks when they were repopulated.

The spread of infection related to a single point source of infection and the resulting within-flock prevalence should be analysed in the light of the possible impact of different housing system. For the *within-flock prevalence* distribution used in the model, a single test of 90 faecal samples was likely to detect 44% of infected flocks. This was calculated using an equation, which assumed that an infected hen shed sufficient *S.* Enteritidis in her faeces to be detected by using standard laboratory techniques.

Vaccination for *Salmonella* has been examined. Injected killed bacterins are thought to have limited efficacy in preventing intestinal colonisation of hens with *S.* Enteritidis, although such bacterins may reduce internal organ (including ovary) infection via stimulation of humoral antibody. Live bacterins – or surface antigen vaccines – may be more effective at modulating intestinal colonization by *Salmonella* because these products may elicit the cell-mediated immune response needed to resist colonization. In the model, the vaccine was assumed to be capable of reducing the frequency of contaminated eggs by approximately 75%. Assuming 25% flock prevalence and the baseline egg storage time and temperature scenario, the probability of illness per serving for a single test and vaccination protocol (positives are vaccinated) is about 70% of a non-vaccination protocol. Given the efficacy of vaccination use based on field evidence, one could assume that universal vaccination might reduce the baseline risk to 25% of the risk resulting from a non-vaccinated population.

3.3.4 Key findings of selected model

There were several key findings of the WHO/FAO RA: The risk of illness per serving increases as flock prevalence increases. Reducing flock prevalence results in a directly proportional reduction of human health risk. Reducing prevalence within infected flocks also results in a directly proportional reduction in human health risk. In contrast, the risk of human illness per serving appears to be insensitive to the number of *S.* Enteritidis in contaminated eggs across the range considered at the time of lay. This may be because the effect of *S.* Enteritidis growth is greater than the initial contamination level in eggs.

3.3.5 Limitation addressed

Reduction or elimination of colonization in the flock is considered extremely important. At the farm level, there are limited strategies to achieve this aim. Approaches include preventing flock exposure by biosecurity or reducing bird susceptibility to colonization by measures such as vaccination or competitive exclusion treatment. A module to assess the relative importance of sources of colonization would be extremely useful to risk managers, and such a module has been initiated. However, at the time of completing of the WHO / FAO RA it was considered that there were at this time insufficient data on flock infection sources for the use of such a module. Using data on between-flock and within-flock prevalence the probability of any random bird being positive can be estimated. The model also demonstrates that the probability of colonization is dependant on age. Although the model can indicate the effect of various generic sources on transmission it cannot, at this time, allow an assessment of the sources of exposure to provide targeted strategies for intervention.

In the current model, the effectiveness of various management interventions for controlling *S.* Enteritidis, i.e. the magnitudes of uncertainty regarding test sensitivity, effectiveness of cleaning and disinfecting, and vaccination efficacy have not been measured. Limitations in the modelling approaches (e.g. distributions, predictive microbiology) were addressed. The RA was based on assumptions and some were considered to be constant between countries. For example, the predictive microbiological inputs, the distribution of within-flock prevalence, and the frequency at which infected hens lay contaminated eggs are examples of biological inputs, which might be constant between countries. Several epidemiological assumptions were necessary:

- Infected hens produce contaminated eggs at a constant frequency that is independent of host, bacterial strain or environmental factors,
- A homogenous population of layer flocks is assumed (e.g. same size, same basic management and environment),
- The model ignores the effect of moulting practices on egg contamination frequency,
- It is assumed that within-flock prevalence is random and independent of hen age or other host, bacterial strain or environmental factors.

More research is necessary to determine the appropriateness of these assumptions. It should be considered whether the model can be adapted to consider changes in these assumptions.

3.4 Data requirements

An overview on the data required is given in the following Table 3.3.

Table 3.3. Data requirements for the model pathway for layers

Main routes	Data requirements
Vertical transmission	Flock prevalence and within-flock prevalence in breeding flocks of the egg production line, separated by breed Transmission rate at hatcheries
Transmission from rearing phase to production phase	Flock prevalence and within-flock prevalence in rearing flocks, separated by breed that includes information on sample size, test methods etc Testing scheme applied (i.e. test and destroy) Sensitivity of the scheme applied
On-farm perpetuation (carry over infection from previously infected flocks)	Prevalence and within-flock prevalence of previous flock, that includes sensitivity of the testing scheme applied Distribution patterns of infected flocks within holdings, regarding housing type Cleaning and disinfection scheme, efficacy of it depending on housing system Elimination of potential reservoirs (e.g. rodents) Management factors, depending on housing system
Horizontal introduction of new infection	Feed supply; requirement for heat treatment; efficacy of control measures Water supply and control Other management issues
Additional factors	Protective measures improving health status of birds, i.e. vaccination Data on the dynamics of within-flock transmission of the agent depending on the housing type

As the housing systems will be changed in the near future, there is strong need to perform research to collect the data necessary.

3.5 Conclusions and Recommendations

The production model predicts the likelihood of a *S.* Enteritidis –contaminated egg occurring. This depends on the flock prevalence, within-flock prevalence, and the frequency that infected hens lay contaminated eggs. The flock prevalence, that is the likelihood of a flock containing one of more infected hens, further depends on factors that serve to introduce *S.* Enteritidis into flocks, e.g. replacement pullets, environmental carryover from previously infected flocks, food contamination, etc.. These aspects have not been addressed in the available exposure assessment.

Another aspect, which should be considered in detail, is the effect of vaccination. In the interventions strategies tested in the WHO / FAO RA, the vaccine was assumed to be capable of reducing the frequency of contaminated eggs by approximately 75%. As within the European Union different vaccination policies are applied in the individual countries, and the contamination level of table eggs may be affected, this should be included in a more advanced model of the production phase.

3.6 References

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4. Turkey production

4.1 Introduction

4.1.1 Industry Structure

Turkey companies are vertically integrated, meaning they control or contract for all phases of production and processing — from breeding through delivery to retail. The industry is maintaining control over research, hatching, growing, feeding, processing, packaging, transportation and marketing. This industry comprises establishments primarily engaged in raising turkeys for meat or egg production. It is divided into two segments: live turkey and turkey eggs. Within the live turkey segment there are a variety of different classes, including fryer-roaster turkeys, young turkeys, yearling turkeys, and mature turkeys (also known as hens or toms). Turkeys are used in a range of meat products such as ground turkey, turkey sausage and turkey bacon, turkey franks, turkey pastrami as well as turkey cutlets and tenderloins. The output of this industry is the sale of live turkeys to the Animal Slaughtering and Processing Industry.

4.1.2 Turkey meat – market situation in Europe

After a strong readjustment in 2002 and 2003, the production of turkey meat in the EU25 was stabilised to 2 million tons in 2004 (Table 4.1). The integration of the 10 new member countries added 342.000 tons to the 1.670 tons million produced in EU 15.

Table 4.1. Turkey production – EU and third countries (´000t)

	1999	2000	2001	2002	2003	2004
Austria	18	20	21	20	20	20
Belgium/Luxembourg	8	7	6	6	5	6
Denmark	11	10	13	12	7	1
Finland	4	6	9	12	14	15
France	692	760	749	698	632	624
Germany	266	292	326	353	352	360
Greece	2	3	2	2	2	2
Ireland	32	34	33	29	29	31
Italy	343	266	369	350	296	292
The Netherlands	43	44	45	48	20	32
Portugal	47	46	47	44	40	39
Spain	21	22	22	20	23	21
Sweden	3	5	4	4	5	4
United Kingdom	267	255	254	238	230	216
EU-15	1.757	1.770	1.900	1.836	1.675	1.663
Czech Republic	12	12	12	12	12	12
Cyprus						
Estonia	1	1	1	1	1	1
Hungary	76	98	110	120	90	90
Latvia						
Lithuania						
Malta	0	0	0	0	0	0
Poland	107	150	190	210	216	230
Slovak Republic	5	5	4	4	2	1
Slovenia	8	8	8	8	8	8
EU-25	1.970	2.050	2.230	2.195	2.010	2.010
Brazil	115	137	165	182	200	226
USA	2.372	2.419	2.490	2.557	2.529	2.441
Canada	139	152	149	147	148	147

Note: Partly provisional , partly estimated; offical statistics on turkey consumption only available from few countries. EU-data based on gross national production. From: ZMP from USDA and national statitics.

This apparent stabilisation is hiding divergences among the countries. In France, Italy and in the United Kingdom the production decreased, whereas in Germany the production of turkey meat increased. The production of the 10 new Member States faced a much more dynamic evolution in 2003 and 2004, especially driven by Poland.

Consumption remained overall stable and is also estimated at 2 million tons in 2004 (Table 4.2). With 6,5 kg per capita/year, Germany is now leading, compared to France (6,2 kg) and Italy (5,1 Kg). Imports of turkey meat preparations (seasoned meat) have increased to 10% (82.176 tons) Turkey meat derived products are primarily sourced from Brazil. Germany and the Netherlands respectively import 38.868 tons and 28.395 tons, which represents nearly 82% of the total amounts of imports (AVEC; 2005).

Table 4.2. Per capita consumption of Turkeys – EU and third countries (kgs)

Country	1999	2000	2001	2002	2003	2004
Austria	4.5	4.4	5.1	5.2	5.1	5.0
Belgium/Luxembourg	3.4	3.0	2.8	3.0	2.5	2.5
Denmark	2.9	2.9	3.1	3.0	2.9	2.9
France	6.4	6.8	7.2	6.7	6.2	6.2
Germany	5.1	5.6	6.3	6.4	6.4	6.5
Italy	5.5	5.7	5.5	5.3	5.1	5.1
The Netherlands	2.6	2.2	2.3	2.5	2.2	1.9
Spain	1.3	1.1	1.4	1.5	1.5	1.5
United Kingdom	4.3	4.3	4.3	4.3	4.0	4.0
EU-15	4.3	4.5	4.7	4.6	4.5	
USA	7.9	7.8	7.9	8.0	7.9	7.8

Note: Partly provisional, partly estimated; offical statistics on turkey consumption only available from few countries. No figures available from Finland and Sweden. From: ZMP from USDA and national statistics.

Table 4.3 shows the amount of turkey produced in selected European countries in 2004.

Table 4.3. Amounts of turkeys produced in the different European Countries in 2004

Country	Amount in Mio (2004)
France	35
Czech Republic	0.67
Denmark	0.15
Estonia	0.02
Germany	9
Greece	0.09
Hungary	4.26
Ireland	1.65
Italy	25
Lithuania	0.10
Malta	0.001
Netherlands	1.11
Poland	0.57
Portugal	7
United Kingdom	8

http://faostat.fao.org/faostat/form?collection=Production.Livestock.Stocks&Domain=Production&servlet=1&hasbulk=&version=ext&language=EN (requested the 28. of September 2005)

4.2 Description of the production type

There are many players in the turkey industry. There are only a few companies that provide the primary breeding stock to a turkey breeder farm. The turkey breeder farm is responsible for breeding hens to produce fertilized eggs that are brought to a hatchery. The hatchery is then responsible for hatching the eggs into viable baby poults, which are then shipped to the commercial turkey farms, where they are raised into adult turkeys. Once the turkeys reach an appropriate weight, they are transported to the processor.

4.2.1 Turkey Breeder Farm

Multiplier breeder turkeys are raised to lay eggs to provide poults (baby turkeys) for the commercial turkey industry. The multiplier breeder poults come from primary breeding stock and are shipped to the breeder farms in special boxes when they are only a few hours old. In order to give natural rapid growth to their offspring to constitute meat birds grown by commercial turkey producer, breeder hens are bred to lay more eggs and toms are bred for more weight. Both toms and hens are hatched the same day and come from different parent flocks to prevent in-breeding.

4.2.2 Brooding

When the breeder poults arrive at the farm, the hens and toms are separated by penning off the areas in the barn. Baby poults are grown in rings which corral the birds close to heaters and the feed and water. The general feeding program is similar to a commercial flock for the first eight weeks of growth and then the hens are placed on a different feeding program to keep them leaner. A breeder producer will place twice as many toms as needed for breeding. When the birds reach 15 weeks of age candidates for the breeding flock are selected. Selection is based on the most desirable and physically superior. Inferior and undesirable toms are removed and sold to the processor. Every bird left is weighed. Only the top 50% heaviest toms are kept for breeding as growth characteristics are most likely to be passed down to the offspring and produce the faster growing poults for the commercial turkey industry.

4.2.3 Housing

Breeder turkeys are raised under specific lighting programs. Toms are raised with 12 hours of daylight per day to ensure good semen production at the right age. Hens are raised on a normal commercial lighting program (14 hours of light per day) until 16 weeks of age. Then the lighting is reduced on a gradual basis down to 6 hours per day by the time the birds are 20 weeks of age. They are maintained at 6 hours per day until 30 week of age when they are taken up overnight to 14 hours of light per day. This is called lighting, which stimulates egg production. Eighteen days later the breeding program is started. Eggs are bred by artificial insemination three times within the first 10 days to boost the chance of fertility, and then once a week throughout the laying season. Hens lay eggs for a 28 - 30 week production period. On average, one hen will lay approximately 105 - 115 eggs during that period. From those eggs, approximately 75% will be successfully hatched into baby poults.

4.2.4 Egg Production

Eggs are collected as often as possible to increase optimum hatchability and eliminate the chance of eggs being broken in the nests. Collected eggs are then put through a three stage sanitizing process to help maintain poult quality. First, the eggs are put through a machine with sanitizing solution. Next, they are dry air fumigated in a tempering room at about 24ºC (75°F). Finally they are placed in storage and held at a temperature of 18ºC (65°F) with humidity at 75%. Although some breeder producers use a fumigation process. Here the eggs are fumigated with chemicals to kill bacteria on the shells. The eggs are then stored for approximately 4 - 6 hours in a temperature-controlled room. Eggs are picked up by the hatchery three times a week and then are shipped in humidity and temperature controlled vans the hatchery. Once the egg production cycle is completed the mature hens and toms are shipped to the processor for use in the further processing industry.

4.2.5 Hatchery

Fertilized eggs from the breeder farm arrive at the hatchery in humidity and temperature controlled trucks. The eggs weigh approximately 80 - 100 g and are slighly larger than a chicken egg. They are creamy-beige in color with brownish speckles. The eggs are incubated for 25 days then moved to a hatcher for 3 days. In total, it takes 28 days for a turkey egg to hatch into a poult.

4.2.6 Commercial Turkey Farm

Day-old poults, weighing 56 grams (2 oz), are transported to the turkey farm within 24 hours of being removed from their hatchers. Prior to receiving the poults, the producer must prepare the housing facilities. The brooding area is cleaned and disinfected, and the heating equipment is checked to ensure that it is operating at the level necessary to maintain an environmental temperature suitable for neonatal poults.

4.2.7 Brooding

Young birds are carefully watched and kept warm during the first few weeks. Depending on the type of housing, brooding temperature on the first day of life ranges from 32°C (90ºF) to 35°C(95ºF) at the eye level of the poults. As the birds down is replaced with feathers, the temperature is gradually lowered by 2° - 3° C per week, down to approximately 21°C (70ºF) at 6 weeks of age. Proper attention is given to prevent poults from crowding or piling on top of each other in the corners of the floor pens. Light intensity for the first 3 days of life will not be less than 50 lux (5 foot candles) to encourage poults to start eating normally. Thereafter, light intensity in the pens provides adequate illumination for normal food and water intake and normal activity.

4.2.8 Housing and Feeding

Turkey buildings must be capable of maintaining an adequate microclimate (as related to relative humidity, dust level, ammonia, and carbon dioxide) over normal weather fluctuations in a given locality. Turkeys of all age groups have to be protected against draft and cold areas in the pen. Many turkeys are grown in large barns called pole barns. These barns are completely open on the inside, allowing the turkeys to roam at will. On most barns, the bottom portions of the side walls may be removed or lifted up to allow fresh air into the barn. Some pole barns may be enclosed by fences so that the turkeys may roam outdoors when the sides are lifted in the summer. A few turkeys are still raised completely outdoors on range during the summer.

Regardless of the type of housing, all turkeys are allowed to move freely throughout the barn and eat and drink at will. The producer's job is to ensure that the young birds receive sufficient feed and water, as well as the right temperature, light and ventilation throughout their growing cycle. They are fed a healthy diet of whole and pelleted grains, as well as vitamins. Tom turkeys require 2.35 kg's (5.2 lbs) of feed for 1 kg (2.2 lbs) of weight gain. This is called the feed conversion. Hen turkeys have a feed conversion of 2.2

and broilers, 2.0. These numbers are based on an average of the figures taken on a year round basis by the Board.

Table 4.4. Classification, Age and Weight of turkeys

Classification	Growth	Market Weight	Yield
Broilers (female)	10-12 wks	Under 5.75 kg	81%
Hens (female)	13-15 wks	5.75 - 9 kg	82%
Toms (male)	16-18 wks	Over 9 kg	83%

Turkey feeding equipment includes a variety of sizes of hanging tube feeders, automatic troughs and high-capacity tanks. Water is provided through bell-type waterers, automatic troughs and range bowls. Space allotment for feeding and drinking allows the birds ease of access.

