Workpackage 2 - Deliverable 2.7

BIBLIOMETRIC MAPPING OF RESEARCH DISCIPLINES IN THE FIELD OF INFECTIOUS DISEASES OF ANIMALS

Jean De Rycke

Institut National de la Recherche Agronomique (INRA),
Animal Health Division
37360 Nouzilly, France

Contact :
E-mail : jean.derycke@tours.inra.fr
Telephone : 33 (0)2 47 42 75 49

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EXECUTIVE SUMMARY

OBJECTIVES

The objective of the study was to inventory disciplines in the field of infectious diseases of production animals using bibliometric methods, and to analyze their importance, relationships and temporal evolution. The ultimate goal was (i) to improve background information on disciplines and subject areas relevant to research funders and programmers and (ii) to compare and critically review bibliometric descriptors applicable to this research sector to monitor research output on a global scale.

METHODOLOGY AND STUDY OUTLINE

Data collection and analysis. Data on research papers published in English from 2006 to 2009 in Europe in the field of EMIDA were extracted from the Web of Science or the CAB databases or analyzed directly on the Web of Knowledge platform, unless otherwise specified. Three complementary schemes of discipline and subject areas classification were used: (i) JCR Subject Categories (SC), reflecting an academic vision of disciplines and considered as the scheme of reference to explore the overall environment of science (ii) CABICODES (CC), specialized in agriculture sciences and (iii) a lexical clustering method focused on generic research themes. Data were analyzed using current bibliometrical procedures, including bibliographical coupling, a method which clusters publications according to their shared citations, and exploratory statistical methods for multifactorial data such as correspondence analysis and hierarchical clustering.

Inventory and linkages. The distribution of disciplines and subject areas for each of the three types of classification was studied sequentially, focusing on the major categories. SC classification, being based on the sources of publications, was applied to both the publications and to their citations, so as to approach the concept of multidisciplinarity. The complementarities and overlaps between the major descriptors of these three schemes was explored quantitatively, with a view to select a set of descriptors of disciplines adapted to this research sector. This lexical scheme of categorization was designed to fulfil three essential criteria: (i) respect of the specific content of the individual publication (ii) homogeneity in the definition of discipline leading to a complementary partition, (iii) unambiguousness in category assignation.

Application to comparison of research subsectors. The SC, CC and lexical modes of classification were then applied to the comparison of the research subsectors defined by the type of production animals (Ruminants, Pigs, Poultry, Fish) or by the type of pathogenic organisms (Bacteria, Viruses, Parasites). As shown by bibliographic coupling, this partition in subsectors was first demonstrated as being highly relevant in terms of cognitive structuring,

Application to temporal evolution. Decennial trends of traditional disciplines and subject areas were analyzed, along with those emerging disciplines and cutting edge issues that cannot be identified by current categorization schemes. This part of the study was aimed at assessing the effective integration by the research sectors of the new concepts and methodologies of the genomics era, and also at measuring the trend magnitude of public health issues in research on animal diseases.

MAIN FINDINGS

Respective weight and temporal trend of disciplines in the field of EMIDA

(i) The classification of disciplines using JCR Subject Categories (SC) gives a global appraisal of the respective weight of academic disciplines common to biology and medicine, such as Microbiology (17%), Immunology (9%), Parasitology (7%) and Virology (6%). In the last ten years, the share of both Parasitology and Virology has globally decreased and during the same period a perceptible shift from journals dedicated to animal health to journals specialized in food science, public health and agriculture is observed. This trend mirrors the priority set on food safety and zoonoses during the last 20 years. The share of publications specifically dedicated to public health issues amounts to about 20% in the scope of EMIDA.

(ii) Decennial trends are different in the major animal categories on a world scale. Global increase of research output amounts to about 200% for Poultry, 180% for Fish, 170 % for Pigs, and 140 % for Ruminants. In Ruminants, Poultry and Pigs, zoonotic diseases show the largest increase (up to 450%), accounted mainly by publications on zoonotic bacteria and, more recently, on zoonotic viruses such as Influenza and West Nile. The global share of publication on major zoonotic agents amounts to about 17% of total publications in Ruminants and Pigs and to 35% in Poultry. In spite of these specific changes, related to emerging epidemics and subsequent public health needs, the relative share of the various research subsectors is relatively stable over time.

(iii) Research in the field of EMIDA appears to have very efficiently integrated the recent biological concepts of the post-genomics era and the share of EU is generally higher that its average share in the world output (about 30%). The decennial increase of research output is also well above baseline (X1.5) for such research thematics as Immunological Mechanisms (x8.4), Organic farming (x6.2), Biotherapeutics and alternative to antibiotics (X4.4), Animal Health Economics (x4.4), Ecological Health (x4), and Animal Welfare (x4). Comparatively, the increase is only moderate for such "hot topics" as: Marker, Diva and Plant Vaccines (x2.3), Population biology (a concept that partially overlaps with Ecological Health) (x2.3), Bioterrorism (x2.0), Emerging vectorial diseases borne by mosquitoes (x1.7) or by ticks (x1.4).

Integration of disciplines

(iv) According to bibliographic coupling, the 12 major research subsectors defined by the combination of an animal host and a category of pathogenic organisms form weakly connected cognitive structures. Proximity between subsectors sharing a same type of pathogenic organisms (Bacteria or Viruses or Parasites) appears generally higher than that between subsectors sharing a same type of animals (Ruminants or Pigs or Poultry), except for Fish, which is expectedly apart. In other words the traditional academic disciplines still strongly structure the research sector, with potentially negative influence on the evolution of interdisciplinarity .

(v) Disciplines were unevenly distributed in the 12 major research subsectors, for instance “Food safety” and “Vaccines” are more linked to “Poultry” than to other animal categories, whereas “Epidemiology”, “Diagnostic” and “Disease Resistance” is more linked to “Ruminants”. For subsectors based on the type of pathogenic organisms, there is a closer proximity between “Food Safety” and “Bacterial Diseases”, between “Vaccines” and “Viral Diseases” and between “Population Genetics” and “Parasitic Diseases”. This analysis opens the discussion on potential strategic approaches to improve collaboration between research subsectors and between disciplines in a given subsector.

Critical review of indicators of disciplines

(vi) The three categorization schemes of disciplines (JCR Subject Categories [SC] - CABICODES [CC]- lexical) are complementary. Whereas SC is universal across sciences and appropriate for macroanalysis and comparison of large research sectors, CC is adapted to a finer grain analysis of agronomic sector. Being based on applied notions, the categorization scheme provided by CABICODES (CC) may be more useful in a research funding and programming perspective. According to this scheme, the research sector comprises three major clusters of disciplines of unequal importance tentatively called (i) Farm & Animal Health, (ii) Safety of Food and Feed chains, and (iii) Ecological Health.

(vii) A shortcoming of the above schemes is their poor ability to describe specific disciplinary notions in relation to the disease process itself such as epidemiology, virulence, vaccines, disease control & prevention: the lexical scheme of classification adequately distinguishes these notions. By comparison, the lexical scheme can be tailored according to the precise objective of the analysis and made both homogeneous and exhaustive with regard to its objectives.

CONCLUSIONS

This study shows that reliable indicators exist to map and monitor research disciplines, either at a global scale or as applied to specific research sectors. Data are descriptive and exploratory, allowing to detect temporal trends, patterns, distribution and linkages between disciplines, to confirm or precise on an objective basis feelings of specialists, to uncover possible unanticipated facts. As shown in other research sectors, these results can be incorporated in the decision process aimed at defining research policy and programme priorities and such mapping tools can primarily contribute to improving the quality of the background information available to programme funders and experts. Provided that they are first analyzed and discussed by expert groups, they can also help identify possible gaps in research competencies at national and transnational levels.

BACKGROUND

The present report forms deliverable DL2-7 of EMIDA workpackage 2. This workpackage is concerned with the "mapping and analysis of existing research, current research needs and research development in Europe, in the field infectious diseases of production animals".

In a previous report of this workpackage, the place of European research in the world landscape was analyzed using bibliometric data extracted from the ISI Web of Science and the CAB Abstracts [1]. A publication database was also developed from the same bibliometric sources, designed to map specific research topics in organizations and in European countries [2].

DISEASES VERSUS DISCIPLINES

The information collected and analyzed in the previous mapping report follows the classical description of the medical and veterinary fields as a collection of disease entities. In the case of infectious diseases, these entities are classically defined as the association of a specified pathogenic agent and an animal target, each combination defining a research field with an acknowledged body of expertise, specific research strategies and agreed priorities. A major interest of the disease approach in bibliometric mapping is that it lends itself to a clear, refutable, delineation of a research topic, namely: the literature retrieved through specific keywords describing both the pathogenic and the host organisms. This strategy was used for example to develop the EMIDA output database to map major research organizations according to their research topics in Europe [2].

Notwithstanding, the disease approach is not sufficient to explore research in infectious diseases of production animals in the wider context of science, to locate its connection with related fields and to identify its borrowings from basic knowledge or innovative methodologies. Priority setting in research on infectious diseases of animals should certainly considers primarily the medical or economic impact of specified diseases, but cannot however neglect the need for an adequate diversity of expertise in research programmes, the introduction of original paradigms or new technologies into applied research, and the strengthening of interdisciplinary collaboration. Additional criteria of analysis of this research field should therefore be sought after, with a view to supporting decision-making processes in research programming and funding. Whereas an evidence-based consensus can generally be reached on disease prioritization, it is more difficult to analyze the respective weight of the disciplines and to set objectives in this matter. To make it feasible, reliable descriptors are needed, which bibliometrics can provide, to a certain extent. The search for such reliable bibliometric descriptors is the chief objective of the present study.

INTERDISCIPLINARITY

Although applied by nature, research on infectious diseases of farm animals is connected to numerous academic and applied disciplines. In very broad terms; it can be presented as being at the intersection of four main groups of disciplines: (i) Core disciplines linked to the nature of the pathogenic agent (e.g. bacteriology, virology, parasitology), the animal host (e.g immunology), or the animal population in its context (e.g. epidemiology); most of these disciplines are shared with the human medical sciences even though they may not apply to the same diseases and organisms nor respond to the same research questions; (ii) Basic support disciplines, from biochemistry and genetics to mathematics and bioinformatics, generic specialities that are common to various branches of the life sciences*;* (iii) Agronomic sciences in relation with animal sciences, more specifically production, breeding, genetics and nutrition, (iv) Ecology, wild life and the Environmental sciences, especially in relation with the wild reservoirs and the circulation of pathogens in the global environment.

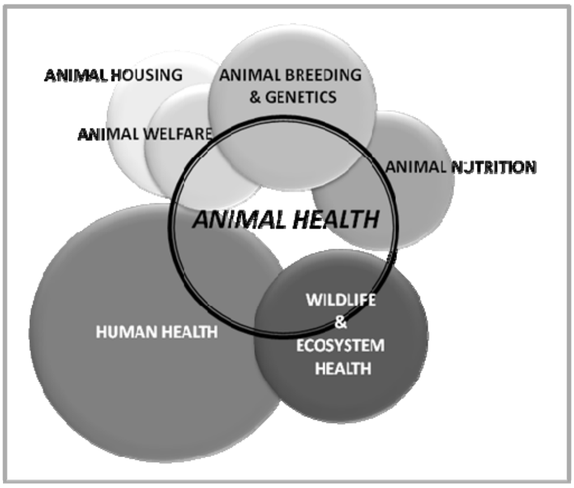
The notion interdisciplinarity, that appears essential in the present study, can be defined as the integration of different disciplines working on a common object [3] [4]. The level of integration can be quite low, with scientists working side by side but not trying to synthesize the cognitive structures of their respective disciplines (multidisciplinarity), up to very high, leading to the emergence of original branches of science (transdisciplinarity). This notion has been conceptualized to a certain extent and methods of measurement exploiting bibliometrical data have been proposed, generally applicable to individual researchers or research teams [5-6], or to research domain identified as being inherently interdisciplinary, such as nanotechnology [7].

INTERACTION WITH OTHER RESEARCH FIELDS

In addition to being highly multidisciplinary, this field of research is inherently connected to two other major fields: human health and wildlife-ecosystem health. The latter, also coined Eco-Health, is described as a transdiscipline at the intersection of the ecological and health sciences [8]. A sustained collaboration between these three research fields, and between the corresponding health systems, is made necessary by the fact that emerging infectious diseases affecting humans often results from a continuum of complex interactions between wildlife, domestic animals and human populations. The necessary integration of the three fields has also suggested the concept of "One-Medicine" forged by Calvin Schwabe in the 80s [9]. The societal endeavour behind this concept is to improve the control and the prevention of emerging zoonoses [10]. However, the most numerous contributions of veterinary research to public health issues in the last 20 years appear essentially related to food safety issues [11] [12].

Animal and related agronomic disciplines are also tightly connected to animal health, especially for those endemic infectious diseases affecting milk, meat or egg production, resulting in economic losses. High producing farm animals are permanently challenged by a variety of factors related to nutrition, housing systems, and stress, which have an impact on the animal resistance to diseases or on the safety of their environment. Animal physiology, welfare and genomics are at the forefront, with genomics being a challenging avenue for research to better control the resistance of farm animal to infectious diseases [13].

As a result, the field of animal infectious diseases is widely open to different disciplines and its boundaries with neighbouring fields are both complex and likely to evolve with time. This inner complexity is schematized below.



ORGANISATION OF THE PAPER

The objective of this study is to use bibliometric methods to identify disciplines in the field of infectious diseases of production animals, to assess their respective weight and their connection using multifactorial data analysis. It also seeks to capture the recent concepts and methodologies that continue to enrich the veterinary sciences.

After a presentation of the methodological framework, two methods of discipline mapping are compared, based on publication records on infectious diseases in major production animal species from 2006 onward in Europe. One method uses the journal categorization scheme of the Science Citation Index (Subject Categories or SC), the other the individual indexation of CAB Abstracts (CABICODES or CC). Applying journal categorization to cited references, it was also possible to appraise the integration of external disciplines by the primary literature. An original scheme of classification based on CAB controlled descriptors was also designed to map essential research themes not referenced with the two first methods. A specific design was also carried out to survey the emergence, in the last ten years, of new research themes or innovative technologies that could not be adequately detected by the above methods. Discipline mapping was finally applied to the different research subsectors that are defined by both the category of animal hosts and the type of pathogenic organisms. In the last section of the report, the main findings are synthesized, with emphasis placed on observations that could be pertinent to research coordination, programming and funding.

STRATEGY AND METHODS

TYPOLOGY OF CATEGORIES

Research publications were the elementary units of analysis. They were categorized according to their association with specified research "disciplines". In the specialized literature this generic term of "discipline" refers to heterogeneous types of information, spanning from academic disciplines to generic research themes. There indeed does not seem to exist a commonly agreed typology of the various notions implied under the term of "discipline" [14]. To prevent ambiguousness we have sought to adhere to the following typology throughout the report:

(i) Research sector: the larger research entity analyzed, here infectious diseases of farm animals, as defined by the literature collected by a defined set of 192 specific search queries (see below). This research sector has been split here into major research subsectors, defined by the combination a category of animal host (Ruminants, Pigs; Poultry & Fish) and a category of pathogenic organism (Bacteria, Viruses/Prions, Parasites). Each subsector (ex: "Viral diseases of Fish" or "Parasitic diseases of Ruminants") corresponds to an acknowledged type of expertise, combining knowledge on a pathogen category and on an animal host.

(ii) Disciplines: either of the two "operational" categories below proposed by the international publication databases:

- WoS Subject Category" (SC): "academic disciplines or broad subject areas" to which belongs the journal where the paper has been published, this journal classification being made by the Journal Citation report (JCR) [15]. The main SCs used in this study are listed below using acronyms in alphabetical order:

ADA	Agriculture, Dairy & Animal Science
AMU	Agriculture, Multidisciplinary
BAM	Biotechnology & Applied Microbiology
BIL	Biology
BIP	Biophysics
BMB	Biochemistry & Molecular Biology
BRM	Biochemical Research Methods
CAN	Chemistry, Analytical
CAP	Chemistry, Applied
CBI	Cell Biology
CME	Chemistry, Medicinal
ECO	Ecology
ENT	Entomology
ESC	Environmental Sciences
EVB	Evolutionary Biology
FIS	Fisheries

FST	Food Science & Technology
GHR	Genetics & Heredity
IDI	Infectious Diseases
IMM	Immunology
MFW	Marine & Freshwater Biology
MIC	Microbiology
MRE	Medicine, Research & Experimental
MUS	Multidisciplinary Sciences
NEU	Neurosciences
PAR	Parasitology
PAT	Pathology
PEO	Public, Environmental & Occupational Health
PHA	Pharmacology & Pharmacy
PLA	Plant Sciences
RBI	Reproductive Biology
TOX	Toxicology
TRO	Tropical Medicine
VET	Veterinary Sciences
VIR	Virology
ZOO	Zoology

- CABICODE (CC): individual indexation of papers by means of classification codes assigned by CAB specialists and indicating the "broad subject areas" of the publication [16]. The main CABICODES used in this study are listed below using acronyms in alphabetical order:

EE110	AGRICULTURAL ECONOMICS
FF005	FIELD CROPS
HH000	PATHOGEN, PEST AND PARASITE AND WEED MANAGEMENT (GENERAL)
HH405	PESTICIDES AND DRUGS: CONTROL
HH410	PESTICIDE AND DRUG RESISTANCE
HH600	HOST RESISTANCE AND IMMUNITY
HH700	OTHER CONTROL MEASURES
LL070	PETS AND COMPANION ANIMALS
LL110	DAIRY ANIMALS
LL120	MEAT-PRODUCING ANIMALS
LL130	EGG-PRODUCING ANIMALS
LL145	WOOL-PRODUCING ANIMALS
LL180	ANIMAL HUSBANDRY AND PRODUCTION
LL240	ANIMAL GENETICS AND BREEDING
LL250	ANIMAL REPRODUCTION AND EMBRYOLOGY
LL500	ANIMAL NUTRITION (GENERAL)
LL510	ANIMAL NUTRITION (PHYSIOLOGY)
LL520	ANIMAL NUTRITION (PRODUCTION RESPONSES)
LL600	ANIMAL PHYSIOLOGY AND BIOCHEMISTRY (EXCLUDING NUTRITION)
LL650	ANIMAL IMMUNOLOGY

LL800	ANIMAL HEALTH AND HYGIENE (GENERAL)
LL821	PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF ANIMALS
LL822	PROTOZOAN, HELMINTH, MOLLUSC AND ARTHROPOD PARASITES OF ANIMALS
LL823	VETERINARY PESTS, VECTORS AND INTERMEDIATE HOSTS
LL860	NON-COMMUNICABLE DISEASES AND INJURIES OF ANIMALS
LL882	VETERINARY PHARMACOLOGY AND ANAESTHESIOLOGY
LL886	DIAGNOSIS OF ANIMAL DISEASES
LL950	TOXICOLOGY AND POISONING OF ANIMALS
MM120	AQUACULTURE (ANIMALS)
MM300	AQUATIC BIOLOGY AND ECOLOGY
PP200	WATER RESOURCES
PP600	POLLUTION AND DEGRADATION
PP710	BIOLOGICAL RESOURCES (ANIMAL)
QQ010	MILK AND DAIRY PRODUCE
QQ030	MEAT PRODUCE
QQ060	AQUATIC PRODUCE
QQ200	FOOD CONTAMINATION, RESIDUES AND TOXICOLOGY
QQ500	FOOD COMPOSITION AND QUALITY
RR130	FEED ADDITIVES
RR200	FEED CONTAMINATION, RESIDUES AND TOXICOLOGY
VV055	IMMUNOLOGY AND ALLERGOLOGY
VV210	PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF HUMANS
VV220	PROTOZOAN, HELMINTH AND ARTHROPOD PARASITES OF HUMANS
VV230	PUBLIC HEALTH PESTS, VECTORS AND INTERMEDIATE HOSTS
VV400	ANIMAL MODELS OF HUMAN DISEASES
YY100	ANATOMY AND MORPHOLOGY (WILD ANIMALS)
YY300	GENETICS AND MOLECULAR GENETICS (WILD ANIMALS)
YY400	PHYSIOLOGY AND BIOCHEMISTRY (WILD ANIMALS)
YY700	PATHOGENS, PARASITES AND INFECTIOUS DISEASES (WILD ANIMALS)
ZZ100	MATHEMATICS AND STATISTICS
ZZ332	ANIMAL ECOLOGY
ZZ360	GENERAL MOLECULAR BIOLOGY
ZZ380	TAXONOMY AND EVOLUTION
ZZ394	BIOCHEMISTRY AND PHYSIOLOGY OF MICROORGANISMS
ZZ395	GENETICS AND MOLECULAR GENETICS OF MICROORGANISMS
ZZ900	TECHNIQUES AND METHODOLOGY

As can be seen above, both SC and CC categories most often refer to academic or applied disciplines but also in some instances to a specific sector of animal production (ex. SC: Fisheries) or a large subject area (ex CC: Food Contamination, Residues and Toxicology), which, strictly speaking, are not disciplines.

