Preventive Veterinary Medicine 103 (2012) 81–92

Contents lists available at SciVerse ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Defining European preparedness and research needs regarding emerging infectious animal diseases: Results from a Delphi expert consultation

M.T.A. Wentholt[a], S. Cardoen[b], H. Imberechts[c], X. Van Huffel[b], B.W. Ooms[d], L.J. Frewer[a,e,*]

[a] Marketing and Consumer Behaviour Group, Social Sciences, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands
[b] Directorate General Control Policy, Federal Agency for the Safety of the Food Chain, Kruidtuinlaan 55, 1000 Brussels, Belgium
[c] Operational Directorate Bacterial Diseases, CODA-CERVA (Veterinary and Agrochemical Research Centre), Groeselenberg 99, 1180 Brussels, Belgium
[d] Office for Risk Assessment and Research, Food and Consumer Product Safety Authority, Ministry of Economic Affairs, Agriculture and Innovation, Catharijnesingel 59, 3511 GG Utrecht, The Netherlands
[e] Centre for Rural Economy, School of Agriculture, Food and Rural Development, Newcastle University, Agriculture Building, NE1 7RU Newcastle upon Tyne, UK

ARTICLE INFO

Article history:
Received 2 May 2011
Received in revised form 18 August 2011
Accepted 19 September 2011

Keywords:
Delphi study
Expert consultation
Emerging infectious animal diseases
European research agenda

ABSTRACT

Emerging and major infectious animal diseases can have significant international impact on social, economic and environmental level, and are being driven by various factors. Prevention and control measures should be prepared at both national and international level to mitigate these disease risks. Research to support such policy development is mostly carried out at national level and dedicated transnational research programmes are still in its infancy. This research reports on part of a process to develop a common strategic research agenda on emerging and major infectious diseases of livestock in Europe, covering a 5–15-year time span. A two round online Delphi study was conducted to explore the views of experts on issues relating to research needs on emerging infectious diseases of livestock in Europe. Drivers that may influence the incidence of emerging infectious animal diseases in both the short (next 5 years) and medium term (10–15 years) were identified. Drivers related to regulatory measures and biological science developments were thought to decrease the incidence, and socio-economic factors to increase the incidence of emerging infectious animal diseases. From the first round a list of threats to animal health was compiled and participants combined these threats with relevant drivers in the second round. Next to identifying threats to animal health, also possible mitigatory actions to reduce the negative impact of these threats were identified. Participants emphasised that interdisciplinary research is needed to understand drivers of emerging infectious animal diseases, as well as to develop prevention and control measures which are both socio-economic and technical. From this it can be concluded that interdisciplinary research combining both natural and social research themes is required. Some of the European member states research budget needs to be allocated so that effective prevention and mitigation strategies can be developed.

1. Introduction

Emerging infectious animal diseases may cause negative social, economic and environmental impacts locally, nationally, regionally and internationally. These impacts are driven by various factors. For example, climatic,

* Corresponding author at: Centre for Rural Economy, School of Agriculture, Food and Rural Development, Newcastle University, Agriculture Building, NE1 7RU Newcastle upon Tyne, UK. Tel.: +44 0 191 222 8272.
E-mail addresses: meike.wentholt@gmail.com (M.T.A. Wentholt), Lynn.Frewer@newcastle.ac.uk (L.J. Frewer).

0167-5877/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.prevetmed.2011.09.021

biophysical, and other anthropogenic factors, such as socio-economic influences, potentially influence contact rates between host, pathogens, and their vectors and reservoirs, ultimately shifting the (animal) disease burden to a regional level and beyond (De La Rocque et al., 2008). A foresight exercise was conducted which aimed to identify Europe's regional and transnational short and medium-term needs regarding preparedness and research focused on preventing and mitigating emerging infectious animal diseases, in order to support timely policy development.

The spread of infectious animal diseases, including zoonotic and vector-borne diseases, is driven by many factors (Reperant, 2010). For example, translocation of people and their livestock, and as a consequence (increased) contact between wild animals, livestock and people (Gummow, 2010). Historically, physical barriers, such as oceans, deserts, or mountain ranges, prevented human movement and thereby the spread of vectors and pathogens (De La Rocque et al., 2008). Industrialisation and economic development may have resulted in increased incidence of emerging infectious diseases. For example, current increases in globalisation, manifested through modern international trade and transport activities, may expedite the spread of disease. Anthropogenic and demographic changes, in particular increase in human population density have been shown to be a significant independent driver of emerging infectious zoonotic diseases, due to, for example, industrialisation, politico-economic aspects or immigration dynamics (Alexander and Weldon McNutt, 2010; Cascio et al., 2011; Jones et al., 2008). As well agricultural development, for example intensification of production systems and movement of livestock, have resulted in steadily increased disease threats to the livestock industry over the past decades as a result of these drivers (King, 2004; Morse, 2004). At the same time, these increased threats have had negative consequences for society in general through negative economic affects, transport bans and travel restrictions, as well as on livestock populations (e.g. the 2007 Q-fever outbreak in the Netherlands).

The multifactorial and transnational nature of drivers related to emerging infectious animal diseases, makes it difficult to enforce effective control and mitigation measures (Reperant, 2010). In order to identify, prevent and moderate the spread of emerging infectious animal diseases, epidemiological vigilance, appropriate diagnostic capacity, risk assessment and regulatory measures are required at both the national and international level. In contemporary society, prevention of, and response to, emerging infectious animal diseases relies heavily on risk assessment and scientific developments. Research is required if effective new disease prevention, control, and policy tools are to be developed, and translated into concrete risk management measures and policies.

Research on prevention and control is often conducted at national level, although it has been noted that, if the (lack of) knowledge about emerging infectious animal diseases is to be managed effectively, more effective and harmonised international research programming may be needed. Networks between research fund providers have been set up with the aim of improving coordination across Europe to create an adequate, and less fragmented research infrastructure.