4.2.9 Transportation

When the birds reach the desired weight, they are quickly transported to a processing plant in specially equipped trucks to ensure transportation is swift and humane. It is in the best interest of producers to keep their turkeys comfortable and in good health, as profits are contingent on the condition of the birds once they reach the processing plant.

4.3 Description of selected model pathway

Hafez (1999) indicated the fact that processing plants have not been able to reduce the incidence of pathogenic bacteria in poultry products effectively means that every effort must be made to reduce any infection in and/or contamination of the live birds before their dispatch to the processing plants. The selected model is an investigation of Hafez et al. (2001) that concentrates on the occurence of Salmonella, Campylobacter and VTEC in commercial turkey flocks during rearing and processing. The objective of the project is to monitor the prevalence of the pathogens and infections in turkey meat flocks and to determine the means of further contamination in a processing plant.

4.3.1 Used materials and methods

Samples for flock monitoring during rearing: Twenty four commerial turkey flocks were monitored for *Salmonella*, 10 flocks for *Campylobacter* and additional 11 flocks for verotoxin producing *E. coli*. Faecal samples were collected at different intervals from 1st week of age through the 16th and 20th/22nd week of age and tested bacteriologically. In the flocks monitored for campylobacter additional faecal samples were collected at 1st day of age. All monitored flocked were reared on different farms. The number of the flocks is identical with the number of the farms.

Sampling in the processing plant: All flocks were slaughtered and processed in the same plant. The processing procedure in this part is partially automated and involves manual killing, mechanical scalding, defeathering, evisceration, final carcass wash using spray water, cooling and finally manual cutting. For *Salmonella,* samples were collected from 7 out of 24 monitored flocks, in which salmonellae could not be detected during the entire rearing period prior to slaughter, were tested on different steps during processing. For *Campylobacter* samples were collected from 6 out of 10 monitored flocks. For VTEC samples were collected from all monitored flocks. In all cases samples in the processing plant were drawn from the following sites: Scalding water, liver swabs, swabs from the skin surface over thigh, lumbosacral and around the cloace of turkey carcasses after evisceration, skin swabs after cooling, skin swabs after further processing and samples from breast muscle after cutting. Figure 4.1 shows the selected model pathway for turkey production.

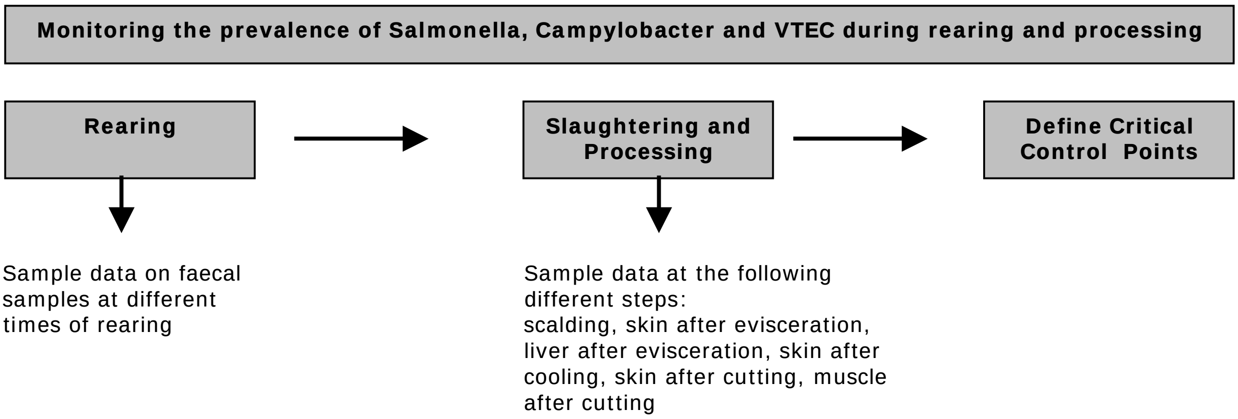

Figure 4.1. Flow chart of the suggested model pathway for turkey production

4.4 Data requirements

Table 4.5 presents an overview of the data requirements of the suggested model pathway for turkey production.

Table 4.5. Data requirements for the proposed model for turkey production

Data for flock monitoring	
Data on turkey flocks	Number of birds in the flock
Data on the possitive samples for the different pathogens	Qualitative data on faecal samples at different times: -1st day -4th day -8th week -12th week -16th week -slaughter
Data for process monitoring	
Data of pathogen isolation at different steps of slaughtering and processing of turkey flocks	Qualitative data on pathogen isolation at different steps of slaughtering and processing: -Scalding -Skin after evisceration -Liver after evisceration -Skin after cooling -Skin after cutting -Muscle after cutting

4.5 Conclusions and recommendations

The investigations of Hafez et al. 2001 on the estimated prevalence of Salmonella, Campylobacter and Verocytotoxin producing Escherichia coli (VTEC) is an important instrument for monitoring the pre-harvest and post-harvest phase of turkey production. For each of the different major pathogens specialist Critical Control Points (CCPs) have been identified along the food chain. These CCPs must be monitored on a regular basis to ensure that control is maintained (Mead et al. 1997; Mead, 1998). The prevention of infection in live birds and the development of improved monitoring programmes and rapid detection methods plays an important role in the future. To control these foodborne organisms more effectively, more information is required on how microbial pathogens enter and move through the food chain, and on the conditions which promote or inhibit the growth of each type of organism. Therefore one important issue might be to evaluate also quantitative data in future monitoring programmes.

4.6 References

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5. Ducks and geese production

5.1 Ducks and geese production in Europe

Ducks and geese are widely farmed in Europe, but the type of farming is different, ranging from rural farms with small number of birds (often mixed species) free of graze in the surroundings, to semi-industrial/industrial productions with thousands of animals.

5.1.1 Duck farming

More than 40 million ducks are raised annually in the European Union (Tables 5.1 and 5.2). Most are produced confined into specialized duck farms in some commercially important duck production areas.

Table 5.1. Number (1000*) of ducks farmed in the years 2000-2004 in Europe.(source of data: Food and Agricultural Organization of the United Nations, FAO)

Country	2000	2001	2002	2003	2004
Austria	95	95	95	47	36
Cyprus	25	50	45	50	50
Czech Republic	446	446	446	446	450
Denmark	296	337	291	260	299
Estonia	20	20	20	10	7
Finland	0	0	0	0	0
France	24489	25644	25781	24163	24000
Germany	1927	2042	2185	2626	2300
Greece	66	66	70	70	70
Hungary	2269	1480	2837	3443	2709
Ireland	190	190	190	190	190
Lithuania	51	48	51	47	47
Malta	0	0	0	0	0
Netherlands	958	867	852	706	723
Poland	3551	3571	3572	3593	4406
Portugal	0	0	0	0	0
Slovakia	1460	1625	1633	1600	1600
Slovenia	200	200	200	200	200
Spain	80	80	80	80	80
United Kingdom	2300	2350	2100	1900	1970

However, it is also diffuse the duck farming primarily for family use or local sale (rural and hobby flocks). In Italy the duck population is about 5 million animals, mainly distributed in free range farms. Ducks farming is primarily for meat production, it is to note the particular production of foie gras in France.

The main breeds are Pekin and Muscovy (Cairina moschata) ducks, but also hybrids such “mulard” (muskovy and mallard hybrid) are common. These species are well adapted to the farming conditions, and they don’t need free open space and water pools. Ducks are also farmed as game birds; in North Italy there are a number of duck farms that produces hybrids of mallard for game purposes. This production, even if in some cases should involve several hundreds of birds, is mainly free-range.

Table 5.2. Duck meat production in 2004 in Europe (source of data: FAO)

Country	Slaughtered/Prod Birds (1000)	Carcass Wt/Yield (.1Gr/A)	Production (Mt)
Austria			
Bosnia and Herzegovina	80	25	200
Croatia	280	14.286	400
Czech Republic	195	16.41	320
Denmark	1.7	18.482	3.142
France	1.6	28.125	4.5
Germany	80.7	29.504	238.1
Greece	21.5	20.698	44.5
Hungary	60	21	126
Ireland	26	25	65
Netherlands	1	20	2
Poland	7	20	14
Serbia and Montenegro	9	21.111	19
Slovakia	1.45	20	2.9
Slovenia	4.6	20.217	9.3
United Kingdom	600	20	1.2
	17.298	22.429	38.798

5.1.2 Description of duck production

Muscovy ducks require 35 days of incubation; eggs of other domestic duck breeds require 28 days. A chicken hen or female duck can set on 9 to 11 duck eggs. Industrial production system of the Muscovy duck is like the broiler farming system; the ducks were raised into closed stables, with a density of 12-14 adults duck/m^2 for the females and 7-10/m^2 for the males, depending on the facilities and the type of the ground surface (sawdust or other materials). The 3 days old ducklings were obtained from few hatcheries (some of the most important are placed in France) and raised for 60 days and 2.5 kg (females) or 90 days and 4.5-5 kg (males).

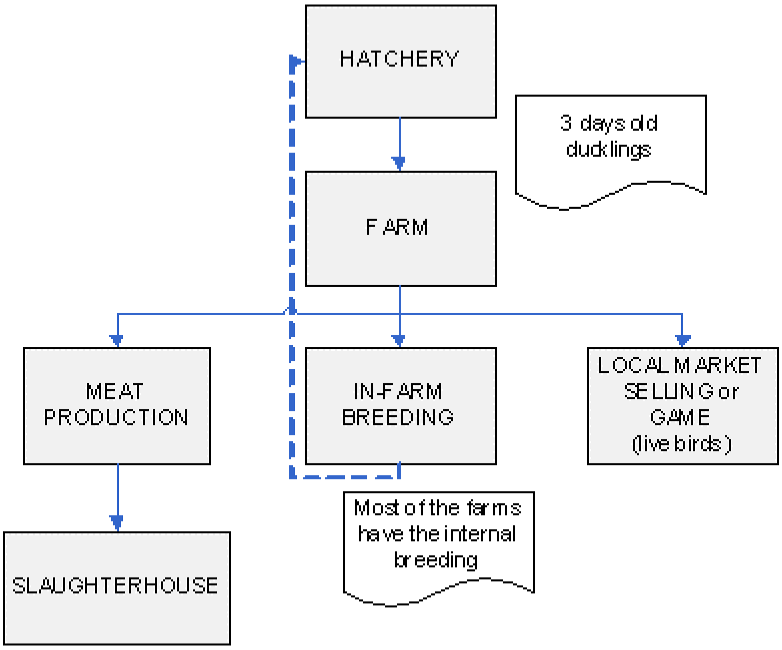

Figure 5.1. Duck production scheme.

Two (a short of weaning and growing/finishing) and three (weaning, growing and finishing) distinct farming periods are defined for females and males, respectively. In these periods different feeding schemes, in terms of type of pellet and feed composition are provided to the birds.

5.1.3 Geese Farming

The number of geese farmed in Europe is about 4 million (Tables 5.3 and 5.4), ten time less than the ducks. Geese are raised almost in all the European countries and the most common breeds are the Emden and Toulouse, but also African and White Chinese are also raised.

Table 5.3. Number (1000*) of geese farmed in the years 2000-2004 in Europe (source of data: FAO)

Country	2000	2001	2002	2003	2004
Austria	22	22	22	41	27
Cyprus	0	0	0	0	0
Czech Republic	132	132	132	132	130
Denmark	7	6	3	8	14
Estonia	8	8	6	6	2
France	830	826	821	807	810
Germany	400	404	408	384	400
Greece	33	33	33	33	33
Hungary	1226	1470	2175	2009	2801
Ireland	55	55	55	55	55
Lithuania	51	48	47	59	52
Poland	764	614	538	698	2864
Slovakia	210	230	230	230	230
Slovenia	270	270	270	270	270
Spain	22	22	22	22	22
United Kingdom	145	120	120	110	105

There are considerable differences in breeds and strains of geese. Geese suffer if they are housed, they should be provided by confined areas (yards) with a house for shelter protection. They are used to have green pasture and free access to water pool. Due to these reasons, the farming of these species is less diffuse and the farms are mainly free-range or small rural/hobby flocks.

In Italy there are no industrial geese farms, only small free range and hobby farms with less than 250 animals. Almost all of them have internal breeding/hatching. About the production cycle, goslings are kept until 4-5 weeks of age closed, and fed with feeders as used for chicks. After this time they are left free of graze and pasture outside. The geese for meat production are farmed for 5-6 months, but some breed can be faster (10-12 weeks).

Table 5.4. Goose meat production in 2004 in Europe: the number of birds slaughtered (*1000) and the amount of goose meat produced in the different countries were shown (source of data: FAO)

Country	*Slaughtered/Prod Animals (1000)*	*Production (Mt)*
Austria	45	165
Bosnia and Herzegovina	260	800
Croatia	270	1.15
Czech Republic	50	200
Denmark	19	86
France	1.4	6.8
Germany	1	4.5
Greece	35	147
Hungary	10.35	43.6
Ireland	320	1.28
Poland	4	18
Serbia and Montenegro	1.75	7
Slovakia	250	1
Slovenia	800	3.4
United Kingdom	618	2.923

5.2 Avian Influenza ecology and epidemiology

Wild aquatic birds, shorebirds and gulls are considered to be the natural host of avian influenza (AI) viruses without showing clinical signs of the disease. In wild aquatic birds the AI viruses replicates in the intestinal tract and are excreted in high concentrations in the faeces (up to 108.7 50% egg infectious doses/gram). Virus may be isolated from untreated lake water where large numbers of waterfowl are found. Contaminated lake or drinking water may therefore result in infection by the faecal/oral route, or possibly by the faecal/cloacal route as a result of 'cloacal drinking'.

Influenza viruses have been isolated from avian species representing most of the major Families of wild birds throughout the world. It is suggested that most birds are susceptible and may be reservoirs of the virus and able to spread the virus to other wild or domestic birds. It is expert opinion that the actual number of susceptible species is likely to be much greater, and to some extent this is demonstrated by the recorded susceptibility of a wide variety of birds in laboratory experiments or investigations of captive birds in quarantine or in ornamental collections.

The main concern is related with the AI viruses of H5 and H7 subtypes, that have shown the capability to mutate from a low pathogenic to a highly pathogenic form of the disease, due to adaptation/mutation when circulating in the domestic poultry (chickens, turkeys, quails). The H5N1 subtype is actually endemic in domestic ducks in South East Asia, and infected animals can shed the virus for about 2 weeks without any clinical sign.

Some preliminary assessments of the risk of introduction of AI in industrial poultry production in Italy showed a critical point in the free-range and rural flocks (often raising ducks or ducks and other species) in the densely populated poultry area (DPPA) of the Veneto and Lombardia region (North Italy).

The industrial poultry farms (also duck farms) have put into force the biosecurity measures described in the EU and national regulations for the control of the AI. In particular, by this regulation, free range farms must keep the birds inside (then they cannot be considered free-range any longer) or ensure the avoidance of contact with wild birds. National and European surveillance programmes for the control of avian influenza are also into force, in wild and domestic birds.

5.3 Model pathway and data requirements

5.3.1 Description of selected model pathway

The modelled process is the industrial duck production, from the weaning to the end (animal ready for slaughtering) (Figure 5.2). The first phase (3 days old ducklings) is considered not at risk for AI introduction, thus it will not be considered in the model. For this process, the production phases are established, and information on the risk factors and protection measures are available. Moreover, the risk of introduction of avian influenza in these farms is relevant, mainly in small ones or in those that have mixed species.