(iii) Research themes: in the present study, this notion has been applied to the classical division of infectious diseases studies into aetiology, epidemiology, diagnostic, virulence, disease control, vaccines & vaccination etc… It refers to generic approaches, common to almost all diseases, irrespective of the type of pathogenic organism and of the animal host. These research themes being not systematically identified through SC and CC categories, they were generally mapped through lexical analysis using keywords.

(iv) Subject areas: areas of science centred on a main subject matter and defining a relatively coherent body of expertise and of research strategies (ex: Post-genomics or Bioterrorism research). Subject areas can be split into specific research topics, often focused on diseases in this particular research sector. In the present study we generally did not go down to this level of analysis.

BIBLIOMETRIC RESOURCES

Most of the analyses were performed on publication records extracted from either the Web of Science (WoS) or the CAB databases, both available on the Web of Knowledge platform run by Thomson Reuters for the Institute for Scientific Information (ISI) [17]. These concern research papers in English for which one author at least was based in the European Union. Some analyses, essentially world decennial trends (Tables 8 and 9), were performed directly on the Web of Knowledge platform. The WoS covers all academic disciplines whereas CAB is specialized in agronomic research including animal and public health research. An interesting particularity of CAB is that each source document is individually ascribed one or more standard classification codes, termed CABICODES (CC), indicating the broad subject areas, irrespective of the JCR subject category (SC) of the source. Both WoS and CAB records include several fields displaying specific descriptors. In CAB, these descriptors can be found in a built-in thesaurus and one field is specifically dedicated to descriptors of organisms (host & pathogens). The complementary assets of these databases justify their combined use in the context of this study.

DEFINITION OF THE RESEARCH SECTOR

A specific challenge of the present bibliometric analysis was to construct a complete set of search queries that would cover in an exhaustive manner, and without major omissions, the research sector of EMIDA, i.e. infectious diseases of production animals. A particularity of this research sector is that it can be satisfactorily described by the combination of disease names (or of the respective pathogenic agents) with those of animal hosts, provided that an exhaustive list of these two types of descriptors can be generated, then prioritized. As described previously in the methodological notice of the EMIDA database [18], lists of all the disease or pathogen descriptors present in the literature could be produced for each animal category, then prioritised using CAB. Eventually a set of 192 basic search queries on diseases as applied to major farm production animal categories such as ruminants (49 queries), pigs (47), poultry (45), fish and shellfish (16) was constructed. Regarding animal descriptors, it should be noted however that queries formulation widely opened the scope to wild animals of the same zoological families. The formulation of all these queries can be accessed through the web interface of the EMIDA database [2].

EXTRACTION OF PUBLICATION RECORDS & FIELD INFORMATION

Unless otherwise specified in the Results section, records from research publications in English from 2006 onward and present in WoS or CAB databases by mid-July 2009 were collected. and processed using the software Bibexcel, a tool box designed by O. Persson, Inforsk, Umeå university, Sweden [19]. This software can be used for various types of analysis such as: extraction of document records, addition of fields, normalization and selection of data, combination of information from several fields, frequency counts, co-occurrences and shared units between separate records. The basic operating principle of Bibexcel is to generate data files that can be imported to MS Excel for further processing.

Two new fields were created on each record: one to identify the group of animal host (field AN -four categories), the other the group of pathogenic agent (field DS - three categories). As indicated above, the addition of these two complementary fields makes possible the allocation of records into any of 12 research subsectors (examples: "bacterial diseases of ruminants" or "parasitic diseases of fish"). In summary, the information extracted from the following fields was essential to this study:

WOS records

AN-	Host animal category
DS-	Pathogenic agent category
SC-	Science Citation Index Subject Category
C1-	Addresses of all co-authors
RP-	Address of corresponding author
ID-	ISI Keywords
CD-	References cited

CAB records

DS-	Host animal category
AN-	Pathogenic agent category
CC-	CABICODES (describing broad research areas)
DE-	CAB keywords

BIBLIOMETRIC TOOLS TO MAP DISCIPLINES

Several bibliometric descriptors have been used to map research fields, in terms of diversity, structure and perimeter [20] Once a research field has been clearly defined, a rather large spectrum of descriptors, based mostly on publications in scientific journals, can be used. For the specific purpose of this study, publication records were analyzed according to the following schemes: (i) patterns of publications established on the basis of the information contained in fields specifically describing disciplines or general subject areas, as applied to the publications themselves or to the literature they cite; (ii) bibliographic coupling based on the references cited by papers, to identify clusters of citing publications sharing a common base of knowledge, and to assess the proximity between pre-defined aggregates of papers [21] [22]; (iii) lexical coupling, also called coword analysis, to improve the typology of research domains based on pre-defined disciplines or subject areas [23].

Two main methods were used to assess the level of linkage between disciplines and visualize their pattern of association: factorial correspondence analysis (FCA), based on Khi-square distances and agglomerative hierarchical clustering (AHC), based on a coupling measure called the Salton's cosine index (SCI) [24] [25]. Khi-square is a measure of distance and Salton's cosine a measure of proximity, both normalized on sample size. More specifically, the SCI measures the number of papers that two disciplines A and B have in common adjusted on the respective size of the two disciplines: SCI= n_{AB} / $(n_A \times n_B)^{-1/2}$.Two statistical software were used: XLSTAT [26]and Ucinet [27]. A more detailed methodological notice will be made available.

INVENTORY AND LINKAGES OF DISCIPLINES

EXTRACTION OF PUBLICATION RECORDS

Records from research papers published in English from 2006 to mid-July 2009 in the 27 countries of the European Union plus Norway and Switzerland, were extracted from both the WoS and the CAB databases, using 192 different search queries describing in an exhaustive manner diseases and their respective major animal hosts (ruminants, pigs, poultry, fish & shellfish). Based on the formulation of the respective search query, two new fields were added on each source record, describing the animal host category and the pathogenic agent category. This led to the allocation of records into one of 12 research subsectors. Being extracted from two independent databases, the two sets of source records were checked for global consistency, based on absolute number and distribution into the 12 research subsectors (Table 1).

Table 1. Global distribution of publications extracted from the WoS and CABI databases.

World output in the research field during the period surveyed amounted to about 35,000 research papers, of which about one third originated from the EU, a figure that is consistent with our previous figure based on a slightly different period [1]. The WoS count for EU (11,826) is higher than the CAB one (10,166), a difference corresponding to about 15% of the total. Overall distribution of papers into research subsectors also appears consistent, although some differences may deserve further analysis. For example, parasitic diseases of the poultry account for 7% of publications in CAB and 4% in WoS (not shown).

SCIENCE CITATION INDEX SUBJECT CATEGORIES (SC)

The JCR Subject Categories categories, generated by the Institute for Scientific Information (ISI), are commonly used as a means to characterize the variety and interaction of disciplines in specific research fields [5] [28] or to map global science [29] [30]. SCs are based on a combination of criteria including inter-journal citation patterns. They apply to the journals in which research papers are published and indirectly to the papers themselves. More than 150 SCs have been inventoried [15], including multidisciplinary ones, and a journal can be assigned to several categories. As recently proposed by A.L Porter [5], the distribution of SCs can be measured either on the publications themselves (herein called “primary” publications) or on the references cited by these primary publications. For any entity studied (organization, research domain, individual researcher), primary publications can be exploited to measure the level of specialization in the core disciplines and specialties, whilst cited references are supposed to also reflect the integration of knowledge from other fields and disciplines. In the present study we have therefore compared the SC distribution on primary publications and on cited references, in an attempt to appraise the importance of certain external disciplines in the knowledge structure of the core disciplines.

ANALYSIS OF PRIMARY PUBLICATIONS

The distribution pattern of all research papers extracted from the WoS shows that 25 SCs are represented at a frequency of at least 1%. The 12 most frequent SCs (from "Veterinary Sciences" down to "Marine and Freshwater Biology") account for almost 85% of the papers (Table 2).

Table 2. Distribution of main JCR Subject Categories (SC) of research papers in the field of infectious diseases of farm animals (with frequency >0.7%).

Quite expectedly, the most frequent category is Veterinary Sciences, representing about one third of the publications, followed by the basic (Microbiology, Parasitology, Immunology, Virology) or applied (Biotechnology & Applied Microbiology, Food Science, Agriculture & Dairy Science) disciplines. Although obviously relevant to this study, the category "Veterinary Sciences" may appear to lack specificity in terms of discipline identification as a number of journals in this category are also ascribed to another SC by the JCR. The alternative SCs of the most frequent of these journals were then examined (Table 3).

Table 3. Multi-assignation of the major journals of the SC "Veterinary Sciences".

The 14 journals in the SC "Veterinary Sciences" with more than 100 papers in the period surveyed accounted for more than 65 % of the totality of papers in this category. Half of these journals are assigned to one or several other SCs, with the result that only about 25% of the papers belong to the sole category "Veterinary Sciences". Journals classified in this category only are known to be generalist in the field of animal health, irrespective of the basic disciplines characterizing the content of articles (bacteriology, parasitology, virology, immunology, etc…). Later in this study we investigate the actual disciplines and subject content of these particular publications using CABICODES and lexical analysis.

From the information of Table 3, the SCs associated to SC "Veterinary Sciences" are respectively: Microbiology, Parasitology, Immunology, Fisheries and Marine & Freshwater Biology. It should be stressed that this linkage is based essentially on the categorization of journals in the JCR and not to the intrinsic content of articles. To get a global picture of SCs linkages as applied to the field of animal infectious diseases, the strength of association between any pair of SCs (also called similarity index) was measured using the Salton's cosine, then a Johnson's hierarchical ascending clustering, using weighted average, was performed on the proximity matrix of cosine measures. A dendrogram including the 28 SCs representing at least 0.8% of articles is shown in Figure 1.

Figure 1. Linkage of JCR Subject Categories (SC) due to multi-assignation of journals.

Three large clusters are identified by the software algorithm: (I, orange) with 12 SCs centered on microbiology and infectious diseases, (II, grey) with 6 SCs centered on Veterinary Sciences , and III (blue) 7 SCs with two subclusters, one centered on biological sciences, the other on zoology and ecology. This clustering should however be interpreted with caution as the overall level of proximity is low.

SC analysis is used here as an introductory approach to discipline mapping in the specific field of research in animal infectious diseases. While it can hardly be used for fine mapping of a specific research field, its potentially universal application lends itself to global science mapping, to comparisons between separate fields of research, research organizations or countries and also to temporal analyses. In the present study we have found it useful to examine whether the pattern of SCs has significantly changed over the last ten years. This statistical survey was performed directly on the WoS platform using the complete set of search queries defining the field of animal infectious diseases, this at the world scale and for years1998 and 2008 (Table 4).

Table 4. Evolution of patterns of JCR Subject Categories (SC) in the research field of animal infectious diseases between 1998 and 2008

There appears to be a highly significant decrease ($p<0.001$) in 3 of the major SCs: Veterinary Sciences (36.5 to 31.3%), Parasitology (8.3 to 7.4%) and Virology (8.0 to 6.2 %), and a significant increase in 7 of them: Food & Science Technology (5.1 to 7.5%), Infectious Diseases (4.5 to 7.3%), Agriculture and Dairy Science (3.7 to 6.9%), Public and Environmental Health (1.4 to 2.9 %), Ecology (1.4 to 2.7%), Biology (0.6 to 1.5%) and Environmental Sciences (0.6 to 1.3%). Keeping in mind that SCs may mainly reflect global publication trends on the part of authors, with little connection to the intrinsic evolution of disciplines themselves, we can infer from these results that there has been a perceptible shift from journals purely dedicated to animal health to journals specialized in food science, public health and agriculture. This trend probably mirrors the tremendous effort of veterinary research in the domains of food safety and zoonoses during the last 20 years. These results point to another observation that would deserve further analysis: the significant decline of Parasitology and Virology as major SCs. Does this decline correlate with the relative share of publications specifically dedicated to viral or parasitic diseases as compared to Bacteriology? This question is addressed in a subsequent section of this study. In any case, one should not forget to set these results into context: a global 156% increase of the research output in ten years (Table 4)

ANALYSIS OF CITED PUBLICATIONS

In WoS publication records, cited references, including abbreviated titles of journals, are displayed in a specific field (tagged "CD"). The SCs of cited journals was sought in the Journal Citation Reports (JCR), Edition 2008 [15], and a tabulated conversion file, containing 2496 different abbreviated titles (very often with several titles for the same journal) was constructed. The conversion file allowed Bibexcel software to automatically translate abbreviated journal titles into their respective SCs, respecting multi-affiliation when relevant. Citations amounted to a total 409,568 citations, for 11,826 publications, i.e. 35 citations on average per publication. An estimated 75% of the journals (or alternative sources) could be converted into SCs. To identify the external research fields and the basic support disciplines to which researchers refer in their work, the range and respective share of SCs in primary and in cited publications was compared (Table 5).

Table 5. Compared distribution of JCR Subject Categories (SC) in primary publications and in the publications cited by these primary publications: 5.1. SCs more frequent in primary publications; 5.2. SCs more frequent in cited references

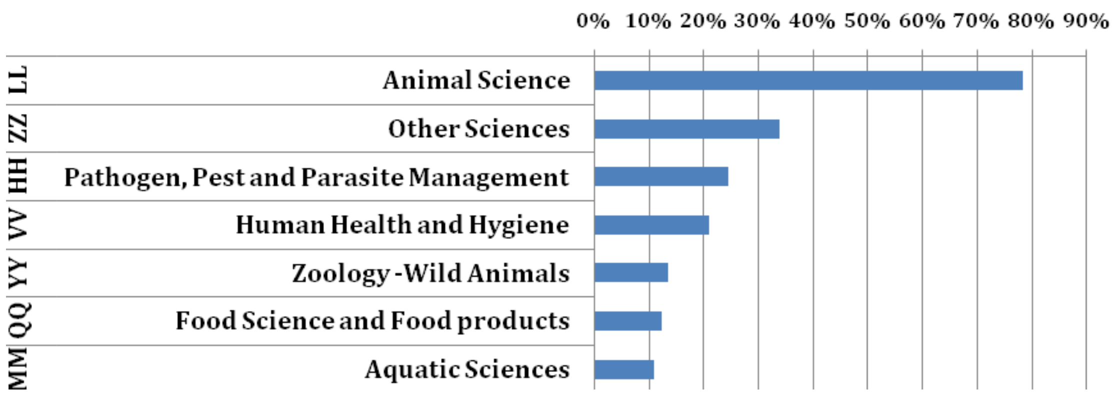
The two distributions are significantly different, as demonstrated by the Khi-square test of goodness of fit ($p<0.001$). For a better visibility, SCs were arranged according to khi-square values, a measure of distance that is independent on sample size, and they were split in two groups: those more represented in primary publications (Table 5.1) and those more represented in cited references (Table 5.2). As expected, applied categories are much more represented in primary publications than in cited references. For example, 6 of the 7 first SCs listed in Table 5.1 belong to applied categories (Veterinary Sciences; Food and Science Technology; Fisheries; Agriculture, Dairy and Animal Science; Marine & Freshwater Biology; Public, Environmental & Occupational Health), the only exception being Parasitology. In contrast, the 7 first SCs in cited references belong to basic and support disciplines (Biochemistry and Molecular Biology, Medecine, General & Internal, Cell Biology, Genetics & Heredity, Statistics & Probability, Evolutionary Biology) and also to category Multidisciplinary Sciences, which include such journals as Nature, Science and Proceeedings of the National Academy of Science USA, which publish papers of reference.

CABICODES (CC)

The major interest of SC classification lay in its universal application. However this mode of discipline mapping, being based on a classification of journals, only indirectly addresses the intrinsic content of publications. A mapping system of a finer grain is then needed to better appreciate the variety, interplay and evolution of disciplines and research themes in the field of animal infectious diseases. In agriculture sciences, the CAB platform provides an interesting scheme of codes, called CABICODES (CC) [16], that could meet this requirement. The CABICODES consist of a hierarchical thesaurus that divides the subject coverage of the CAB Abstracts database into 23 major sections. Each section then includes a series of codes that divides that subject into more specific subjects. The 250 CABICODES themselves are typically used to describe subjects difficult to qualify using keywords alone and, in contrast to SCs, they relate to the individual content of each publication. The interest of CABICODES to mapping animal health research has been illustrated in our previous mapping report for EMIDA [1]. The distribution of the 34 CCs with a frequency of at least 2% is presented in Table 6

Table 6. Distribution of the main CABICODES (CC) of research papers in the field of infectious diseases of farm animals (restricted to those with frequency of at least 2%)

The three major CCs (LL821 PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF ANIMALS, LL822 PROTOZOAN, HELMINTH, MOLLUSC AND ARTHROPOD PARASITES OF ANIMALS and VV210 PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF HUMANS), expected to cover the research field under study (animal and veterinary public health), did account for a cumulated 90% of source records. These CCs are indeed at the top of the hierarchical classification. Grouping of CABICODES in sections, according to the letters of the codes, makes possible an overall appraisal of the importance of sections peripheral to animal science:



According to the above summary statistics, at least 20% of publications in the sector of animal infectious diseases are also related to public health issues. These publications are concerned with zoonotic diseases, especially with food-borne related issues. This also means obviously that about 80% of publications are concerned with issues strictly specific to animal diseases. Other interesting data concern the share of publications dealing with diseases of wild animals (14%) diseases of aquatic animals, which probably includes a large part of the former (12%.).

Like with SC classification, publications are generally assigned several CCS. In contrast to SCs, linkage between CCs reflects a hierarchical mode of classification. To examine more closely how CCs are clustered due to multi-assignation, the matrix of affinity measures between pairs of CCs was submitted to a clustering analysis. The resulting dendrogram is shown in Figure 2.

Figure 2: Linkage of CABICODES (CC) due to multi-assignation of publications

Three majors clusters are proposed by the software algorithm: (I, blue): 10 CCs with two linked sub-clusters, one centered on the molecular characterization on pathogenic organisms (ZZ series), the other on aquatic ecology and wildlife diseases, including parasitology and vectors; (II, brown): a major central cluster with 15 CCs including a large part of the LL series describing animal and veterinary sciences in the production context; and (III, pink): 9 CCs centered on food and feed contaminants of the food chain (QQ series), including pest and drug resistance (HH series). On the basis of affinities between CCs, the research field analyzed can thus be provisionally described as comprising three major clusters called Eco-Health (cluster I), Farm & Animal Health (Cluster II) and Safety of Food and Feed chains (Cluster III). In a research programming perspective, the vision proposed by this global classification largely based on applied notions may even be more interesting than the classical division by academic disciplines or Subject Categories.

To further test the usefulness of CC categorization as a complement to SC description in the research sector, their statistical association was analyzed using correspondence analysis. This was made possible on the CAB publication records after a systematic conversion of journal names into their respective SC (Journal Citation Reports (JCR), Edition 2008 [15]) The objectives of this analysis was (i) to confirm any anticipated closeness of CCs and SCs related to the same discipline or broad subject area; (ii) to identify those specific areas were CCs really cover original notions not already covered by SCs. To derive the major observations and also to improve the legibility of final scatterplot, the results are shown for the 18 most frequent SCs and the 45 most frequent CCs (Figure 3).

Figure 3. Two-dimension scatterplot of correspondence analysis between JCR Subject Categories (SC) and CABICODES (CC).

In this complete scatterplot, outlying CC categories are easily discernible. These are groupable into 5 coherent clusters covering the following broad notions: (I) Food safety, (II) Immunology, (III) Fish diseases, (IV) Parasitology and (V) Wild animals. Moreover, these clusters are linked to specific SCs in a predictable and consistent way: for Cluster (I): FST (Food and Science Technology); Cluster (II): IMM (Immunology) and MRE (Medecine, Research & Experimental); Cluster (III): MFW (Marine & Freswater Biology) and FIS (Fisheries); Cluster (IV): PAR (Parasitology); Cluster (V); ECO (Ecology). It is interesting to observe that the two latter clusters are close to one another in the same quadrant of the scatterplot and that they include two CCs of the series ZZ: ZZ380 TAXONOMY AND EVOLUTION and ZZ332 ANIMAL ECOLOGY. The categories in these two clusters fairly well describe the concept of Ecological Health as described in the introduction of this report and it is interesting to note that it is essentially associated with parasitic diseases. The relative proximity between these descriptors is confirmed by the Salton's cosine values.

