



Towards One Health: Evolution of international collaboration networks on Nipah virus research from 1999-2011

Sophie Valeix

Networks



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Towards One Health: Evolution of international collaboration networks on Nipah virus research from 1999-2011

The world is now facing the emergence of new pathogens and the return of old ones at an unprecedented speed. Among the wide range of emerging diseases, zoonoses – infections naturally transmitted between vertebrate animals and humans – represent a new, complex global problem for public health and require new forms of science leading to new forms of governance. The 'One Health' policy concept developed a few years ago by international public health institutions proposes that research institutions gather together animal, human and environmental health research by intensifying cooperation among scholars working on zoonoses at the global scale. Unfortunately, and after years of promotion of One Health throughout the world, the policy seems to be blocked at the stage of a burgeoning movement, with no concrete achievements and little evidence of successful implementation. This paper considers the global research carried out about Nipah virus, an emerging zoonotic agent, and explores the extent to which patterns of international scientific collaboration have evolved since Nipah's emergence. Through the combination of bibliometrics, social network analysis (SNA) and a collection of researcher narratives, this work presents insights on the evolution of scientific networks associated with emerging zoonoses such as Nipah and discusses the consistency of these networks with One Health policy.

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The Dynamic Drivers of Disease in Africa Consortium is a multidisciplinary research programme designed to deliver much-needed, cutting-edge science on the relationships between ecosystems, zoonoses, health and wellbeing with the objective of moving people out of poverty and promoting social justice. It is focusing on four emerging or re-emerging zoonotic diseases in four diverse African ecosystems – henipavirus infection in Ghana, Rift Valley fever in Kenya, Lassa fever in Sierra Leone, and trypanosomiasis in Zambia and Zimbabwe.

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Contents

CONTENTS	I
LIST OF TABLES AND FIGURES	II
ACRONYMS	III
ABSTRACT	IV
1. INTRODUCTION	1
2. NIPAH VIRUS AND THE 'ONE HEALTH' CHALLENGE	2
2.1. Nipah virus and its pandemic risk: between complexity and uncertainty	2
2.2. Exploring the meaning and applicability of the 'One Health' concept	4
3. BIBLIOMETRICS AS A WINDOW INTO NETWORKS OF SCIENTIFIC RESEARCH	6
4. HYPOTHESIS AND METHODS	10
4.1. Bibliometric and social network analysis	10
4.2. Pilot actor interviews	11
5. INTERNATIONAL KNOWLEDGE FLOWS ON NIPAH VIRUS FROM 1999 TO 2011	13
5.1. Evolution of the network general structure, degree centrality and knowledge brokerage	13
5.1.1. 1999-2002	13
5.1.2. 2003-2007	14
5.1.3. 2008-2011	14
5.1.4. Evolution of degree centrality	15
5.1.5: Evolution of knowledge brokerage	15
5.2. Evolution of the network composition	16
5.2.1. Evolution of scientific collaborations by field	16
5.2.2. Evolution of scientific collaborations by economic status	17
5.2.3: Evolution of scientific collaborations by type of organisation	18
5.3. Nature of collaborations and related needs and opportunities for future improvements	19
5.3.1. Nature of collaborative relationships	19
5.3.2. Barriers to international collaboration	20
5.3.3. Collaboration: downsides and pay-offs	20
6. DISCUSSION – CONCLUSION	22
6.1. Support for initial hypotheses	22
6.2. Evolution of Nipah virus research networks: General features and their alignment with One Health	22
6.2.1. Network development	22
6.2.2. Evolution of social capital and diversity of collaborators	24
6.2.3. Long term future of Nipah networks	25
6.3. Supporting international collaboration networks to address emerging zoonoses	26
6.4. Study limitations	27
6.5. Future directions	27
BIBLIOGRAPHY	29

List of Tables and Figures

<i>Table 4.1:</i> Information on the people interviewed.....	12
<i>Figure 5.1:</i> Networks of collaborative organisations publishing on Nipah across three periods from 1999-2011	13
<i>Figure 5.2:</i> Visualisation of knowledge brokers in the collaboration networks of the three periods studied.....	15
<i>Figure 5.3:</i> Polar representation of networks according to field.....	16
<i>Figure 5.4:</i> Polar representation of networks according to economic status.....	17
<i>Figure 5.5:</i> Collaboration networks of organisations publishing on Nipah differentiated according to their country's economic status: high, middle or low income	18
<i>Figure 5.6:</i> Polar representation of networks according to type of publishing organisation	18
<i>Table 6.1:</i> Main features that characterises Nipah virus scientific cooperation networks from 1999 to 2011 relevant to the application of One Health.....	23