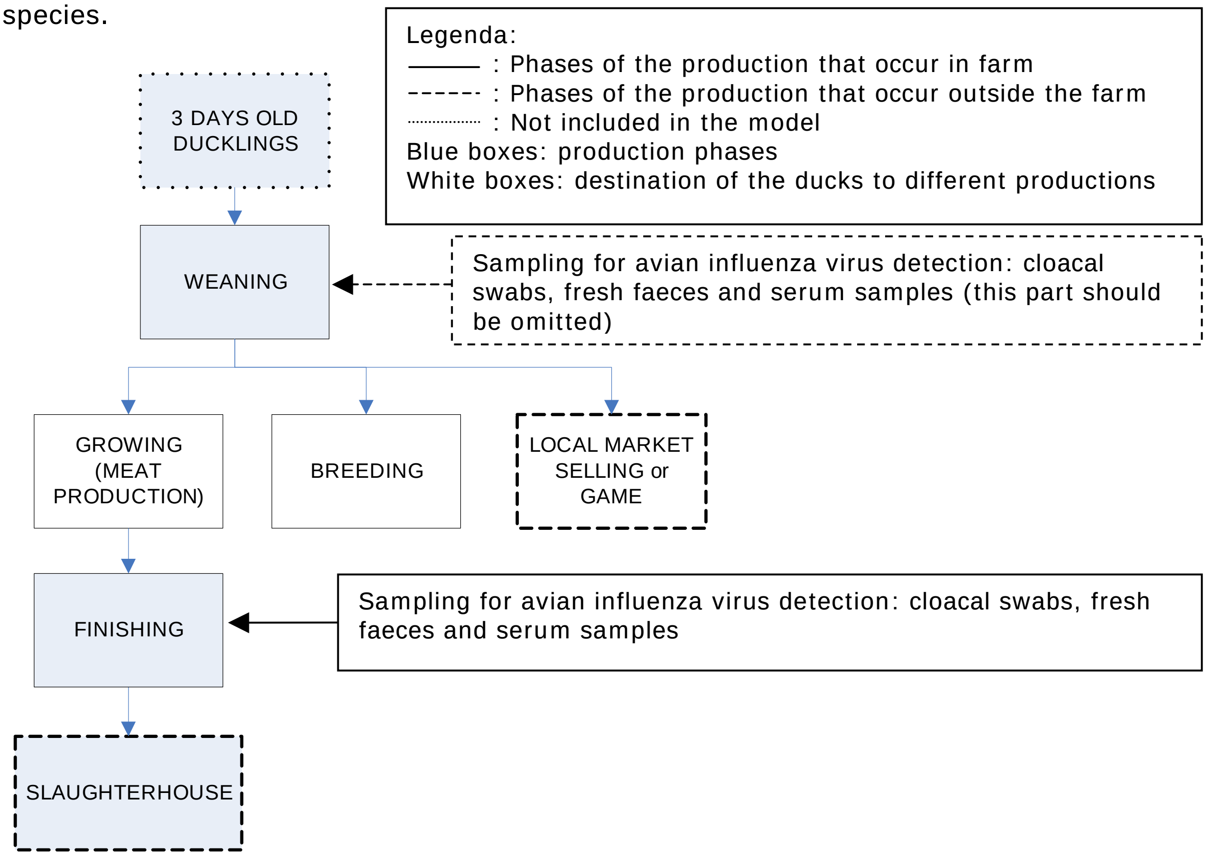

Figure 5.2. Flowchart describing the model pathway.

The pre-harvest model should describe, quantitatively, the likelihood of the introduction of an Avian Influenza virus subtype H5 or H7 into a non infected farm and the changes in prevalence and numbers that occur within each step, attributable to specific factors. Uninfected flocks can become infected via direct contact with infected wild birds or via environmental sources (carryover infection from previously infected flocks by crew, trucks or via surface water contaminated by wild birds faeces). The considered risk factors will be the distance to areas with surface waters (polls, lakes, ponds, rivers…) where wild birds (in particular mallards, swans and other dabbling ducks) are present, the rate of AI isolation from the considered wild birds species and the rate of contacts (trucks, lorries, crew) by time unit (mainly for the introduction from an infected farm). Also the probability of AI detection at farm level and the time from the introduction into a duck farm to the detection of AI will be considered. The inputs to the model include the results of sampling on the different levels of the chain:

1. cloacal swabs from living birds into the farm in the different phases
2. sampling on wild birds in the areas at risk of introduction
3. data on production aspects (birds growth rate (gr/day), mortality …).

The estimation of the prevalence and quantity of an infectious agent can be influenced by various epidemiological and farm management factors.

From the weaning period onward, the risk of introduction will be estimate, taking into account the difference between the phases. The introduction of AI subtypes H5 and H7 into a farm will determine the spread within the farm and an increase in the prevalence in the final farming period, with a rate that should be estimate by SIR/SEIR models (van der Goot et al., 2005).

5.3.2 Data requirements

Quantitative modelling of the pre-harvest pathway requires quantitative information. Data can be collected from a number of sources, which include national surveillance data, epidemiological surveys, industrial surveys, research publications, unpublished research work and government reports. The data sources are not limited to the presented ones.

Considering the areas at high risk of AI introduction (areas where AI epidemics occurred in the past, or where migratory birds and wetlands are present), the following data should be collected:

- No. of ducks and geese farms in the areas and density other poultry farms (especially turkeys)
- Surface water presents in the area (lakes, ponds, rivers…)
- Distance from the duck farms to the surface water places
- Data on kind and amount of “contacts” (trucks, lorries, crews for intervention in farm such vaccination or other animal loading…) in a time unit (week or day)
- Presence and consistence of wild bird population in the area (mallards, and other wild birds possible carriers of avian influenza viruses)
- Monitoring activity on poultry farms and wild birds in the selected areas for AI viruses detection (passive (dead birds testing) and active (sampling of live birds) surveillance on wild birds is already in place in Europe).

5.4 Conclusions and recommendations

Actually there is an increasing concern about the AI and the possible introduction into industrial poultry production. The aim of the model is to estimate the probability of introduction of avian influenza virus subtype H5 and H7 in duck flocks by different contacts, taking in account environmental factors (distance to areas with surface water and wild dabbling ducks) and all the epidemiological and farm management factors that influence this parameter. The different intervention methods integrated in a risk reduction strategy have different effects on the risk of introduction. These measures can be broadly divided in methods to prevent contact with wild birds, increase in biosecurity and increase the resistance of ducks (vaccination). The adopted measures and their effects should be taken into account in the pre-harvest chain model.

This model should help in the management of risk factors related with the ducks and geese farming, often performed in a semi-industrial way, in areas with high risk of AI introduction. The information should be used to drive decision about intervention measures such vaccination, to implement in the situations identified at high risk of AI introduction and spread.

5.5 References

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6. Pig production

6.1 Introduction

Pork is the most consumed meat in the world. In Europe, pork consumption represented around 43% in 2004, followed by poultry (22.2%) and beef (20%) (DBMC, 2005). The increased consumption throughout the world lead to changes in the swine industry. In all the major pig-producing countries there has been a marked reduction in the number of pig herds over the past decades, and a standard increase in herd size on those farms remaining in production.

Table 6.1. Production of pigmeat in the European Unit (Eurostat, 2005). This indicator expresses the total carcass weight of pigs slaughtered in slaughterhouses and on the farm, whose meat is declared fit for human consumption (1000 T).

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
EU (15 countries)	-	15976	16317	16250	17637	17983	17587	17533	17730	17787	17924	-
Euro-zone	-	13057	13399	13162	14378	14831	14621	14625	14752	14895	-	-
Belgium	1012	1035	1061	1006	1077	993.1	1055	1072	1044	1029	1032	-
Czech Republic	465	461	491	476	468	458	456.1	459.9	467.6	464	425.5	380.3
Denmark	1519	1475	1457	1523	1631	1642	1624	1714	1759	1762	1809	1793
Germany	3604	3602	3635	3564	3834	4103	3982	4074	4110	4239	4308	4499
Estonia	30.5	35.4	31.7	30	32	-	29.9	31.2	35.6	36.1	38.43	38.07
Greece	142.5	142.4	142.2	142.1	142.6	138.3	141.4	136.6	139.4	133.6	136.7	130.4
Spain	2102	2175	2316	2401	2744	2892	2912	2993	3070	3190	3191	3164
France	2126	2144	2183	2220	2313	2353	2318	2315	2350	2333	2311	2275
Ireland	214.8	211.2	210.7	219.9	241.6	249.7	230.4	239.8	229.7	218.8	204.3	205.2
Italy	1347	1346	1410	1396	1412	1472	1488	1510	1536	1589	1590	1515
Cyprus	42.5	42.8	45.6	46.1	47.6	-	-	-	-	54.31	55.22	54.68
Latvia	53.8	62.6	39.5	37.05	36.48	34.62	31.54	31.65	35.89	36.91	36.8	37.8
Lithuania	82	93	89	87	96	91	85	64	85.7	91.3	97.12	105.6
Luxembourg	7.726	7.896	8.853	8.672	8.924	11.61	10.23	9.904	11.69	12.32	11.45	10.82
Hungary	351.9	332.8	409.8	354.9	349.2	402.1	375.1	-	-	510.3	486.5	475.1
Malta	-	8.47	8.82	10.19	10.4	-	9.519	9.93	10.41	9.822	8.47	8.889
Netherlands	1673	1622	1624	1376	1725	1711	1623	1432	1377	1253	1287	1297
Austria	-	466.2	480.6	488.6	508.3	519.6	502	488.5	511.5	505.9	515.5	501
Poland	1655	1975	2032	1862	1995	2010	1892	1820	1981	2094	1923	1926
Portugal	292.2	282	299.1	302.7	329.7	344.2	327.1	315.2	328	327.8	315.1	327.1
Slovenia	62.7	60.8	60.5	61	61	72.2	38.01	35.79	37.08	37.26	34.62	31.68
Slovakia	-	-	-	-	-	-	177.6	174.3	164.4	183.3	166.9	-
Finland	-	166.3	170.8	178.9	183.9	182.5	172.3	175.5	183.9	193	198.1	203.3
Sweden	-	308.8	319.8	329.3	330.4	325.4	277	275.9	283.8	287.5	294.5	275.1
United Kingdom	1035	992.2	997.9	1094	1155	1047	923.1	781.4	795.3	714.5	720	703.3
Bulgaria	207	256	252	227	248	267	243	-	-	-	-	-
Croatia	125	110	109	112	121	122	114	-	-	-	-	-
Romania	746	662	683	668	617	-	-	-	-	-	-	-

(-) Not availabe

Concurrently, there have been major changes in systems of production aimed at simplifying management, reducing costs and increasing production efficiency. Factors associated with the increasing size of units involved in pig production, increased intensiveness and the nature of some of the systems in use have become a matter of public concern in recent years (English and Edwards, 1999).

China is the major pig-producing country in the world, with nearly 50% of the pig population, followed by the USA and Germany (DBMC, 2005). The 25 countries that comprise the EU are the second largest swine-producing region in the world. Germany, Spain and France are the major producers in the EU (DBMC, 2005). The pig production within 25-EU has, however, witnessed a slight decrease in the past years (0.7% from 2003 to 2004) (Eurostat, 2005).

Pig production can be held under two major types of systems: outdoor and indoor production. The indoor housing systems vary from being relatively extensive to totally intensive.

6.2 Description of production types

Systems in which breeding sows live in free-range outdoor conditions have been traditionally used in many countries (Anon., 1997). Even though the number of extensive units is significantly lower than intensive ones, their popularity has again increased in recent years in some European countries, due to the consumer's increasing concern on animal welfare and quality of the animal products.

Indoor systems represent the majority of the pig production farms on the major producing countries. These systems can be divided in three broad categories, based on the manure system adopted: deep litter systems, scraped systems and slatted systems, the last one being the most widely used throughout the EU (Anon., 1997). Regardless the manure system, this chapter will focus on indoor pig production types.

Different types of indoor production are described, all including three main stages:

1) Breeding, gestation and farrowing;
2) Rearing of young weaned pigs in nurseries (up to about 25-30 Kg);
3) Growing and finishing to slaughter weight (usually between 110-130 Kg).

The classification of the production types is based on the site on which each stage takes place (Harris and Alexander, 1999):

- One-site production (farrow-to-finish)
- Traditional two-site production (Fig. 6.1)
- Medicated early weaning (MEW)
- Modified medicated early weaning (MMEW)
- Two-site isowean production
- Three-site isowean production (Fig. 6.2)
- Multiple-site isowean production

In one-site production systems, all the three stages take place in one site. These systems were frequent in the early days of the industrialization of pig production, but were often presented with animal health, welfare and waste disposal problems (Cameron, 2000). The other production types imply the physical separation of one or two stages of production.

The MEW system was implemented to establish a high health status on pig herds. It is based on the principle that older sows that have had several litters pass on strong protective immunity through colostrum and milk to their piglets, which greatly reduces the chances of piglets becoming infected with endemic pathogens carried by the sows or present in the environment, at least for the first 4 or 5 days of life. (Cameron. 2000). In this system, pregnant sows are administrated with antimicrobial agents from 5 days before and until 5 days after farrowing, and piglets from birth until 10-20 days of age. Pregnant sows are farrowed in isolation in all-in/all-out farrowing rooms, piglets are weaned and placed in an isolated nursery on a separate site at about 5 days of age, and the pigs are subsequently transferred to an isolated grower-finisher unit on a thirds site at 6-10 weeks of age (Harris and Alexander, 1999). The MMEW system, also known as segregated early weaning or isowean, is similar, but the sows are farrowed on the source farm in the normal way, not in an isolated farrowing house; the piglets are weaned between 5 and 28 days, depending on the specific diseases to be eliminated (Cameron, 2000).

In multi-site systems (two-site, three-site, multiple-site isolated wean-to finish) the breeding, gestation and farrowing stages of production are isolated from the other stages of production (Harris, 2004). These systems have been developed based on the theory that piglets reared in isolated cohorts immediately after weaning remain specific pathogen free (Cameron, 2000). Multi-site isowean systems have been implemented increasingly in the past decades, not only for the control of pathogens infectious to pigs, but also aiming at reducing human disease via pork consumption and through contaminated waste products (Cameron, 2000).

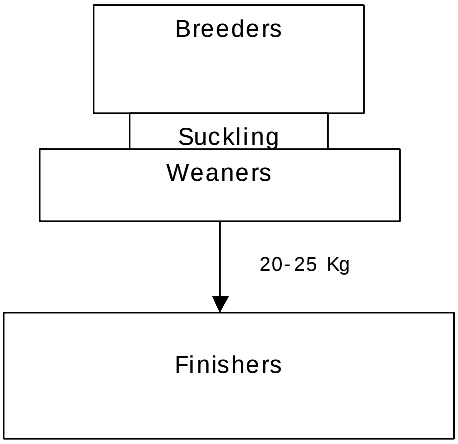

Figure 6.1. Traditional two-site production

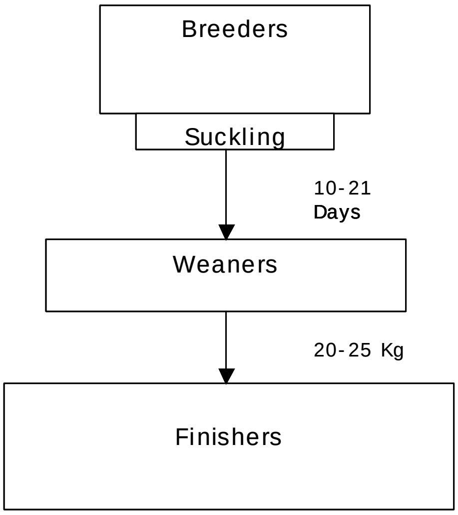

Figure 6.2. Three-site isowean with AIAO farrowing, weaning and grow-out each separate site.

In the multiple-site isowean system, each week's weaning fills the nursery accommodation on one site and each week's emptying of a nursery site (7 weeks after filling) populates the grower-finisher accommodation on one site (Harris and Alexander, 1999).

In the majority of the production systems now used, the management is made on an all-in, all-out (AIAO) basis: the animals are moved into and out of the facilities in distinct groups, preventing commingling of groups. The aim is to reduce the spread of disease. Facilities are cleaned and disinfected thoroughly between groups of animals (Cameron, 2000).

Breeding may be done by natural service or artificial insemination (AI). Sows are typically moved from dry sow to farrowing accommodation 3 to 7 days before the expected farrowing date (115 days after service). Weaning typically takes place abruptly between 3 and 5 weeks of age, although some farms still wean as late as 8 weeks. If intensive housing is used, pigs will be moved from the first stage weaner accommodation to larger, second stage accommodation after 2-4 weeks. If more extensive housing is used, weaners may remain in the same pen until 30-40 Kg or until slaughter (Anon., 1997). Growers move to finishing stage at 12-15 weeks, and finishing is the last production stage before transport to the slaughter plant. At the slaughterhouse, pigs stay in the lairage for a few hours before being slaughtered (van der Gaag., 2004).

6.3 Description of selected model pathway

The pig production chain consists of several stages (Figure 3).

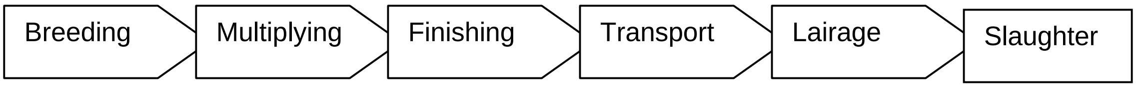

Figure 6.3. Schematic structure of the pig production chain.

Salmonella spp. is the main pathogen representing a risk for foodborne disease through the consumption of pig products. As multiple-site systems are designed to minimize spread of infection and contamination, the hypothetic model described here will focus on the initial introduction of *Salmonella* to a pig herd. Several potential vectors of introduction of disease can be identified in different stages of production.

Feed can represent a source of exposure to pigs in all the production stages. The agent can also be introduced via human contact – caretakers, veterinarians, truck drivers – or via pet animals, wild animals, birds or insects. Environmental contamination or inappropriate cleaning or disinfection of the pig house can represent a risk of infection of the animals as well.