To increase transnational cooperation and coordination of research programmes in Europe on emerging infectious diseases of production animals (including zoonoses), a network of national research funders in Member and Associated States of the EU was established (EMIDA ERA-NET). Its aim is to work towards a common strategic research agenda on emerging and major infectious diseases of livestock, covering a 10–15-year time span. An important objective is to initiate and coordinate jointly funded programmes and ultimately support European policy development regarding the management of emerging infectious animal diseases (for more information see: www.emida-era.net/). The scope of the EMIDA project is to examine existing research activities, and gaps in knowledge, associated with emerging and major infectious diseases of production animals, including fish and bees and those conditions that pose a threat to human health. A literature review of relevant foresight studies in the animal health area conducted by the Foresight and Programming Unit of the EMIDA project was a first step in the identification of drivers for emerging infectious animal diseases as well as threats to animal health in order to establish a common strategic research agenda (EMIDA, 2009).

In order to meet the objectives of EMIDA Work-package 4 (http://www.emida-era.net/index.php?page=workpackages&), Delphi methodology (Linstone and Turoff, 1975) was adopted as it delivers the practicability of a survey, with benefits in terms of availability and potential to systematically include a broad range of experts from appropriate disciplinary backgrounds.

The Delphi method essentially involves the repeated polling of experts using anonymous questionnaires. Responses are used in subsequent rounds as controlled feedback, and the final round responses are used to produce a group judgement (Linstone and Turoff, 1975). The literature indicates substantial variations of the method exist, in terms of whether two or more rounds are used, whether or not the first round is structured (quantitative) or unstructured (qualitative), whether the process takes place using paper-and-pencil questionnaires or 'online', whether the process is synchronous or asynchronous, and so on (e.g. Gordon and Pease, 2006; Rowe et al., 1991). The aims of the approach may also vary, and Delphi may be used in order to gain expert *consensus* or identify *dissensus* where this exists (for example, in the case of a Policy Delphi; Turoff, 1970). In the area of agrifood policy, research has typically used larger samples, in order to include experts covering the range of geographical dispersion and interdisciplinary expertise required to develop appropriate policy strategies (Wentholt et al., 2009, 2010; Frewer et al., 2011). Other applications of Delphi across a diverse range of areas have been reported, for example, in the optimisation of European manufacturing (Armbruster et al., 2007), optimising the economics of biotechnology in agricultural production (Menrad, 2000), or pharmaceutical innovation relevant to diseases of poverty (Coles et al., in preparation). For an up-to-date review, see Rowe and Wright (2010).

There is considerable variation how Delphi surveys may be implemented. Empirical research has shown that the method (in its various forms) leads to better (e.g. more accurate) judgements and forecasts than interacting groups (Rowe and Wright, 1999, 2001). Delphi methodology has been applied in the area of animal health (Van Der Fels-Klerx et al., 2002), to map future dynamics of disease transmission (Suk et al., 2008), and the evaluation of the expert perception of determinants of equine welfare (Collins et al., 2009).

The study presented here utilised an online Delphi survey applied to the collation of international expert opinions relating to emerging infectious animal diseases. The objectives were to systematically identify major disease drivers of, and threats associated with emerging infectious animal diseases so that (pan-European) future research priorities can be set. The time frame was on research in the short term (the next 5 years), and potential changes required to this research strategy in the medium term (the next 10–15 years). In addition, participants' views on Europe's current status with regard to preparedness for emerging infectious animal diseases were collated in order to verify the need for change to existing research portfolios.

2. Methods

A two round online Delphi study was conducted to explore the views of different experts on issues related to emerging infectious diseases of production animals in Europe in the short term and in the medium term. The outcomes of the study would provide elements upon which a common EU strategic research agenda focusing on infectious animal disease identification, control and prevention in Europe could be developed. Only experts within the European research area were consulted as study participants, as the objective was the development of an integrated and harmonised European research agenda regarding the management of emerging infectious animal diseases.

2.1. Study participants

As part of the activities within EMIDA, a review of foresight studies was conducted prior to initiation of the Delphi (EMIDA, 2009). This study facilitated the identification of a range of disciplines relevant to the management of emerging infectious animal diseases. Subsequently, a database of 217 relevant European experts was constructed (see Table 1). All partners involved in the EMIDA consortium were requested to submit names of possible participants based on the different disciplines identified ("cascade" methodology). The database was checked to determine whether there were sufficient participants across disciplines and European member states. Where necessary (and where possible), participants from under-represented areas were added to the participant list through a request to EMIDA partners to provide additional participant names.

Table 1
Sample characteristics of Delphi study[a].

Characteristics	Round 1		Round 2	
Invited	217		143	
Participated	143		108	
Gender				
Female	33		22	
Male	107		86	
Age group				
20–35 years	8		7	
36–45 years	26		20	
46–55 years	73		56	
56–65 years	32		25	
66+ years	1		0	
Relevant work experience				
<5 years	14		10	
6–10 years	22		20	
11–15 years	19		18	
16–20 years	32		25	
21+ years	46		37	
Area of expertise[b]	Main	Additional	Main	Additional
Animal diseases, zoonoses (incl. antimicrobial resistance)	46	28	36	25
Veterinary medicine (in general)	41	29	33	21
Epidemiology	23	29	16	24
Risk assessment	22	36	22	35
Immunology/vaccinology	17	20	15	18
Risk management	14	36	14	36
Bacteriology	13	23	11	21
Virology	12	24	9	20
Animal welfare	10	19	9	16
Public health	9	27	6	24
Parasitology	7	16	7	15
Wildlife	5	20	3	15
Risk communication	3	15	3	12
Mathematics (incl. modelling)	2	14	1	12
Other[c]	39	58	31	48

[a] Not all participants filled in these questions.
[b] Participants were asked to select one *main* area of expertise and select – if appropriate – *additional* area(s) of expertise. Some participants provided multiple responses to 'main area of expertise'.
[c] Other, including: Agro-economy, Entomology, Animal genetics, Communication, Criminology (including Fraud, Terrorism), Demography, Food/Feed, Ecology/Nature conservation, Meteorology/Climate, Sociology.

All participants who had been invited to take part in the first round were subsequently invited to participate in the second round.