Acronyms

BC	Betweenness Centrality
CDC	Centre for Disease Control and Prevention, Atlanta
COP	Communities of Practice
CSIRO	[Australian] Commonwealth Scientific and Industrial Research Organisation
HICs	High Income Countries
FAO	Food and Agricultural Organization of the United Nations
GLEWS	Global Early Warning System
HIV/AIDS	Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome
LICs	Low Income Countries
LMIC	Low and Middle Income Countries
MICs	Middle Income Countries
NGO	Non-Governmental Organisations
OIE	World Organisation for Animal Health (Office International des Epizooties)
PEI	Planet Earth Institute
RNA	Ribonucleic Acid
SNA	Social Network Analysis
WAHID	World Animal Health Information Database
UK	United Kingdom
US	United States
WHO	World Health Organization

Abstract

This paper reports changing patterns in international cooperation on Nipah virus research over time through social network analysis of bibliographic data, combined with direct interviews with participating scientists. Social assets and weaknesses derived from emerging zoonoses research networks have been identified. After having synthesised what the One Health concept represents from the literature, the paper explains how social network theories can provide insights into the feasibility of the implementation of One Health policies and actions, and identify areas which require deeper qualitative analysis. It then completes the results of observations and measures of the networks by actor narratives. Finally, it discusses the relevance of the author's findings for targeted support of international and interdisciplinary collaboration in the fight against emerging zoonoses worldwide.

Introduction

The world is now facing the emergence of new pathogens and the return of old ones at an unprecedented speed. Emerging diseases¹ have been linked to global changes that involve anthropogenic factors (increased numbers of people, urbanisation, and higher frequency of long distance exchanges) in interactions with environmental phenomena (climate change, loss of biodiversity) (Brown 2004; Daszak 2005; Daszak *et al.* 2013; Wilcox and Colwell 2005). Among the wide range of emerging diseases, zoonoses - infections naturally transmitted between vertebrate animals and humans - represent at least 60 per cent of infectious human diseases and over 75 per cent of emergent infections, and are thus a major concern (Jones *et al.* 2008).

Because they do not respect national borders and involve human, animal and environmental health, these particular diseases constitute a special challenge for public health professionals. As a new complex global problem, they require new forms of science and research, leading to new forms of governance. The study of emerging zoonoses requires a consideration of animal, human and environment health at the same time. The 'One Health' policy concept developed a few years ago by international public health institutions proposes that research institutions gather together these three domains by intensifying cooperation among scholars at the global scale. Unfortunately and after years of promotion of One Health throughout the world, One Health still seems to be blocked at the stage of a burgeoning movement without concrete achievements (Leboeuf 2011). Since little evidence of successful implementation can be found in the literature, it is fair to wonder if a real shift toward this new One Health paradigm has already or will ever take place. If the international scientific community is to develop the practice of globally sharing knowledge produced among scientific fields and among nations, as required in the practice of One Health, one cannot ignore the social dimensions of this challenge. Fortunately, social sciences provide useful tools to clarify the social dimensions of health-related studies (Rosenfield 1992).

Nipah virus encephalitis is a good example of a novel infectious disease transmitted to humans through an animal reservoir (bats) and infected livestock (pigs) and which was totally unknown before 1998. The role of the environment and of human behaviour in the emergence of Nipah virus intersect with the fact that new close contact between pig farms and trees attractive to bats was the origin of the first recognised transmission of the virus to people in 1998. Since then, epidemics have occurred in several places in South Asia² and research work carried out on the Nipah virus constitutes quite a rich amount of knowledge so far. Yet, although the threat of fatal Nipah virus infection in people persists in south Asia, no vaccines or other therapies have been developed, and the risk of a future Nipah pandemic is not negligible (Luby 2013).

This paper explores the extent to which patterns of international scientific collaboration have evolved over time by focusing on research into the Nipah virus since its emergence and across a decade. Through the combination of bibliometrics, social network analysis (SNA) and a collection of researcher narratives, the paper presents insights on the evolution of scientific networks associated with an emerging zoonosis such as Nipah and discusses the consistency of these networks with One Health policy, Nipah virus and the 'One Health' challenge.

¹ The use of 'emerging diseases' in this paper includes both emerging and re-emerging infections.

² Malaysia, Singapore, Bangladesh and India.

1. Nipah Virus and the One Health challenge

2.1. Nipah virus and its pandemic risk: between complexity and uncertainty

That zoonoses constitute a major issue for the prosperity of the biosphere and a major burden for humans, animals and ecosystems in general no longer needs to be proven. For instance, economic losses to health and livestock sectors due to zoonotic diseases for the period 2000-2010 were estimated at US\$20 billion and at US\$200 billion for the indirect losses caused to economies (World Bank 2010). Models show that research and surveillance on zoonotic pathogens are economically profitable. Some scholars claim that it is cheaper to invest in zoonosis surveillance and prevention than to react retrospectively, making the overall societal benefit of surveillance and preparedness, all sectors included, higher than the cost of the measures taken (Roth *et al.* 2003; Zinsstag *et al.* 2007; Zinsstag and Tanner 2008). Among the wide range of zoonotic pathogens circulating between animals and humans, Jones *et al.* in 2008 highlighted those coming from wildlife, and particularly Ribonucleic Acid (RNA)³ viruses, as deserving particular attention because they are able to mutate easily and thus to cross species barriers quite easily. RNA viruses have been important pathogens in infectious disease emergence in humans. Nipah virus, a zoonotic RNA virus which emerged in 1998 in Malaysia represents an important potential threat for global public health. This virus can be transmitted from wild animals (fruit bats) to livestock (pigs) and to humans. In addition to indirect contact, in Bangladesh Nipah has been found to be transmissible from humans to humans by direct contact (Gurley *et al.* 2007). This important feature of the virus implies a pandemic⁴ risk.