During the finishing stage, the introduction of infected animals in the herd for replacement can be a source of *Salmonella*. During transport, the fastening of the animals and the origin of the animals influence the potential risk of exposure to the agent. As the animals are kept before slaughter at the lairage stage, exposure to *Salmonella* can occur.

Considering the individual animal as the basic unit of exposure of the pre-harvest model, several individual factors can influence the probability of infection: frequency of exposure, dose, age and immune status of the animal and colonization resistance. The co-effect of other pathogens might play a role and should be considered in a risk assessment model (Figure 6.4).

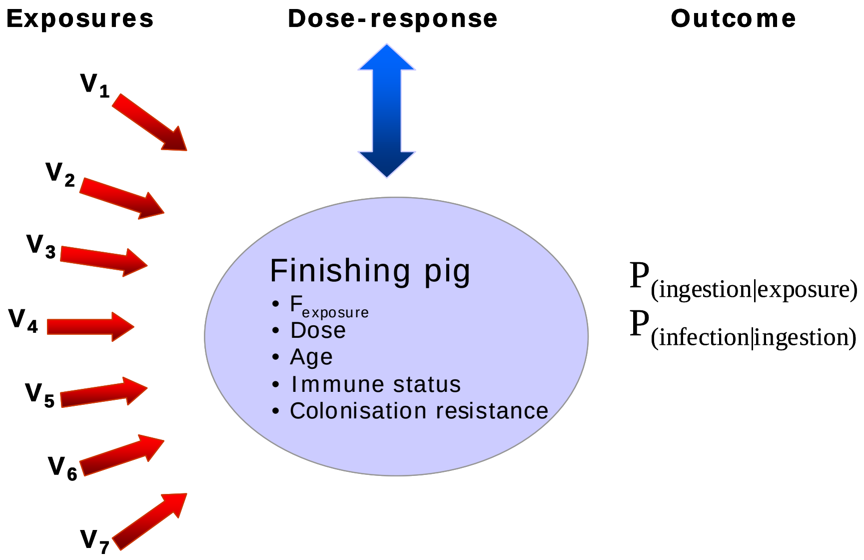

Figure 6.4. Conceptual model of the potential vectors of infection, factors that might affect the dose-response and probability of infection.

6.4 Data requirements

The pre-harvest model requires quantitative information regarding the sources of exposure on the different stages of production.

Table 6.2. Data requirements for the pre-harvest model

Route of infection		Data requirements
Feed		Daily intake Type of feed Use and dosage of feed additives Probability of contamination Distribution of CFU/g on contaminated feed Clustering of contamination in feed rations Seasonality of contamination levels Accumulative intake
Human contact		Frequency of entrance on the production house Frequency and type of contact with pigs Contact with other pigs prior to entering the pig house Time spent in the pig house Routine before entering the pig house
Other animals (pets, wild animals, birds or insects)		Protection against entrance/ presence of animals
Environment	Water	Manure system Cleaning/ disinfection frequency
	Air	Ventilation system
Introduction of new animals		Number of animals Infection state of the animals
Transport		Origin of the animals
Lairage		Origin of the animals Duration

6.5 Conclusions and recommendations

The objective of pre-harvest models in pig production is to estimate the introduction and spread of infectious agents throughout the production stages till slaughter, aiming at prevention or reduction of contamination. Several parameters influence the infection of the animals in the different stages.

Disease control programs have been voluntarily implemented for *Salmonella* in several European countries (Denmark, Sweden, The Netherlands, Germany). The adopted measures to prevent contamination on the pig production systems should be taken into account on pre-harvest risk assessments.

Pig production can be held under different types of production system. The housing system and implemented management type have major impact on the presence and transmission of disease, as well as on the option for control. Among the currently used production types, pigs reared in multiple-site isowean systems are exposed to fewer infectious agents. All in/ all out management is essential to prevent contamination and spread of disease.

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7. Dairy production

7.1 Introduction

We refer the reader to the paper by van Arendonk and Liinamo (2003) and to the publication by CEAS (2002) reviewing the environmental impact of dairy production in the EU, both of which provide excellent discussion of the structure of the EU dairy industry. We summarise in this and the subsequent section key points and data from these documents to provide some background to European dairy production.
At the time of publication of these documents, the European Union produced 22% of the world's milk and held the largest single share of the world market. As at 1997, Germany (5,026,000 head), France (4,476,000 head) and the UK (2,498,000 head) held the greatest numbers of dairy cattle, but a substantial decline in dairy cattle numbers (26%) had been observed across the EU between 1984 and this date, as a result of the introduction of dairy cattle quotas. Correspondingly, Luxembourg (47,000 head), Greece (182,000 head), Portugal (362,000 head) and Finland (383,000 head) held the lowest numbers of dairy cattle.

Milk has historically played an important role in the epidemiology of food-borne disease. Raw milk and milk sold as pasteurized have been implicated in a number of food poisoning outbreaks worldwide (see as examples Anon, 1996; Anon, 1999; Goh et al., 2002; Upton et al., 1994). Considering the situation in England and Wales, twenty two food-poisoning outbreaks were associated with milk and dairy products between 1992 and 1996 (CDR, 1997). A broad range of pathogens have the potential to be milk-borne as a result of carriage and subsequent shedding by dairy cattle; for example, *E.coli* O157, *Salmonella* spp., and *Campylobacter* spp. (CDR, 1997). A model framework for the dairy production chain together with an indication of key data requirements is therefore an important tool for the management of milk-associated risks.

7.2 Dairy production

Considering production systems and referring again to van Arendonk and Liinamo (2003) and discussion of the environmental impact of dairy production in the EU (CEAS, 2002), the dominant dairying breed in the EU is Holstein/Friesian, accounting for over 95 percent of herds throughout the EU. Some geographically localised variations on the Holstein/Friesian line exist.

In 1997, the most recent year to which these publications refer, the largest herd sizes were observed in the UK and the Netherlands, and smallest herds in Greece, Spain, Italy, Austria, Portugal and Finland. An increase in milk yield in all member states was observed between 1985 and 1997. An increase in the average herd size coupled with a decrease in the total number of dairy cattle in each member state has inevitably led to a move towards fewer, larger herds, within a framework of increasingly intensive dairy farming.

The authors in both publications identify four common dairying systems within the EU; high input, high output; low input, low output ("pasture systems" common in Ireland and in parts of the UK and France); Alpine or Mountain; and Mediterranean systems. The majority of EU dairy production systems (83% of EU dairy cow numbers and 85% of EU milk production) fall into the first category, which consititutes intensive, high-production dairy farming; herds are typically large (44 cows in the Netherlands up to over 70 cows in the UK) and calving rates are optimised to this particular system; typically calving occurs on a year-round basis, with a marginal Spring bias in some countries. In more Northerly locations dairy cattle can be housed for up to 8 months of the year and sometimes overnight in cooler seasons such as Spring and Autumn. The authors of the EU report note that a young average herd size is indicative of a corresponding high replacement rate. As at 1997, the highest average milk yields were recorded in Sweden (7.2 tonnes per head), the Netherlands (6.5 tonnes per head) and Finland (6.4 tonnes per head). Organic dairy systems are also in operation.

To describe an example dairy herd, we consider a generic system within which animals are divided into a number of categories; unweaned, weaned, bulling heifers, in-calf heifers and dry and lactating cows. Physical interaction between animals in these distinct groups is limited (Turner *et al.* (2003)). The life cycle of a dairy cow may be simply described as follows: the animal is initially unweaned, is subsequently weaned and eventually matures into the "dry" category (Turner *et al.* (2003)). It is from this stage as an adult that the animal moves into the "dry/lactating cycle" which typifies intensive dairy production systems. Within a given dairy herd, a certain proportion of cows (in the UK typically around 80% of the total of dry plus lactating animals) is in lactation at any one time.

Table 7.1. Number of dairy cows

	1985	1987	1989	1991	1993	1995	1997	1999	2001	2002	2003	2004
EU (15 countries)	-	-	-	-	-	22534	21883	21148	20271	-	-	-
Euro-zone	-	-	-	-	-	18542	18065	17451	16848	-	-	-
Belgium	945.1	921.76	871.7	805.8	701.6	691.9	633.2	630.95	624.5	-	584.59	568.6
Czech Republic	-	-	-	-	-	-	-	-	-	-	469.4	-
Denmark	896.4	811	759.4	741.65	714.1	702.5	670.4	640.19	623.4	609.6	596.03	-
Germany	-	-	-	-	5364	5271	5193	4765.1	4549	-	4372	-
Estonia	-	-	-	-	-	-	-	-	-	-	119.82	-
Greece	218.9	232	233.1	213.82	218	179	184	153.79	172.3	-	149.2	-
Spain	-	1783.5	1822	1516	1371	1239	1261	1207.3	1159	-	1118.4	-
France	6506	5840.8	5494	4969	4613	4677	4476	4425.2	4191	-	4019.3	-
Ireland	1528	1443.7	1400	1293.1	1274	1267	1268	1173.8	1148	-	1135.7	-
Italy	3075	3023.8	2930	2535.6	2287	2113	2078	2125.6	2239	-	2079.9	-
Cyprus	-	-	-	-	-	-	-	-	-	-	26.612	-
Latvia	-	-	-	-	-	-	-	-	-	-	184.27	-
Lithuania	-	-	-	-	-	-	-	-	-	-	448.1	-
Luxembourg	70.29	64.207	59.73	52.287	50.89	47.75	47.44	45.448	43.99	-	41.238	-
Hungary	-	-	-	-	-	-	-	-	-	-	309.16	-
Malta	-	-	-	-	-	-	-	-	-	-	7.607	-
Netherlands	2412	2165.7	1996	1908.9	1804	1763	1643	1649.7	1606	1541	1535.2	-
Austria	-	-	-	-	-	706.5	720.4	697.9	598	-	-	-
Poland	-	-	-	-	-	-	-	-	-	2851	2875.9	-
Portugal	-	387.97	398.2	394	375	364	362.1	356.74	337.7	-	328.49	-
Slovenia	-	-	-	-	-	-	-	-	-	-	130.71	-
Slovakia	-	-	-	-	-	-	-	-	-	-	214.47	-
Finland	-	-	-	-	-	402.3	382.6	373.64	351.8	-	327.98	-
Sweden	-	-	-	-	-	481	468	448	425.3	-	402.52	-
United Kingdom	3257	3052	2932	2778.7	2786	2629	2496	2454.3	2203	-	2206.4	-
Bulgaria	-	-	-	-	-	-	-	-	-	-	366.39	-

(-) not available

Table 7.2 shows the number of holdings with dairy cows in Europe from 1985 to 2004.

Table7.2. Holdings with dairy cows in Europe between 1985 and 2004.

	1985	1987	1989	1991	1993	1995	1997	1999	2001	2002	2003	2004
EU (15 countries)	-	-	-	-	-	1009.3	910.72	749.43	688.9	-	-	-
Euro-zone	-	-	-	-	-	910.51	821.44	678.36	617.5	-	-	-
Belgium	44.58	38.007	33.864	29.168	24.818	22.046	19.607	19.053	17.94	-	16.569	15.82
Czech Republic	-	-	-	-	-	-	-	-	-	-	11.219	-
Denmark	31.77	26.718	23.027	20.729	17.93	16.392	13.169	11.162	9.797	8.895	7.95	-
Germany	-	-	-	-	236.05	209.42	185.9	152.65	131.81	-	121.52	-
Estonia	-	-	-	-	-	-	-	-	-	-	12.398	-
Greece	73.42	60.695	55.043	47.165	39	28	24	12.058	20.612	-	10.907	-
Spain	-	250.84	231.99	185	148	114.6	105.87	69.1	67.093	-	63.718	-
France	328.7	291.4	241.17	201	169	158.57	145.77	135.4	120.92	-	112.26	-
Ireland	76.7	69.4	57.1	50.7	46.4	42.1	39.1	34.217	30.868	-	26.882	-
Italy	337.7	310.48	241.77	196.8	147.1	113.19	101.65	95.704	96.674	-	82.541	-
Cyprus	-	-	-	-	-	-	-	-	-	-	0.25	-
Latvia	-	-	-	-	-	-	-	-	-	-	61.108	-
Lithuania	-	-	-	-	-	-	-	-	-	-	193.41	-
Luxembourg	2.311	2.017	1.84	1.691	1.549	1.42	1.309	1.212	1.104	-	1.027	-
Hungary	-	-	-	-	-	-	-	-	-	-	22.013	-
Malta	-	-	-	-	-	-	-	-	-	-	0.153	-
Netherlands	61.31	57.524	54.844	47.61	43.181	40.063	37.267	35.062	31.303	29.647	28.377	-
Austria	-	-	-	-	-	90.732	86.085	77.967	74.41	-	-	-
Poland	-	-	-	-	-	-	-	-	-	873.8	808.65	-
Portugal	-	107.89	103.02	100.2	99.9	86	70.2	32.923	24.234	-	21.573	-
Slovenia	-	-	-	-	-	-	-	-	-	-	20.258	-
Slovakia	-	-	-	-	-	-	-	-	-	-	17.007	-
Finland	-	-	-	-	-	32.36	28.68	25.072	21.143	-	18.699	-
Sweden	-	-	-	-	-	17.743	15.788	13.963	11.173	-	9.72	-
United Kingdom	52.88	48.308	45.092	42.364	40.162	36.675	36.329	33.892	29.823	-	27.875	-
Bulgaria	-	-	-	-	-	-	-	-	-	-	-	-

(-) not available

7.3 Decription of the selected model pathway

For illustrative purposes we have selected for detailed consideration a typical pasteurisation process, occurring in a larger-scale, off-farm dairy. We describe a generic dairy production chain which has been motivated by the situation observed in England and Wales but is broadly relevant as a schematic of a generic dairy production chain. We describe the pathway generically in Figure 7.1 and summarise the model pathways as discussed more thoroughly in Clough et al. (2006); the reader is referred to this paper for a more detailed description of the key issues and a correspondingly more detailed flowchart.

The dairy farm, which might typically be of the high-input, high-output type described in the previous section, is the first link in the dairy production chain. Milk produced by cattle therein may be either collected by tanker or processed (pasteurized) on-site. We focus our attention for the purposes of this chapter upon the more usual system within which milk is processed off-farm, in keeping with this larger-scale, high-intensity production environment. There are, however, important distinctions to be made between milk processed in this way and milk processed in an often smaller on-farm setting, and we again refer the reader to e.g. Clough et al. (2006) for a detailed comparison of the two environments and refer to the distinctions only briefly in the next paragraph.

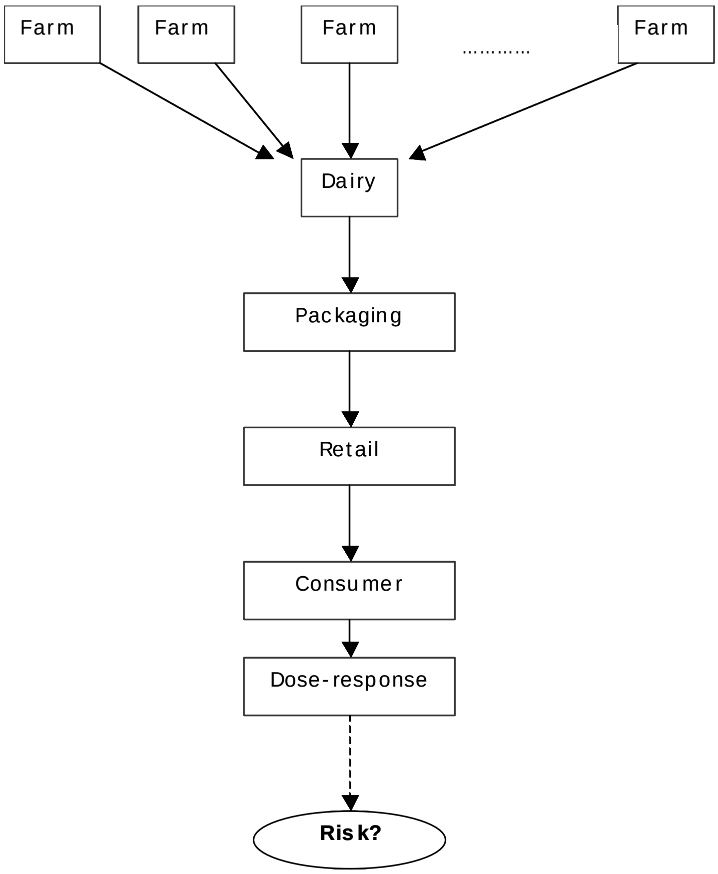

Figure 7.1. Flowchart describing the generic dairy production chain

For off-farm processing, milk is collected, often from a number of farms in succession, taken to a separate site and stored in a large silo with milk from other premises prior to pasteurization. Pasteurization then takes place on a continuous (rather than batch) basis; pasteurized milk is packaged and then transported by another tanker to the point of retail. As discussed, often volumes of throughput are large and operations of this kind are frequently large-scale in nature. (In contrast, the processing of milk on-farm is often much smaller-scale. The farmer may process both milk from his own cows and/or milk which has been brought in from other producers. Milk processed within this environment is either distributed commercially (though on a much smaller scale than that from the larger off-farm dairies) or can be sold at the farm gate).