In this scatterplot, the major contribution to total inertia is due to outlier categories. A second FCA was thus performed including only the central categories, not easily distinguishable on the first scatterplot (Figure 4)

Figure 4. Two-dimension asymmetric scatterplot of correspondence analysis restricted to the central SCs and CCs of Figure 3 scatterplot.

This analysis suggests the tentative grouping proposed in the figure, although perimeters are not as clear as with "outliers" of the first round. In examining this scatterplot, one should also keep in mind that discrimination along the horizontal axis, with 60% of contribution to the total inertia is much better than along the vertical axis (17% of contribution). The tentative grouping covers the following notions: (VI) Public Health, including antibioresistance, (VII) Molecular Microbiology involving both viruses and bacteria, (VIII) Animal Genetics, and (IX) Animal Nutrition and Breeding. The remaining CCs all pertain to veterinary and animal sciences (series LL of CCs) without a clear distinction between the underlying themes of research. In addition, there is a good overall agreement between SCs and CCs localization on the scatterplot. It is worth noticing that the SCs MIC (Microbiology) and VIR (Virology) are clearly associated with CCs describing molecular and genetic methods of characterization (ZZ series). This observation may be related to the fact that journals in the MIC and VIR categories mostly publish papers on the molecular biology and the genetic characterization of pathogenic organisms.

LEXICAL ANALYSIS BASED ON CAB DESCRIPTORS

SC and CC can lead to a fine mapping of disciplines and research areas, especially if they are used in combination. Notwithstanding, a research area appears insufficiently characterized, the one roughly covering the cluster called Specific to "Veterinary Sciences" in Figure 4. This cluster includes CCs describing various animal & veterinary subjects, and the SC VETERINARY SCIENCES is clearly linked to them. However it appears that apart from LL650 ANIMAL IMMUNOLOGY and LL886 DIAGNOSTIC OF ANIMAL DISEASES, the CC scheme does not cover research themes relevant to the disease process itself such as epidemiology, virulence, vaccines, and disease control & prevention. Lexical analysis was then applied to CAB records to identify clusters of CAB descriptors apt to map these generic research themes and measure their respective weight in research output. Diagnostic and Immunity being already covered by CCs, this particular study also provided an opportunity to examine the correspondence between CAB descriptors and CC indexing.

In CAB records, subject descriptors appear in the field DE. They are assigned for each publication by a subject specialist at CAB International and listed in the CAB Thesaurus, which makes possible both a control and a normalization of the vocabulary [31]. The principle of the method was to allocate descriptors from the 10,166 CAB records in the different research themes targeted, taking into account their overall frequency, then to examine their mode of clustering by factorial correspondence analysis. The clustering was performed step by step through an iterative process, to select descriptors specific to the 9 large research themes mapped, i.e. EPIDEMIOLOGY (EPID), DIAGNOSTIC (DIAG), MICROBIAL GENETICS (MIGE), VIRULENCE (VIRU), IMMUNITY (IMMU), VACCINES (VACCI), DISEASE CONTROL (DICO), DISEASE RESISTANCE (DIRE), FOOD SAFETY (FOSA). To be selected a descriptor had also to be present in at least 5 records. Any descriptor found ambiguous with regard to the objective of this study was rejected. For instance, we discarded some descriptors of genetic methods that appear to be ascribed in a rather undiscriminating manner by CAB specialists to either the animal hosts or to the pathogenic organisms.

Briefly, a DE field was present in 99% of CAB records. Of 5,899 different descriptors, 2482 (42%) were present in at least 5 records. The iterative selection process resulted in a final set of 109 descriptors grouped in the six targeted clusters Descriptors were then automatically converted into their respective cluster name using Bibexcel software. The final distribution of publications in the nine clusters describing research themes is shown in Table 7.

Table 7. Distribution of publications in the 9 lexical clusters describing research themes (part A) and measurement of their proximity by the Salton's cosine measure (part B)

According to this method of categorization, EPIDEMIOLOGY appears as the largest of these research themes (with 32% of papers related to it), followed by DIAGNOSTIC (24%), FOOD SAFETY (19%) VIRULENCE (16%), IMMUNITY (14%), DISEASE CONTROL (13%), MICROBIAL GENETICS (12%), VACCINES (9%), and DISEASE RESISTANCE (5%). EPIDEMIOLOGY, as mapped here, encompasses a range of different approaches, from purely descriptive surveys to mathematical modelling of epidemics, through quantitative risk analysis. A sub-classification scheme for epidemiology would be appropriate and is feasible using CAB descriptors (not shown). The highest proximities between research themes can be derived from the Salton' cosine values in part B of Table 7. Five pairs of research themes are above the threshold of 0.3 which points to a high level of proximity: IMMUNITY and VACCINES (0.393), EPIDEMIOLOGY and DIAGNOSIS (0.324), EPIDEMIOLOGY and DISEASE CONTROL (0.314), IMMUNITY and VIRULENCE (0.305), EPIDEMIOLOGY and FOOD SAFETY (0.304).

One completed and validated, the clustering process eventually resulted in the allocation of the almost complete set of CAB publication records into these nine original categories. The overall discriminating power of this lexical mapping of research themes was then examined by plotting the results of correspondence analysis performed from a two-way contingency table containing the 109 selected descriptors and their nine summary categories (Figure 5).

Figure 5. Scatterplot of correspondence analysis between specific CAB descriptors selected for their ability to describe nine research themes in the field of animal health infectious diseases.

In this complete scatterplot, which accounts for 38% of the total inertia, the three most outlying research themes are easily distinguishable, namely FOOD SAFETY, MICROBIAL GENETICS, and DISEASE RESISTANCE. Due to the relatively low contribution to total inertia, the visual proximity between MICROBIAL GENETICS and DISEASE RESISTANCE on the plot may not adequately reflect the actual level of proximity between these two research themes, a question treated for all the disciplines in the next section of this report. In any case, genetics descriptors that indiscriminately refer to both pathogenic agents and animal hosts were rejected, as carefully as possible.

A second round of correspondence analysis was then performed removing the three "outlying" research themes and their related descriptors, with a view to better characterize the inner descriptors (Figure 6).

Figure 6. Scatterplot of correspondence analysis of CAB descriptors describing research themes without the outlying clusters of Figure 5.

The new scatterplot accounts for 49% of the total inertia. The six inner clusters are now more discernible, including the anticipated overlapping between the most proximate of them. A major observation is the clear separation along the horizontal axis (31% of total inertia), of EPIDEMIOLOGY , DISEASE CONTROL and DIAGNOSTIC, on the one side, and VACCINES, IMMUNITY and VIRULENCE, on the other. Discrimination along the vertical axis (17% of total inertia) is clear for DIAGNOSTIC only. Close interrelationships, resulting in partial overlapping, are observable firstly between IMMUNITY, VACCINES and VIRULENCE, three research themes focused on the animal host, and secondly between EPIDEMIOLOGY & DISEASE CONTROL, focused on the animal population. One should bear in mind that in a scatterplot from factorial correspondence analysis the visual distance between any two points does not respect the exact measure of proximity, such as provided for instance by the Salton's cosine (Table 7 B).

It was at last important to check the closeness of descriptors of both types that were related to similar subject areas. This was visualized through a factorial correspondence analysis with the 9 lexical thematic clusters and a selection of CABICODES (Figure 7). Pairwise proximities were measured by the Salton's cosine index (SI).

Figure 7. Scatterplot of correspondence analysis between lexical thematic clusters and selected CABICODES

In this scatterplot the linkage between related categories is perceptible, notably for:

- FOOD SAFETY and CCs dedicated to Food Contamination (QQ200, SI=0.660) and Public Health: (VV210, SI=0.660 and VV220, SI=0.317);

- IMMUNITY and CCs dedicated to Immunity (LL 650, SI=0.715) and to Host resistance (HH600, SI=0;492);
- VACCINES and CCs dedicated to Host Resistance (HH600; SI=0.797) and to Immunity (LL650, SI=0.450)
- MICROBIAL GENETICS and CCs of the series ZZ dedicated to molecular and biochemical analysis of microorganisms (ZZ380; SI=0.567 - ZZ395; SI=0,497 - ZZ360; SI=0.419). One interesting feature of this group is its relative closeness with pathogens of wild animals (YY700; SI=0.209), a confirmation of data shown in Figure 3 in which the linkages between CCs and SCs is analyzed.

These three groups of descriptors are spotted in three different quadrants of the scatterplot, distant from the center, while the large categories EPIDEMIOLOGY, DIAGNOSTIC, and DISEASE CONTROL, are grouped in a same quadrant, rather close to the centre, in proximity to CCs also describing large areas of the Veterinary Sciences (LL821, LL822, LL886). One should keep in mind that closeness between descriptors of different types does not mean identical coverage of publications. For instance CC886 (Diagnosis of Animal Diseases Diagnosis) is, quite expectedly, very close to the LEX DIAGNOSTIC (SI= 0.653) but identifies 12% of the publications extracted from the CAB, whereas LEX DIAGNOSTIC identifies 24% of them (Table 12). This observation stresses the fact that a given descriptor possesses an internal validity related to the exact perimeter that it describes, and that any comparison between specific entities, such as research sectors, countries, laboratories, etc…, should obviously use the same type of descriptor.

EMERGING DISCIPLINES AND CUTTING EDGE ISSUES

The descriptors developed so far in this study covers a large number of disciplines and research themes. However, especially when based on pre-defined categories, like SCs and CCs, these may miss or underscore emergent and transdisciplinary themes, the mapping of which needs specific keyword searches. This complementary analysis was carried hereafter on subjects considered as having significantly developed or emerged in the last 10 years. We have generally applied the concept of emergence to disciplines and generic themes and not to diseases themselves, with the exception of vector-borne diseases likely to emerge with global climate change, which we have split into two categories: mosquito-borne (Blue tongue, African Horse Sickness, Rift Valley Fever, West-Nile, Leishmaniasis) and Tick-borne (Babesiosis, Theileriosis, Ehrlichiosis, Anaplasmosis, Rickettsiosis) [32].

Two types of themes are presented: those that are shared with all biological sciences (Table 8) and those that are more specific to medical and agronomic sciences, as they are represented in the CAB database (Table 9). For each category, two main indicators were adopted: (i) the quantitative evolution during the last ten years at the world scale and (ii) the share of EU in 2008. This analysis was carried out directly on the CAB database platform, and not on extracted records, as the research sector of animal infectious diseases can be covered in its entirety by a combination of CABICODES. All the combinations of keywords and of CABICODES used for these specific searches appear in the legends of the tables.

Table 8. Emerging and cutting edge themes in the biological sciences: evolution of the volume of research publications between 1999 and 2008.

Table 9. Emerging and cutting edge themes in the medical & agronomic sciences: evolution of the volume of research publications between 1999 and 2008.

For the biological sciences nine themes have been selected, of which three were practically inexistent in the general literature ten years ago: Nanotechnologies, MicroRNAs, Systems Biology & Synthetic Biology (Table 8). In 2008, 33 articles in the sector of animal infectious diseases were concerned with microRNAs, a number of them in Herpes or Influenza viruses (not shown). The large group of "omics" disciplines including Genomics, Proteomics, Transcriptomics, Metabolomics and the associated Bioinformatics (partially covered by the preceding categories), show an impressive increase of x160 in the sector of animal infectious diseases, as it started from a single record in 1999. This decennial increase appears comparatively higher than the general background (x40), which may reflect that these new disciplines were adopted with a certain lag to applied sectors of research. This observation also holds true for post-genomics, a notion largely redundant with the previous ones. In comparison, the lower relative increase in genome research, ie. sequencing, mapping and annotation (x14 versus x7) probably correlates with the fact that this discipline developped well ahead of the "omics" era. On the whole, it appears that research in animal infectious diseases has efficiently integrated these new biological concepts and that the share of EU in these cutting-edge issues is generally higher that its average share of the world output in the field of animal infectious diseases (about 30%). For Imaging and Cell Biology, the increase is about the same in animal infectious diseases and in the biological sciences in general (x2 to x3), but lower than in the medical sciences in particular (x5, not shown). It will now be interesting to examine whether this integration is evenly distributed in the different subsectors of research concerned.

The decennial evolution of the 14 agronomic and medical sciences appears in Table 9. The choice of these themes is largely based on the perception of the author on the evolution of animal health research and its associated fields in the last ten years. Depending on the subject, the number of publications was multiplied by a factor ranging from 1 to 8 in the sector of animal infectious diseases, against a general baseline of about 1.5 in the Veterinary Sciences in EU (see Table 4). A significant increase above baseline is observed with Immunological Mechanisms (x8.4), Organic farming (x6.2), Biotherapeutics and alternative to antibiotics (X4.4) Animal Health Economics (x4.4), Ecological Health (x4), and Animal Welfare (x4). One should keep in mind, however that the data recorded for such new multidisciplinary concepts as Ecological Health may essentially reflect the use of a newly forged descriptor in the literature. Comparatively there has been but a moderate increase for the following subjects: Marker, Diva and Plant Vaccines (x2.3), Population biology (a concept that partially overlaps Ecological Health) (x2.3), Bioterrorism (x2.0), Emerging vectorial diseases borne by mosquitoes (x1.7) or by ticks (x1.4). The lack of a sharp increase (at least up to year 2008 included) for these two categories often considered as new research priorities for research deserve to be emphasized. The world share of EU appears above its average value for Organic Farming (53%) and Animal Welfare (43%) and below for Ecological Health (13%) and Bioterrorism (23%).

DISTRIBUTION OF DISCIPLINES IN RESEARCH SUBSECTORS

BREAKDOWN IN RESEARCH SUBSECTORS

Traditionally, the research sector under analysis is subdivided according to the category of production animals (Ruminants, Pigs, Poultry, Horses, Rabbits, Fish, Bee, etc…) or to the type of pathogenic agents (Bacteria, Viruses, Parasites, etc…). This division is generally perceived as relevant as it links research to specific field issues and problem-solving approaches. In addition, it is generally acknowledged that each of these research subsectors is associated with a specific body of knowledge and competencies, both contributing to structuring the scientific communities. The overall distribution of these subsectors in WoS-extracted research publications (Europe, 2006 to July 2009) is shown in Figure 8 for the main production animal categories.

Figure 8. Distribution of research subsectors as defined by animal categories and by type of pathogenic organisms, in publications extracted from the Web of Science in the sector of animal infectious diseases in Europe (2006-2009).

This figure provides an indicative estimate of the respective weight of major category of animals in publications from EU during the period surveyed, and, for each category of animals, of the share of each type of pathogenic organisms. These figures should however be interpreted with caution as many publications are associated with several categories of animals, especially those dealing with food safety or with the contamination of animal environment, notably aquatic. Moreover, query formulations were designed to open the selection to related families of wild animals, be it mammals, birds or fishes (queries can be accessed through the web interface of the EMIDA database [2]). This could explain for instance the relatively high number of publications recorded here for Fish and Shellfish with the WoS (22%).

We have used bibliographic coupling to examine whether this acknowledged research substructuring is in agreement with the so-called “cognitive structure” of the sector. The phrase “cognitive structure” refers to the fact that researchers sharing the same intellectual base in a given discipline tend to cite common references in their publications. This approach is based on the coupling of citing publications according to their shared citations and on the subsequent constitution of citing publication clusters [21-22] . To challenge the hypothesis that the proximity of citing publications, as defined above, is higher within than between research sub-sectors, we have examined in which subsector categories fall the publications included in a same cluster.

As a preliminary observation, there was a total of 409,568 cited papers, for 11,826 publications, i.e. 35 citations on average per publication. Of these cited papers, 31% were cited only once, and 28% were cited more than five times. The clustering process, which was performed retaining only those references cited at least 5 times, is summarized in Table 10.

Table 10. Bibliographic coupling and clustering of citing publications in the major sector of animal infectious diseases (2006 to July 2009 in Europe).

As expected, two criteria determined the number of clusters of citing publications: (i) the minimal number of references shared by any two citing publications and (ii) the minimal number of citing publications per cluster. In accordance with recommended methods, we selected clusters of publications with at least 5 references in common between any two publications, and grouping at least 6 publications. This process, which secured a high level of internal proximity within clusters, led to 131 clusters which were eventually analyzed for their specificity in terms of animal category and type of pathogenic organisms. The overall homogeneity of these clusters with regard to animal and pathogens categories is shown in Figure 9.

Figure 9. Categorization of clusters of publications based on their shared references.

A major observation is the high level of homogeneity within clusters, 61 % of them being related to a same animal category and 78% to a same type of pathogenic agent. This observation confirms on an objective basis the strong influence of these two factors on the cognitive structure of the research sector under analysis. It also shows that the fish subsector is highly independent from others. Whereas the share of publications on Fish is about half those on Ruminants (Figure 8), the percentage of Fish one-type clusters is close to that of Ruminants (22 and 26%). This observation means that in a context where the animal host is already a strong factor of cognitive structuring, the fish subsector constitutes a relatively independent entity with lower interaction with the other subsectors.

The pairwise proximity between these 12 subsectors was also measured by bibliographic coupling, retaining references cited at least five times. The resulting symmetrical matrix of Salton's cosines is shown (Table 11)

Table 11. Bibliographic coupling of the 12 major research subsectors as defined by the category of animals and the type of pathogenic agents: symmetrical matrix of Salton's cosines showing pairwise proximity.

Only 3 out of these 66 measures pass the threshold of 0.25 which is generally considered as expressing a significant strength of association in bibliographic coupling [21]. These highest values link subsectors with the same type of pathogenic organism, respectively PIG-BAC and POUL-BAC (0.333), PIG-PAR and RUM-PAR (0.331), PIG-BAC and RUM-BAC (0.281). To improve the representation of the mutual linkage of the 12 subsectors, a hierarchical clustering was performed using the above measures of proximity (Figure 10).

Figure 10. Linkage of the 12 major research subsectors due to references shared by the corresponding publications

In spite of a globally low level of proximity between subsectors, the software algorithm proposes four separate clusters, i.e. from top to bottom of the diagram: **(I)** RUM-VIR, PIG-VIR, POUL-VIR; **(II)** FISH-BAC, FISH-PAR, FISH-VIR; **(III)** RUM-PAR, PIG-PAR, POUL-PAR; **(IV)** POUL-BAC, PIG-BAC, RUM-BAC. In other words, 3 clusters are centered on each of the three types of pathogenic agent and one of the animal type, namely: Fish.

In conclusion, bibliographic coupling first indicates that the 12 major research subsectors constitute cognitive structures that are weakly interconnected, and therefore appear as relatively separated entities. Also, the proximity between subsectors concerned with a type of pathogenic organisms (Bacteria, Viruses or Parasites) appears generally stronger than that concerned with a type of animals, at least for farm animals (Ruminants, Pigs, Poultry). For fish diseases, the animal notion appears to comparatively bear more specificity than the type of pathogenic organism. This analysis thus confirms the pertinence of the division into research subsectors based on their underlying cognitive structure. We have then examined if the weight and distribution of the disciplines inventoried in Part A of this study were comparable in these subsectors. This was applied to both JCR Subject Categories and lexical thematic clusters.

LINKAGE BETWEEN RESEARCH SUBSECTORS AND SUBJECT CATEGORIES (SC)

Being based on the classification of journals, SCs reflect the association with research disciplines but also with publishing practices of specialized research communities. Factorial correspondence analysis was carried out from data contained in two separate contingency tables: one with the 28 most represented SCs (as displayed in Table 2) versus the four categories of animal, and the other with the same 28 most represented SCs versus the three types of pathogenic agents. The scatterplots derived from these analyses are shown (Figure 11).

Figure 11. Scatterplot of correspondance analysis between JCR Subject Categories and animal hosts (top) or pathogen categories (bottom).