Despite the obvious general need to develop material and human means to tackle zoonoses, it is unclear how much time and money should be devoted to Nipah, as it has so far 'only' caused outbreaks in Asia. Moreover, although Nipah virus is still recognised as responsible for sporadic cases of human disease in Bangladesh (Luby *et al.* 2009), it is not yet at an endemic⁵ stage in any part of the world. For this reason, in 2014, Nipah does not receive much attention. For instance, Nipah is excluded from the three main diseases (the 'big three') on which the health part of the Millennium Development Goals is focused (Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome (HIV/AIDS), tuberculosis and malaria). Nor is Nipah included in the neglected diseases like the parasitoses that appear immediately behind the 'big three'.

Although Nipah does not fit yet in the rhetoric for protecting the poorest from the burden of disease, it has stimulated a lot of research since 1999. Several reasons appear from the literature to justify this strong interest from scientists to study Nipah. First, it is a virus of bats and bats have been found to be wild reservoirs for many emerging pathogens, and especially of viruses in the Paramyxoviridae family. The Paramyxoviridae includes Nipah and also mumps, measles and rinderpest viruses. Second, Hendra virus (belonging to the same genus as Nipah⁶) causes infections in humans and horses in Australia. The two viruses being very close, research carried out on one has fed and stimulated research on the other. Third, Nipah has recently been identified in bat blood samples in Ghana and Madagascar (Peel *et al.* 2012). This has stimulated an active search for the virus in other African countries, with the idea that Nipah's geographic distribution may follow the natural distribution of Old World fruit bats and that the virus might even have originated from the African continent (Hayman and Yu *et al.* 2012). It appears however, that the productive research carried out on Nipah depends on high income countries (HICs), motivated by the fear that the virus may colonise northern

³ Ribonucleic Acid qualifies the virus' genetic material.

⁴ A spread of the virus to all or several continents at the same time.

⁵ Maintaining itself in a given population infecting continuously.

⁶ Nipah and Hendra viruses constitute the Henipavirus genus.

parts of the globe. As studies have now shown the possibility of human-to-human transmission, the risk of spreading the virus all over the world in quite a short time, as a pandemic, is a cause for serious concern in developed countries.

With the increasing importance in wealthy societies of non-communicable diseases like cancer or degenerative conditions, public opinion tends to overlook the rising risk posed by emerging or re-emerging infectious diseases. Because we live in a newly globalised and interconnected world, emerging zoonotic diseases are relatively new issues to tackle. In the literature on public health policy this has resulted recently in calls for new approaches to decision making. In the Routledge Handbook of Global Public Health, Parker and Sommer (2011) talk about a paradigm shift from 'international health' to 'global health'. The first has involved health regulations to ensure safe trade and travel, whereas the second, more adapted to the globalised era, emphasises effective state internal decisions to prevent and fight contagious diseases in a more interventionist way.

For example, Figuié (2013) explains that the international public health community should no longer reason in terms of 'international threat management' but in terms of 'global risk governance'. She argues that emerging infectious diseases constitute new modern risks. This new type of risk is a systemic risk because it is generated, 'at the crossroads between natural events, economic, and social, and technological developments, and policy driven actions, at both the domestic and international levels'. The view that emerging infections are multi-dimensional problems has also been highlighted by Daszak 2005; Daszak *et al.* 2013; Jones *et al.* 2008; Wilcox and Colwell 2005, and, more recently, by Wood *et al.* 2012. They portray zoonosis emergence and transmission as combinations of social, politico-economic and environmental processes for which the drivers and responses are still poorly understood. They all insist on the urgent need to address emerging zoonotic diseases in a more holistic, interdisciplinary and integrative way than it is currently the case.

Because of the multi-component nature of emerging zoonoses, it appears quite impossible to calculate precisely or even estimate closely the potential consequences of a potential pandemic (Figuié 2013). Because of the multiple dimensions involved in Nipah emergence and occurrence, we can say that Nipah fits Figuié's description of 'anticipated catastrophes' characterised by a global dimension and a high level of uncertainty. In a Nipah pandemic, the number of casualties could possibly reach hundreds of millions⁷ and it is quite impossible to estimate the total consequences considering the indirect socio-economic impact.

International institutions involved in public health now are seeking a new global form of governance to manage the risks posed by emerging infectious diseases. No single country would be spared serious damage to its animal and human populations from a global pandemic. In potential future pandemic scenarios, there is no reason for developed countries to encounter less important losses than developing regions. In fact, with a high density of people in some big cities, we can expect huge consequences. Paradoxically, the poorest people living mostly in tropical regions are expected to be the first affected because pathogens emerge mainly in warm and humid climates. These developing countries appear to have the least resources to respond early and efficiently in order to prevent the spread of the given pathogen to other nations. Thus, wealthy countries should invest heavily in international development to ensure that the most vulnerable countries acquire the necessary capabilities.