Following pasteurization, milk is packaged and is transferred to the point of retail, where it is stored until it is purchased. Consumers buying the completed product will then store the product in a domestic refrigerator and may or may not subject the milk to further heat treatment prior to consumption.

7.4 Data requirements

We now consider each of the stages in the milk and dairy production chain in turn, focusing as discussed on the off-farm pasteurization scenario, and discuss the data requirements of each. We describe the dairy production chain in terms of a generic pathogen, and the framework is in principle relevant for all potentially milk-borne organisms. Again we summarise the model pathways and identification of data requirements discussed in greater depth in Clough *et al.* (2006).

7.4.1 The farm

The first stage of the dairy production chain is the farm, at which stage cows are milked and the resultant milk is stored in a bulk tank. Information on herd prevalence (here defined as the proportion of positive herds), animal-level prevalence (the percentage of positive animals within positive herds), numbers of viable bacteria or colony forming units (cfu) shed by infected animals in infected herds, rates at which contamination (direct and indirect) of milk with VTEC O157 occurs, levels of contamination and storage conditions in the bulk tank is needed for the first stage of exposure assessment. The principal outcomes from this stage which will feed into the next production stage are (i) the probability that the bulk milk tank is contaminated, and (ii) the amount or levels of faecal and/or pathogen contamination in the bulk tank (if present).

7.4.2 Transport between the farm and the dairy

For this stage, data on the typical storage temperature in the transporting tanker (necessary in order to determine whether bacterial growth might occur), the amount of milk transported in a given tanker and the number of farms from which milk is collected into a given tanker are needed. Levels of faecal and/or bacterial contamination (outputs from the first stage of the model) are important. The principal outcomes from this stage are (i) the probability that a typical storage silo is contaminated, and (ii) level or amount of contamination in contaminated silos.

7.4.3 The dairy

Key variables here may be divided up into pre-, during and post-pasteurization groups. Prior to pasteurization data on storage conditions in silos (so that one can evaluate the likelihood of bacterial growth in this environment), numbers of tankers contributing to a silo, and volume of silos are important. Considering the pasteurization process, pasteurization is the main Critical Control Point in the dairy production chain. Data relating to the probability that and mechanisms by which a pasteurization failure occurs are needed. If failure does take place, information on the likely levels of surviving bacteria is required. Finally, post-pasteurization, knowledge of the rates and levels at which post-pasteurization contamination occur is required, and information about the distribution of organisms in contaminated consignments following either a failed pasteurization or a post-pasteurization contamination event is needed. Outputs from this section are the probability that a given consignment is contaminated, and the likely levels of contamination present either as a result of pasteurization failure or post-pasteurization contamination.

7.4.4 Packaging

It is important here to have information on how the packaging process works, and on variables such as package sizes, storage conditions within the packaging environment, the market share within different environments (doorstep delivery versus milk purchased from shops), length of storage and types of packaging used. The outcomes from this stage are (i) the proportion of contaminated cartons after the packaging stage and (ii) the number of viable organisms in contaminated cartons.

7.4.5 Transport between the point of packaging and the point of retail

As in the case of milk being transported in its raw state between the farm and the dairy, data on the storage conditions maintained in the transportation phase is required, as well as information on the time in transit. The outcomes of interest here are (i) the proportion of contaminated cartons post-transport and (ii) the number of cfus in contaminated cartons post-transport.

7.4.6 Storage at the point of retail

Data on conditions of storage at the point of retail (refrigerator temperatures; time inside the refrigerator; time outside a refrigerated environment) are needed here. Ultimate outcomes are (i) the proportion of contaminated cartons occurring after storage and (ii) number of viable organisms in contaminated cartons post-storage.

7.4.7 Consumption and dose response

Crucial is some knowledge of consumption patterns of milk; in particular the sources of variation in consumption patterns (geographical and/or cultural differences may exist), the breakdown of consumer groups, the consumption patterns within these groups (particularly consumption patterns in susceptible groups), and how much milk is consumed without further heat treatment. Furthermore, information regarding storage conditions in the typical home (e.g. refrigerator temperatures, length of storage) is useful. Milk stored for a long time will spoil, and as a result should be rejected prior to consumption; however it is not clear how (or indeed if) the growth of pathogenic bacteria relates in any systematic way to the growth of spoilage organisms. Information on this should be sought.

Following on from this, data on the dose response relationship is fundamental to a meaningful assessment of the likely health burden arising from this environment; so, given consumption of milk contaminated with a certain number of viable organisms, the risk assessor requires the best quantitative information on the probability that a given consumer will become ill. The outcome from the MRA model will be a “best estimate” of the overall number of illnesses resulting from milk consumption, along with a distribution representing the combined effects of uncertainty and variability throughout the milk production chain.

7.5 Conclusions and recommendations

Microbial Exposure and Risk Assessments for milk-borne organisms can in principle be carried out, and a few have been implemented (see, for example, Clough *et al.* (2006) for a qualitative approach to assessing exposure to Vero-cytotoxigenic *Escherichia Coli* (VTEC) O157 from milk sold as pasteurised, and Nauta *et al.* (1998) for a quantitative assessment of exposure to *Mycobacterium paratuberculosis* in pasteurised milk).

It is likely that full assessments of risks and/or exposure from pathogenic organisms via milk remain sparse as a consequence of some of the key areas in which relevant data are lacking; as one example, Clough *et al.* (2006) identify a number of key uncertainties which impede the implementation of a full quantitative assessment of the risks in the context of VTEC O157: there is little information concerning the levels of VTEC O157 in lactating animals (studies which explicitly enumerate the bacteria are rare); evidence concerning potential seasonal variation in the shedding of VTEC O157 in cattle is inconclusive; little information concerning the rates of contamination and cross-contamination of the bulk milk tank could be identified; laboratory limitations dictate that it is not possible for a given contaminated batch of milk post-pasteurization to determine whether pasteurization failure or post-pasteurization contamination has occurred; it is unclear whether one can extrapolate between the growth of spoilage organisms (for which data are available) and the growth mechanisms of VTEC O157; and finally there is scant information regarding the pathogenicity of different bacterial strains. Nauta *et al*. (1998) use expert opinion to parameterise an important variable in their model, namely the expected number of *M. paratuberculosis* cfu per ml arising in milk via cattle displaying signs of clinical Johne's disease, again highlighting a key area in which experimental and field data are lacking.

The evidence from the milk-related exposure assessments which have been conducted thus far suggests that there are a number of areas in which field and laboratory-based studies could provide valuable information which is currently lacking. It is undoubtedly the case that studies addressing both specific (to particular pathogenic organisms) and general (more process-related) research questions are warranted.

7.6 References

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8. Beef production

8.1 Introduction

This chapter details a model pathway and data requirements for a pre-harvest risk assessment for beef. Within the EU, there is a high degree of variability associated with the amount of beef produced (see Table 8.1). The major producers are: France, Germany, UK, Spain and Ireland. As with many animal products, there is a consumer demand for organic meat and therefore beef cattle are also reared under these regulations (EEC 2004).

8.2 Description of Production Type

The beef eaten within Europe comes from two main sources (Europa, 2005). The first source of beef is from calves that were born to milking calves, which accounts for around 66% of the market. The remaining beef comes from calves born to ‘suckler cows’, where the mother will give all of her milk to the calf and the father is from a meat-producing breed (as beef production is the primary objective). Ninety percent of all beef produced are from these two sources, the outstanding 10% is veal. Veal is produced from calves that are fed on a mostly liquid diet of milk to produce a typically white or light coloured meat.

Table 8.1. Production of cattle meat (Eurostat, 2005). Covers the carcass weight of bovine animals (calves, bullocks, bulls, heifers and cows) slaughtered in slaughterhouses and on the farm, whose meat is declared fit for human consumption

	Production of cattle meat (1000t)											
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
EU (15 countries)			7966	7954	7889	7651	7691	7416	7265	7466	7360	7425
Euro-zone			6594	6861	6801	6573	6647	6342	6257	6412	6314	
Belgium	367	349	349	353	331	296	273	275	285	305	275	281
Czech Republic	193	162	168	161	148	132	127	108	106	109	110	97
Denmark	203	190	185	182	175	163	157	154	153	154	147	150
Germany	1604	1420	1408	1482	1448	1366	1374	1304	1361	1316	1226	1263
Estonia	43	31	26	22	19	19					12	15
Greece	76	74	70	71	69	68	65	63	60	62	62	62
Spain	485	472	508	565	592	651	678	632	642	676	703	714
France	1704	1627	1683	1735	1718	1630	1609	1528	1566	1640	1632	1565
Ireland	528	448	481	538	570	595	644	577	489	540	568	563
Italy	1188	1173	1181	1182	1160	1113	1164	1154	1133	1134	1128	1151
Cyprus	4	4	5	5	5	5					4	4
Latvia	107	68	48	27	26	26	23	22	19	16	21	22
Lithuania	162	116	87	83	90	81	77	75	40	38	43	48
Luxembourg	7	6	7	8	8	8	9	8	11	11	11	11
Hungary	98	72	59	59	56	46	46	46			35	38
Malta			2	2	2	2				2	1	1
Netherlands	611	604	580	580	565	534	508	471	372	384	365	381
Austria			196	222	206	198	203	204	215	212	208	206
Poland	474	415	380	410	423	424	380	344	312	277	321	298
Portugal	115	94	104	100	104	90	96	100	94	105	105	119
Slovenia	58	52	51	54	56	48	46	46				36
Slovakia											10	11
Finland			96	96	99	93	90	90	89	90	94	91
Sweden			143	137	149	142	144	150	143	146	140	142
United Kingdom	859	916	974	702	696	705	678	707	652	692	696	724
Bulgaria	112	85	65	80	57	56	63	66				
Croatia	37	31	29	24	28	28	25	27				
Romania	238	239	192	178	187	150						

Within Europe there are two methods of raising weaned calves to slaughter weight: pasture-based diet or cereal-based diet (Europa, 2005). Pasture-based (or 'extensive') systems are commonly used in countries such as the UK, Ireland etc. where cereals are hard to grow but where the land is pastoral. Beef cows reared under this system grow more slowly, usually to higher weights and produce meat that is more mature and stronger tasting. Calves from suckler calves tend to be reared under this system. Figure 1 summarises the links between the dairy and beef suckler herds in the UK; this is likely to be similar to other countries that produce beef under this extensive system. In the southern areas of Europe it is more common for cows to be reared under a cereal-based system since the climate supports cereal production but not pasture in summer. Under this system, cows will grow much faster and the younger, cereal-fed beef has a lighter taste and colour. Calves originating from dairy herds tend to be reared under this system.

8.3 Description of selected model pathway

This chapter will focus on the rearing of animals for beef production under the UK system. This system is likely to be similar to many in Europe and especially Northern European countries, i.e. those that rear cattle 'extensively'. In order to fulfil the main goal of beef farming, that is raising calves to slaughter weight for human consumption, there are general farm management practices that are followed within a typical herd.

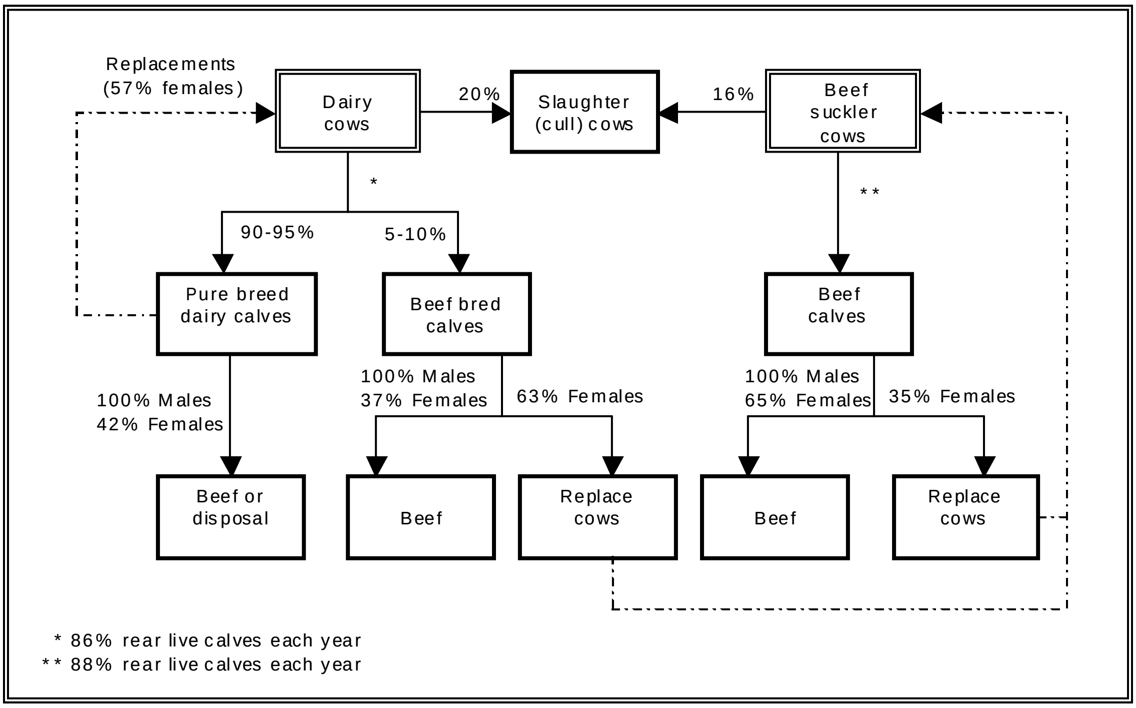

Figure 8.1. Schematic of links between UK dairy and beef suckler herds (based on diagram within Food Chain Group, 1999)

A cattle herd is either a spring or autumn calving herd and given this classification, the remaining major events in the life cycle of a beef cow can be described as summarised in Table 8.2.

From this information, a model pathway can be produced (see Figure 8.2) to estimate the prevalence of an infection[1] in the population of beef cattle sent to slaughter and hence into the food chain. For simplicity, this model will focus on the spring calving and calves that have been brought from a dairy farm, but could be modified for other production systems.

Within each phase of the model pathway a disease transmission model could be developed, which could (if desired) include the environment as a source of infection. Including the environment within transmission models has become more popular recently, particular for models for VTEC O157 (e.g. Turner, 2003). Information on the infectious disease transmission modelling is available in the Appendix of the section on 'Infectious Disease Modelling' in the WP14 Report on Modelling Techniques (Lo Fo Wong *et al.*, 2005). For simplicity, it is assumed that the disease dynamics for the hazard of interest can be mathematically described using an SI (Susceptible-Infected) model.

Table 8.2. Summary of beef calf production according to calving time (Philips, 2001)

	Spring calving (Feb-April)	Autumn calving (Sept-Nov)
Calving rate	90 calves/100 cows	89 calves/100 cows
Weaning age	5-8 weeks (at housing)	8-10 weeks (either weaned at turn out or turned out with dam and weaned during summer)
First year turn-out to pasture	Mid April (may be born at grass)	Spring/Summer (approx 5-8 months)
First year entering winter housing	November (approx. 6-9 months)	November (approx. 1-2 months)
Age at slaughter	18-24 months*	12-24 months*

*differ depending upon the reference referred to

Importantly, the pre-harvest model would need to take into account the housing and pasture phases of the production cycle as the transmission dynamics of the infection are likely to differ. Finally it is important to note that it might not be necessary to consider all of the production cycle (i.e. from birth to slaughter). This will depend on factors such as the risk question, management factors to be considered as part of any risk reduction strategy, data availability and available time.

Calves purchased at a few days of age from dairy herds are raised as beef animals in suckler herds on land that would not otherwise be used for agricultural purposes (Philips, 2001) or fed milk replacer and reared in non-mothering systems. The majority of dairy calves are reared in non-mothering systems, where the calves are fed milk replacer then reared to fattening. Calves are generally kept in individual pens or in small groups until about 5 to 8 weeks of age. After 8 weeks of age, the calves are penned together in larger groups in which complex social structures develop. Adequate bedding needs to be provided, usually straw, although sand and wood shavings are also used (Philips, 2001).

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[1] It is assumed that the infection is bacterial and causes human illness, but does not necessarily cause symptoms in beef calves/cattle, e.g. E. coli O157.

The natural time point for the initiation of the model (i.e. $t = 0$) is the day that the dairy herd calves arrive on the farm, if they arrive as one batch or the day that the first batch arrives if multiple batches are purchased.