These scatterplots are meant to illustrate the distances of the categories in red (Pathogens on top panel and Animals on bottom panel) based on their relation with SCs. This representation in two-dimensions can be considered as accurate as the first two factors account for 76.8% (Animals), and 99,6% (Pathogens) of the total inertia, respectively. Such percentages were expected as the minimum number of categories in the original contingency tables was 4 and 3, respectively. The global observation is that both the Animal and Pathogen categories are well separated in terms of their SC attributes, in other words that SCs are not evenly distributed between them. To facilitate the interpretation of this scatterplot a table of measures of proximity (Salton's cosine measures) between SCs and research subsectors is also provided (Table 12)

Table 12 : Pairwise proximity between major JCR Subject Categories (SC) and research subsectors defined by the type of production animals or the type of pathogenic organisms

With regard to Animal categories (top panel), the less distant of them appear to be Pigs and Poultry. According to the position along the horizontal axis, Fish are clearly in opposition with the other categories (Figure 11). Several SCs are located in the central part of the scatterplot, displaying rather undifferentiated profile of distribution, e.g. Immunology (IMM), Microbiology (MIC), Biotechnology and Applied Microbiology (BAM), Multidisciplinary Sciences (MUS). This central position is in accordance with the similarity of their measures of proximity with animal categories (Table 12). In comparison, other SCs clearly fall into separate quadrants of the scatterplot, in conjunction with a particular animal category. For Ruminants: Agriculture, Dairy and Animal Science (ADA), Parasitology (PAR), Pathology (PAT), and Biophysics (BIP), the latter being probably due to biophysical studies on prion proteins. For Poultry, Entomology (ENT), probably in relation with insect transmitted arboviroses such as West-Nile; For Fish: Zoology (ZOO), and Environmental Sciences (ESC). Ecology (ECO) is more associated with Poultry and Fish than with the other animal categories. The SCs which are spotted close to Pigs (IDI, BRM, PEO, MRE) should not be interpreted as being specifically linked to this category of animals, as shown by measures of proximity (Table 12). They are in fact about equally distributed in Pigs, Ruminant and Poultry but being rare in Fish their location is slightly shifted leftward in the splot. Most of these patterns are related to underlying factors. For instance, the seemingly strong association between Ruminants and ADA is probably linked to the fact that a major production disease such as mastitis is frequently published in journals of this category.

When the pathogen category is considered (bottom panel), there is a remarkable contrast between Parasites and the two other Pathogen categories along the horizontal axis, and between Bacteria and Viruses along the vertical axis, leading to a good separation of the three categories. Some SCs are clearly grouped in the quadrant of a specific pathogen: for Parasites: Parasitology (PAR), Zoology (ZOO), Ecology (ECO), Entomology (ENT); for Bacteria: Microbiology (MIC), Food and Science Technology (FST), Agriculture, Dairy and Animal Science (ADA) and Toxicology (TOX); for Viruses: Virology (VIR), Pathology (PAT), Biochemical and Research Methods (BRM), Medecine Research and Experimental (MRE) and Cell Biology (CBE). All these observations are consistent with pairwise measures of proximity (Table 12). The other SCs are more or less grouped at the centre of gravity of the plot, indicating a more even distribution between Pathogen categories. Some of the observed relations were obviously expected and they at least validate the method of analysis. Others traits are more interesting to observe, for instance the relative separation of the category Parasites and its associated SCs, in relation with wildlife and zoology.

LINKAGE BETWEEN RESEARCH SUBSECTORS AND LEXICAL CLUSTERS

As reported in a previous section of this report, lexical clusters were designed to provide a categorization of generic research themes, applicable to practically all types of infectious diseases, and irrespective of the animal host. It was therefore particularly interesting to examine whether they were evenly distributed between animal or pathogen categories. As with SCs above, contingency tables were constructed and factorial correspondence analysis was carried out leading to the scatterplots shown in Figure 12.

Figure 12. Scatterplots of correspondance analysis between CAB descriptors thematic clusters and animal hosts (top) or pathogen categories (bottom).

Again these scatterplots constitute a fair description of the pattern of relations between categories, the two factors accounting for 87% of the inertia value for the Animal categories (top panel), and 100% of the Pathogen categories (bottom panel). The latter figure is not surprising as there are only three categories in the lower dimension of the contingency table. To interpret correctly the complex pattern of associations suggested by this scatterplot, a table of pairwise measures of proximities (Salton's cosine index) between lexical categories and subsectors is also provided (Table 13).

Table 13 : Pairwise proximity between lexical clusters describing research themes and research subsectors defined by the type of production animals or the type of pathogenic organisms

The left panel shows a clear opposition along the horizontal axis between Ruminants and the other Animal categories, an opposition accounted for by four research themes that are relatively more tightly associated with Ruminants (Figure 12): Epidemiology, Disease Control, Diagnostic and Disease Resistance. Along the vertical axis, there is clear contrast between Fish, on the one side, and Pigs & Poultry on the other. Research themes Vaccines and Food Safety fall in the same quadrant as Pigs and Poultry. More unexpected is the observation that research theme Immunity seems (i) more tightly related to the animal category Fish and (ii) relatively distant from the category Vaccine to which it is naturally associated in publications, as shown in Figure 7. The latter observation, would mean that the notion of Animal causes a separation between publications on immune mechanisms and on vaccines, a separation perceptible along the vertical axis of the scatterplot. This conclusion is consistent with the analysis of pairwise measure of proximity (Table 13) showing that in Fish, in contrast with all other species, there is a relative dissociation between Immunity, on the one side, and Vaccine, on the other.

The three Pathogen categories (bottom panel) form a large triangle, the summits of which are located in different quadrants of the scatterplot, which means that research themes are not evenly distributed within these categories. The most noticeable features are the association between Viroses and Vaccines, between Food safety and Bacteria, and between Parasitoses and Molecular Genetics. The latter observation should be put in relation with the large amount of publications concerned with the taxonomy and molecular characterization of parasites. Immunity, Diagnostic and Virulence are rather central to the three type of pathogens, whereas Disease Control is closer to Viroses, Epidemiology to Parasitoses and Disease Resistance to Bacterioses.

EVOLUTION OF RESEARCH SUBSECTORS IN THE LAST TEN YEARS

The quantitative evolution of research output from 2000 onward was examined, with a view to detecting possible disparities between the different research subsectors that were analysed in previous section of this report. This survey was carried out directly on the WoS platform using the same disease queries as those used to extract publication records. The same queries were applied to publications issued in 1998 and in 2008, respectively. The results were classified according to the nature of the pathogenic agent and additional subcategories were created for group of agents of primary importance such as prions or major zoonotic bacteria or viruses (Figure 13).

Figure 13. Yearly evolution of research output in different subsectors at world scale from 2000 to 2009.

There appears to be a marked disparity between animal categories. The global increase of research output during this period of 10 years was estimated to be 198% for poultry, 180% for Fish, 170 % for Pigs, and 140 % for Ruminants. In ruminants, poultry and pigs, zoonotic diseases show the largest increase, due to zoonotic bacteria: 165% for ruminants (Salmonella and enterohemorrhagic E. coli); 178 % for poultry (Salmonella and Campylobacter) and to zoonotic viruses, with a sharp increase in pigs (450%) and poultry (643%) (due to Influenza in both species and, to a less extent, to West-Nile Fever in Poultry). It should be noted that the global share of publication on major zoonotic agents amounts to about 17% of total publications in Ruminants and Pigs and to 35% in Poultry. The number of publications on protozoan parasites appear to have declined in Ruminants, Poultry and Fish in the recent years. Such a decrease is also observable for prions in ruminants, this after an initial 200% increase from 2000 to 2007. In spite of these specific changes which appear to be related to emerging epidemics and societal needs, the overall picture is that of a relative stability in the respective share of research subsectors over time.

SYNTHESIS AND CONCLUSION

SYNTHESIS ON DISCIPLINES DESCRIPTORS

The main objective of this study was to document and analyze the interplay of disciplines and generic research themes in the field of infectious diseases of production animals. To this end, three types of bibliometric descriptors were used concurrently and compared: the JCR Subject Categories (SC), the CABICODES (CC) and lexical categories defined by clusters of descriptors (LEX). It is recalled that these descriptors do not have the same foundation and henceforth do not cover exactly the same notions even when their heading happens to be very similar:

- SCs qualify the journals in which research articles are published and they address all fields of science; their structure being more horizontal than hierarchical;
- CCs are assigned for each article individually by CAB specialists and they are specialized in agronomical sciences and public health. Their structure is hierarchical;
- Lexical clusters (LEX) are designed to cover research theme transversal to all infectious diseases. They are assigned individually to publications on the basis of specific descriptors appearing in the list of keywords. They have been designed to describe complementary fields, and their structure is therefore vertical.

The categories defined by these three types of descriptors are therefore different according to both the principle of their construction and the perimeter that they target. Each type of descriptor thus possesses an internal relevance that can be used to compare different research entities (countries, research sectors, research organizations, research teams, individual researchers), or to carry out time trends studies. The conclusions derived from comparisons using one type of descriptor are valid and interpretable inasmuch as data have been processed correctly. In spite of this heterogeneity between descriptors, some of them describe analogous notions and it was important, firstly, to measure their linkage as applied to a set of publications, and, secondly, to check quantitatively if their coverage was comparable in terms of publications spotted. The integration of results obtained with different types of descriptors is therefore a major component of the discussion below.

As regards linkage of descriptors of different types, there is a good overall agreement between those that obviously refer to the same notion. This is illustrated in factorial correspondence scatterplots (Figures 3 and 4 for SCs *versus* CCs and in Figure 7 for CC *versus* LEX), and confirmed pairwise by the Salton's cosine measure of affinity. More unexpected is the closeness of categories covering distinct notions such as Parasitology, Wildlife and Taxonomy/Evolution (Figure 3 and Figure 7), which may illustrate the existence of a transdisciplinary cluster focused on the biodiversity of parasites of wildlife animals.

The proximity between two descriptors of different types does not mean of course that their coverage is identical. This is illustrated in Table 14 in which CC and LEX descriptors are grouped according to subject areas and applied to the same set of publication records.

Table 14. Synthesis on major descriptors from Subject Categories (SC), Cabicodes (CC) and lexical clusters (LEX).

There seems to be a good agreement in the coverage of SC, CC and LEX descriptors describing for instance Immunity (10 to 14% of records) or Genetic resistance to disease (5-6%). But the comparison is more difficult to do for such notions as food safety, which is based for LEX on a defined set of keywords (shown in Figure 5) and for CC on the CC QQ200 (Food contamination, residues and toxicology) and on two CCs describing public health issues (VV210 and VV220). In the same way, a major discipline like parasitology is estimated at 10% with SC and to 19% with CC, probably because the latter index included also insect disease vectors.

This comparison of descriptors shows that (i) no one type of descriptors is able to fully describe the sector under study according to different angles and (ii) that descriptors describing the same subject area, although closely linked, do not exactly identify the same perimeters of publications. The major advantage of a lexical scheme is that it relies on defined descriptors and keywords present in individual publications. Being tailored to a defined categorization, it can be made both homogeneous and reasonably exhaustive with regard to the objectives of this categorization, a property which neither SC nor CC has. The validation of such a scheme can of course include the study of linkage with related SCs or CCs, SC remaining the universal reference. The respective weight and the connection of the nine categories defined by the present lexical scheme, derived from detailed data displayed in Table 7, are summarized in the illustration below where the relative size and and the proximity of categories is respected. Whichever the scheme of categorization, it remains again relatively reliable to compare entities such as research sector, countries, organizations, or to perform time-trend studies.

APPLICATION OF CATEGORIZATION SCHEMES TO RESEARCH SUBSECTORS

In this study, we applied both the SC and the lexical schemes of discipline categorization to research subsectors defined by either the type of production animals, restricted to the major ones (Ruminants, Pigs, Poultry, Fish) or the type of pathogenic organisms (Bacteria, Viruses, Parasites). The perimeter of these subsectors has been defined on the basis of the descriptors used in queries. This option, which amounts to taking into account all the words present in publication records (including title and summary), could have broadened the dimension of each subsector as compared to a procedure restricted to specific descriptor fields (DE and ID in WoS records). In fact only about 2 % of publications fall in at least two different categories of animals, and 3% in at least two pathogen categories, which means that this partition defines well separated and complementary entities.

Bibliographic coupling showed on an objective basis that this double division also adequately reflects the cognitive structure of the whole research sector. Proximity within a same type of pathogen discipline was shown to be higher than within a same type of animals, except for Fish (Figure 10). A finer analysis of the scientific content of publications in clusters of bibliographic coupling (not reported here) shows that proximity often rests on the family or even the species of the pathogenic agents themselves, which means that recognition between research communities in this sector is highly specialized and therefore rather restricted in scope.

The overall distribution of SCs and lexical themes confirm the distance between Fish and the other Animal groups (Figures 12 & 13). But specificities were also observed for the other categories of animals as well as shown in the table below for SCs:

ANIMALS

RUMINANTS	Agriculture, Dairy and Animal Science (ADA), Pathology (PAT), Parasitology (PAR), Biophysics (BIP)
PIGS	………………………………………
POULTRY	Ecology (ECO), Zoology (ZOO), Entomology (ENT)
FISH	Fisheries (FIS), Marine and Freshwater Biology (MFW), Microbiology (MIC), Zoology (ZOO), Ecology (ECO)

PATHOGENIC ORGANISMS

BACTERIOSES	Microbiology (MIC), Food and Science Technology (FST), Agriculture, Dairy and Animal Science (ADA), Toxicology (Tox),
VIROSES	Virology (VIR), Medecine, Research & Experimental (MRE), Multidisciplinary Sciences (MUS)
PARASITOSES	Parasitology (PAR), Ecology (ECO), Zoology (ZOO)

For lexical themes, these could be expressed in terms of relative proximity, for instance Food safety and Vaccines for Poultry, Epidemiology, Diagnostic and Disease Resistance for Ruminants. As regards subsectors based on pathogenic organisms, there is a relative closer proximity between Food Safety and Bacteria, Viroses and Vaccines, and between Parasites and Microbial Genetics. The underlying patterns accounting for this uneven repartition of some disciplines and generic research themes in research subsectors would be interesting to analyse in-depths, at the level of research subject.

APPLICATION TO TEMPORAL EVOLUTION

In the present study, time trends analyses over the last ten years were carried out with three different descriptors: (i) classical discipline categories, such as mapped by SCs

(Table 4), (ii) emerging disciplines and subject categories (Tables 8 & 9), and (iii) types of diseases within each animal group (Figure 13). These three analyses needed a direct interrogation of the WoS platform database with *ad hoc* queries. The overall decennial increase of publications (from 1999 to 2008) was estimated at about 160% worldwide.

Regarding SCs, an increase of about 2% of publications in SCS related to food safety and public health is perceptible with a concomitant decrease of the same order of magnitude in the share of publications in the SCs Parasitology and Virology. Also the share of publications in journals belonging to the category Veterinary Sciences has decreased by about 5% (Table 4). These trends corroborate the significant shift of research programmes toward pathogenic agents of veterinary public health importance, particularly bacteria responsible for foodborne zoonoses, but also prions and Influenza. This is fully confirmed by the evolution of disease types in each animal category (Figure 13). The decennial increase is the highest for poultry diseases (198% as compared to 140% for ruminant diseases) due to the surge of publications on foodborne bacterial agents (mostly Salmonella and Campylobacter) and in the more recent period on viruses like Influenza and West-Nile. For all animal groups but pigs there is a comparatively higher increase of the share of publications dedicated to bacteria. In fish, this increase would deserve an in-depth analysis to examine the respective contribution of environmental versus food safety issues. A concern that would also need a closer attention is the consequence over the long term on concentrating competencies and research funds on a small number of diseases of veterinary public health importance without considering the risk of losing expertise on other diseases, as might be currently the case for diseases of poultry.

The concept of emergence, generally applied to new diseases in this research sector, was applied here to disciplines and cutting-edge issues. They were separated in two groups, those common to all biological sciences (Table 8) and those specific to medical and agronomic sciences (Table 9). In the field of animal infectious diseases, publications using bioinformatics and associated "omics" have increased by a factor 160 against 40 for the general background, which shows that these new scientific approaches has been efficiently adopted by the research sector, and particularly in Europe. By comparison, the modest doubling of publications related to cell biology may indicate that cellular microbiology, a new transdiscipline aiming at elucidating how pathogenic organisms exploit the biology of the host cells, is not sufficiently developed. This hypothesis should be examined further by experts. Among the agronomic and medical subject areas examined, there was a marked increase above the average for such themes as Mucosal Immunity (x 8.4), Organic farming (x 6.2), Biotherapeutics and alternative to antibiotics (x 4.4) Animal Health Economics (x 4.4), Ecological Health (x4), and Animal Welfare (x4). The apparent lack of sharp increase in essential emerging issues as vectorial diseases (x 2.3) may be of concern. In all these emerging and cross-cutting issues the share of Europe is generally well above its average share (30 to 35%).

INTER-AND TRANS- DISCIPLINARITY

As confirmed on an objective basis in this study, research on animal infectious diseases is at the cross-road of numerous disciplines and subject areas, being concerned with at least three major sectors of science: infectious diseases, animal sciences and wildlife and ecosystems (cf. schema on page 8). By depicting how different disciplines are associated in a given research sector or a specific body of knowledge, bibliometrical descriptors do provide some measurement of the interplay of disciplines. Applied to a large research sector as the present one, the resulting picture is however akin to a mosaic where the respective weight and degree of linkage of categories is assessed, but where one may miss the dynamic aspect of discipline integration, in particular the progressive forging of new concepts leading from interdisciplinarity to transdisciplinarity [33]. Bibliometrical descriptors are probably more adapted to evaluate interdisciplinarity in smaller well defined entities such as a researcher, a research team, a laboratory, a research project.

One specific endeavour to capture the notion interdisciplinarity in a dynamic way was to compare the distribution of SCs in primary publications and in cited papers. This was at least a way to identifying the basic and methodological disciplines to which papers (representing the core disciplines) refer more frequently. By far, cited references more often relate to basic and support disciplines (Biochemistry and Molecular Biology, Medecine, General & Internal, Cell Biology, Genetics & Heredity, Statistics & Probability, Evolutionary Biology, etc...) than to other applied disciplines in animal sciences. This would mean that the cognitive structure of the research subsector is essentially based on basic disciplines in biology and medicine.

If bibliometrical mapping can hardly qualify the exact nature of the link between disciplines when applied to a large research sector (multi-, inter- or trans-disciplinarity), it is nonetheless possible to spot papers associating two major disciplines whose alliance is recognized as leading to a real integration of scientific concepts and knowledge. In the sector of infectious diseases of animals, this can be exemplified by two research areas: animal genetic resistance to disease [13] and ecological health [8], for which data have been collected in the present study. Animal Genetic resistance to disease account for about 6 % of the papers extracted from the CAB in this study (Table 7), a figure which should be put in relation with the expectations on the selection of animals with desirable health traits. The weight of papers on Ecological Health could not be directly estimated in this study but wild animals (mammals, birds and fishes) were present in the "host component" of the search queries used to extract publication records. It is therefore possible to appraise this component using the CABICODE YY700 (Pathogens, Parasites and Infectious Diseases of Wild animals). The percentage of papers associated with this category (in Europe) amounts to about 11% (Table 6).

Ecological health is itself generally integrated to a wider concept, called "One Health" that seeks to integrate human and animal health systems in order to improve the detection and control of zoonoses [9]. The "One health" concept is viewed by its promoters as an operational driver to improve cooperation, communication and education in the medical and veterinary sciences, including interdisciplinary research. One should not forget however that zoonotic agents account for about 20% of publications on infectious diseases of animals, which means that 80% of them deal with purely veterinary diseases. For those diseases the priority is probably to improve connection with animal sciences, including nutrition, reproduction, physiology, housing and welfare. Other areas of interdisciplinarity would also deserve to be examined closely, in particular host-pathogen interactions, a fast moving and multifaceted research front that, in which requires various competences on both the pathogenic agents and the animal host, not only on immunological mechanisms but also different aspects of the biology of the animal host.

RESEARCH MAPPING AND RESEARCH PROGRAMMING

Bibliometrics provides reliable indicators to map science, either at a global scale or as applied to specific research sectors. Whatever the grain of the analysis, the information provided is quantitative and comparative, the comparisons including the weight of disciplines and research themes, their distributions into different subsectors, their temporal evolution etc. They are however basically descriptive and exploratory, allowing to detect patterns and linkages between factors, to confirm on an objective basis intuitions of specialists, and to uncover possible unanticipated facts. How can these results be incorporated in the decision process aimed at defining research policy and programme priorities? Research mapping can primarily contribute to improving the quality of the background information available to programme funders and experts. Provided that the grain of analysis is fine enough, these studies can also bring forward specific issues to be discussed by experts, in particular on possible gaps in research.