In this complex system, science has a very important role to play to prevent and manage communicable diseases. Scientific discoveries are one of the engines of the production of vaccines and medical treatments, prevention and containment measures. There is a need for disciplines from

⁷ Considering the context of globalisation could make it worse than the 1918 flu pandemic which killed approximately 40 million people (Taubenberger and Morens 2006).

the life sciences (such as virology, genetics, immunology, medicine, epidemiology, pharmacology, ecology), as well as from other fields such as the social sciences (sociology, ethnology or anthropology), mathematics (modelling) or physics (diagnostic devices) to be applied to understanding and managing the risks associated with emerging infectious diseases.

In summary, recent literature calls for a new governance system for managing globalised health risks, in which scientific research is the first area in which organisational change is required. The most important concept illustrating this call was developed jointly by international institutions in charge of animal and human health⁸ under the 'One Health' movement. Because of the complexity and uncertainty associated with its emergence and transmission, described above, Nipah virus represents an excellent case to study the application of One Health policy.

2.2. Exploring the meaning and applicability of the One Health concept

Developed jointly by international organisations involved in human and animal disease emergence (mainly OIE, WHO and FAO) in 2004, One Health is probably the most promising policy that expresses the needs and challenges for global public health.

Supporters of One Health advocate the fostering of interdisciplinary collaboration and international coordination for the prevention and control of emerging diseases and in particular zoonotic infections (Gibbs 2014). One health policy involves the active sharing of knowledge and resources at two different levels simultaneously. The first level is the increase of the extent to which countries throughout the world work together to manage emerging disease risks (Hayman and Gurley *et al.* 2012). There has been a multiplication of various organisations pursuing public health objectives in the last decade, notably with the new involvement of private or semi-private organisations (Parker and Sommer 2011). However, it is not obvious that these organisations have brought greater coherence to the existing institutional structures. Instead, this proliferation has contributed to a greater fragmentation of responsibilities and programs in international public health, which now requires a better 'international fluidity' (Fee *et al.* 2008; Parker and Sommer 2011). The second level is more collaboration among scientific fields and among the many different sectors of government and non-government actors. This implies far more collaboration among a wide range of stakeholders such as scientists from various disciplines, veterinarians, physicians, conservationists, government officers and policy makers. Functional implementation of One Health also implies replacing the current format of international cooperation between independent and territorial states with 'global projects conducted by coalitions of public, private and nongovernmental organisations' (King 2002:774).

Despite abundant recent literature recognising the interdependency of humans, animals and the environment and advocating the adoption of a common vision for international institutions, it is still difficult to find practical applications of the One Health concept. Health management responses to emerging diseases still reflect sectorial divisions both, at the research and policy levels. Wood *et al.* (2012) emphasise the fact that interdisciplinary or systemic approaches are too frequently ignored in reductionist paradigms in the natural sciences and this is another reason to integrate social sciences contributions with research (see Introduction above). In 'Making sense of One Health', Leboeuf (2011) qualifies One Health as 'soft governance' within the broader global health perspective. Indeed, despite the fact that One Health now motivates all sorts of cooperative projects, it is not yet supported by a strong institutional power and is therefore fragile and uncertain. The future of One Health relies on the shared vision of the actors involved and any obstacle to the consensus is a hindrance to the goal of pandemic prevention. Leboeuf emphasises the difficulty of finding financial resources in the current period of tight budgets to support inter-agency cooperation as well as for

⁸ World Organisation for Animal Health (OIE), World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO).

combined animal and human health systems in general. The experts from 23 countries at the Winnipeg meeting in 2009 highlighted the gaps that One Health was encountering. According to them, there was a great need for political commitment at multiple levels to foster the change of attitudes required to make multidisciplinary partnerships a common practice and include local capacity building, encouraging stakeholder and community engagement and developing trans-boundary approaches. It seems that, year after year and conference after conference, efforts to apply the One Health concept still only represent abstract guidelines for governments, away from the reality of practices on the ground. Unfortunately, actual recommendations have not constituted more progress in One Health activities beyond an increased awareness about the concept itself (Rubin *et al.* 2013).

2. Bibliometrics as a window into networks of scientific research

As noted previously, science constitutes an important pillar of sound policy making in the management of emerging zoonoses. Understanding the evolving system of scientific research in this field is thus crucial to the pursuit of the 'One Health' goal. With the information and communication technology revolution, researchers⁹ have been increasingly connected with each other in virtual networks, even though physically separated by geographic distance.