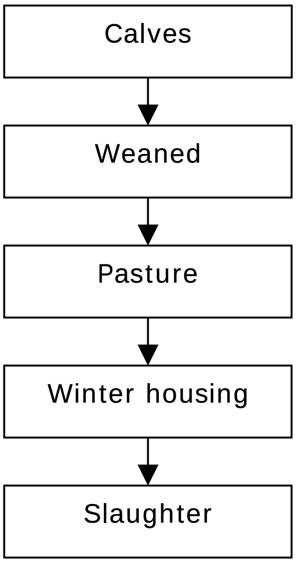

Figure 8.2. Model pathway for beef production in the UK

Weaning will occur at between 6 and 8 weeks of age when a calf is between 55-65kg and eating about 1kg of concentrates per day. Following weaning, concentrates continue to be offered ad-libitum together with grass, hay or straw and by 12 weeks old the calf is usually weighing between 90 to 110kg (UK Agriculture, 2005). This is typically a stressful phase for animals and can therefore have an impact on the disease transmission, for example infected animals may have a higher shedding rate. From Table 2 it can be seen that the weaning phase typically takes place indoors.

When at pasture, a variety of grazing systems can be used to ensure that cattle receive sufficient grass for the turn-out period (~6 months of the year). Such systems include: continuous grazing, rotational grazing, paddock grazing and strip grazing. If the model incorporates the environment then the system adopted could potentially be important. For example, continuous grazing will mean that the cattle are continuously exposed to the hazard within the environment (due to faecal contamination of the pasture). However, strip grazing will mean that after certain periods of time they are moved to new grass and hence no longer exposed to the faecally contaminated environment that they had previously grazed. Compared to when housed, the transmission of the infection between cattle may occur at a lower rate due to lower stocking densities.

During the winter, the animals are housed. This environment must not overly restrict their natural movement, lying down or rumination. However, compared to when at pasture, the contact between cattle is much closer and due to this, disease (including the hazard of interest) can spread rapidly. As a consequence of this good hygiene practices are needed. It is usual to use straw bedding which, if kept dry and clean, helps to keep the cattle clean during housing and to prevent the buildup of pools of faecal material. The animals enter the foodchain at 18 – 24 months (depending on calving time and weight).

8.4 Data requirements

Below is a list of some of the data requirements that would be needed in order to produce a mathematical model for the pathway given in Figure 2; it is not exhaustive. Both the data requirements for the farm management aspects of the model and for a SI transmission model are listed.

8.4.1 Farm management data requirements

- Initial conditions (*t = 0*) & generic information
    - Number of calves purchased and when (e.g. whether calves are bought in one batch or bought as multiple batches over a short time period)
    - All-in-all-out farm or will new calves (e.g. autumn calves) be bought onto the farm later on in the production cycle (if so, when, how many and information on contact between the different groups of cattle).
    - Assign date as *t = 0*

- Calves/weaning
    - Number of calves per pen (5 – 8 weeks old)
    - Number of calves per pen (>8 weeks old)
    - Information on time at which weaning occurs

- Pasture
    - Date of turn-out
    - Information on grazing patterns (if including environment).
    - Information on whether the whole herd is grazed together or in smaller groups. If the latter, need information on number of groups and group size.

- Winter housing
    - Date at which cattle are turned-in.
    - Number of pens in housing; number of cattle per pen
    - Time period for which cattle are housed

- Slaughter
    - Proportions of cattle sold at certain times (i.e. whether cattle are sold in one batch or in smaller batches over different time periods)

8.4.2 Infectious disease transmission model data requirements

- Initial conditions (*t = 0*)
    - Within group prevalence for new stock coming onto farm

- Generic information
    - Information on disease characteristics for calves and, if different, older cattle. For example, duration of infectiousness.
    - Parameter for disease transmission while (a) housed and (b) at pasture.
- Environment inclusion
    - Amount of pathogen present in the housing at time *t = 0.*
    - Amount of pathogen present on pasture at the time of turn-out

- Amount of pathogen each animal will shed per unit time
- Information on the decay of the pathogen in the different environments (house/pasture), which will be dependent on many factors, e.g. temperature, soil type etc.
- Dose-response information for calves and older cattle
- Parameter describing the rate or probability of infection due to contact with the environment.

8.5 Conclusions and recommendations

The beef industry is complex to model due to the different timings of calving and also the different sources of calves (dairy/beef herds). The model pathway and data requirements described here are for spring calves produced from a dairy farm. By only considering this source of beef, the model was greatly simplified.

The model pathway could be simplified further by not considering the entire production system, for example only considering the final stages prior to slaughter and omitting the environment from the model. However, considering all of the production cycle enables risk reduction strategies to be investigated for all of the life-stages for beef cattle. Likewise, including the environment increases the resolution of the model and enables further risk reduction strategies to be considered (e.g. differences in grazing patterns). In designing a pre-harvest model for any food producing animal, the most important factor is to consider whether the final model design addresses the risk question posed. This includes its potential to investigate the risk reduction strategies of interest to the risk manager, whether there is enough data available to parameterise the model and, finally, whether there are enough resources to develop such a model.

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9. Sheep production

9.1 Introduction

Sheep are reared for many purposes, but are predominantly reared for producing meat for both domestic and export markets. However, wool and milk products add to the value of sheep industry. Within the 15 EU countries in 2003, it was estimated that there are 87,408 thousand sheep (see Table 9.1; Eurostat). The large majority of these sheep are produced in the UK, Spain, Italy and France. As with many farming practices, sheep can be reared conventionally or under organic regulations; the latter is a growing market within the EU.

Table 9.1. Number of sheep (Eurostat, 2005)

	Number of sheep (1000)							
	1993	1995	1997	1999	2001	2002	2003	2004
EU (15 countries)							87408	
Belgium		158	155	160	156		146	151
Czech Republic							102	
Denmark		145	142	143	152	131	144	
Germany		2335	2315	2724	2771		2697	
Estonia							46	
Greece		9598	9515	8832	9058		9326	
Spain		21302	24857	23962	23823		23486	
France		10056	9824		9231		8989	
Ireland				5319	4807		4850	
Italy		10690	10890	11017	8312		7953	
Cyprus								
Latvia							39	
Lithuania							17	
Luxembourg		7	7		7		7	
Hungary							1296	
Malta							15	
Netherlands		1671	1465	1401	1296	1186	1185	
Austria		364	384	352	320	309	325	
Poland						345		
Portugal	3305	3427	3414	3584	3459		3356	
Slovenia							106	
Slovakia							326	
Finland		115	103	77	67		67	
Sweden		462		437			448	
United Kingdom		28373	29491	30583	24280		24429	
Bulgaria							1599	

9.2 Description of Production Type

It is likely that sheep production within the EU will vary between countries. As a consequence of this, this model pathway has been produced based on the UK sheep industry, where sheep are reared on a diverse range of habitats – from lowland to upland areas. This system exploits the diverse geographic terrain of the country (Williams, 1999). Hardy ewes are bred extensively in the harsh hill areas dominated by poor grazing and rough terrain; these ewes account for 50% of the national flock. Replacement ewe lambs produced in the hill areas and not kept as hill breeding stock are crossed with upland rams to produce crossbred ewes, which account for a further 40% of the national flock. The upland produced crossbred ewes are then crossed with lowland breeds to produce prime lambs that are finished on rich lowland pastures for slaughter.

This system is illustrated in Figure 9.1. As the predominant reason for sheep rearing is for the production of lamb, this model pathway will only consider this last element of the production cycle, that of young lambs being reared on lowland pasture.

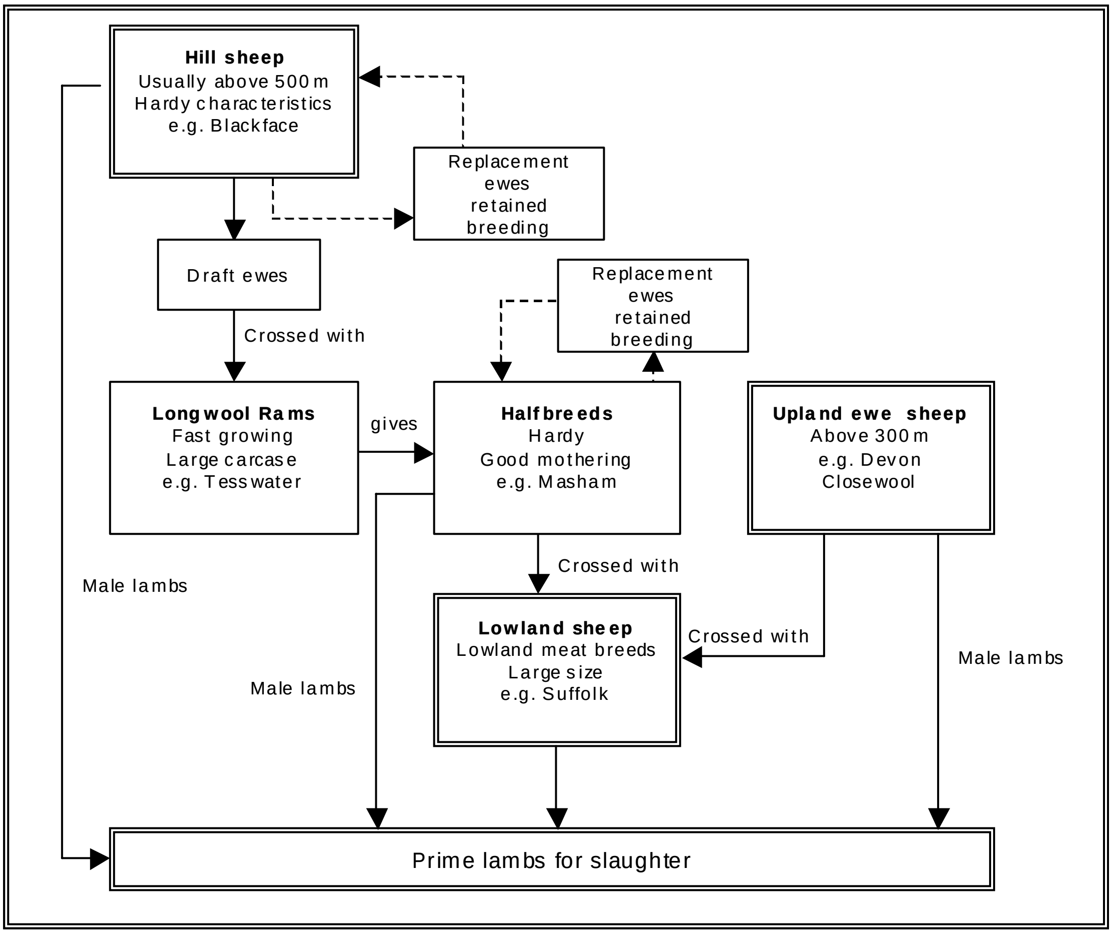

Figure 9.1. Schematic simplification of the structure of the sheep industry (based on diagram published by National Sheep Association)

In the lowland areas, due to the abundance of fresh pastures, farmers are able to produce a large number of lambs (i.e. 160-170 lambs per 100 ewes) in a very short time period and at high stocking rates (i.e. 10 to 15 ewes per hectare) (Williams, 1999). The farm's economic success, however, is dependent upon capitalising on the highest market prices for lambs, and, accordingly, the management practices of lowland flocks, in general, are centred on tupping (mating) and lambing. Further, as all lowland farms are aiming for economic success, there is little variation in the timing of these management practices and, hence, the activities undertaken during a typical farming year can be defined for each month as outlined in Table 9.2. As summarised, during specific times of year, the flock is segregated into groups (e.g. pre- tupping, tupping, lambing, post-lambing). These groups will not necessarily always contain the same animals; a practice that will ultimately have an impact on disease transmission within the flock. Each year 20% of the flock is culled and replaced annually (Williams, 1999).

9.3 Description of selected model pathway

As described above, this pathway will concentrate on the rearing of lowland ewes and their lambs using the production cycle given above in Table 2. An important attribute of the model will be the necessity to include the potential mixing of groups, the birth of new lambs, the depopulation of lambs, the culling of spent ewes and the arrival of their replacements. Figure 2 gives a suggested model pathway to estimate the prevalence of an infection[2] in the population of lambs sent to slaughter and hence into the food chain. The year is split into 7 phases: (1) Purchase replacements (2) Tupping (3) Post-tupping (4) Housing (5) Lambing (6) Turnout (7) Sell lambs/cull ewes. Although this pathway considers a whole year in the lamb production cycle it is might not be necessary to consider all of it.

Table 9.2. Typical farming year for lowland ewe flocks (Source: Williams, 1999; NSA, 2004)

Month	Management practice
August	• Examine flock and cull ewes in poor condition • Purchase replacement stock • Lambs sold for slaughter
September	Check ewes and rams for condition Two weeks prior to tupping ewes put onto good grazing land Teaser rams may run with flock for three weeks Remaining lambs placed on store feed rations
October/November	• Tupping (mating): exact dates depend upon required lambing date • Two to four rams run with approximately 40 ewes per ram • Maintain same groups for a month after tupping • Remaining lambs finished for market
December	• Scan ewes to identify barreners (ewes with no lambs) and assess feeding requirements
January	• House ewes in pens of 20-40 animals so that animals with similar feeding requirements are kept together • May shear flock during housing
March- April	• Lambing period • After lambing move ewe and lambs to individual pen for 24-48 hours. • Lambs from a triplet are transferred to a ewe with a single lamb • Turn out ewes and lambs to small paddocks in small groups before moving animals to larger fields. If weather is not good, the ewes and lambs may be kept indoors in groups of 10 ewes plus lambs
June	• First spring-born lambs are ready for slaughter (around 40kg)
July	• Dip sheep for ectoparasite control • Wean lambs around 4 months of age. Ewes removed and put onto bare pasture and lambs moved onto young grass • Majority of lambs sold for slaughter

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[2] It is assumed that the infection is bacterial and causes human illness, but does not cause symptoms in sheep, e.g. E. coli O157.

This will depend on factors such as the risk question, management factors to be considered as part of any risk reduction strategy, data availability and available time.

Within each phase of the pathway an infectious disease transmission model could be developed – thus allowing the sheep management practices to be combined with the microbiological aspects of disease transmission. This would be a complex task however, primarily due to the changes in the groupings of animals and the consideration of the flock structure (i.e. lambs and ewes/rams). The structure of a transmission model for this pathway, i.e. whether a Susceptible-Infected (SI) or Susceptible-Infected-Recovered (SIR) model is dependent on the hazard and its effect on the host.

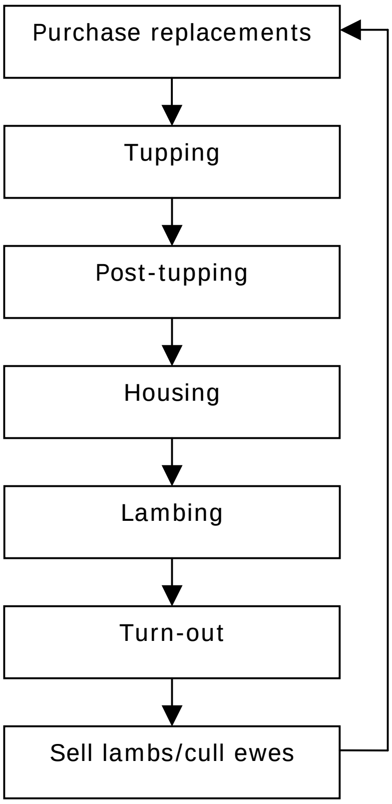

Figure 9.2. Selected model pathway for pre-harvest sheep production

However, for simplicity, it is assumed that a SI model will suffice here and so the model will developed in the same way as described in the Appendix of the section on 'Infectious Disease Modelling' in the WP14 Report on Modelling Techniques (Lo Fo Wong *et al.*, 2005). Lastly it is important to note that for grazing animals, the contribution of the environment can be a factor. Infectious disease models have been adapted to incorporate this fact (e.g. Turner, 2003) but here, again for simplicity, this aspect is only covered in brief.

The model pathway assigns $t = 0$ to be a random day in August, which is assumed to be the day before the replacement ewes/rams are brought onto the farm. The model will need to consider the prevalence of both the remaining flock and replacement stock at this time and also the groupings of these animals. On-farm quarantine may or may not be applied to the new stock; in the UK this is typically 7 days.

Once the replacement stock have joined the ‘old’ stock, the ewes are put onto good grazing grass (September) and ‘tupped’ (mated) in November/December. The exact date will be dependent on the required lambing date so, to describe a random farm, information would be required on this source of variation. For tupping the sheep are split into random groups and remain in these groups for another month. After tupping the ewes are re-grouped in a similar way to the situation at during the purchase replacements stage of the model.

The pregnant ewes are housed at about 3 weeks prior to lambing (this time/date will be dependent on the dates of tupping and the gestation period); the barren ewes may be grouped together and remain outside. The housed ewes will be put into pens; the ewes are assigned to pens based on the number of expected lambs each ewe is expected to produce. Lambs are then produced, of which around 15% of lambs will die annually (due to ailments such as infectious disease, congenital defects, predators etc.) and this might need to be included in the model, especially if there is a link between ill lambs and infection with a food-borne pathogen.