The notion of gaps in research cannot obviously be addressed on the sole evidence given by bibliometrical indicators, however accurate and reliable they may be. By essence, the notion of gap is not an absolute one: it refers to some ideal pattern, or to pre-set objectives. For instance in animal health research, one cannot found a gap analysis on the mere comparison of research output between countries, without proper reference to national specificities (disease status, existence of a disease prioritization scheme, etc…). Also, the method of gap analysis is closely dependent on the type of entities examined. For instance, specific approaches are necessary to handle such different issues as the lack of knowledge on a specific disease or the improper balance of disciplines in a research sector. In any case, the identification of gaps, but also of opportunities, requires a close co-operation between specialists and programme funders, in order to critically review all the relevant pieces of evidence (among which bibliometrical mapping such as provided by the present study) and setting up priorities accordingly. In the context of the Era-Net EMIDA, this role is assigned to the Foresight and Programming Unit (FPU) in charge of the establishment of a common strategic agenda. It is hoped this bibliometrical analysis on disciplines, together with the previous EMIDA report on the place of Europe in the world research landscape [1] will contribute to supporting the expert consultation process in FPU.

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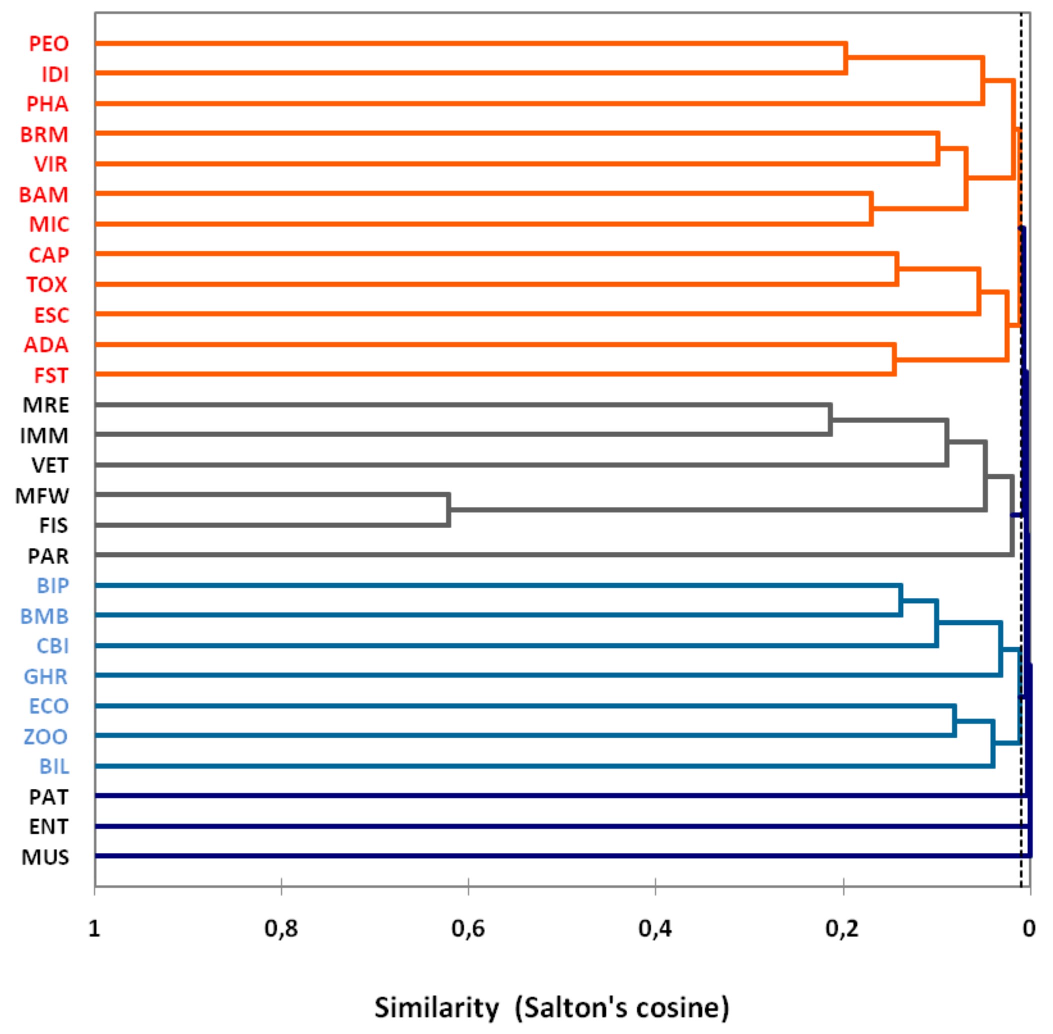
FIGURES

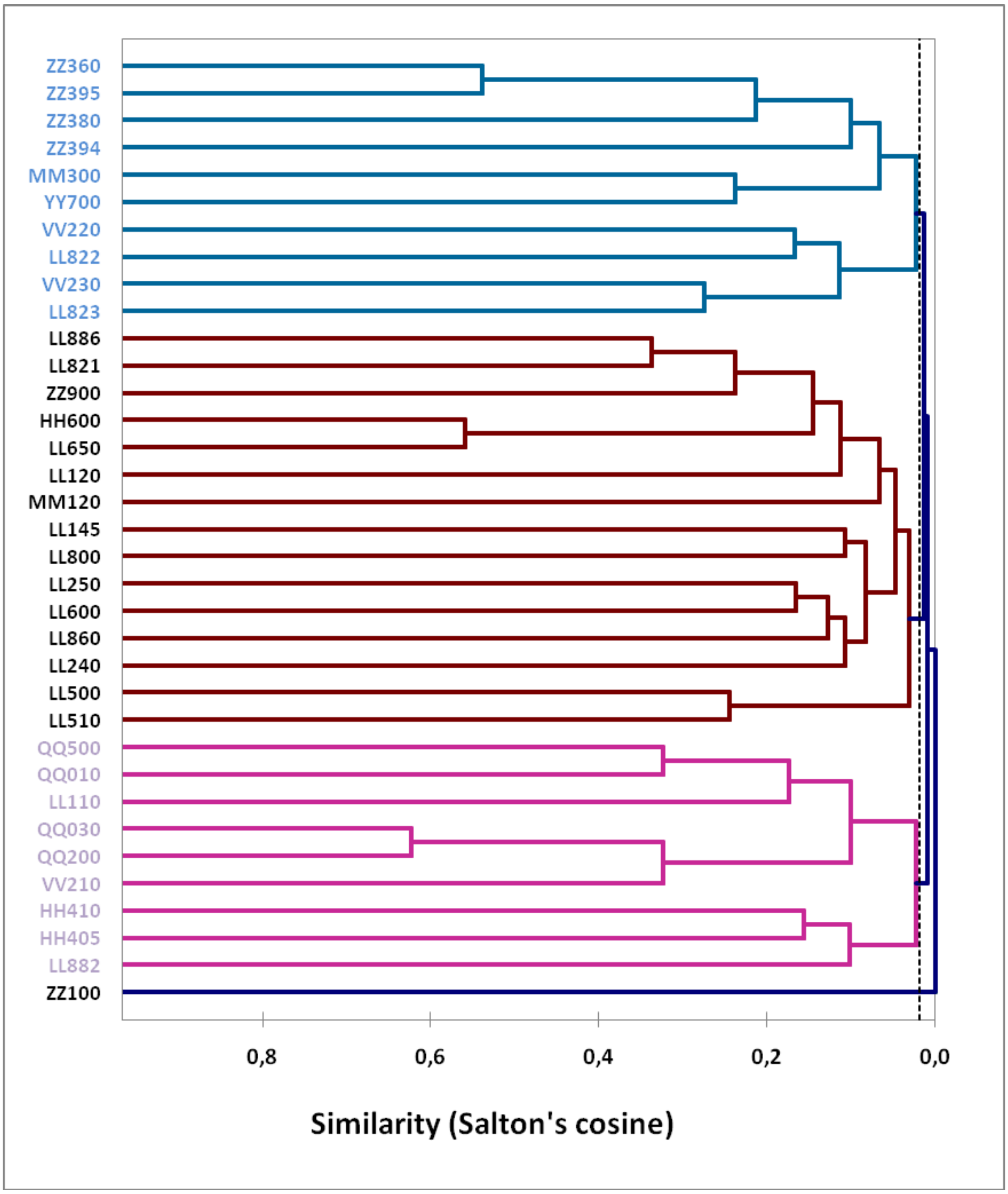
FIGURE 1. Linkage of JCR Subject Categories (SC) due to multi-assignation of journals.

Dendrogram obtained with Johnson's hierarchical clustering (weighted average) on matrix of proximity measures (Salton's cosine) between each pair of the 28 most frequent categories in the field of animal infectious diseases (XLSTAT Software). SC in abbreviated form on the left (full name of acronyms in alphabetical order pp 12-14). Levels of similarity measures are shown (linear scale). SCs are grouped in three main classes represented by different colours.



<u>FIGURE 2</u>. Linkage of CABICODES (CC) due to multi-assignation of publications.

Dendrogram obtained with Johnson's hierarchical clustering on proximity matrix of similarities measures (Salton's cosine) between each pair of the 35 most frequent categories in the field of animal infectious diseases (XLSTAT Software). CC in abbreviated form on the left (full name of acronyms in alphabetical order pp 12-14). Levels of similarity (linear scale) are shown. The 3 major clusters are identified by different colours.



<u>FIGURE 3</u>. Two-dimension scatterplot of correspondence analysis between JCR Subject Categories (SC) and CABICODES (CC).

Distances between pairs of variables were measured by the Khi-square measures from a SC x CC contingency table including the 18 most frequent SCs (red) and 45 most frequent CCs (blue). Distances were submitted to factorial correspondence analysis (Ucinet software). Full name of acronyms in alphabetical order pp 12-14. Contribution of factors 1 and 2 to total inertia= 59 %.

Five "outlying" CC clusters are observable, broadly covering the following notions: (i) Food safety, (ii) Immunology, (iii) Fish diseases, (iv) Parasitology and (v) Wild animals. In each cluster, proximity between CCs and related SCs is observed.

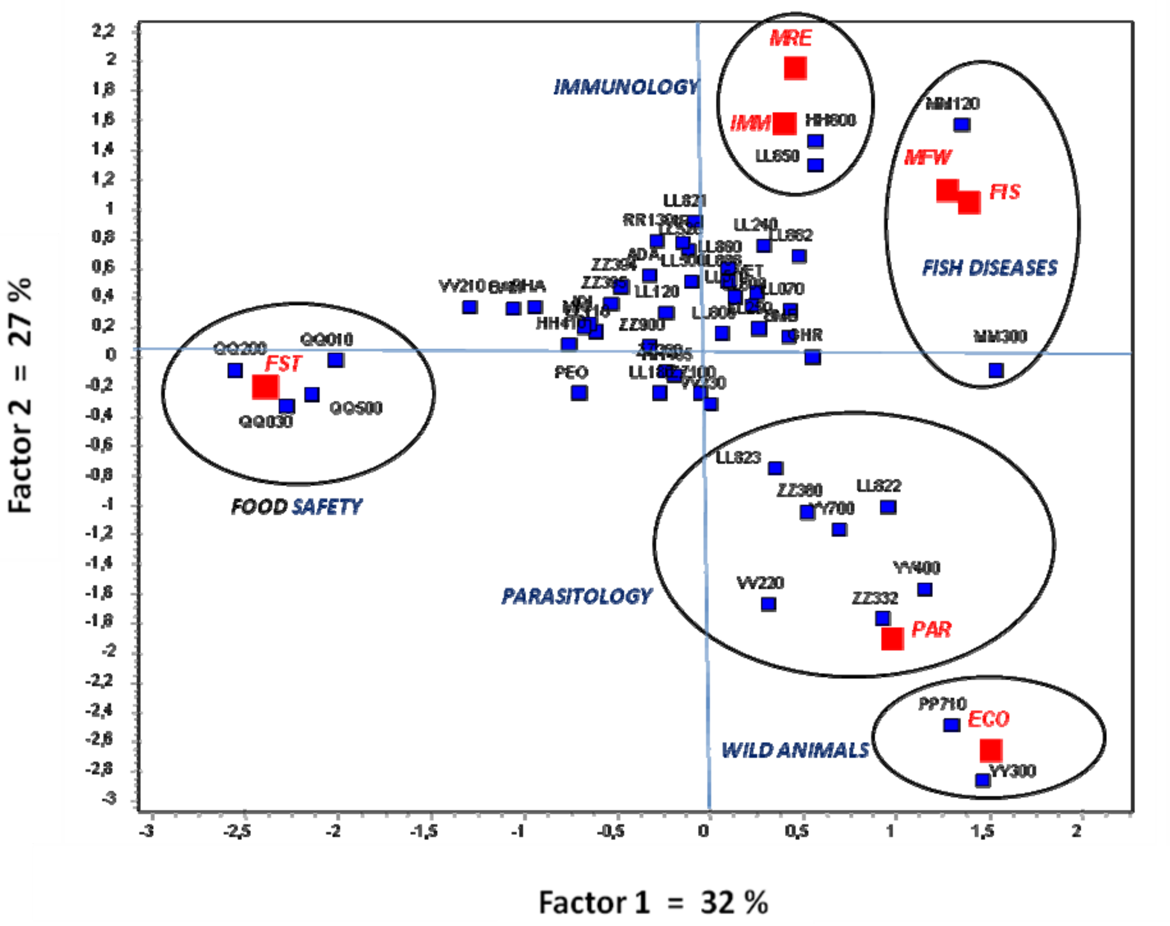
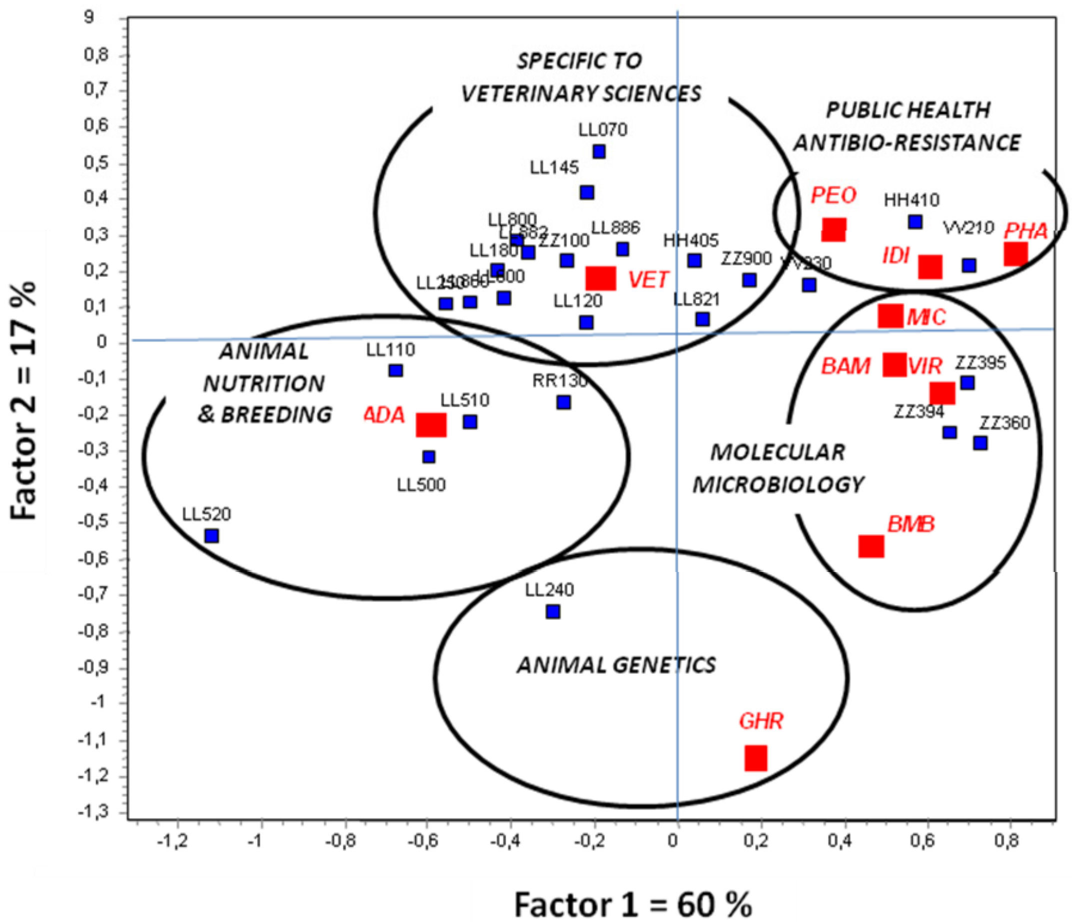


FIGURE 4 . Two-dimension scatterplot of correspondence analysis restricted to the central SC and CC categories of Figure 3 scatterplot.

Distances between pairs of variables were measured by the Khi-square from a SC x CC contingency table including the central categories displayed in Figure 3. Distances were submitted to factorial correspondence analysis (Ucinet software). Full name of acronyms in alphabetical order pp 12-14. CC in blue, SC in red. Contribution of factors 1 and 2 factors to total inertia = 77% with 60% for factor 1.

Four CC clusters are observable, covering the following notions: (1) Public Health including antibioresistance, (2) Molecular microbiology involving both viruses and bacteria, (3) animal genetics, and (4) Animal nutrition and breeding. The remaining CCs are aggregated with the SC "Veterinary Sciences". In each cluster, proximity between CCs and related SCs is observed.



<u>Figure 5.</u> Scatterplot of correspondence analysis between specific CAB descriptors selected for their ability to describe nine research themes in the field of animal health infectious diseases.