International flows of knowledge about emerging zoonoses are impossible to determine with precision, but in practise they involve formal meetings and conferences and a large number of informal discussions in person or by virtual exchanges. In recent decades, international organisations have established panels of official cooperation networks, from small to large in size, involving close interactions (working groups) as well as web-based exchanges of information. For example, in 2006 the OIE developed the World Animal Health Information Database (WAHID). Following the WAHID interface, the OIE, FAO and WHO jointly built the Global Early Warning System (GLEWS), an online outbreak alert system which combines and coordinates the alert and disease intelligence mechanisms of the three organisations to assist in prediction, prevention and control of animal disease threats. This initiative makes current information on the occurrence of communicable diseases (and especially zoonoses) accessible online for medical practitioners, decision makers or anyone else who is interested. It relies on the countries' willingness to provide and update disease information in the system. Unfortunately for emerging diseases like Nipah encephalitis, little or no information appears on these sites since only a few outbreaks have occurred and most occurred before the creation of GLEWS. Also, these networks mostly send information in only one direction. In the case of an outbreak for example, an animal or human health official from the concerned country would transmit epidemiological data¹⁰ about the case to the OIE but OIE would not systematically send similar information back to that official. For this reason, it is difficult to use such databases as true networks for exchanging knowledge between actors involved in Nipah information production and management.

However, it is possible to study and visualize scientific knowledge flows by looking at the networks of collaborators as shown by co-authorships in published scientific papers. Indeed, bibliometric data offer a chance to explore networks of researchers who share professional interests because they publish jointly in peer-reviewed journals. Studying co-authorships has become quite a useful tool for social scientists. From the bibliometric data available through online databases of peer-reviewed literature such as Scopus, it is easy to know who is publishing with whom, from what geographic regions and about which topics. Using this information to visualize networks of scientists is a new approach and allows the direct observation of social links, groups and influences. The fact that researchers are increasingly publishing in peer-reviewed journals in cooperation with other researchers (Wagner and Leydesdorff 2005) makes the act of publishing a social process which requires communication and exchange of knowledge. Co-publishing includes a bilateral selection process, which may be organised competitively in the sense that both sides are interested in being partners (Schmoch and Schubert 2008). Adams *et al.* (2005) qualify scientific collaboration as being a 'channel of knowledge flows between scientists'. The social study of scientific networks is a powerful tool which makes possible the visualization of repeated exchanges between social agents that indicate a relationship of trust and real knowledge transfer, a requirement for implementation of One

⁹ In this thesis, the word 'researcher' is employed to qualify a professional who mainly publishes in peer-review journals, it does not regard the level of studies or position occupied.

¹⁰ Including location, number of victims, symptoms, measures undertaken.

Health, as noted earlier in this paper. This analysis assumes that collaboration through peer-reviewed paper publication is a social act, and that it involves knowledge sharing through social networks of researchers.

In 2012 Anholt *et al.* explored factors that make interdisciplinary collaborations successes or failures, by considering the objective of integration of veterinary, medical and environmental sciences. Their findings were mainly centred on social features. In fact, the establishment of good professional linkages seemed to depend on meetings taking place first within the private sphere. What mattered most were those factors that contributed to solid personal relationships based on trust and respect. Co-publishing about emerging zoonotic diseases is, then, a similar social act that is closely related to social practices. What, then, can network theories reveal that is relevant to understanding the feasibility of the One Health concept in the context of emerging zoonoses?

The theory of practice-based knowledge is based on the assumption that practice and experience are very important components of learning, and that knowing is inseparable from doing (Orlikowski 2002; Hislop 2013). Knowledge is then a combination of explicit or codified information and tacit skills, the latter necessitating social interactions to be transmitted¹¹ (Clark *et al.* 2000; Polanyi 1966). I will explore two essential notions that sociologists developed during the past decades and that derive from this perspective: social capital and communities of practice.

Social networks are structures with nodes representing social agents (individuals, organisations, etc.) and links among nodes symbolising the relationships between those agents. Networks have been increasingly studied in research because they explain much about the dynamics of globalisation (Hislop 2013). They provide a social context for knowledge production and transfer, the social phenomena at the centre of academic and increasingly non-academic research. However, network theories are only partially studied in the framework of health knowledge as a global public good that circulates between organisations internationally, as implied by the global health paradigm. Nonetheless, it is promising to attempt to draw One Health inferences from existing social network theories, such as the notions of social capital and communities of practice. This is what this paper attempts to do.

Social capital represents the resource generated by one's set of relations. The definition of social capital varies in the literature. In fact, three different emphases have been made by three authors who have done significant work on this notion, each of which is worth exploring. Bourdieu (1980) distinguished social capital from the two other forms of capital, economic capital and cultural capital. He described social capital as a way of acquiring power in hierarchical societies. Indeed, a person with a limited access to social relations (with a low level of social capital) would be influenced and dominated by the people with higher social capital. Coleman in 1988 developed the concept of the individual benefit of social capital; it provides opportunities and help but also incurs obligations and expectations by the development of trust. Finally, Putman (1997) emphasised the importance of social capital to community equilibrium and development as a benefit that goes beyond the nodes (individuals) of networks themselves. He saw social capital as a way to engage civic society. Nahapiet and Ghoshal (1998) combined these different views and retained the notion that social capital involves much more than the simple benefit to individuals from close links with others. Social capital constitutes a sum of the resources '[...] embedded within, available through and derived from the network [...]'. (Nahapiet and Ghoshal (1998)) A connection between two individuals in a network thus can bring a positive outcome for other individuals. Jackson (2008) defines such externalities in

¹¹ For example, we can read a manual which explains everything on how to use a virus diagnostic test. However, it does not mean that we would actually be able to carry out the diagnosis properly. A way to solve that problem is to carry out the test with someone who has experienced the test, which means someone who has the tacit knowledge related to the test practice.

networks as occurring, ‘when the utility or payoffs to one individual are affected by the actions of others, although those actions do not directly involve the individual in question’.