2.2. Design

Questionnaire development was conducted by a group of EMIDA members (whom had earlier reviewed relevant foresight studies on emerging animal diseases (EMIDA, 2009)), together with two researchers familiar with the development, and application of Delphi surveys, as with the interpretation of resulting data (Wentholt et al., 2009, 2010). Initially, two small workshops were held. The aim of the first meeting was to discuss the topics to be included in the first round of the Delphi study, after which a subset of the members developed a draft questionnaire. During the second meeting, the draft questionnaire was discussed by all group members and further refined.

To test the first questionnaire, a pilot study was conducted (October 2009). Participants in the pilot study ($n = 13$ experts) were collected via the research team, and were invited via E-mail to respond to the survey within one week. Reminders were subsequently sent to those participants who had not responded. The E-mail invitation explained their role as a pilot participant, and potential pilot participants were asked to respond to the survey as if completing it in the main study, and were requested to note the time spent on completing the survey. In addition to the questionnaire, participants were asked to provide feedback on the clarity of the questions, difficulty level of the written language, completeness of the questionnaire with regard to topics and the appropriateness of the time period required. In addition, space was provided to allow pilot participants to make additional comments if needed. Following the pilot study, some minor changes in wording were made, and, where relevant, questions were formulated to encompass both time frames rather than just one.

The literature review on existing foresight studies (EMIDA, 2009) revealed various definitions of both 'drivers' and 'threats'. Therefore, within the Delphi study, a standardised definition of these was provided to ensure all participants were using the same definitions.

Driver: *a driver or driving force is an external condition acting on a large scale (climate, energy, technology, social events), which has the potential to directly or indirectly influence animal and human health (in this case the (re)-emergence of infectious diseases).*

Threat: *a threat is a hazard that affects directly (or indirectly) animal and/or human health, like a pathogen, pathogen-carrier or a (bio)terrorism event.*

2.3. Survey development

The Delphi study was implemented using an interactive web-site. All questionnaires were presented in English. To increase survey accessibility, participants could obtain a Word version of the questionnaire via the survey team, which could be completed off-line and returned by E-mail, fax or surface mail to the researchers. Six participants used this approach in the first round and one participant in the second round.

For the main Delphi surveys, participants from the database received an E-mail invitation to participate in the online survey and were subsequently given 3½ weeks to respond to the survey (round 1 conducted in November/December 2009 and round 2 in February/March 2010). E-mail reminders were sent to participants who had not yet responded a week prior to the response deadline. Four days after the deadline had passed the database was closed. Their responses were analysed using quantitative and qualitative methods as appropriate.

In the first round questions primarily addressed a qualitative response, mainly consisting of open-ended items. Only the first survey initially provided an introduction about the objectives of the EMIDA project and the aims of the Delphi study. The second round survey included, where applicable, feedback from the first round responses, primarily in terms of newly developed questions or statistical averages. Full versions of the questionnaires are available from the corresponding author upon request. Both rounds included questions on three major topics:

2.3.1. Preparedness for emerging infectious animal diseases

Participants were asked their opinion on European preparedness regarding the identification, control and prevention of infectious animal diseases (ratings on 5-point scales, anchored by 1 = "completely agree" to 5 = "completely disagree" and "no opinion"). Responses were statistically summarised (in percentages) and provided as graphical feedback in round 2. In the second round, participants were asked whether they agreed that European capacity to identify emerging infectious animal diseases is stronger than European capacity to control them. In addition, participants were asked whether they agreed that European capacity to prevent emerging infectious animal diseases is stronger than European capacity to control them. For both these questions, responses were collected through the following categories: "agree", "disagree", or "no opinion". Besides these questions, participants were asked in the first round whether existing predictive methodologies were adequate. From the literature review (EMIDA, 2009) four predictive methodologies currently used within the area of animal health were selected: these included the literature review, scenario study, horizon scanning, and workshop (see Appendix A). The methodologies were rated on a 5-point scale (anchored by 1 = 'completely agree' to 5 = 'completely disagree' and 'no opinion').

2.3.2. Drivers of future threats to emerging infectious animal diseases

Participants were asked in the first round to identify which drivers of animal diseases and (emerging) threats to animal health they expected to be important in the short term (the next 5 years) and the medium term (the next 10–15 years). In the second round, these drivers were coded into superordinate categories, and participants were asked to rate whether each driving force would increase or decrease the incidence of infectious animal diseases in Europe in both short and medium term (rating scale items: "increase incidence of infectious animal diseases"; "decrease incidence of infectious animal diseases"; "no effect on incidence of infectious animal diseases"; in addition, a "no opinion" response option was provided). In addition, a condensed list of 34 threats to animal health was developed from the first round qualitative responses, and participants were asked to rate their importance in the second round, again in both the short and medium term. These threats were divided into five related groups: 'disease agents'[1]; 'complex infections'; 'specific animal diseases'; 'route of transmission';

[1] The item was phrased in the questionnaire: "family of agents".

and 'other emerging threats[2] (Appendix B). These classifications were agreed by the researchers involved in developing the survey. The extent to which these threats were estimated by participants to pose an important threat to animal health was rated by participants on a five-point scale (anchored by 1 = "very important" to 5 = "very unimportant", with a "no opinion" option). Following completion of these ratings, participants were asked to select the three most important threats and to link these three threats to the drivers which were also included in the second questionnaire, in order to investigate participant opinion regarding the driving forces related to the most important threats.

2.3.3. Future research topics relating to emerging infectious animal diseases

In the first round, qualitative questions inquired after what future research topics need to be addressed at the European level, in both the short and medium term. In the second round, these responses were coded and ordered, and participants were asked to rate the extent to which they agreed or disagreed whether each issue should be prioritised. Ratings were made on a 5-point scale (anchored by 1 = "completely agree" to 5 = "completely disagree" and "no opinion").

2.3.4. Background information

At the end of the first round, some background information about the participants themselves was gathered, such as gender, age, and area of expertise. In addition, space was provided to allow participants to make additional comments if needed. Participants who did not return information about their background in the first round also received these additional questions in the second round.