Distances between pairs of variables were measured by the Khi-square from a 9 by 109 contingency table with the 9 research themes and 109 selected descriptors. Distances were submitted to factorial correspondence analysis (Ucinet software). Contribution of factors 1 and 2 factors to total inertia = 37%. Three clusters are clearly distinguishable on the scatterplot, namely: (i) MICROBIAL GENETICS, (ii) DISEASE RESISTANCE, and (ii) FOOD SAFETY. The undistinguishable internal categories were submitted to a further analysis (cf. Figure 6)

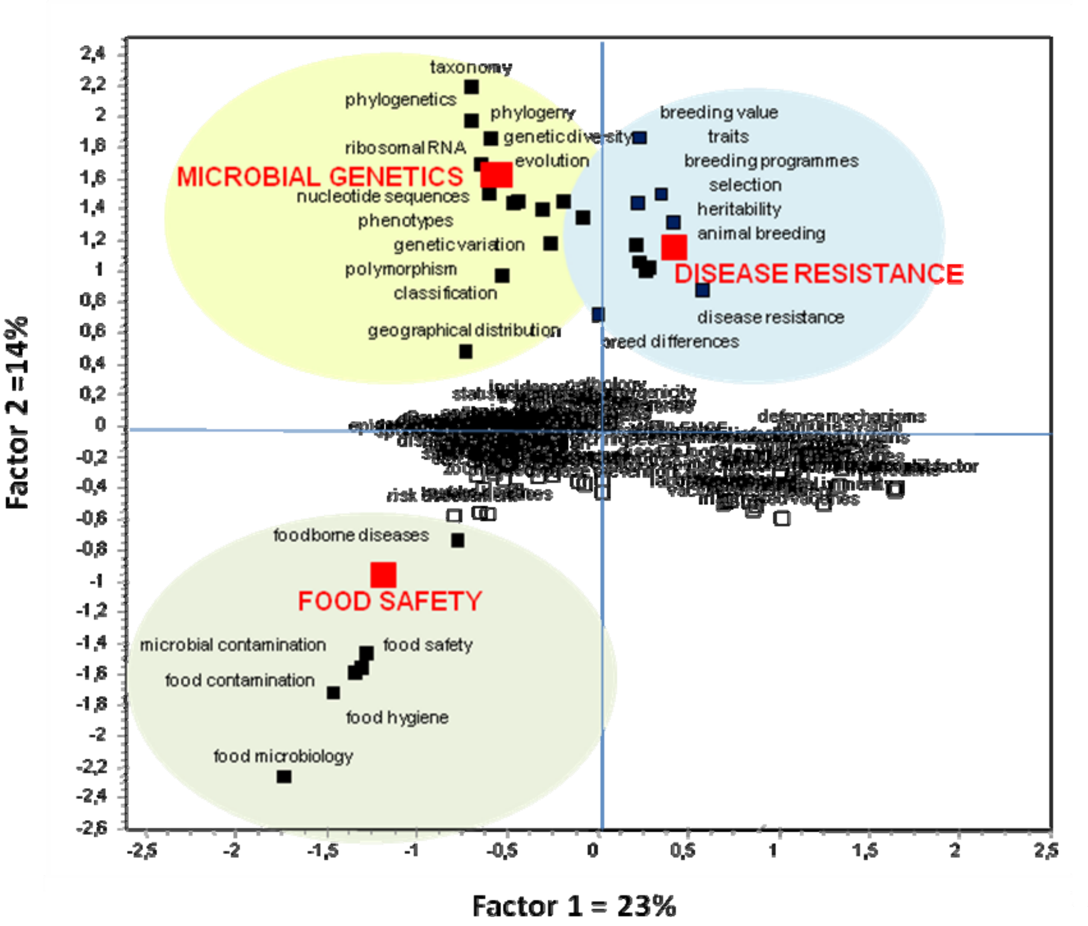
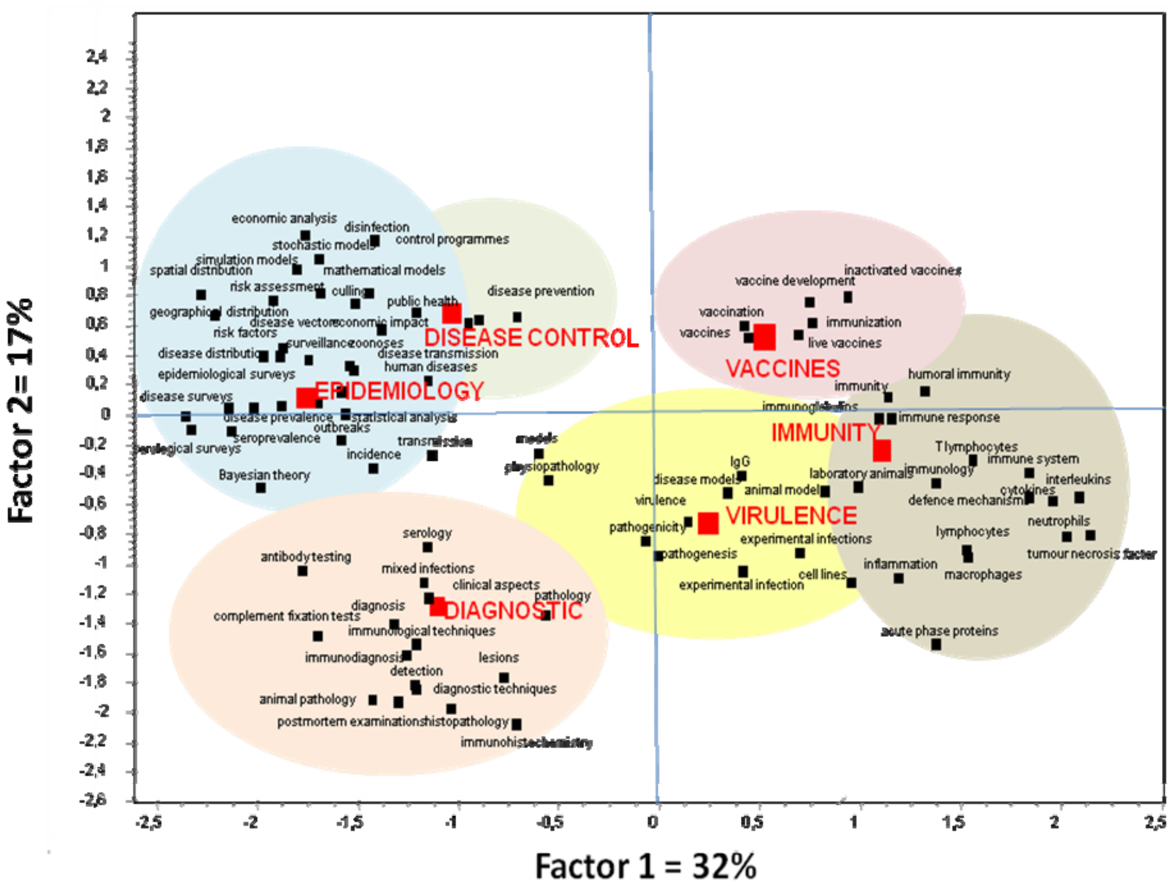


FIGURE 6. Scatterplot of correspondence analysis of CAB descriptors describing research themes without the outlying clusters of Figure 5.

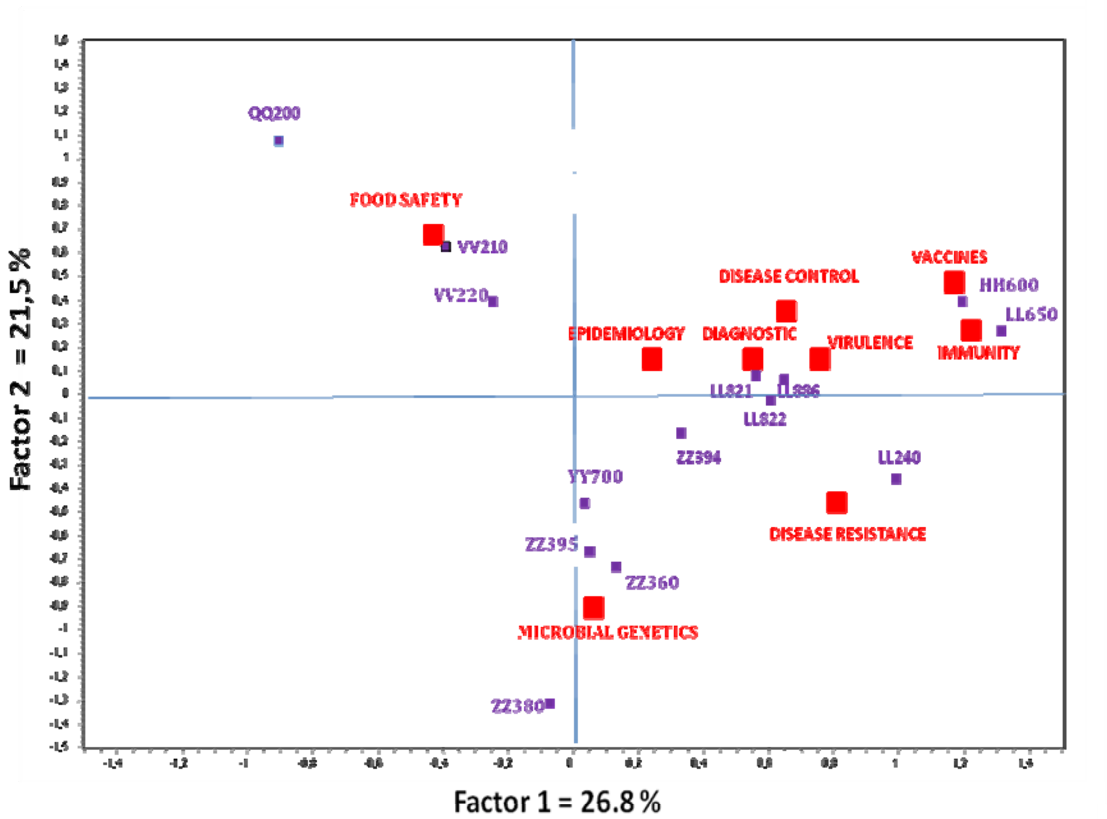
The distance between variables was measured from a two-way contingency table (88 descriptors x 6 research themes). The six clusters are tentatively visualized by different colours although limits remain blurred: (i) EPIDEMIOLOGY and (ii) DISEASE CONTROL, predictably proximal to each other, (iii) VACCINES, (iv) IMMUNITY and (v) VIRULENCE, also interconnected, and (vi) DIAGNOSTIC.



<u>FIGURE 7.</u> Scatterplot of correspondence analysis between lexical thematic clusters and selected CABICODES

The distance between variables was measures by the Khi-square from a 9 x 14 contingency table including 14 CABICODES (CC) versus the 9 lexical thematic clusters. CC in blue. Lexical clusters in red.

CC full names (also see Table 6): **LL821**: PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF ANIMALS; **LL822**= PROTOZOAN, HELMINTH, MOLLUSC AND ARTHROPOD PARASITES OF ANIMALS; **LL886**= DIAGNOSIS OF ANIMAL DISEASES; **LL650**= ANIMAL IMMUNOLOGY; **LL240**= ANIMAL GENETICS AND BREEDING; **QQ200**=FOOD CONTAMINATION, RESIDUES & TOXICOLOGY; **VV210**= PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF HUMANS; **VV220**= PROTOZOAN, HELMINTH AND ARTHROPOD PARASITES OF HUMANS; **ZZ395=** GENETICS AND MOLECULAR GENETICS OF MICROORGANISMS; **HH600**= HOST RESISTANCE AND IMMUNITY; **ZZ360** = GENERAL MOLECULAR BIOLOGY; **ZZ394=** BIOCHEMISTRY AND PHYSIOLOGY OF MICROORGANISMS; **ZZ380**= TAXONOMY AND EVOLUTION; **YY700** = PATHOGENS, PARASITES AND INFECTIOUS DISEASES (WILD ANIMALS);



<u>FIGURE 8</u>. Distribution of major research subsectors as defined by animal categories and by type of pathogenic organisms, in publications extracted from the Web of Science in the sector of animal infectious diseases in Europe (2006-2009).

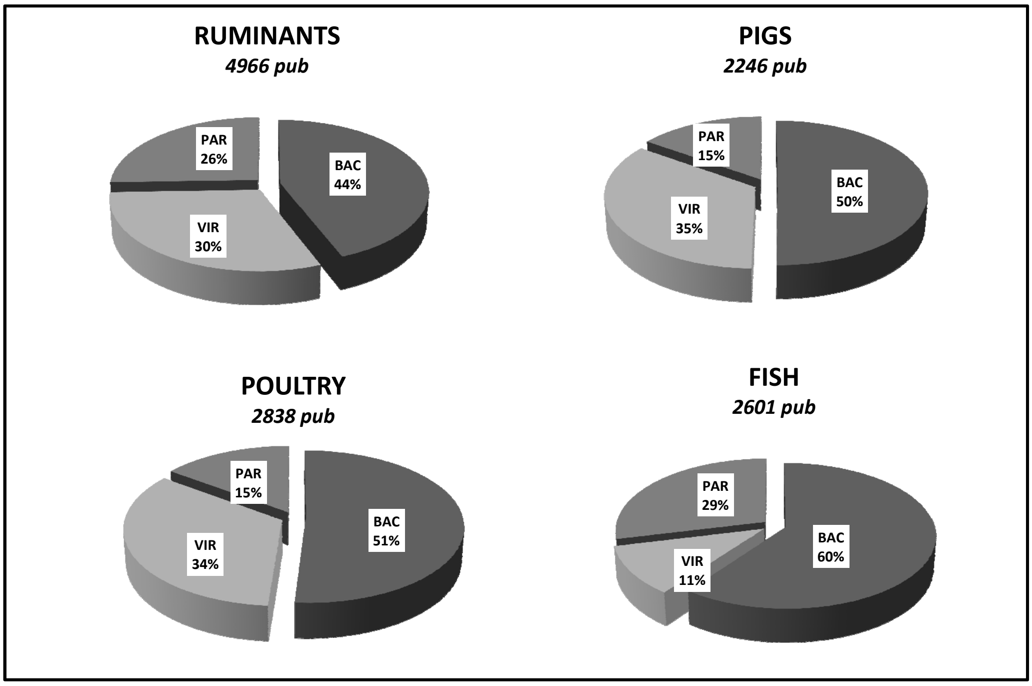
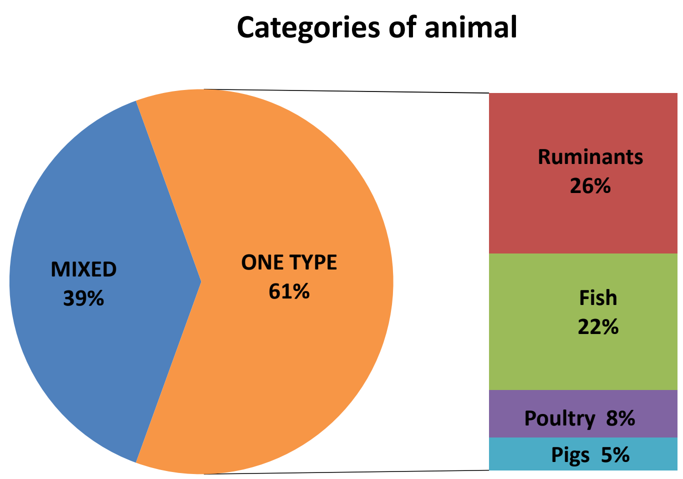


FIGURE 9. Categorization of clusters of citing publications based on their shared references.

Publications within the 131 selected clusters were classified according to the categories of animals and to the type of pathogenic organisms to which they were related. “One type” refers to clusters with publications all related to a single category and “mixed” to those where several categories were represented.



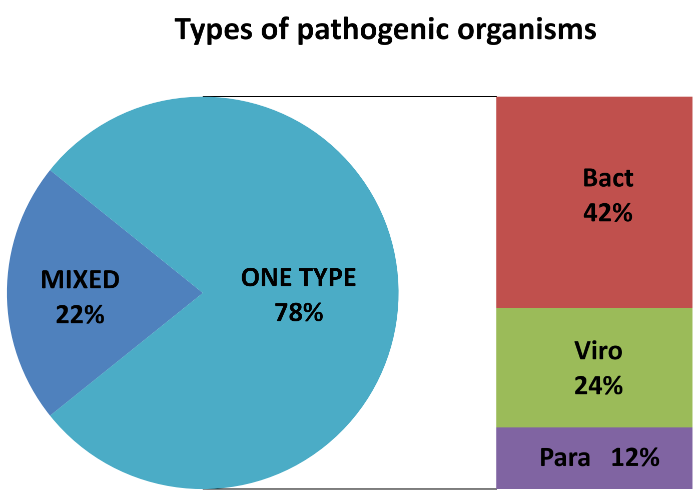


FIGURE 10. Linkage of the 12 major research subsectors due to references shared by the corresponding publications.

Dendrogram obtained with Johnson' hierarchical clustering on proximity matrix of similarity measures (Salton's cosine) as displayed in Table 11 (method of weighted average, XLSTAT software). Animal host categories: Fish (FISH), Pig (PIG), Poultry (POUL), Ruminants (RUM). Pathogenic agents categories: Bacteria (BAC), Viruses (VIR).Parasites (PAR).

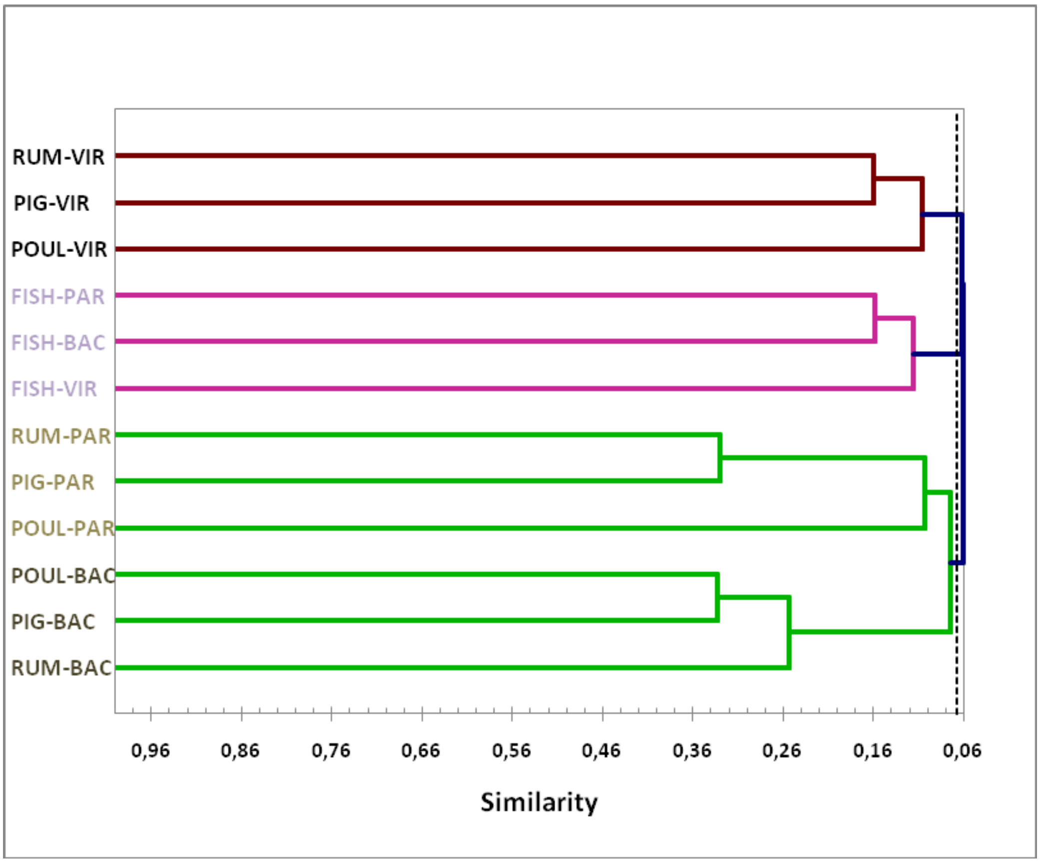
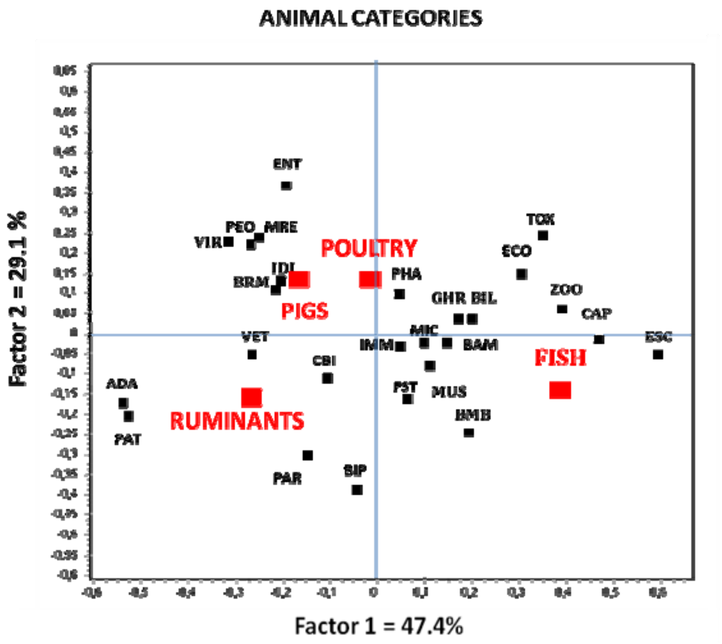


FIGURE 11. Scatterplot of correspondance analysis between JCR Subject Categories and animal hosts (top) or pathogen categories (bottom).

The distance between variables was measured by the Khi-square from contingency tables including for one dimension the 28 most represented SCs and for the other dimension either the four animal categories (Top) (4X28 contingency table) or the three major types of pathogens (Bottom) (3x28 contingency table). Ucinet software. Full name of acronyms in alphabetical order appear pp 12-14. MFW and FIS have been omitted, as they are exclusively associated with Fish.



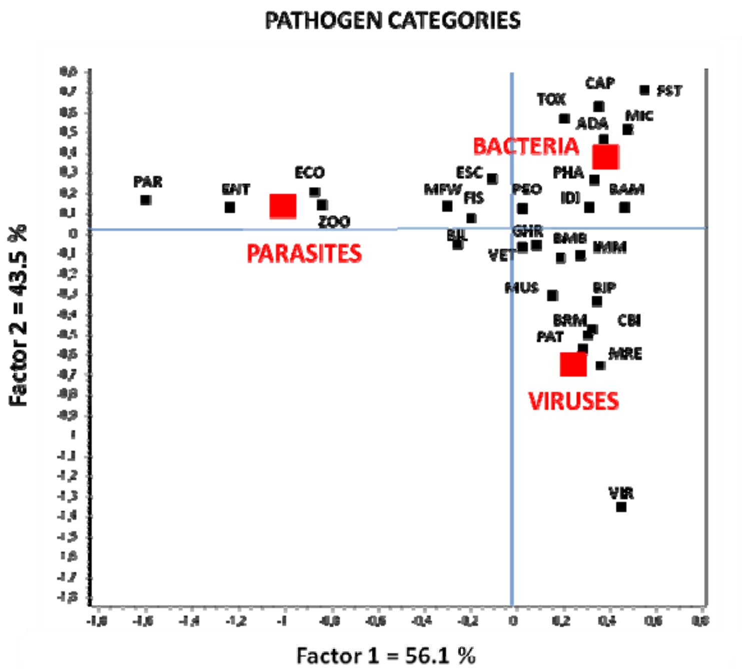


FIGURE 12. Scatterplot of correspondance analysis between CAB descriptors thematic clusters and animal hosts (top) or pathogen categories (bottom).