Social capital thus includes positive externalities. In relation to the topic of this paper, the positive externalities coming from researchers (working on emerging zoonoses), include collaborative networks that deliver to others the benefits of being aware of the situations in other places such as the status of an epidemic in another country, the progress in diagnostic capacity and in capacities that improve prevention and responses to emerging diseases. In addition to the creation of new links with individuals, another way of building social capital is to occupy a strategic position in networks. Burt (1992 and 2001) developed the theory of ‘structural holes’ in networks, which correspond to empty spaces between disconnected segments or groups of people. Those spaces can be filled by individuals, called ‘knowledge brokers’. The social capital represented by structural holes confers on knowledge brokers a double advantage. Brokers find themselves participating in the knowledge flows but also controlling them since they constitute privileged intermediaries between groups of people.

A second notion to consider in parallel with social capital is the concept of communities of practice (COPs). A COP is a group of people engaged in the practice of a common activity and thus who share common knowledge, identity and values. The idea of reciprocity and mutual involvement is present in both the notion of social capital and of COPs (Wenger 2000). In our case, a COP could, for example, encompass microbiologists and immunologists working on Nipah virus vaccine development in a particular country or region. One could think that small groups which share unique norms and values are not so consistent with the new paradigm of global health, in which the objective is uniform views leading to uniform measures worldwide. Abbasi *et al.* (2011) addressed this issue through an analysis of social networks of research co-authorships. They first demonstrated that scholars had a real interest in co-publishing papers (increase their performance¹²), which reinforced the application of Coleman’s idea of the benefit that social capital building has for an individual in the case of scientific research. They also showed that the key to a higher research performance was to develop connections with many distinct scholars and to repeat the cooperation with the same people. That agrees with the previously mentioned need for trust and knowledge transfer between research partners. Finally, the Abbasi *et al.* results suggested that scholars should give priority to maintaining a strong co-authorship relationship to only one co-author of a group of linked co-authors, rather than create many relationships with members of the same group, if they wish to maximize benefits to themselves. This suggests that key organisations or individuals¹³ could serve as unique and sufficient bonds between different communities. In this regard, communities of practice of research on emerging zoonoses could express their own norms and values, but be guaranteed organised dialogue with other relevant groups through these key organisations (nodes), solving the problem of fragmentation (raised above) as a barrier to One Health. Anholt *et al.* (2012) argued in the same direction. They highlighted the role of trusted intermediary actors between groups of researchers in the same field or profession. These knowledge brokers might indeed constitute the solution for effective interdisciplinary collaborations in emerging disease research as part of the One Health pathway.

Building social capital and encouraging the establishment of communities of practice bonded with each other seem to be necessary to achieve One Health objectives. It is nonetheless necessary to go beyond the creation of social links to ensure that the links actually lead to positive outcomes. These links must be associated with the idea of capacity building, raised earlier in the paper. In 1998, Nahapiet and Ghoshal showed the necessity for social capital to drive an organisation to acquire actual learning and innovation. This would only be possible through the transformation of social

¹² The performance was calculated according to the g-index, taking into account the quantity as well as quality of the research.

¹³ The scale of the organisation will be the one retained in the methods for SNA so is more relevant to consider here.

capital into intellectual capital. They defined intellectual capital as a form of capital a social group encompasses in terms of both knowledge and knowing capabilities. They also said that an organisation's intellectual capital is higher than the simple sum of knowledge and knowing capabilities of every participant. This can also be true at a larger scale. Intellectual capital resulting from the links created between research organisations could be greater than the sum of the knowledge and knowing capabilities of each organisation in the network. Intellectual capital thus would be indispensable for making sound science-based policies for management of emerging zoonoses.

I note here the point that network graphs, which are the principal analytical tool of network analyses, have an important limitation. Despite their usefulness to visualize network structures and provide an estimation of the degree of cooperation (by counting the links and estimating the distance between nodes), they do not provide information on the nature of the relationships depicted or show if the people really share norms and values and capacity building. Looking at graphics is not sufficient to determine the existence of real communities of practice and the creation of intellectual capital. That is why interviews with actors (researchers) were also included in this analysis.