3. Results

3.1. Sample characteristics

In the first round, 217 experts were invited to participate in the Delphi survey. Of these, 143 (66% response rate) participated in the first round of which 108 (76% response rate) also participated in the second round. Participants were predominantly male (77% in round 1 and 80% in round 2). In both rounds, most participants were over 46 years old and held more senior positions within their organisations throughout Europe (Tables 1 and 2).

With respect to their main area of expertise, participants from *animal diseases*, *zoonoses* and *veterinary medicine* were over-represented in comparison to the other areas of expertise. This may be a consequence of the use of cascade methodology to access personal contacts of the EMIDA consortium, as well as the topic of the research (Frewer et al., 2011).

[2] The item was phrased in the questionnaire: "epidemiological situation".

Table 2
Response rates and distribution across EU member states.

Geographical location		Number of responses	
Region[a]	Country	Round 1	Round 2
Atlantic		53	36
	Belgium	7	4
	France	21	14
	Ireland	2	2
	Netherlands	14	9
	United Kingdom	9	7
Continental		26	21
	Austria	3	3
	Czech Republic	6	5
	Germany	11	8
	Switzerland	6	5
Mediterranean		27	23
	Israel	4	4
	Italy	18	16
	Spain	5	3
Nordic/Baltic		32	27
	Denmark	9	9
	Finland	5	4
	Lithuania	3	2
	Norway	5	4
	Sweden	9	7

[a] This regional division reflected the assumed influence of climate zones on emerging diseases and epidemiological factors such as proximity to other areas where animal diseases were emerging (European Environment Agency).

3.2. Preparedness for emerging infectious animal diseases

3.2.1. European preparedness regarding the management of emerging infectious animal diseases

In the first round, participants were requested to rate Europe's preparedness regarding the management of emerging infectious animal diseases, specifically with regard to their identification, control and prevention. About half of the respondents (49%) thought that the European capacity to *identify* emerging infectious animal diseases is adequate, against 33% of whom thought

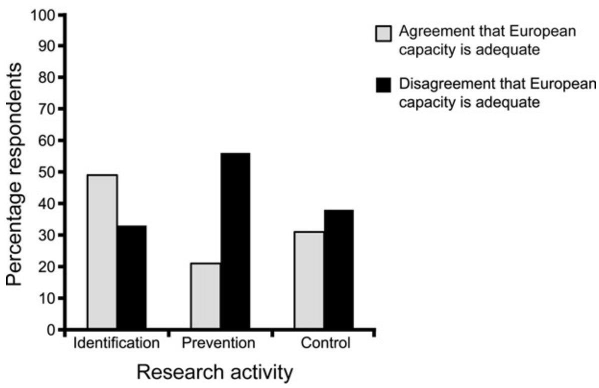

Fig. 1. Opinions of experts regarding EU capacity to identify, prevent or control emerging infectious animal diseases. The level of agreement was measured with a 5-point scale. 'Agreement' is aggregated from the categories 'completely agree' and 'agree', and 'disagreement' from the categories 'completely disagree' and 'disagree'. 'Neither agree nor disagree' is omitted from this figure for ease of interpretation.

Driving forces	Increase in incidence		Decrease in incidence		No effect on incidence	
	short	medium	short	medium	short	medium
Increased movement of animals	97	96	1	0	2	4
Increased globalisation of trade	94	87	1	2	5	11
Increased emergence of novel infectious animal diseases	89	87	4	9	7	4
Increased interaction between wildlife and production animals	87	84	1	2	12	14
Increased trade in animal products	86	81	0	2	14	18
Climate change	77	89	0	1	23	10
EU Expansion	79	72	3	9	18	19
Increased movement of humans	74	71	0	3	26	26
Increased trade in food	63	64	0	2	37	34
Intensification of agricultural production systems	53	54	12	12	35	34
Increased European (EU) differentiation in animal health regulation	45	41	24	37	31	22
Increased food production	44	50	3	2	53	48
Increased international differentiation in animal health regulation	42	55	16	23	43	22
Increased surveillance and monitoring	17	9	71	84	12	8
European (EU) regulatory harmonisation in the area of animal health	11	5	64	76	25	19
Increased control measures, in the EU	9	9	80	83	11	9
International regulatory harmonisation in the area of animal health	8	5	71	81	21	14
Novel vaccine development	4	6	75	89	21	5
Increased control measures, outside of the EU	4	6	81	87	15	7

Majority over 80%
Majority between 50-80%
Minority over 20%
'Lack of consensus', between 20-50%
Minority below 20%

Fig. 2. Effect of driving forces on the incidence of infectious animal diseases in Europe in the short and medium term. N.B. Increased globalisation of trade implies that driving forces other than just animal movement are relevant, for example, feed-borne and vector-borne disease which can be exported and imported across increasingly broad geographical and economic regions.

it is inadequate (Fig. 1). In contrast, a slight majority of participants (56%) disagreed that the European capacity to *prevent* emerging animal diseases is adequate (21% agreed). Regarding the adequacy of European capacity to *control* the occurrence of infectious animal diseases, participants were ambivalent (Fig. 1). Overall, participants indicated that further development of research in regard to risk management activities is required, in particular with regard to preventive measures.

3.2.2. *Efficacy of predictive methodologies*

The four predictive methodologies were all rated as useful and only slight differences were observed in the ratings: workshop (80% agreed usefulness, 3% disagreed); horizon scanning (75% agreed usefulness, 5% disagreed); scenario study (73% agreed usefulness, 9% disagreed); and literature review (70% agreed usefulness, 14% disagreed). In addition, participants were asked to suggest additional methodologies, of which different modelling approaches (e.g. epidemiological modelling, mathematical modelling, and quantitative predictive modelling) were suggested as appropriate, together with applications of holistic systems and applying a combination of methods.