The ewes and lambs are placed in isolation for 24 hours and then put out to pasture. For the first week, they will be grazed on pasture near to the winter housing and after that the ewes and lambs are grazed at pastures further afield at lower stocking densities. Again the animals will be grouped here, and in different groups to before.

As described in Table 2, the first batch of lambs is sold in June which is when they are approximately 16 weeks of age. For each week after this, batches of lambs that have reached 4 months of age are sold with the majority of lambs being sold at the end of the month. Some lambs do remain on the farm, but are removed from the ewes at the beginning of August and put onto young grass. The ewes are grazed on bare pasture and barren and random ewes are culled (20% of flock).

9.4 Data requirements

Large data requirements would be necessary in order to develop such a model. Below some of the key data requirements have been listed, for both the farm management aspects of the model and also the SI transmission model. The list is not exhaustive. The data requirements have been considered for each step of the model pathway, however the data required for the initial conditions are also listed.

9.4.1 Farm management data requirements

- Initial conditions ($t = 0$)
    - Flock size (number in each age group: ewes and lambs)
    - Number of ewes/lambs per grouping of sheep
    - Assign date as $t = 0$

- Purchase replacements ($t = 1$)
    - Number of replacement ewes/rams
    - Probability that farm quarantines new stock and length of quarantine
    - Information on how replacements are mixed with ‘old’ stock

- Tupping
    - Number of groups; number of ewes and rams per group
    - Probability of ewe conceiving; probability of being a single lamb, twins or triplets.
    - Duration of tupping
    - Duration of gestation

- Post-tupping
    - Information on the reallocation of the ewes to their former groups.

- Housing/lambing
    - Day at which pregnant ewes are housed
    - Number of pens in housing; number of ewes per pen
    - Time period for which ewes/lambs are housed
    - Lamb mortality rate

- Turnout
    - Time spent on pasture near to winter housing
    - Grouping information for ewes and lambs on pasture further afield (number per group/field)

- Sell lambs/cull ewes
    - Proportions of lambs sold at certain ages
    - Proportion of total lambs produced sold/proportion of lambs retained on farm
    - Grouping information for the ewes and remaining lambs
    - Number of ewes culled

9.4.2 Infectious disease transmission model data requirements – environment not considered

- Initial conditions ($t = 0$)/Replacement stock ($t = 1$)
    - Within flock/group prevalence for resident stock
    - Within group prevalence for replacement stock

- Generic information
    - Information on disease characteristics for (a) ewe/ram and (b) lamb. For example, duration of infectiousness.
    - Parameter for disease transmission for ewes/rams while (a) housed and (b) at pasture.
    - Parameter for disease transmission for lambs while (a) housed and (b) at pasture.

For completeness, although not considered here in detail, to include the role of the environment in the risk assessment, the following information would also be required:

- Farm management data requirements
    - Information on grazing patterns during the year

- Infectious disease transmission model data requirements
    - Amount of pathogen present in the environment (house/pasture) at time $t = 0$.
    - Amount each animal type will shed per unit time
    - Information on the decay of the pathogen in the different environments (house/pasture), which will be dependent on many factors, e.g. temperature, soil type etc.
    - Dose-response information for ewes/lambs
    - Parameter describing the rate or probability of infection due to contact with the environment.

9.5 Conclusions and recommendations

The model framework described above could be adopted for many hazards that infect sheep, including those relating to veterinary public health. However, the inclusion of the entire farm management and disease transmission aspects (especially if the environment is to be included) would result in a very complex model. The model could be simplified in many ways, for example only considering certain stages such as those that cover the time between the birth and depopulation of the lambs. As mentioned above, the design of the model pathway will depend on factors such as the risk question, management factors to be considered as part of any risk reduction strategy, data availability and available time. In conclusion, the development of the full model described here would provide an excellent insight into the transmission of disease within sheep flocks and, in particular, how farm management practices affect these dynamics and how infection can persist on a farm over consecutive years.

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10. Fish production

10.1 Introduction

Aquaculture is the controlled cultivation of water organisms. Worldwide there exists different fish farming systems, depending mainly on the species to be grown on and the existing natural resources. Therefore we focus on the broad principles of the most important finfish aquaculture systems with special emphasis on the most commonly production systems in Europe, the fresh water rearing of salmonids. The diversity of fish farming is a reflection of the very different types of fish farmed and the extent to which the farmer undertakes the entire cycle of operations within his farm. However, it also reflects the varying levels of intensification which may be adopted and it is the more intensive methods which will be described here in greater detail.

The rapid increase of the aquaculture worldwide indicate the great importance of this branch of animal production: Since 1950 world marine and inland capture fisheries production increases on average by 6 %, trebling from 18 in 1950 to 56 million tonnes in 1969. During the 1970s and 1980s the average rate of increase declined to 2 % per year, falling to almost zero in the 1990s. This is due to the majority of stocks being fully exploited, many fishing areas apparently reached their maximum potential for capture fisheries production. In contrast growth in aquaculture production has shown the opposite trend; increasing rates grew by about 5 % per year from 1950 to 1969 and by about 8 % per year during the 1970s and 1980s, and it is increased further to 10 % per year since 1990. Overall, [3]fish production by aquaculture contributes to 3,9 % of the global yields of water organisms (including aquatic plants) and increased to 27,3 % in 2000. Table 10.1 lists the yields in aquaculture in comparison to the global fish catch.
The global patterns of fish production owe much to China's activities; fisheries production accounts for 32 % of the world total. In 2002 China remains the largest producer, with reported fisheries productions of 44,3 million tonnes (16,6 and 27,7 million tonnes from captures and aquaculture, respectively), but the statistics reported from China is questioned.

Table 10.1. World fisheries production and utilization (excluding aquatic plants)

Million tonnes	1995	2001	2002	*2003
Inland (fresh- and brackish water)				
Capture	7.2	8.7	8.7	9.0
Aquaculture	**14.1**	**22.5**	**23.9**	**25.2**
Total	21.4	31.2	32.6	34.2
Marine				
Capture	84.3	84.2	84.5	81.3
Aquaculture (Mariculture)	**10.5**	**15.2**	**15.9**	**16.7**
Total	94.8	99.4	100.4	98.0
Total capture (Inland and marine)	91.6	92.9	93.2	90.3
Total aquaculture (Inland and marine)	**24.6**	**37.8**	**39.8**	**41.9**
Total world fisheries	116,1	130,7	133,0	132,2

* estimated

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[3] Fish means all water organisms excluding algae. Finfishes are the fish per se (with gills, spine and fins). Shellfish includes bivalve molluscs (for instance mussels or cockles) and crustaceae (for instance crabs and lobsters).

Other major producer in fisheries are, Japan, India and Europe. Within Europe, Norway rank in first place followed by Greece, Spain and Denmark. Beside China, the most expanding aquaculture nations are Chile, Greece and Turkey.

Compared to land animal farming, fish farming is much more complex because there are many more species of fish farmed, each with different biological demands. While some fish are marine and others need freshwater, many fish can be farmed in brackish waters. Certain migratory fish, such as salmon, breed in rivers where the eggs hatch and the fry live until ready to go off to the sea before eventually returning to spawn as mature adults; so salmon farmers need a freshwater hatchery as well as a seawater farm to rear the stock up to marketable size. Different species are adapted to live at different temperatures and tropical fish usually cannot be farmed in temperate climates unless the water is warmed artificially. Fish also vary greatly in their food requirements ranging from carnivores like eels or salmon, which require a high proportion of animal protein in their diet, via omnivores (e.g. european carps) with less selective tastes, to herbivorous fish, such as grass carp. A further complication is the early part of the life cycle which involves a variety of different larval stages, each with different food requirements. A fish farmer may undertake the entire production cycle from spawning of mature adults through early-rearing and on-growing to production of marketable fish. Alternatively the cycle may be short-circuited in various ways, for example by using supplies of wild juvenile fish if they cannot be bred in captivity. *Polyculture* of finfish consists of a combination of different fish species within the same production unit. This contrasts with *monoculture* of a single species. In the case of migratory fish it may even be possible to release hatchery-reared juveniles into the wild and rely on their homing instinct for recapture. This is sometimes called *"sea ranching"* and is a variation of *"culture-based fisheries"* in which wild fish populations are boosted by hatchery-reared juveniles.

The industrialized finfish production systems are generally characterized by the following factors:

1. Use of rearing units for each stage in the production cycle (see Fig. 1).
2. High stocking rates to achieve maximum yields of marketable fish in relation to available rearing space.
3. Use of scientifically formulated diets, usually in the form of a compounded pellet.
4. A high degree of automation applied to husbandry operations such as feeding, grading and harvesting.
5. Close control over the production cycle, wherever possible stretching from egg via larval rearing to marketable fish and broodstock.

Fish species to be farmed can be classified according to whether this takes place under freshwater, brackish water, or truly marine conditions. Certain families appear under more than one category because so-called 'anadromous' species of wild salmon, trout, ayu, striped bass or sturgeon normally breed in freshwater but migrate to live at sea for a major part of their life cycle, whereas 'catadromous' fish, such as eels, do exactly the opposite. A striking feature of certain fish species is their ability to live and thrive under different conditions. For instance mullet can withstand widely different salinity levels ("euryhaline") with the result that they can be farmed successfully in freshwater ponds as well as marine enclosures. This characteristics of adaptility (crowding or changing water quality), is one of the most important biological factor determining the suitability of a particular fish species for farming. The most commonly farmed group of fish, namely the cyprinid or carp family, is highly adaptable to fluctuating temperature, oxygen level, poor water quality and can be heavily stocked without apparent stress (but cannot withstand changes in salinity, "stenohaline"). If a particular species of fish becomes stressed when crowded under farm conditions, it is likely to stop feeding and consequently growth and survival rates will be poor due to infections. On the other side, eels cannot be reproduced in captivity and few marine fish have a simple larval development, but the incentive of a high market price has led to their successful farming.

10.2 Description of production types: the classification of aquaculture facilities

Beside the above mentioned techniques (Mono - polyculture, sea ranching, culture-based fisheries, extensive and intensive fish farming), aquaculture facilities can be devided in three main system groups: *open*, *semiclosed* and *closed* techniques.

10.2.1 Open systems

The open system farming is the oldest of the aquaculture system and is characerized by the use of the environment as the actual fish farm. The water needed for fish cultivation does not require to be pumped into a certain plot. The water organisms are cultured in certain devided areas of the sea (shore enclosures) or lake. Bivalve mollusk <u>bottom</u> culture or <u>fish cages</u> (or fish pens) are examples. The main advantage is that capital expenses is low and less management have to be done. The level of intensification is in the case of shore enclosures extensive, while stocking densities in net cages can be high (from 15 to 20 kg/m^3 for fingerlings to 30-40 kg/m^3 for on-growing fish). The disadvantage is the low level of control over environmental condition thereby leading to losses through diseases, poachers and predation. Moreover the growth rate and the uniformity of the product are variable. Many factors should take into consideration for the adequate site selection, i.e. tidal effects, sedimentation, currents or the availability of food.

10.2.2 Semiclosed systems

Semiclosed systems are the most popular method of finfish culture. Water is taken from a natural source (well, lake or sea) and is directed into a specially designed facility (i.e. raceways, ponds or tanks). The water either makes a single pass through the installation and is discharged or a part of the water volume is retained and recirculated. In general the main advantages over open systems is the better control of the cultured organisms for instance temperature, feeding, water-flow, aeration and disease control

There are also some drawbacks of semiclosed aquaculture systems. They can be more expensive and a complex operation management have to be done. Furthermore, because more animals can be reared in these systems there is a greater possibility of deterioration of water quality with the result of disease, stress and hygienic problems.

The main holding systems used in semiclosed systems are ponds (embanked or excavated), raceways and tanks. The ideal site for a semiclosed system is determined by how the animals are to be grown. These different holding systems require different types of sites. The source of water must be of good quality, and it must be available in quantities sufficient for the farmers' needs and meet the demands of the finfish. Water quality should always be established before a site is selected. If water does not come from a constant source such as a deep well, the amount of water will fluctuate, and this must be planned. There may also be a problem of too much water; there may be flooding during the spring when ice melts or during periods when there are *heavy rains*. Besides getting water, the discharge of the water after it has gone through semiclosed system must be considered. The soil, in the case of earthen ponds (the main holding systems for trouts in Germany), is also critical. While some measures can be taken to seal a pond if it does not hold water, this is troublesome and expensive. Furthermore, earthen ponds contribute to hygienic problems and could be the cause of fish diseases. Predators and pests in an area can cause problems. In some cases, birds can be major consumers of cultured fish, the most important bird pests in Germany are cormorant and could be the cause of secondary infections due to wounds.

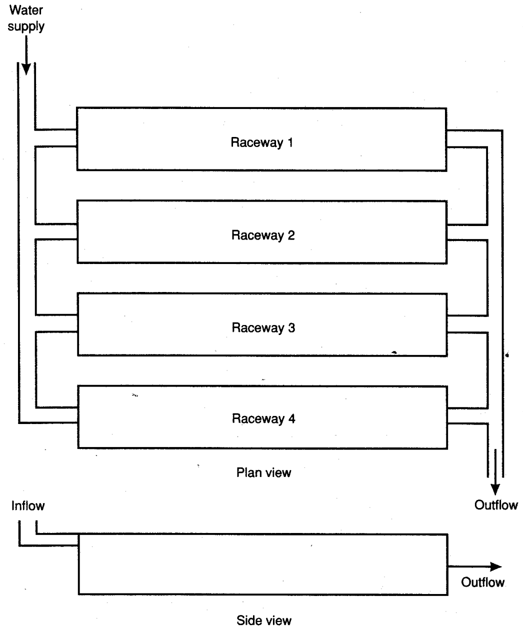

Figure 10.1. Parallel raceway design

10.2.3 Closed systems (recirculating systems)

Closed systems are defined as those in which little or no water is exchanged and the water is subject to extensive treatment. These have made little impact on the commercial aquaculture industry, although some laboratory reports are very promising. Extremely high densities of organisms may be raised under these conditions if they are managed properly. The major advantage to closed systems is that they allow the farmer to have complete control over growing conditions. The temperature may be carefully regulated, which is not economically possible in semiclosed systems where much of the water is replaced on a regular basis. No parasites or predators are introduced from the environment, and microbial diseases - if properly managed - are less often introduced. Weather conditions are never a problem, and harvesting is simple. Food and drugs can be added efficiently into the system. All this allows the organism to grow quickly and uniformly. Because there is a reduced need for a large water supply, the choice of the site for the farm is expanded; a farmer could raise marine organisms in artificial seawater hundreds of kilometers from the sea. Another future consideration is that with our ever dwindling water availability, closed aquaculture systems may be the only viable culture methods in many instances; other types of systems require much more water.

There are also problems with the closed system. Because water is reused and the density of the animals is so great, the filtration/treatment systems must be very good, and the water must generally be pumped through these systems at a fairly high speed. This, in turn, requires an excellent managing since there is no natural safety buffer in the form of significant amounts of clean water brought in from outside the system. Because the system can be controlled with respect to optimal living conditions for the animals in question, disease control should not be a great problem. However, if a disease organism does find its way into the system, it can spread quickly because of the high stocking densities that are used and because the water is often warm (allowing rapid replication of the disease organisms). If diseases are undetected by the manager for even a short time, they can decimate a stock. There is also the problem of the capital equipment and operating costs, which may be substantial, since there is a greater dependence on machinery to treat the water.

10.3 The farming cycle of the rainbow trout

The farming cycle of the rainbow trout can be sub-divided into three stages: incubation, fry rearing and on-growing.

Incubation

This stage relies on a supply of high quality water, ideally from a spring or borehole at constant temperature. Incubation may be carried out in hatchery trays or baskets held in series in plastic or fibreglass troughs resting 3 cm above the bottom, and supplied with water from a feeder channel. A litre of eggs requires an inflow of 3-5 litres/minute; a tray of 10.000 eggs requires 5.000 litres/day. An alternative system is the jar or vertical incubator, usually of fibre glass or plastic and holding from 5-100 litres of eggs.

Fry Rearing

After hatching the fry are transferred to rectangular or circular fry tanks, usually of fibreglass or plastic, with an inflow pipe, a central outflow and an overflow pipe. The standard size of a rectangular tank is 2 m x 2 m x 50-60 cm deep. At about 1 month old the fry can be stocked at 25 kg/m^3 with a water through-flow of 1 litre/minute/kg, this reducing to 1 litre/minute/ 2.5 kg as the fry reach 10 g size. After reaching 500 fish/kg they can be held in any form of tank or raceway but should not be placed in earth ponds until 16 weeks post-fertilisation, as a precaution against whirling disease.

On-growing

The three major systems for land-based farms are ponds, raceways or tanks.