3. Hypothesis and methods

The global changes that the world is currently witnessing represent both challenges and opportunities for public health. The challenges reside in the environmental disturbances resulting in the increasing emergence of pathogens, the mal-distribution of the disease burden and the globalisation of health risks. At the same time, the growing environmental consciousness, the democratisation of information and communication technologies and the systemic approaches to research constitute promising opportunities to meet the challenges.

Social network theories and analysis may provide insights into the capabilities and policy needs for the improvement of international cooperation as required by the One Health concept. In this paper SNA has been applied to the study of networks of co-authorships of scientific papers about Nipah virus published in the thirteen years immediately following its discovery (1999 to 2011) to test the following hypothesis:

If the global response to the discovery of Nipah virus in 1998 was shaped by the One Health paradigm, then SNA of scientific co-authorship in the period following discovery should reveal evidence of a progressive increase in the level of social capital for organisations, a greater involvement of interdisciplinary studies and a greater cooperation between organisations belonging to a different fields, a greater involvement of countries around the world and especially of developing countries where the virus could possibly emerge (tropical low and middle income countries (LMIC)), a greater cooperation between organisations of different types (private/public partnerships and with international organisations) and the accumulation of intellectual capital through local capacity building in areas where the virus was found.

4.1. Bibliometric and social network analysis

Publicly available bibliometric information from articles published in peer-reviewed journals was used to analyse the flow of knowledge between scientists involved in Nipah virus research. In the Scopus online database, articles and reviews containing the words 'Nipah virus' in their titles, abstracts or key words were retained and their corresponding data extracted into Excel files. Between 1999 and 2011, the chosen period for the study, 514 such papers were published. From these the affiliation names of 155 authors who published between three and 36 papers each, over the period 1999-2011 were extracted as a .txt file. A hundred and sixty organisations (some authors being related to several organisations) participated in the publication of one to 15 papers each. For the purpose of a time-based analysis, the initial 13 years have been separated into three periods of four or five years: 1999–2002; 2003–2007; and 2008–2011. The 'organisation,' and not the individual researcher, was chosen as the main study unit for analysis because of the difficulty in assuring that surnames are correctly spelled in the journal and thus that papers were attributed correctly to individual authors.

Networks of organisations publishing on Nipah virus were constructed using Pajek, an open source software package for social network analysis¹⁴. Organisations were differentiated according to their academic field, their type of structure and their country's economy. Organisations were sorted into four categories of academic fields: human medicine; veterinary medicine; environmental health (containing ecological and ecosystem studies); and interdisciplinary. The latter was defined as organisations which carried out studies that contributed to at least two of the first three categories. Five categories of structure were defined: universities (universities, schools and colleges); government agencies (national and sub-national public institutes); hospitals (government-funded

¹⁴ Available at <http://pajek.imfm.si/doku.php?id=download>.

hospitals and other medical treatment facilities); private sector (commercial firms, private laboratories and private clinics) and; others (non-governmental organisations (NGO), foundations and intergovernmental institutions such as the OIE). The economic status of an organisation's country was determined according to the 2013 World Bank classification of income¹⁵ which classifies countries into 'high income'; 'middle income' and 'low income'. This categorisation permits clear graphical distinction among these categories in the networks graphs built in Pajek.

The network graphs were sorted by components¹⁶, which allowed a clear visualisation of organisations publishing alone or in collaboration with others, and identified small networks. In addition to the network graphs, the layout option 'circular' was used to draw the same networks but with a separation of the nodes into poles in order to better visualise the links between different fields, types and economies over time. The structure category 'hospitals' was positioned close to the poles 'universities' and 'government agencies' because hospitals belong to the public sector and are often located on university campuses.

After the networks were constructed, the structure and characteristics of links over time were analysed to test the proposed hypotheses, as follows:

- The increase of the global level of social capital was measured by: (1) the degree centrality calculus (which corresponds to the number of links each organisation has on average during one period), and (2) the count of knowledge brokers based on the betweenness centrality measure (BC). This number corresponds to the 'number of times an actor connects pairs of other actors, who otherwise would not be able to reach one another' (Hawe *et al.* 2004; Safahieh *et al.* 2013);
- Greater involvement of interdisciplinary organisations and a greater cooperation between organisations belonging to different fields was tested by analysis of the change in shape of polarised networks over time;
- The increasing involvement of countries worldwide along with an increasing involvement of developing countries where the virus could possibly emerge was measured by the number of countries publishing and observation of their position in the networks (especially the position of developing countries);
- Greater cooperation between organisations of different types was tested by observation of changes in the shape of polarized networks over time.

4.2. Pilot actor interviews

The last component of the hypothesis (transformation of social capital into intellectual capital through local capacity building) could not be tested by observation of the graphs or by centrality measures. Therefore, the issue of capacity building was investigated through the collection of actor narratives by interview. These interviews provided a more anthropological assessment of the feasibility of One Health in practice and of the actors' experiences in scientific collaboration in the field of emerging zoonosis research in general. That is why Skype interviews (or email questionnaires when interviews were not possible) with professionals (researchers or/and government officials) were conducted (see Figure 4.1). The participants were selected according to the fact that they actively participated in Nipah virus peer-reviewed research during the period 1999-2011. Some of the participants were recommended by previous interviewees (snow ball sampling). The participants were from high income countries as well as from regions with limited resources. Interviews and

¹⁵ See <http://data.worldbank.org>.