3.3. *Drivers of future threats to animal health*

3.3.1. *Driving forces on the incidence of infectious animal diseases in Europe in the short and medium term*

Increased globalisation of trade, increased transportation of animals or animal products, and increased contact between animals, and between humans and animals, were perceived to result in an increase of the incidence of emerging infectious animal diseases (Fig. 2). Against this, drivers related to regulatory and control measures (including improved risk management and novel prevention strategies) were perceived as resulting in potential decreases in the incidence of infectious animal diseases.

Disagreement between the expert participants regarding the direction of impact of some drivers was also observed. These related to differentiation between international and European animal health regulations, and increased food production (Fig. 2).

3.3.2. Future threats to animal health

In the first round threats to animal health in both the short and medium term were identified qualitatively. For the second round, the responses were collated and divided into five groups according to the type of threat. All threats were rated 'important', though the threats within the groups 'Disease agents', 'Complex infections', and 'Route of transmission' were regarded as being slightly more important in the short term than in the medium term (Manova, comparisons between short and medium impacts by threat, respectively, $F(1,42) = 4.85$; $p = .03$ and $F(1,58) = 4.99$; $p = .03$ and $F(1,71) = 5.17$; $p = .03$).

Participants were asked to select the three most important threats, and to link these to the drivers already identified. In order to identify the relation between the threats and drivers, majority agreement is suggested for those items when more than two-third of the participants selected the driver. These results are summarised in Fig. 3.[3] The threats 'introduction of exotic diseases in Europe', 'emerging unknown/novel pathogens', 'emerging and re-emerging agents', and 'zoonoses' were most frequently connected to drivers related to the increase or decrease in incidence of emerging infectious animal diseases (in the short and/or medium term).

3.4. Future research topics relating to emerging infectious animal diseases

A long list of participant suggestions was obtained regarding potential research topics focusing on emerging infectious animal diseases which will need to be addressed at the European level (in both the short and medium term). These were allocated into superordinate categories, each of which was rated regarding its importance as a European research topic in the second round and have been divided into research priorities and research disciplines (Table 3). Participants rated all future research topics as important. In addition, no significant differences were found between any of the topics, regarding whether they were short or medium term priorities.

4. Discussion

From the first, mostly qualitative, round, one theme appeared from the responses as being very important: preparedness for emerging infectious animal diseases. This theme appeared not only within the questions polling management of emerging infectious animal diseases, but also when identifying research priorities, and drivers for these diseases. Participants identified various drivers relating to regulatory and control measures. With respect to European preparedness in regard to prevention, identification and control of emerging infectious animal diseases, participants indicated that further development of research into risk management activities are required and that their current status is not adequate. In general, current knowledge and disease control tools are not adequate within Europe. This result provides empirical support for the conclusion that greater investment in preparedness has to be an essential component of resource allocation.

Table 3
Future research topics as included in the second round questionnaire split over research priorities (*topical*) and research disciplines.

Research priorities	Research disciplines
Emerging diseases	Biology
Host–pathogen interaction	Climatology
Improve surveillance (diagnostics)	Ecology
Improve/develop early warning systems	Economics, related to animal health
Improvements in emergency preparedness	Entomology
Improvements in emergency response	Epidemiology
Resistance of pathogens to, e.g. anti-microbials	Immunology
Vaccine development	Risk analysis
Vector related research	Virology
Zoonoses (in general) and zoonotic pathogens	

Part of the identified future research priorities dealt with the need to improve (or develop) systems relating to surveillance, early warning, emergency preparedness and emergency response. The identified research priorities focused as well on biological science developments, such as research relating to vaccine development and identification of vectors or emerging pathogens. In addition, participants identified several research disciplines that are relevant to research on emerging infectious diseases. They identified both disciplines from biological science (for example, epidemiology or virology) as well as socio-economical disciplines (such as economics, risk communication and risk management).

The results suggested that socio-economic drivers, such as movement of animals, international trade, globalisation, interaction between wildlife and production animals, climate issues, and EU expansion, would increase the incidence of emerging infectious animal diseases. Furthermore, participants indicated that improved regulatory, policy and natural science developments, such as novel vaccines, may help to reduce the incidence of such diseases. From this, one might conclude that interdisciplinary research which addresses both natural and social drivers of emerging infectious animal diseases needs to be developed if effective prevention and mitigation strategies are to be operationalised.

The predictive methodologies included in the Delphi survey (literature review, scenario study, horizon scanning, and workshops), were all confirmed as useful when applied to the area of animal health and emerging infectious animal diseases. The methodologies suggested by participants mainly consist of different types of data modelling, which provides a relatively simple platform to test in theory (possibly) complex real-world issues. In addition,

[3] From the rated drivers (see also Fig. 2), only those drivers that were selected by ≥75% of respondents to either increase or decrease the incidence were selected for Fig. 3. The selected threats each had at least one driver connected to them that was combined 15 times or more in one of both time frames.

Drivers	Selected threats							
	Threat of introduction exotic diseases in Europe	Emerging unknown / novel pathogens	Emerging & re-emerging agents	Zoonoses	Arboviruses	Virus	Vector-borne diseases	Antibiotic resistance
Increase in incidence								
Increased movement of animals	○ ●	○ ●	○ ●	●	○ ●	○ ●	○	
Increased globalisation of trade	○ ●	○ ●	○ ●	○ ●				
Increased trade in animal products	○ ●	○ ●	○	○ ●				
Climate change	○ ●	○			○ ●		○ ●	
EU expansion	○ ●		○ ●	○ ●				
Increased emergence of novel infectious animal diseases	●	○ ●			○ ●			
Increased movement of humans	○			○ ●				
Increased interaction between wildlife and production animals		○		○ ●				
Decrease in incidence								
Increased surveillance and monitoring	○ ●	○	○ ●	●	○	○		●
Novel vaccine development	○	○	○			○	●	
Increased control measures, in the EU	○	○	○	●	●			●
Increased control measures, outside the EU	○ ●		●					
International regulatory harmonisation in the area of animal health	○			●				
European (EU) regulatory harmonisation in the area of animal health				●				

Fig. 3. Relation between threats and drivers to emerging infectious animal diseases. The white circles indicate when the majority of participants agreed that there was a strong relation between drivers and threats in the short term, and the black circles when there was majority agreement in the medium term. When both white and black circles appear in a cell, the majority of participants agreed that the relationship existed in both the short and medium term. Key: (○) majority agreement in short term (i.e. more than two-thirds agreed). (●) Majority agreement in medium term (i.e. more than two-thirds agreed).

data modelling allows for validation of scenarios which are similar to those found in the field, and therefore may save resources, either immediately or in the future. Furthermore, participants suggested that using a 'combination of methods' (in other words, triangulation of results from different data streams) may facilitate the effectiveness of prediction. Integrating this with earlier reported outcomes, the use of triangulation of data might be to apply different interdisciplinary research approaches to provide information relevant to the prevention and mitigation of emerging infectious animal diseases.