The distance between variables was measured by the Khi-square from a contingency table including the 9 thematic clusters versus the four animal categories (top) (4X9 contingency table) or versus the three major types of pathogens (left) (3X9 contingency table). Ucinet software.

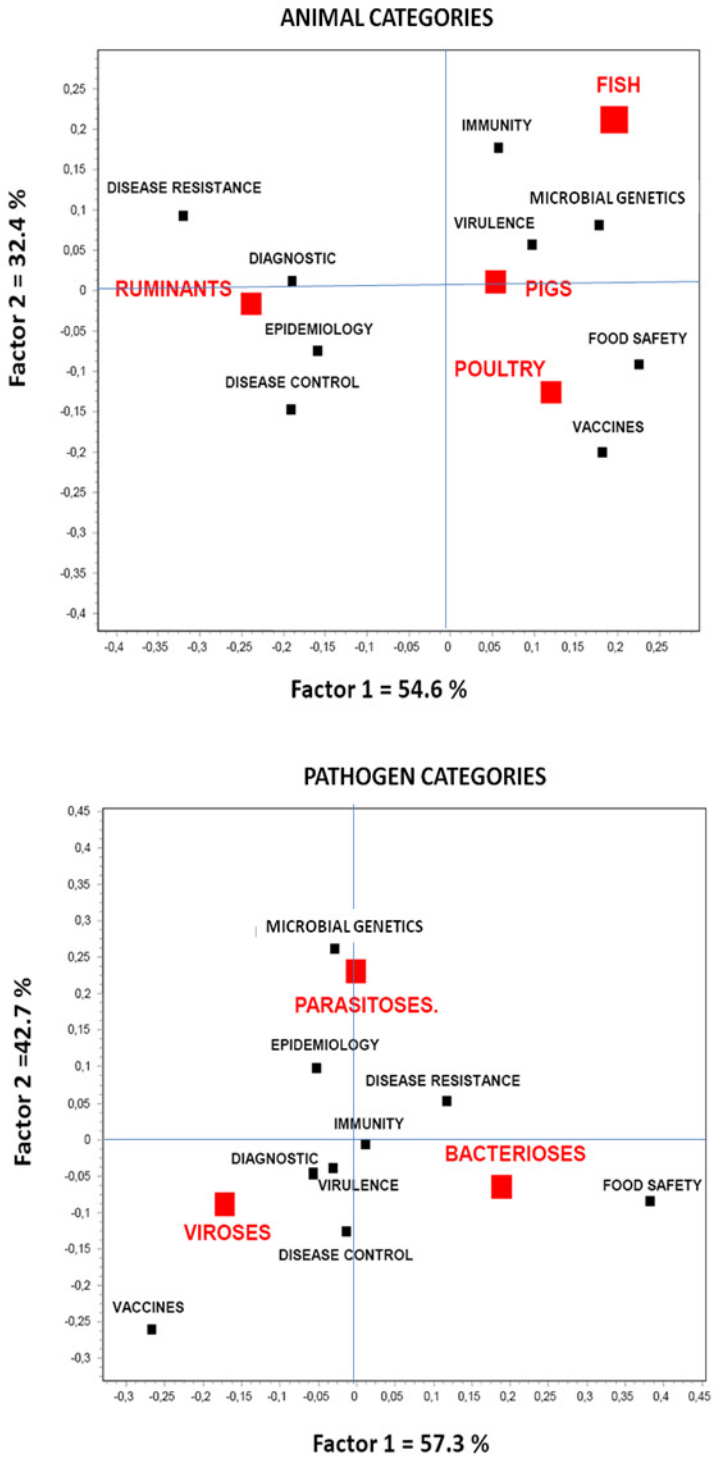
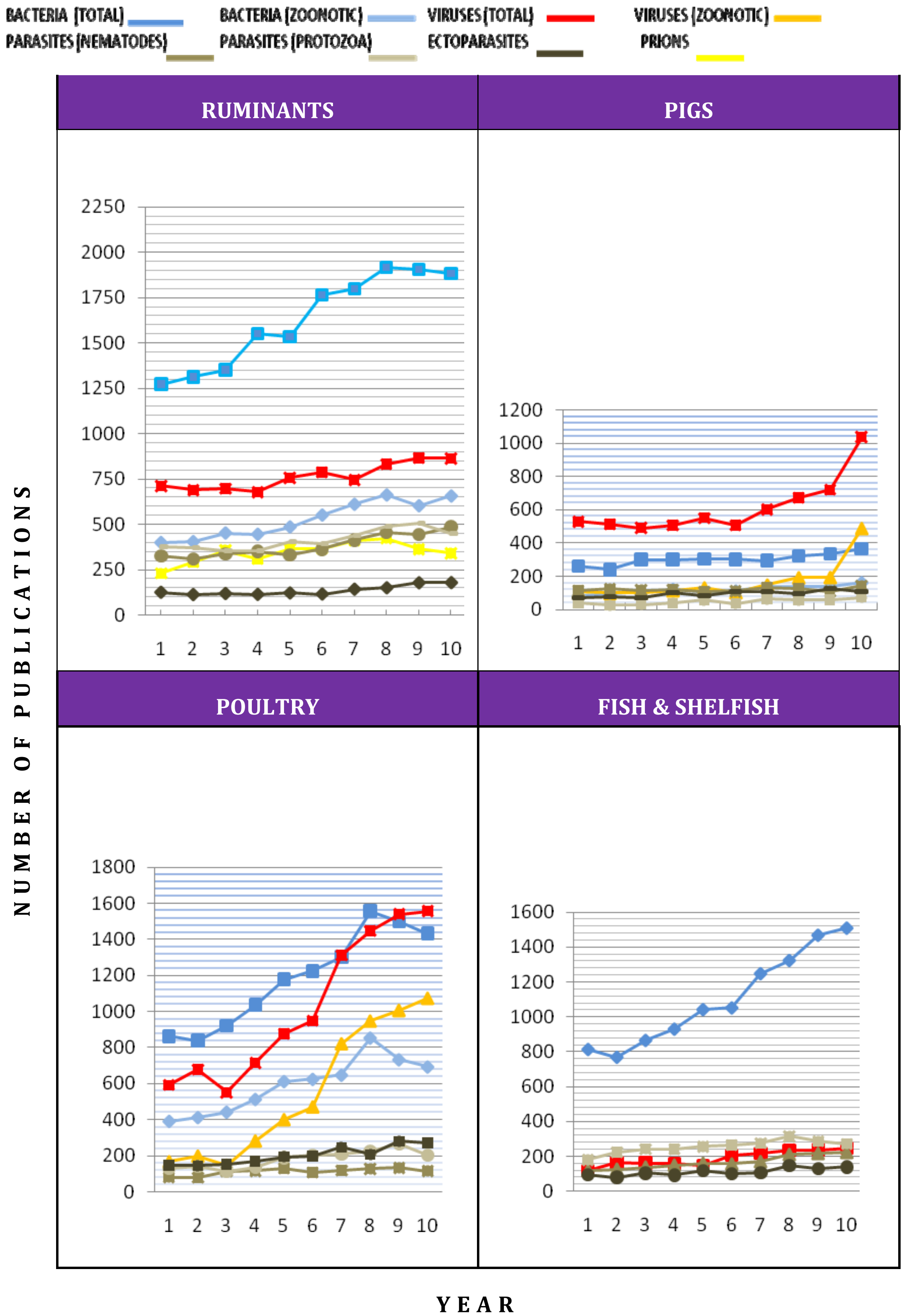


FIGURE 13. Yearly evolution of research output in different subsectors at world scale from 2000 to 2009. Horizontal Axis: 1=2000 to 10=2009.



TABLES

TABLE 1. Global distribution of publications extracted from WoS and CAB databases.

Publications were extracted using the same queries and at the same date. Collection includes research papers on infectious diseases of farm animals in English from year 2006 to July 2009 with authors based in the 27 countries of the European Community+ Norway and Switzerland

	WOS *11826 pub.*	CAB *10166 pub.*
ANIMALS		
RUMINANTS	42%	46%
POULTRY	24%	25%
FISH	22%	17%
PIGS	19%	19%
PATHOGENIC AGENTS		
BACTERIAL DISEASES	52%	50%
VIRAL DISEASES	30%	29%
PARASITIC DISEASES	23%	27%

Table 2. Distribution of main JCR Subject Categories (SC) of research papers in the field of infectious diseases of farm animals (with frequency >0.7%).

JCR SUBJECT CATEGORIES	[1]ABR.	[2]NUMBER	% TOTAL	[3]CUMUL % TOTAL
Veterinary Sciences	VET	4398	32.3%	32.3%
Microbiology	MIC	2508	18.4%	42.7%
Parasitology	PAR	1401	10.3%	49.3%
Biotechnology & Applied Microbiology	BAM	1328	9.8%	59.1%
Immunology	IMM	1303	9.6%	62.7%
Food Science & Technology	FST	1166	8.6%	67.8%
Virology	VIR	884	6.5%	71.8%
Infectious Diseases	IDI	858	6.3%	73.7%
Agriculture, Dairy & Animal Science	ADA	811	6.0%	77.2%
Biochemistry & Molecular Biology	BMB	670	4.9%	80.9%
Fisheries	FIS	662	4.9%	82.7%
Marine & Freshwater Biology	MFW	596	4.4%	83.4%
Public, Environmental & Occupational Health	PEO	383	2.8%	84.7%
Pharmacology & Pharmacy	PHA	355	2.6%	85.4%
Medicine, Research & Experimental	MRE	345	2.5%	85.7%
Genetics & Heredity	GHR	320	2.4%	86.6%
Zoology	ZOO	298	2.2%	87.9%
Ecology	ECO	292	2.1%	89.1%
Biochemical Research Methods	BRM	286	2.1%	89.5%
Environmental Sciences	ESC	215	1.6%	90.5%
Cell Biology	CBI	190	1.4%	90.9%
Toxicology	TOX	186	1.4%	91.1%
Pathology	PAT	165	1.2%	91.4%
Entomology	ENT	149	1.1%	92.1%
Biology	BIL	143	1.1%	93.2%
Chemistry, Applied	CAP	136	1.0%	93.2%
Biophysics	BIP	118	0.9%	93.3%
Multidisciplinary Sciences	MUS	104	0.8%	94.1%

[1] ABR= abridged SC

[2] Due to assignation of journals to several SCs, cumulated number is higher than the number collected (11,826)

[3] percentage of total number of publications collected

TABLE 3. Multi-assignation of the major journals of the SC "Veterinary Sciences".

Journals with more than 100 publication records extracted during the period surveyed are listed.

JOURNAL	Nb PAPERS	SC CATEGORIES	[1] CUMUL %
VET MICROBIOL	514	Microbiology Veterinary Sciences	11.7%
VET PARASITOL	461	Parasitology Veterinary Sciences	22.2%
VET REC	295	Veterinary Sciences	28.9%
VACCINE	285	Immunology Medicine, Research & Experim Veterinary Sciences	35.4%
PREV VET MED	204	Veterinary Sciences	40.0%
AVIAN PATHOL	154	Veterinary Sciences	43.5%
VET IMMUNOL IMMUNOPATHOL	147	Immunology Veterinary Sciences	46.8%
J FISH DISEASES	142	Fisheries Marine & Freshwater Biology Veterinary Sciences	50.1%
VET J	137	Veterinary Sciences	53.2%
FISH SHELLFISH IMMUNOL	130	Fisheries Immunology Marine & Freshwater Biology Veterinary Sciences	56.1%
DISEASE AQUAT ORG	128	Fisheries Veterinary Sciences	59.0%
RES VET SCI	109	Veterinary Sciences	61.5%
BULL VET INST PULAWY	107	Veterinary Sciences	64.0%
VET RES	106	Veterinary Sciences	66.4%

[1] Cumulated percentage out of total number of papers in category "Veterinary Sciences" = 4398

<u>TABLE 4</u>. Evolution of patterns of JCR Subject Categories (SC) in the research field of animal infectious diseases between 1998 and 2008.

SCs are ordered according to their frequency in 2008; positive or negative trend between 2008 (4159 papers) and 1998 (2665 papers) is highlighted when the Khi square (Khi²) of the difference is highly significant (p<0.001).

SUBJECT CATEGORIES	2008		1998		Khi²	Signif.
	NB	%	NB	%		
VETERINARY SCIENCES	1300	31.3%	972	36.5%	29.78	**<**
MICROBIOLOGY	696	16.7%	406	15.2%	0.08	>
BIOTECHNOLOGY & APPLIED MICROBIOLOGY	361	8.7%	228	8.6%	0.54	<
IMMUNOLOGY	360	8.7%	199	7.5%	0.65	>
FOOD SCIENCE & TECHNOLOGY	312	7.5%	136	5.1%	9.10	**>**
PARASITOLOGY	307	7.4%	220	8.3%	4.56	**<**
INFECTIOUS DISEASES	305	7.3%	120	4.5%	**14.77**	**>**
AGRICULTURE, DAIRY & ANIMAL SCIENCE	288	6.9%	99	3.7%	22.53	**>**
VIROLOGY	259	6.2%	212	8.0%	12.15	**<**
BIOCHEMISTRY & MOLECULAR BIOLOGY	216	5.2%	133	5.0%	0.11	<
FISHERIES	171	4.1%	122	4.6%	2.42	<
MARINE & FRESHWATER BIOLOGY	171	4.1%	100	3.8%	0.01	>
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH	121	2.9%	38	1.4%	12.12	**>**
PHARMACOLOGY & PHARMACY	116	2.8%	61	2.3%	0.59	>
ZOOLOGY	113	2.7%	55	2.1%	1.46	>
ECOLOGY	111	2.7%	37	1.4%	9.50	**>**
GENETICS & HEREDITY	103	2.5%	50	1.9%	1.37	>
MEDICINE, RESEARCH & EXPERIMENTAL	103	2.5%	54	2.0%	0.55	>
BIOCHEMICAL RESEARCH METHODS	75	1.8%	34	1.3%	1.71	>
CELL BIOLOGY	71	1.7%	53	2.0%	1.60	<
BIOLOGY	61	1.5%	17	0.6%	7.97	**>**
ENVIRONMENTAL SCIENCES	55	1.3%	17	0.6%	5.73	**>**
TOXICOLOGY	46	1.1%	28	1.1%	0.01	<
MULTIDISCIPLINARY SCIENCES	41	1.0%	29	1.1%	0.52	<

TABLE 5. Compared distribution of JCR Subject Categories (SC) in primary publications and in the publications cited by these primary publications.

Legend: [1] Total number of primary publications: 11,826;[2] Total number of convertible references : 195,533; [3] The khi square test of goodness of fit for the frequency distribution all over the 58 categories is significant (p<0.001). SCs are arranged according to Khi-square values.

5.1: SCs more frequent in primary publications

ISI SUBJECT CATEGORIES	[1]PRIMARY PUBLICATIONS	[2]CITED REFERENCES	[3]*KHI-SQARE*
VETERINARY SCIENCES	32.3%	20.0%	*9149*
FOOD SCIENCE & TECHNOLOGY	8.6%	4.4%	*3928*
FISHERIES	4.9%	2.1%	*3127*
AGRICULTURE, DAIRY & ANIMAL SCIENCE	6.0%	3.4%	*2183*
PARASITOLOGY	10.3%	7.1%	*1927*
MARINE & FRESHWATER BIOLOGY	4.4%	2.3%	*1840*
PUBLIC, ENVIRONM. & OCCUPAT. HEALTH	2.8%	1.8%	*698*
MEDICINE, RESEARCH & EXPERIMENTAL	2.5%	1.6%	*644*
ZOOLOGY	2.2%	1.3%	*632*
TOXICOLOGY	1.4%	0.9%	*301*
ENVIRONMENTAL SCIENCES	1.6%	1.1%	*293*
CHEMISTRY, MEDICINAL	0.6%	0.3%	*250*
ENTOMOLOGY	1.1%	0.7%	*245*
REPRODUCTIVE BIOLOGY	0.6%	0.4%	*166*
AGRICULTURE, MULTIDISCIPLINARY	0.7%	0.5%	*154*
CHEMISTRY, APPLIED	1.0%	0.7%	*149*
DENTISTRY, ORAL SURGERY & MEDICINE	0.3%	0.1%	*134*
ORNITHOLOGY	0.3%	0.2%	*122*
CHEMISTRY, MULTIDISCIPLINARY	0.3%	0.2%	*94*
PHARMACOLOGY & PHARMACY	2.6%	2.3%	*91*
DERMATOLOGY	0.3%	0.2%	*70*
PLANT SCIENCES	0.6%	0.5%	*65*
PEDIATRICS	0.3%	0.2%	*51*
BIODIVERSITY CONSERVATION	0.3%	0.2%	*33*
BIOTECHNOLOGY & APPLIED MICROBIOLOGY	9.8%	9.4%	*32*
NUTRITION & DIETETICS	0.5%	0.4%	*17*

1 ## 5.2. SCs more frequent in cited references

JCR SUBJECT CATEGORIES	[1]PRIMARY PUBLICATIONS	[2]CITED REFERENCES	[3]*CHI-SQARE*[3]
MULTIDISCIPLINARY SCIENCES	0.8%	4.9%	*42798*
BIOCHEMISTRY & MOLECULAR BIOLOGY	4.9%	11.0%	*14749*
MEDICINE, GENERAL & INTERNAL	0.3%	1.6%	*9386*
CELL BIOLOGY	1.4%	3.8%	*8255*
GENETICS & HEREDITY	2.4%	3.5%	*1011*
STATISTICS & PROBABILITY	0.1%	0.3%	*806*
EVOLUTIONARY BIOLOGY	0.7%	1.3%	*743*
MICROBIOLOGY	18.4%	20.9%	*652*
INFECTIOUS DISEASES	6.3%	7.7%	*637*
PHYSIOLOGY	0.2%	0.4%	*493*
COMPUTER SCIENCE, INTERDISCIPLINARY APPL.	0.1%	0.3%	*454*
BIOCHEMICAL RESEARCH METHODS	2.1%	2.7%	*355*
ONCOLOGY	0.3%	0.5%	*339*
BIOPHYSICS	0.9%	1.3%	*334*
IMMUNOLOGY	9.6%	10.8%	*321*
PATHOLOGY	1.2%	1.6%	*211*
ECOLOGY	2.1%	2.5%	*146*
CHEMISTRY, ANALYTICAL	0.7%	0.9%	*125*
GASTROENTEROLOGY & HEPATOLOGY	0.2%	0.3%	*121*
VIROLOGY	6.5%	7.1%	*115*
BIOLOGY	1.1%	1.3%	*111*
HEMATOLOGY	0.4%	0.5%	*94*
MATHEMATICAL & COMPUTATIONAL BIOLOGY	0.3%	0.5%	*93*
CLINICAL NEUROLOGY	0.2%	0.3%	*46*
ENDOCRINOLOGY & METABOLISM	0.2%	0.2%	*45*
NEUROSCIENCES	0.6%	0.7%	*43*
BEHAVIOURAL SCIENCES	0.4%	0.5%	*41*
ENGINEERING, ENVIRONMENTAL	0.3%	0.3%	*7*
WATER RESOURCES	0.2%	0.3%	*6*
OCEANOGRAPHY	0.3%	0.3%	*4*
DEVELOPMENTAL BIOLOGY	0.2%	0.3%	*1*
TROPICAL MEDICINE	0.7%	0.7%	*1*

TABLE 6. Distribution of the main Cabicodes (CC) of research papers in the field of infectious diseases of farm animals (with frequency of at least 2%).