10.3.1 Earth ponds

This traditional system comprises a single or double series of earth ponds, excavated on a level site and relying on gravity feed. The ponds are supplied from a watercourse via an inlet channel. Each pond discharges to an effluent channel and finally to the river further downstream. The ponds are usually unlined but if the substrate is porous the bottom can be covered with a layer of clay. Sometimes they are lined with polyethylene sheeting. A typical pond size is 30 m x 10 m x 1 m deep at the intake, sloping to 1.5 - 2 m at the outflow. Flow rates are quite slow at 1-1.5 litres/second, resulting in 3-6 water changes per day. Average stocking density is 2 kg/m^3.

Advantages: Inexpensive, easily excavated. Disadvantages: Requires a level site and regular cleaning to avoid degradation of food/faeces. Fish are not easily observed. Husbandry procedures (harvesting, grading, treatment) are not easy

10.3.2 Raceways
This rearing system is the original North American system. Raceways come in a variety of designs and sizes and consist of a series of parallel channels. Typically they may be 30 m long x 2.5 m wide x 0.7 m deep and constructed of concrete. They rely on high flow rates of clean water.

Advantages: High stocking densities, ease of husbandry. Disadvantages: Requires high flow rates, Hygiene problems lower down the system, fish can waste energy swimming, damage to fish by concrete walls.

10.3.3 Tanks
Usually circular and constructed of concrete or plastic (fibreglass). Tanks are typically 4 m in diameter and 0.75 m deep. The concrete base slopes from the circumference to a central drain. They can be dug into the ground or kept above ground, and are usually covered with lids. Water enters through a peripheral inlet at about 4 litres/second and flows in a circular fashion before leaving at a central outlet comprising a stand pipe surrounded by a screen.

Advantages: Easy erected and maintained, self-cleaning, each tanks are individually contolled via valves. Disadvantages: Cost expensive

10.4 The farming cycle

10.4.1 Broodstocks
Broodstocks are usually held in raceways or large ponds at much lower stocking densities and lower feeding rates than required for production fish. However, they are fed well prior to spawning and are usually stripped manually at 3 years old. Stripping is much easier under anaesthesia. Anaesthetic must be rinsed off afterwards because the smallest residue affects sperm motility. It is important to avoid breaking the eggs or allowing any blood contamination as this may block the micropyle and reduce fertilisation success. The technique is to strip the male first, followed immediately by the female, into a plastic container with no trace of detergent or disinfectant. The optimum ratio is 1 ml of milt to 8,000 eggs (10,000 eggs 5 mm in diameter occupy 1 litre). Milt and eggs are gently stirred with clean, dry hands, taking care to avoid direct sunlight or any temperature shocks at this stage. After fertilisation the eggs, are water-hardened for 10 minutes before transfer to incubator trays or bottles.

10.4.2 Hatchery

The newly fertilised or 'green' eggs remain sensitive to temperature shocks and physical movement for 15-18 days, when the eyes become visible as two black dots. From the 'eyed' stage until hatching the eggs are relatively tough and can withstand sorting, handling and transport. Unfertilised or damaged eggs can be killed by 'shocking' the eyed eggs, which involves pouring them to another container held 40-50 cm below. Healthy eggs remain undamaged and are returned to trays or jars to continue development. The incubation period of eggs from different females at the same temperature can vary by as much as 5-6 days. In general the incubation period is approximately 300 degree-days. Poor hatchability occurs at temperatures much above 18°C or below 4°C. The newly-hatched yolk sac fry will continue to absorb yolk for 2-6 weeks, depending on temperature, before reaching the swim-up stage and actively feeding. Commencement of feeding is a critical period. Some managers offer feed whilst the fry are still in hatchery troughs but others wait until transfer to fry tanks. Fry must be fed well using the smallest crumbs, and all excess removed. Once adapted to feeding, food is offered little and often for 20 hours per day via automatic feeders. Such a system is essential for good fry production. Body weight will double every week or so and the diet is adjusted accordingly. An increase in diet size is to be avoided if it proves too big for some of the fish.

10.4.3 Fry tanks

At 500 fish/kg the fry can be moved to tanks or raceways but, as previously mentioned, must not be stocked into earth ponds until about 16 weeks post-fertilisation (7-8 cm). Management changes required during this period involve alterations in feed rates and pellet size and possibly adjustments to water-flow rate and depth. In any trout population a hierarchical structure is established, resulting in differential growth rates and a big variation in individual size. Tail and fin nipping is a likely consequence. This can be much reduced with regular grading (starving fish for 12 - 24 hours beforehand) but the procedure will stress fish unduly if carried out too frequently and will result in reduced growth rates. A suitable regime is to grade once in the fry tanks, once on transfer to larger tanks and two or three times whilst growing. Figure 10.2 shows a flow chart of the trout farming processes leading to different finfish products.

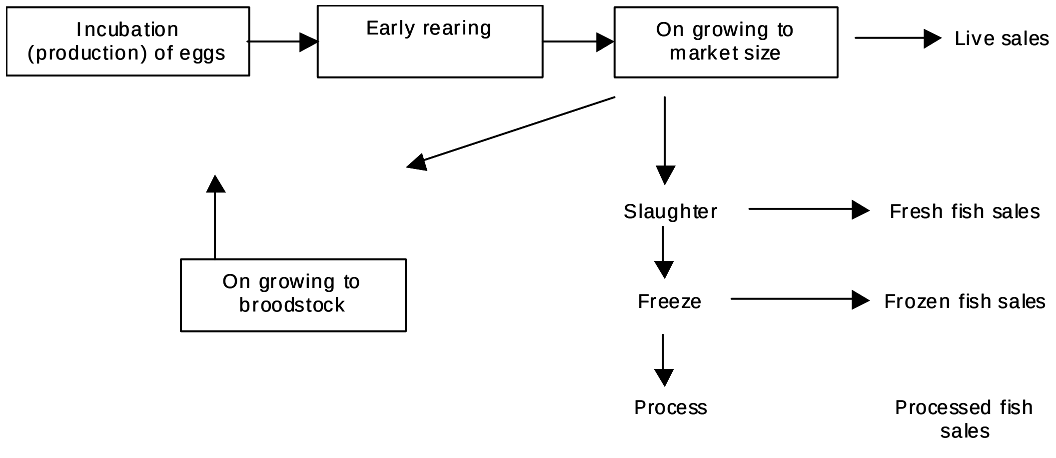

Figure 10.2. Flow chart of the trout farming processes

10.5 Pre-harvest risk assessment

Risk assessments are addressed to which microorganisms or chemicals are introduced into a fish farm which - in turn - depends on the farming system used and the site, respectively. It has been emphasized that the choice of the location - beside other components - depends on which fish species is used for farming. Therefore, pre-harvest risk assessment should take into consideration the special farming systems (i.e. intensive or extensive fish farming), freshwater culture or marineculture and the production types (open, closed, semiclosed).

For open sytems (for instance cage culture of finfish, shore enclosures or bottom mussel culture) several sources give raise to faecal or chemical contamination of fish. The sources of greatest impact will differ from area to area, depending on the contribution and distribution of the sources in that area, the effect of rainfall on the contribution from individual sources and the geographical proximity of the sources to the harvesting area. Examples are effectiveness of sewage treatment processes, discharges from sewer and surface water overflows, river flows, farming activities and direct land run-off. Tides, currents (hydrodynamic effects), and environmental factors like season, temperature, wind and sunshine will alter the magnitude of the contamination from any one source. It is accepted that while health risks associated with human sources may be of greatest risk, animal wastes may contain micro-organisms pathogenic to humans (e.g. *E. coli* 0157, *Salmonella*, *Campylobacter*, *Cryptosporidium*). Table 10.2 lists the possible sources of contamination of fish farmed in open aquaculture systems. As a further example, methyl mercury and natural algae toxins, such as ciguatoxin or domoic acid, pose problems principally to marine fish held in aquaculture and also for man if fish are eaten.

Table 10.2. Possible sources of contamination of fish farmed in open aquaculture systems.

Source	Level risk to public health
Municipal sewage plant	Most significant risk because of many contributing population and volume; type of treatment important
Industrial waste	Significant risk if wastes involve human pathogens or chemicals which can be bio-accumulated; important because of volume of waste
Sewer overflow	Significant risk because of untreated human waste
Animal feedlots	Potential human risk because of large aggregation of animals and ability of some domestic animals to transmit human diseases (pigs, poultry, cattle)
Waste discharges from boats	Potential human risk due to possible intermittent discharge of small quantities of raw sewage
Street drain	Potential human risk because of some potential for human sewage discharge
Rural land with domestic animals	Significantly less risk than direct human sources

In semi closed systems there is principally the possibility that micro-organisms or chemicals can be introduced to a fish farm by means of food or water depending on the source and site, respectively. Two examples should demonstrate this problem:

The dioxin content of farmed finfish and of finfish caught in the wild are nearly of the same magnitude. As stated above intense farmed carnivores such as trout or salmon need a high qualitative diet with a high proportion of animal protein in their diet. This is solved by adding fishmeal and fish oil to the diet. Several investigations showed that farmed fresh water and sea water fish contains dioxins and that the source of contamination are marine "industry" fish from which fish meal and fish oil is produced. These fish contain variable amounts of dioxins, depending on the fish species and location of catch. The same findings were for organo tin compounds (tributyl tin, TBT) which has been detected in significant levels in trout food and therefore in trout from aquaculture farms.

Beside chemical contaminants there is the possibility of microbial pollution of a freshwater fish farm, especially after heavy rainfall if a fish farm is situated near rural areas with domestic animals, animal feedlots or when a sewage plant is situated above the fish farm. In those cases it is possible that microorganisms being pathogenic to man (and fish) can invade the farm and fish via water. It is also conceivable that zoonoses are brougth into a fish farm through broodstock fish or fingerlings. The same situation can also occur when fish are reared in seawater tanks in semi-closed or closed systems, leading to contamination of water and fish with bacteria, that are in the sea water from the start or shedding from the fish as the normal endemic mikroflora via faeces. Table 10.3 lists the possible micro-organisms which can transmitted from fish to man and lead to diseases. From this it can be concluded that there are two distinct sources that give raise to infection: in the case of *pre-harvest* risks, pathogens can be transmitted from water to man or infections can be set by handling fish.

Table 10.3. Micro-organisms which can transmitted from fish to man (zoonoses)

Species	Pathogenic to fish	Infection route / hazard to man
1. Mycobacterium marinum	Yes	Handling with fish, infection route by contact, lead to skin lesions
2. Streptococcus iniae	Yes	Infection route by contact
3. Photobacterium damselae	Yes	Infection route by contact
4. Vibrio alginolyticus	Yes	Infection route by contact
5. [4]V. vulnificus	Yes, biotyp 2	infection route by contact (biotyp 1 und 3) and oral intake, infection lead to heavy skin lesions
6. Erysipelothrix rhusiopathiae	No	Infection route by contact
7. V parahaemolyticus	Not yet determined	oral intake, wound infection
8. V cholerae	No	oral intake, diarrhoe
9. Escherichia coli	No	oral intake, diarrhoe
10. Aeromonas spp.	Yes	oral intake, diarrhoe
11. Salmonella spp.	Yes	oral intake
12. Staphylococcus aureus	No	oral intake
13. Listeria monocytogenes	No	oral intake
14. Clostridium botulinum (Typ E)	No	oral intake
15. C. perfringens	No	oral intake
16. Campylobacter jejuni	No	oral intake, diarrhoe
17. Delftia acidovorans	Not yet determined	oral intake
18. Edwardsiella tarda	Yes	oral intake
19. Legionella pneumophila	No	oral intake
20. Plesiomonas shigelloides	No	oral intake

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[4] There is some evidence that V vulnificus biogroup 2 strains can also cause human disease, e.g. wound infections

Post harvest infections are achieved mainly after slaughter or after processing the fish. This leads in most cases to diarrhoic diseases by oral intake once fish is contaminated with pathogens (see Fig. 10.1). An example of pre-harvest diseases are skin infections from handling marine animals (confinement, grading, harvesting). *Vibrio vulnificus* - as an example for this - is a ubiquitous halophilic marine vibrio and opportunistic human pathogen that can cause severe wound infections and septicaemia with mortalities for cases of septicaemia as high as 50 percent when there is no therapy. Another example is the mycobacteriosis of fish which is a is chronic disease caused by *Mycobacterium marinum* and is sometimes not apparent. Humans can be infected through small skin wounds via the water, symptoms are located skin granulomas ("swimming pool" granulomas). This is mainly a problem in aquaristics but could be a potential pre-harvest risks in freshwater farming.

11. Perspectives

During the third workshop of Workpackage 14 in Berlin, Germany (November 23–24, 2005), participants discussed a joint project proposal for the 7th Framework Programme of the EU. One point of discussion was whether we should focus exclusively on the pre-harvest phase or if we should include the entire production chain. It was agreed that (veterinary) public health should be the main driving force for this research effort, but some arguments for focussing primarily on the pre-harvest phase of food production were identified:

- *Political interest* - a demand for research activities that feed new information into the food chain.
- *Applied interest* - identification and assessment of the effect of intervention and control measures at pre-harvest
- *Academic interest* - limited work done in pre-harvest risk assessment modelling (concluding from MVN WP14)

We considered that the link from pre-harvest to the rest of the production chain (i.e. harvest, post-harvest, retail and consumption) could be handled in less detail or linked-up to existing work or planned activities.

An increased level of detail/focus on the pre-harvest phase of production would allow the investigation/modelling of multiple pathogens, the properties of their interaction and the possibilities for synergy and cross-protection of control measures.

The area of pre-harvest research is broad and varies greatly between member states and regions. In order to focus our research efforts we considered four main choices to help define our research interests (the 4 P's):

1. Production type,
2. Pathogen(s) of interest within that production type,
3. Pathway to model within that production type given the pathogen(s) and
4. Partners with the appropriate expertise and capacity given the production-pathogen-pathway combination.

It is our intention that the model(s) developed in this (pilot) study will serve as a framework for other main animal productions in Europe, since many of the considerations that go into it are generic by nature.

11.1 Production

Pig production was chosen as one of the main animal production forms in Europe, posing a considerable public health burden with both 1.) established pathogens, 2.) emerging pathogens and 3.) re-emerging pig pathogens. In this respect there are two major production forms that tie in with the occurrence of pathogens in these three classes: conventional (industrial or intensive) vs. organic (extensive, free-range) pig farming. We want to investigate at synergies and potential cross-protection of pre-harvest intervention and control measures. An interesting development in pig production is a shift of pre-harvest production towards eastern European countries. This may affect animal health, public health, economics and consumer-related issues (protection, awareness, demands). The final dimension calls for the inclusion of social sciences in the project.

11.2 Pathogen(s)

We discussed selecting some model-pathogens that represent the three types of pathogens: Salmonella (established, lots of information available), Mycobacterium avium (emerging) and Toxoplasma (re-emerging). However, we are not excluding any pathogens (incl. classical zoonoses) until we have assessed which pathogens are of importance in what regions in Europe. An alternative selection of model-pathogens could be based on epidemiological aspects of the pathogen, such as the mode of transmission or infection pattern (e.g. surface contamination, faecal spread or systemic infection, survival, ability for proliferation), which influences potential control measures. An added layer of interest is the issue of antimicrobial resistance of pathogens in pig production.

11.3 Pathway

The question is if we should limit us to a (limited) number of model pathways at pre-harvest that include the main factors of interest (e.g. potential intervention opportunities) or if we should attempt to model the farm phase in as much detail as possible. We consider to include transport of live-animals (i.e. animal movement), both between farms and to slaughter. This includes the transport of live-animals across country borders (international trade) where the issue of export and re-import complicates matters quite a bit (though mainly further down the production chain). The interaction between environment and production, as well as the risk of transmission (either way) of pathogens through direct animal-human contact are also considered.

Potential intervention and control measures and their (relative) effect can be investigated, assessing the possibility of cross-protection of control measures, as well as synergy between food safety and animal health benefits. Meaning, do animal health/welfare control measures have a positive effect on public health and vice versa? Animal health is an important animal welfare parameter.

11.4 Partners

Project partners that may have an interest in this application are both pig producing and pork-importing countries. Since this is an opportunity to obtain data collected specifically for risk assessment, we want to involve partners with the capacity to collect and provide field data, as well as economic and social information. So the consortium will consist of institutes with expertise in risk assessment, epidemiology, diagnostics, economics and/or social sciences.

With the above-mentioned trend of increased pig production in eastern Europe (under management of western European producers), as well as to involve new EU member states, we will attempt to attract Eastern European research Institutes in this work.

To ensure that the main focus of the project remains on microbial risk assessment, members of the WP14 group will start drafting a proposal, then share it with the rest of the network for input.

11.5 In conclusion

We are aiming for a detailed pre-harvest assessment of multiple pathogens to fill a knowledge gap that is need to inform the rest of the production chain. However, we should not forget the public health aspects and look for the connection to the rest of the food chain (e.g. separate work package or existing/planned work by others). We will explore how food safety initiatives might benefit animal health (and therefore provide a financial incentive to producers) and welfare (thereby addressing an additional consumer demand). The main challenge of the proposal will be to merge animal health, public health, economics and social sciences.