All threats identified by participants in round 1 were rated to be of importance in the second survey round. The threats were combined with the drivers to obtain a more clear association of how these threats might spread or be moderated. The 'threat of introduction of exotic diseases in Europe' and 'emerging unknown or novel pathogens' were thought to be possibly reduced in the *short* term through increased surveillance and monitoring, novel vaccine development, increased control measures, and international regulatory harmonisation. In addition, these same factors were thought to possibly decrease the incidence of zoonoses in the *medium* term. With regard to a possible increase in incidence no clear relationship was identified. When comparing the different outcomes of the survey, zoonoses and vector-borne diseases were not just identified as important threats but also identified as future research priorities, indicating their significance. The drivers that were most frequently related to these significant threats were 'increased movement of animals' and 'increased need for surveillance and monitoring'.

Delphi methodology is often applied to the development of consensus across an expert group regarding an issue or policy option. The Delphi study presented was employed at an exploratory stage of research, and will contribute to the development of a common strategic research agenda on emerging and major infectious diseases of livestock. The strength of this study is that implicit research priorities have been made explicit through empirical analysis, which not only reflects and aggregates the views of disparate experts, but may also test assumptions which have not hitherto been questioned. The outcomes are presented as aggregated or averaged responses. It is also important to note that "outlier" opinion may be of importance, but the relatively low level of interdisciplinarity in expertise may have resulted in a bias towards homogeneity in initial responses, and so potentially "outlier" responses could not be rated by the participants in round 2.

The differences between the short and medium term time frames were not marked. A broader differentiation between times might have provided a more distinct difference (e.g. Suk et al., 2008). However, several participants noted that it was difficult (if not unfeasible) to foresee the future, regardless of a specification of time frames.

There was lack of consensus across the participant group regarding the (direction of) impact of some potential drivers of emerging infectious animal diseases. If this study aimed for consensus of opinions, then ideally, these issues would have been further investigated in a subsequent round (or rounds) including feedback from the previous round. However, the study aimed to report research priorities as suggested by the respondents, which were obtained within these two survey rounds. In addition, given that the results from this Delphi study, including those where consensus did not occur, were presented to the participants of the subsequent consensus workshop, it may be assumed that further discussion regarding participant disagreement was discussed by workshop members in the subsequent consensus workshop (EMIDA, 2010). Alternatively, lack of consensus might indicate the participants' uncertainty whether or not a specific issue was relevant, or uncertainty in the extent to which participants were certain of their answer. Uncertainty analysis as described by Walshe and Burgman (2010) might help determine whether this was indeed the case, and may provide a solution when applied to future exercises. It is of relevance to note that a number of 'economic' quantitative modelling techniques (as far as they concern the allocation of resources to different disease-control strategies) have been used to provide information to help decision makers choose appropriate livestock health and disease-control strategies. These include mathematical programming, network analysis, decision analysis, simulation and cost–benefit analysis all have been applied to livestock disease-control decisions (for reviews see Bennet, 1992; for examples of application see Harvey et al., 2007). Such approaches might usefully be applied to the context of emerging infectious animal diseases given the economic importance of the animals affected.

An important result is that more emphasis should be given to prevention and control measures, as opposed to mitigation. The prioritisation is acknowledged by many risk managers active in this area, and other European activities have led to the same conclusions. For example, the European Technology Platform for Global Animal Health and the associated EU project DISCONTOOLS have identified the need for developing effective tools for controlling infectious and contagious animal diseases, for example through more effective epidemiological assessments, economic evaluations and risk analysis and, in the longer term, breeding for resistance (European Technology Platform for Global Animal Health, 2011). The fact that similar results have been reached through application of different methods lends support to the robustness of the overall conclusions, as well as the need for an interdisciplinary approach to animal disease management.

Finally, a bias in responses may have been associated with the type of sampling used. Although a sampling frame which focused on multiple areas of expertise has been applied to select experts, most participants reported their area of expertise to lie within animal diseases, veterinary medicine and epidemiology. The use of cascade-methodology may have affected the participant list as more experts in certain areas of animal health were recruited because more experts in these areas were originally involved in the EMIDA network. In addition, the use of this methodology within this network may have resulted in a bias towards participants from the Atlantic region. Therefore, a comparative analysis based upon these four regions, which could have identified research priorities specific to a region or threats more predominant in certain regions, has not been performed. Whilst every effort was made to include a range of expertise from individuals with a range of disciplinary backgrounds with an interest in the area of infectious animal diseases, the sample was dominated by participants indicating that their main interest was in animal diseases, veterinary medicine and epidemiology. It is suggested that this reflects a bias in the institutional recruitment of expertise to the study of infectious animal diseases, as well as the differential regional resource allocated to the area of research across Europe. Therefore a criticism of the study was that recruitment was not assessed against a "European map" of interested expertise, although, to our knowledge, this information is not accessible at the current time. The use of co-nomination (where respondents are asked to identify suitable participants to be additionally included in the study, whilst at the same profiling their own expertise), may represent a useful approach to identifying additional experts in foresight studies whilst at the same time facilitating the "mapping" of relevant expertise (Nedeva et al., 1996) and should be considered in future research of this type. As a consequence, the division into regions was incorporated in the subsequent consensus workshop providing outcomes on both pan-European as well as the four regional levels, although it should be noted that the workshop involved fewer participants than were included in the Delphi survey owing to logistic limitations and availability of participants (EMIDA, 2010).