DESCRIPTION	CABICODE	% TOTAL
PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF ANIMALS	LL821	55.9%
PROTOZOAN, HELMINTH, MOLLUSC AND ARTHROPOD PARASITES OF ANIMALS	LL822	19.1%
PRION, VIRAL, BACTERIAL AND FUNGAL PATHOGENS OF HUMANS	VV210	15.5%
GENETICS AND MOLECULAR GENETICS OF MICROORGANISMS	ZZ395	12.7%
ANIMAL IMMUNOLOGY	LL650	12.4%
HOST RESISTANCE AND IMMUNITY	HH600	12.0%
DIAGNOSIS OF ANIMAL DISEASES	LL886	11.5%
PATHOGENS, PARASITES AND INFECTIOUS DISEASES (WILD ANIMALS)	YY700	11.1%
MEAT-PRODUCING ANIMALS	LL120	9.8%
GENERAL MOLECULAR BIOLOGY	ZZ360	9.7%
TECHNIQUES AND METHODOLOGY	ZZ900	9.6%
DAIRY ANIMALS	LL110	8.9%
FOOD CONTAMINATION, RESIDUES AND TOXICOLOGY	QQ200	8.8%
AQUACULTURE (ANIMALS)	MM120	6.5%
PESTICIDES AND DRUGS: CONTROL	HH405	6.3%
ANIMAL GENETICS AND BREEDING	LL240	5.7%
BIOCHEMISTRY AND PHYSIOLOGY OF MICROORGANISMS	ZZ394	5.4%
MEAT PRODUCE	QQ030	5.0%
AQUATIC BIOLOGY AND ECOLOGY	MM300	4.7%
TAXONOMY AND EVOLUTION	ZZ380	4.5%
PROTOZOAN, HELMINTH AND ARTHROPOD PARASITES OF HUMANS	VV220	4.3%
MILK AND DAIRY PRODUCE	QQ010	4.2%
PESTICIDE AND DRUG RESISTANCE	HH410	4.1%
NON-COMMUNICABLE DISEASES AND INJURIES OF ANIMALS	LL860	3.9%
VETERINARY PESTS, VECTORS AND INTERMEDIATE HOSTS	LL823	3.6%
ANIMAL PHYSIOLOGY AND BIOCHEMISTRY (EXCLUDING NUTRITION)	LL600	3.2%
ANIMAL NUTRITION (PHYSIOLOGY)	LL510	3.1%
ANIMAL REPRODUCTION AND EMBRYOLOGY	LL250	2.8%
MATHEMATICS AND STATISTICS	ZZ100	2.5%
ANIMAL HEALTH AND HYGIENE (GENERAL)	LL800	2.3%
VETERINARY PHARMACOLOGY AND ANAESTHESIOLOGY	LL882	2.3%
FOOD COMPOSITION AND QUALITY	QQ500	2.2%
ANIMAL NUTRITION (GENERAL)	LL500	2.2%
PUBLIC HEALTH PESTS, VECTORS AND INTERMEDIATE HOSTS	VV230	2.0%

TABLE 7. Distribution of publications in the 9 lexical clusters describing research themes (part A) and measurement of their proximity by the Salton's cosine measure (part B).

Part A

Symetrical contingency table with total number of papers allocated to each research theme cluster on the diagonal (white characters). Number of publications common to each pair in other cells. Total number of records analyzed : 10,166.

Research theme	EPID	DIAG	FOSA	VIRU	IMMU	DICO	MIGE	VACC	DIRE
Epidemioloy (EPID)	3629	1027	850	449	203	731	361	244	147
Diagnostic (DIAG)	1027	2766	389	499	327	403	234	256	71
Food Safety (FOSA)	850	389	2149	226	116	293	177	143	40
Virulence (VIRU)	449	499	226	1805	514	185	146	275	110
Immunity (IMMU)	203	327	116	514	1573	190	77	509	115
Disease Control (DICO)	731	403	293	185	190	1497	56	397	77
Microbial Genetics (MIGE)	361	234	177	146	77	56	1311	49	114
Vaccines (VACC)	244	256	143	275	509	397	49	1064	33
Disease Resistance (DIRE)	147	71	40	110	115	77	114	33	606

Part B

Matrix of Salton's cosine measures of proximity (from 0 to 1). Colour intensity correlates with level of affinity with higher values in green ad lower values in red.

Research theme	EPID	DIAG	FOSA	VIRU	IMMU	DICO	MIGE	VACC	DIRE
Epidemiology (EPID)		0.324	0.304	0.175	0.085	0.314	0.166	0.124	0.099
Diagnostic (DIAG)	0.324		0.16	0.223	0.157	0.198	0.123	0.149	0.055
Food safety (FOSA)	0.304	0.16		0.115	0.063	0.163	0.105	0.095	0.035
Virulence (VIRU)	0.175	0.223	0.115		0.305	0.113	0.095	0.198	0.105
Immunity (IMMU)	0.085	0.157	0.063	0.305		0.124	0.054	0.393	0.118
Disease Control (DICO)	0.314	0.198	0.163	0.113	0.124		0.04	0.315	0.081
Microbial Genetics (MIGE)	0.166	0.123	0.105	0.095	0.054	0.04		0.041	0.128
Vaccines (VACC)	0.124	0.149	0.095	0.198	0.393	0.315	0.041		0.041
Disease Resistance (DIRE)	0.099	0.055	0.035	0.105	0.118	0.081	0.128	0.041	

<u>TABLE 8.</u> Emerging and cutting edge themes in the biological sciences: evolution of the volume of research publications between 1999 and 2008.

CAB search carried out in November 2009. Results, and sorted according to increase between 1999 and 2008.

[1]*BIOLOGICAL THEMES*	TOTAL CAB			[2] SPECIFIC TO ANIMAL INFECTIOUS DISEASES			
	2008	1999	*Ratio 08/99*	2008		1999	*Ratio 08/99*
				Nb	*EU share %*		
NANOTECHNOLOGIES	*104*	*0*	.....	*5*	*40%*	*0*	.....
MICRORNA	*269*	*0*	....	*33*	*27%*	*0*	.....
SYSTEMS BIOLOGY & SYNTHETIC BIOLOGY	*69*	*1*	***69.0***	*4*	.....	*0*	......
BIOINFORMATICS & "OMICS"	*1504*	*39*	***38.6***	*160*	*43%*	*1*	***160.0***
POST GENOMICS	*802*	*31*	***25.9***	*61*	*46%*	*1*	***61.0***
GENOME MAPPING	*722*	*109*	***6.6***	*140*	*28%*	*10*	***14.0***
IMAGING	*1395*	*470*	***3.0***	*332*	*43%*	*109*	***3.0***
CELL BIOLOGY	*396*	*197*	***2.0***	*93*	*49%*	*53*	***1.8***

[1] <u>Keywords used</u> :

NANOTECHNOLOGIES= NANOTECHNOLOG ; MICRORNA= MICRO$RNA OR SI$RNA; **SYSTEMS BIOLOGY & SYNTHETIC BIOLOGY**= SYSTEM*_BIOLOGY OR SYNTHETIC_BIOLOGY; **BIOINFORMATICS & "OMICS"**= BIOINFORMATICS OR METABOLOM* OR PROTEOM* OR METAGENOM; **POST GENOMICS**=POST$GENOMIC* OR FUNCTIONAL_GENOMIC* OR TRANSCRIPTOM*; **GENOME MAPPING** = GENOME_MAP* OR GENOME_ANNOTATION OR GENOME_SEQUENC*; **IMAGING**= IMAGING; **CELL BIOLOGY**=(CELL*_SIGNAL* OR CELL*_MICROBIOL* OR CELL_BIOL* OR CELL*_RECEPTOR*)

[2] as defined by the combination of specific cabicodes CC= LL82* OR LL88* OR LL9* OR LL650 OR YY7* OR YY8* OR YY9*

TABLE 9. Emerging and cutting edge themes in the medical & agronomic sciences: evolution of the volume of research publications between 1999 and 2008.

CAB search carried out in November 2009. Results, and sorted according to increase between 1999 and 2008

APPLIED THEMES	[1] TOTAL CAB			[2] SPECIFIC TO ANIMAL INFECTIOUS DISEASES			
	2008	1999	Ratio 08/99	2008		1999	Ratio 08/99
				Nb	*EU share %*		
IMMUNOLOGICAL MECHANISMS	603	61	***9.9***	184	*36%*	22	***8.4***
ORGANIC FARMING	2294	1040	***2.2***	80	*53%*	13	***6.2***
BIOTHERAPEUTICS & ALTERNATIVE TO ANTIBIOTICS	1759	471	***3.7***	298	*32%*	67	***4.4***
ANIMAL HEALTH ECONOMICS	494	48	***10.3***	97	*37%*	22	***4.4***
ECO-HEALTH	121	36	***3.4***	16	*13%*	4	***4.0***
ANIMAL WELFARE & PAIN	848	553	***1.5***	187	*43%*	47	***4.0***
POPULATION BIOLOGY	4488	1844	***2.4***	998	*31%*	430	***2.3***
MARKER, DIVA & PLANT VACCINES	157	52	***3.0***	57	*30%*	25	***2.3***
BIOTERRORISM	91	22	***4.1***	22	*23%*	11	***2.0***
DISEASES LIKELY TO EMERGE IN EUROPE DUE TO CLIMATE CHANGE: MOSQUITO-BORNE	1458	805	***1.8***	489	*45%*	292	***1.7***
DISEASES LIKELY TO EMERGE IN EUROPE DUE TO CLIMATE CHANGE: TICK-BORNE	876	750	***1.2***	602	*34%*	546	***1.1***

[1] **Keywords used : IMMUNOLOGICAL MECHANISMS=** MUCOSAL_IMMUNOLOGY OR DENDRITIC_CELL* OR ANTIGEN_PRESENTING OR TOLL_LIKE_RECEPTOR* OR TLR OR CHIMIOKINE*; **ORGANIC FARMING=** ((ORGANIC SAME (FARM OR AGRICULTURE)) OR (ECO* SAME (FARM OR AGRICULTURE))); **BIOTHERAPEUTICS & ALTERNATIVE TO ANTIBIOTICS=** BIOTHERAPEUTICS OR (ALTERNATE* SAME ANTIBIO*) OR ANTIMICRO*_PEPTIDE OR PR$BIOTIC* OR (PLANT SAME MEDICINE); **ANIMAL HEALTH ECONOMICS=**CC: EE117; **ECO-HEALTH=** ECO*_HEALTH OR CONSERVATION_MEDICINE ; **ANIMAL WELFARE=** CC : LL810; **POPULATION BIOLOGY=** POPULATION_BIOLOGY OR MOLECULAR_EPIDEMIOLOGY OR PHYLOGEN; **MARKER, DIVA & PLANT VACCINES =** MARKER_VACCINE* OR (DIVA AND VACCINE*) OR (PLANT AND VACCINE*); **BIOTERRORISM=** BIOTERRORISM OR AGROTERRORISM OR BIOLOGICAL_WARFARE; **DISEASES LIKELY TO EMERGE IN EUROPE DUE TO CLIMATE CHANGE: MOSQUITO-BORNE=** BLUE_TONGUE OR BTV OR RIFT_VALLEY_FEVER OR RFV OR WEST_NILE OR LEISHMANI* OR AFRICAN_HORSE_SICKNESS; **DISEASES LIKELY TO EMERGE IN EUROPE DUE TO CLIMATE CHANGE: TICK-BORNE=** BABESI* OR THEILERI* OR EHRLICHI* OR ANAPLASM* OR RICKETTSI*.[2]

[2] as defined by the combination of specific cabicodes CC= LL82* OR LL88* OR LL9* OR LL650 OR YY7* OR YY8* OR YY9

<u>TABLE 10.</u> Bibliographic coupling and clustering of publications in the sector of animal infectious diseases (2006 to July 2009 in Europe).

Citing publications were paired according to the number of their shared references and clustering was performed according to a single link clustering algorithm (Bibexcel software). The line in yellow shows the clusters eventually selected for subsequent analysis (at least 5 shared references and at least 6 publications per cluster).

[1] Minimal nb of shared references	Nb of pairs	Nb clusters total	Nb public.	Mean cluster size	Nb clusters >4	Nb clusters >5
4	6738	286	2643	9.2	170	141
5	4434	282	2141	7.6	165	131
6	3082	265	1703	6.4	135	104
7	2124	231	1309	5.7	95	66
8	1516	182	989	5.4	71	49
9	1096	146	721	4.9	46	30
10	801	123	551	4.5	32	21

[1] between any two publications

<u>TABLE 11.</u> Bibliographic coupling of the 12 majors research subsectors defined by the category of animals and the type of pathogenic agents: symmetrical matrix of Salton's cosines showing pair wise proximity.

Animal host categories: Fish (FISH), Pig (PIG), Poultry (POUL), Ruminants (RUM). Pathogenic agents categories: Bacteria (BAC), Viruses (VIR), Parasites (PAR). Measures above 0.160 are highlighted**.**

	FISH-BAC	FISH-PAR	FISH-VIR	PIG-BAC	PIG-PAR	PIG-VIR	POUL-BAC	POUL-PAR	POUL-VIR	RUM-BAC	RUM-PAR	RUM-VIR
FISH-BAC	1.000	0.158	0.157	0.154	0.067	0.064	0.160	0.049	0.075	0.141	0.060	0.062
FISH-PAR	0.158	1.000	0.075	0.055	0.101	0.053	0.053	0.152	0.055	0.051	0.104	0.048
FISH-VIR	0.157	0.075	1.000	0.022	0.018	0.056	0.026	0.020	0.079	0.024	0.019	0.043
PIG-BAC	0.154	0.055	0.022	1.000	0.172	0.148	0.333	0.039	0.040	0.281	0.089	0.037
PIG-PAR	0.067	0.101	0.018	0.172	1.000	0.174	0.061	0.101	0.035	0.070	0.331	0.042
PIG-VIR	0.064	0.053	0.056	0.148	0.174	1.000	0.042	0.041	0.151	0.046	0.036	0.160
POUL-BAC	0.160	0.053	0.026	0.333	0.061	0.042	1.000	0.129	0.132	0.227	0.039	0.030
POUL-PAR	0.049	0.152	0.020	0.039	0.101	0.041	0.129	1.000	0.103	0.039	0.105	0.033
POUL-VIR	0.075	0.055	0.079	0.040	0.035	0.151	0.132	0.103	1.000	0.035	0.032	0.061
RUM-BAC	0.141	0.051	0.024	0.281	0.070	0.046	0.227	0.039	0.035	1.000	0.096	0.077
RUM-PAR	0.060	0.104	0.019	0.089	0.331	0.036	0.039	0.105	0.032	0.096	1.000	0.051
RUM-VIR	0.062	0.048	0.043	0.037	0.042	0.160	0.030	0.033	0.061	0.077	0.051	1.000

<u>TABLE 12 </u>: Pairwise proximity between major JCR Subject Categories (SC) and research subsectors defined by the type of production animals or the type of pathogenic organisms

Proximity was measured by the Salton's cosine measure (from 0 to 1). The 20% highest and 20% lowest measures in each group are highlighted. Developed SC names appear in alphabetical order pp 12-14.

	RUMINANTS	PIGS	POULTRY	FISH	BACTERIA	VIRUSES	PARASITES
ADA	0,245	0,073	0,111	0,016	0,266	0,062	0,049
BAM	0,165	0,115	0,169	0,178	0,292	0,171	0,033
BIL	0,051	0,022	0,074	0,057	0,055	0,056	0,073
BIP	0,077	0,021	0,028	0,051	0,058	0,085	0,017
BMB	0,136	0,065	0,084	0,153	0,151	0,154	0,072
BRM	0,094	0,077	0,078	0,037	0,074	0,15	0,029
CAP	0,032	0,046	0,047	0,084	0,117	0,011	0,023
CBI	0,085	0,04	0,057	0,047	0,063	0,12	0,022
ECO	0,056	0,03	0,124	0,086	0,062	0,03	0,184
ENT	0,059	0,029	0,106	0,011	0,024	0,02	0,163
ESC	0,038	0,03	0,077	0,115	0,098	0,039	0,075
FIS	0,001	0,002	0,003	0,482	0,138	0,1	0,147
FST	0,191	0,083	0,138	0,16	0,381	0,026	0,019
GHR	0,078	0,038	0,107	0,083	0,103	0,096	0,064
IDI	0,161	0,117	0,155	0,06	0,219	0,13	0,059
IMM	0,178	0,13	0,151	0,156	0,224	0,218	0,078
MFW	0,002	0,01	0,013	0,437	0,129	0,081	0,159
MIC	0,229	0,204	0,192	0,238	0,497	0,101	0,05
MRE	0,098	0,077	0,113	0,025	0,072	0,186	0,023
MUS	0,053	0,018	0,054	0,046	0,049	0,074	0,03
PAR	0,27	0,088	0,11	0,139	0,031	0,028	0,602
PAT	0,106	0,064	0,021	0,016	0,051	0,12	0,024
PEO	0,104	0,093	0,106	0,028	0,126	0,077	0,081
PHA	0,08	0,088	0,083	0,076	0,154	0,066	0,037
TOX	0,024	0,095	0,051	0,083	0,126	0,016	0,041
VET	0,43	0,282	0,233	0,156	0,363	0,353	0,267
VIR	0,16	0,165	0,144	0,037	0,022	0,451	0,007
ZOO	0,053	0,046	0,099	0,106	0,059	0,04	0,181

TABLE 13 : Pairwise proximity between lexical clusters describing research themes and research subsectors defined by the type of production animals or the type of pathogenic organisms.

Proximity was measured by the Salton's cosine measure (from 0 to 1). The ten highest and ten lowest measures are highlighted.

	POULTRY	RUMINANTS	PIGS	FISH	BACTERIA	VIRUSES	PARASITES
DIAGNOSTIC	0,22	0,38	0,21	0,13	0,33	0,34	0,20
DISEASE CONTROL	0,20	0,29	0,13	0,07	0,25	0,26	0,13
DISEASE RESISTANCE	0,09	0,20	0,08	0,08	0,16	0,13	0,11
EPIDEMIOLOGY	0,31	0,42	0,22	0,13	0,35	0,34	0,32
FOOD SAFETY	0,32	0,22	0,20	0,15	0,38	0,19	0,16
IMMUNITY	0,16	0,23	0,19	0,17	0,24	0,25	0,17
MICROBIAL GENETICS	0,21	0,18	0,13	0,17	0,19	0,18	0,22
VACCINES	0,21	0,16	0,16	0,08	0,17	0,32	0,08
VIRULENCE	0,20	0,23	0,20	0,17	0,25	0,28	0,17

TABLE 14. Synthesis on major descriptors (SC, CC, LEX)

Descriptors represented at a frequency of at least 5% are presented and grouped according to subject proximity. Descriptors in italics were not found groupable.

TYPE	DESCRIPTORS	% FREQUENCY
LEX	DIAGNOSTIC	24
CC	DIAGNOSIS OF ANIMAL DISEASES	12
CC	PROTOZOO, HELMINTH, MOLLUSC AND ARTHROPOD PARASITES OF ANIMALS	19
SC	PARASITOLOGY	10
LEX	FOOD SAFETY	19
SC	BIOTECHNOLOGY & APPLIED MICROBIOLOGY	10
CC	FOOD CONTAMINATION, RESIDUES AND TOXICOLOGY	9
SC	FOOD SCIENCE TECHNOLOGY	9
LEX	IMMUNITY	14
CC	ANIMAL IMMUNOLOGY	12
SC	IMMUNOLOGY	10
LEX	VACCINES	9
CC	HOST RESISTANCE & IMMUNITY	12
CC	ANIMAL GENETICS & BREEDING	6
LEX	DISEASE RESISTANCE	5
CC	GENETICS & MOLECULAR GENETICS OF ORGANISMS	13
LEX	MOLECULAR MICROBIOLOGY	12
CC	GENERAL MOLECULAR BIOLOGY	10
SC	BIOCHEMISTRY & MOLECULAR BIOLOGY	5
CC	MEAT-PRODUCING ANIMALS	10
CC	DAIRY ANIMALS	9
SC	AGRICULTURE DAIRY AND ANIMAL SCIENCES	6
CC	AQUACULTURE (ANIMALS)	6
SC	FISHERIES	5
CC	*PRION, VIRAL, BACTERIAL & FUNGAL PATHOGENS OF ANIMALS*	*56*
LEX	*EPIDEMIOLOGY*	*32*
SC	*VETERINARY SCIENCES*	*32*
SC	*MICROBIOLOGY*	*18*
CC	*PRION, VIRAL, BACTERIAL & FUNGAL PATHOGENS OF HUMANS*	*16*
LEX	*VIRULENCE*	*16*
LEX	*DISEASE CONTROL*	*13*
CC	*PATHOGENS, PARASITES & INFECTIOUS DISEASES OFWILD ANIMALS*	*11*
CC	*TECHNIQUES & METHODOLOGY*	*10*
SC	*VIROLOGY*	*7*
SC	*INFECTIOUS DISEASES*	*6*
CC	*PESTICIDES & DRUGS*	*6*