It is possible that a "bias" in the summarised Delphi summaries might arise because of the differential weighting of experts with different types of expertise. Arguably statistical comparison of the opinions and views of different experts would enable identification of such biases, although it is difficult to obtain a sample totally representative of all relevant expertise, or indeed establish relative weights regarding the inputs of different experts into the final conclusions. In the research reported here, the domination of experts identifying a dominant expertise in the area of animal disease zoonoses and veterinary medicine reflects the issue under discussion. Whilst meaningful statistical comparison between experts in these domains and other types of expertise regarding opinions and priorities is not practical in the current study, given the very low numbers of participants in the latter categories, this may be a comparison which is relevant in future studies where the distribution of different types of expertise is more equal across expertise domains.

5. Conclusions

Within this study, drivers related to regulatory and control measures were perceived as resulting in a potential decrease, as the more socio-economic drivers would increase the incidence of emerging infectious animal diseases. The drivers 'movement of animals' and 'increased need for surveillance and monitoring' were the principal drivers to which the threats were connected. More specifically, the first driver was identified as potentially increasing the incidence of threats, and the latter driver may reduce the incidence. The most frequently related threats were: 'threat of introduction exotic diseases in Europe', 'emerging unknown/novel pathogens', 'emerging and re-emerging agents', and 'zoonoses'.

Participants within this study have not only identified threats to animal health, but also identified possible mitigatory actions to reduce the negative impact of these threats. In order to control emerging infectious disease threats, resource allocation should increasingly focus on the development of effective policy measures regarding emergency preparedness. Furthermore, resources are needed to fund natural sciences development that support these risk management measures, such as research relating to disease agents (e.g. host–pathogen interaction), route of transmission (e.g. vector-borne diseases). Participants have emphasised that socio-economic research is needed to understand drivers of emerging infectious animal diseases, as well as to develop control measures which are both socio-economic and technical. Therefore, resources are needed to study socio-economic factors which may be relevant to the prevention and mitigation of emerging infectious diseases. Examples include supply chain management, risk communication and risk management systems, and economic drivers. Participants also identified that an interdisciplinary approach is required in the future if the mitigation and prevention of infectious animal diseases is to be optimised.

Acknowledgements

This research was funded by EMIDA ERA-NET "Coordination of European Research on Emerging and Major Infectious Diseases of Livestock" (funded by the European Commission's Seventh Framework Programme, Project No. 219235), Workpackage 4. The views expressed here are entirely those of the authors. We would particularly like to thank all participants for their time and effort to fill in the questionnaires. Additionally, the authors would like to thank Ana Belén Aguilar Palacios, Joan Calvera, Milan Podsedníček, Oystein Ronning, Scott Sellers, and Dominique Vandekerchove for their input.

Appendix A. Definitions of predictive methodologies as included in the Delphi study

A.1. Literature review

Providing an overview of (published) study results (information or data sources) regarding a specific topic of (future) interest. The review may follow a specific type of structure for collating and analysing the relevant literature. Such studies may vary in terms of timescale, domain, topic, literature/information used. In addition, the aim of the literature review may vary. For example, such aims may include performing a "gap analysis" for priority setting.

A.2. Scenario study

Involves bringing together (expert) stakeholders in order to get people to map possible outcomes of a particular future scenario. Scenarios are stories that represent some future event. Such studies may vary in terms of timescale, domain, topic, and presence/absence of structured guidelines (e.g. for the storyline), and by whether the scenario is created by the researcher or the participants. Scenarios can help to get people to consider what they would do given an unfavourable forecast, as well as that scenarios can be used to gain acceptance of forecasts.

A.3. Horizon scanning

Consideration of future risks based on information from any source in order to identify priority areas and develop short-term projects (such as desk studies and expert workshops) to mitigate potential risks. Such 'horizon scans' may vary in terms of timescale, domain, topic, and methodology, but they are similar in the sense of scanning for information and extrapolating the results to the future. They may involve exploring novel and unexpected issues, as well as persistent problems or trends relevant to the topic.

A.4. Workshop

Can be used for future plans, solving problems, or fact-finding (gathering knowledge). It is a meeting in which the selected stakeholders (participants) are the primary resource. Stakeholders are selected based upon their knowledge or relevant experience regarding the topic. A workshop is usually structured (through an agenda). A workshop differs from the methods defined above, by having a pre-defined topic set by the organiser.

Appendix B. Categorised future threats to animal health, divided into five groups according to the type of threat, collated from round 1 responses

B.1. Disease agents

Arboviruses
Bacterial agents
Non-zoonotic diseases
Parasites
Pestiviruses
RNA virus
Virus
Virus, endogenous
Zoonoses

B.2. Complex infections

Complex/multifactorial disorders
Digestive system disorders
Infectious abortigenic agents
Locomotory system diseases
Mastitis
Production diseases
Reproductive disorders
Respiratory disease complexes

B.3. Specific animal diseases

Aquaculture diseases, (fish, molluscs)
Bee diseases
Other animal diseases

B.4. Route of transmission

Airborne infections
Direct contact zoonoses
Food borne agents
Rodent borne diseases
Vector borne diseases
Water borne agents

B.5. Other emerging threats

Antibiotic resistance
Bioterrorism
Emerging and re-emerging agents
Emerging unknown/novel pathogens
Endemic diseases in Europe (threat of dissemination in Europe)
Increase in virulence
Opportunistic diseases
Threat of introduction exotic diseases in Europe

Appendix C. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.prevetmed.2011.09.021.

References

Alexander, K.A., Weldon McNutt, J., 2010. Human behavior influences infectious disease emergence at the human–animal interface. Frontiers in Ecology and the Environment 8, 522–526, doi:10.1890/090057.

Armbruster, H., Jung, H., Erceg, P., Pandza, K., Dreher, C., 2007. Managing knowledge in manufacturing: results of a Delphi study in European manufacturing industry. International Journal of Foresight in Policy 3 (3), 256–276.

Bennet, R.M., 1992. The use of 'economic' quantitative modelling techniques in livestock health and disease-control decision making: a review. Preventive Veterinary Medicine 13 (1), 63–76.

Cascio, A., Bosilkovski, M., Rodriguez-Morales, A.J., Pappas, G., 2011. The socio-ecology of zoonotic infections. Clinical Microbiology and Infection 17 (3), 336–342.

Coles, D., Frewer, L.J., Ruto, E., Korthals, M. Incentivisation of the pharmaceutical industry to develop products targeting neglected diseases; a three phase Delphi study, in preparation.

Collins, J., Hanlon, A., More, M.J., Wall, P.G., Duggan, V., 2009. Policy Delphi with vignette methodology as tool to evaluate the perception of equine welfare. The Veterinary Journal 181, 63–69.

De La Rocque, S., Rioux, J.A., Slingenbergh, J., 2008. Climate change: effects on animal disease systems and implications for surveillance and control. Scientific and Technical Review 27 (2), 339–354.

EMIDA (Work Package 4 (Foresight & Programming Unit)), 2009. Overview of foresight studies. http://www.emida-era.net/upload/pdf/Report_FPU_Foresight_reviews_final_v11_050809.pdf (accessed 21 April 2011).

EMIDA (Work Package 4), 2010. Strategic Research Agenda Workshop. http://www.emida-era.net/upload/pdf/Final%20STRAW%20report%20incl%20annexes.pdf (accessed 21 April 20110.

European Environment Agency. Key past and projected impacts and effects on sectors for the main biogeographic regions of Europe. http://www.eea.europa.eu/data-and-maps/figures/key-past-and-projected-impacts-and-effects-on-sectors-for-the-main-biogeographic-regions-of-europe (accessed 14 July 2010).

European Technology Platform for Animal Health, 2011. http://www.etpgah.net/ (accessed 8 August 2011).

Frewer, L.J., Wentholt, M.T.A., Marvin, H.J.P., Ooms, B.W., Fischer, A.R.H., Coles, D., Rowe, G., 2011. The use of Delphi methodology in agrifood policy development: some lessons learned. Technological Forecasting and Social Change, doi:10.1016/j.techfore.2011.05.005.

Gordon, T.J., Pease, A., 2006. RT Delphi: an efficient, "round-less" almost real time Delphi method. Technological Forecasting and Social Change 73 (4), 321–333.

Gummow, B., 2010. Challenges posed by new and re-emerging infectious diseases in livestock production, wildlife and humans. Livestock Science 130 (1–3), 41–46.

Harvey, N., Reeves, A., Schoenbaum, M.A., Zagmutt-Vergarab, F.J., Dubéd, C., Hill, A.E., Corsoe, B.A., McNab, W.B., Cartwright, C.I., Salman, M.D., 2007. The North American animal disease spread model: a simulation model to assist decision making in evaluating animal disease incursions. Preventive Veterinary Medicine 82 (3–4), 176–197.

Jones, K.E., Patel, N.G., Levy, M.A., Storeygard, A., Balk, D., Gittleman, J.L., Daszak, P., 2008. Global trends in emerging infectious diseases. Nature 451, 990–993, doi:10.1038/nature06536.

King, L.J., 2004. Emerging zoonoses and pathogens of public health concern: Introduction. OIE Revue Scientifique et Technique 23 (2), 429–433.

Linstone, H.A., Turoff, M., 1975. The Delphi Method: Techniques and Applications. Addison-Wesley, London.
Menrad, K., 2000. Economic implications of agrofood biotechnology. Scientific Food and Agriculture 80 (5), 539–546.
Morse, S.S., 2004. Factors and determinants of disease emergence. Revue Scientifique et Technique International Office of Epizootics 23 (2), 443–451.
Nedeva, M., Georghiou, L., Loveridge, D., Cameron, H.H., 1996. The use of co-nomination to identify expert participants for technology foresight. R and D Management 26 (2), 155–168.
Reperant, L.A., 2010. Applying the theory of island biogeography to emerging pathogens: toward predicting the sources of future emerging zoonotic and vector-borne diseases. Vector-Borne and Zoonotic Diseases 10 (2), 105–110.
Rowe, G., Wright, G., Bolger, G.F., 1991. The Delphi technique: a re-evaluation of research and theory. Technological Forecasting and Social Change 39 (3), 235–251.
Rowe, G., Wright, G., 1999. The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting 15 (4), 353–375.
Rowe, G., Wright, G., 2001. Differences in expert and lay judgements of risk: myth or reality? Risk Analysis 21 (2), 341–356.
Rowe, G., Wright, G., 2010. The Delphi technique: current developments in theory and practice. Technological Forecasting and Social Change 77 (5), 836.
Suk, J.E., Lyall, C., Tait, J., 2008. Mapping the future dynamics of disease transmission: risk analysis in the United Kingdom Foresight Programme on the detection and identification of infectious diseases. Euro Surveillance 13 (44), pii=19021.
Turoff, M., 1970. The design of a policy Delphi. Technological Forecasting and Social Change 2 (2), 149–171.
Van Der Fels-Klerx, I.H.J., Goossens, L.H.J., Saatkamp, H.W., Horst, S.H.S., 2002. Elicitation of quantitative data from a heterogeneous expert panel: formal process and application in animal health. Risk Analysis 22 (1), 67–81.
Walshe, T., Burgman, M., 2010. A framework for assessing and managing risks posed by emerging diseases. Risk Analysis 30 (2), 236–249.
Wentholt, M.T.A., Rowe, G., Konig, A., Marvin, H.J.P., Frewer, L.J., 2009. The views of key stakeholders on an evolving food risk governance framework: results from a Delphi study. Food Policy 34 (6), 539–548.
Wentholt, M.T.A., Fischer, A.R.H., Rowe, G., Marvin, H.J.P., Frewer, L.J., 2010. Effective identification and management of emerging food risks: results of an international Delphi survey. Food Control 21 (12 (S1)), 1731–1738.