¹⁶ A group of organisations linked together by the fact they publish at least one paper together.

questionnaires were transcribed into notes and analysed alongside with the social network graphs interpretation.

Table 4.1: Information on the people interviewed

Background/discipline(s)	Organisation	Country of origin	Main collaboration experience
Human medicine, Virology, Pathology	Temasek Life Sciences Laboratory, Singapore	Malaysia	United States, Australia
Biochemistry, Molecular Biology, Immunology, Biophysics – Veterinary Medicine side	Washington State University, US	United States	US/Germany
Human Medicine, Infectiology, Epidemiology, Global health	Stanford University, US	United Kingdom	Bangladesh
Veterinary Medicine, Conservation Biology, Ecology	Colorado State University	United Kingdom	Ghana
Veterinary medicine, Epidemiology	Forestry Commission of Ghana - Wildlife Division	Ghana	United Kingdom

4. International knowledge flows on Nipah virus from 1999 to 2011

5.1. Evolution of the network general structure, degree centrality and knowledge brokerage

After having excluded isolated nodes, which represent organisations that are publishing by themselves, and which therefore provide no information about collaboration, only one large network has been studied overtime. On the graphs in Figure 5.1 the degree of centrality value is represented by a varying size of node. The larger the node, the larger the value of degree centrality and the higher the number of links to the given node.

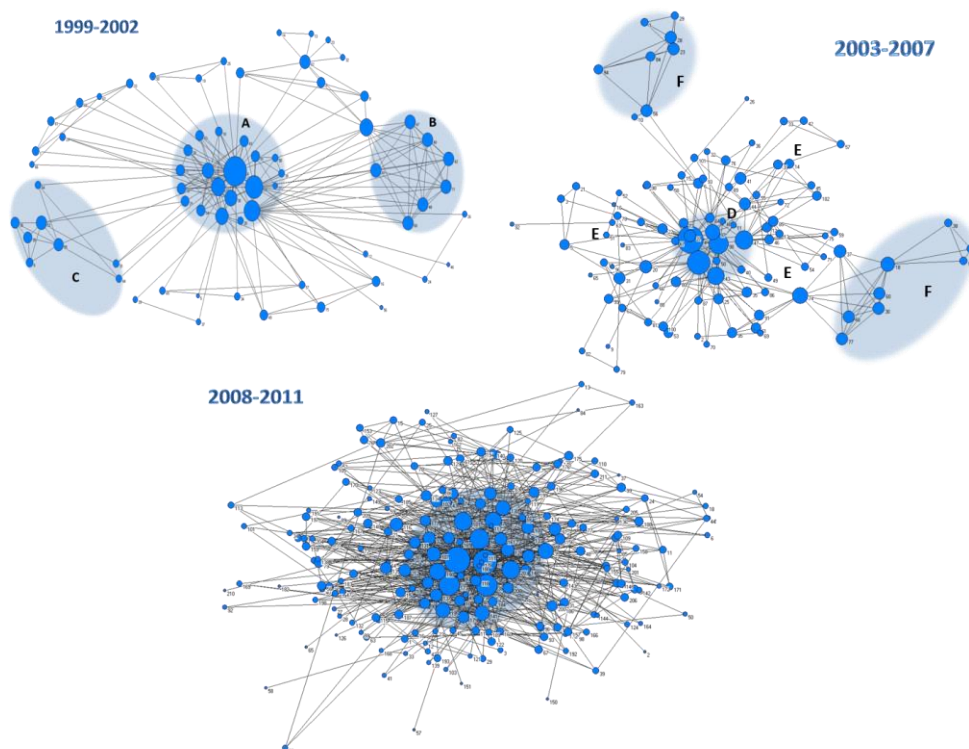


Figure 5.1: Networks of collaborative organisations publishing on Nipah across three periods from 1999-2011

5.1.1. 1999-2002

The collaboration network¹⁷ (containing organisations that co-published) encompasses 68 nodes out of the 114 in total (when including isolated nodes). There is quite a clear distinction between the centre and the periphery (see Figure 5.1.). The organisations that collaborated the most are the Centre for Disease Control and Prevention (CDC), with 40 collaborators, the University of Malaya (24) and the Australian Animal Health Laboratory (19). Their corresponding nodes are the largest in the network. I could identify three groups of organisations that were highly collaborating with each other

¹⁷ For the purpose of this analysis, the networks considered (called 'collaboration network') contain only organisations in which authors do not publish by themselves but in association with authors coming from other organisations.

(nodes of a relatively large size). These are groups of organisations actually located mostly in the same geographic regions (see disks A, B and C in Fig. 5.1). The first group (disk A) is composed of the Centre for Disease Control and Prevention (Atlanta, US) and most of the Malaysian organisations. This is also the most central community in the network. The second one (Disk B) is made up of Australian organisations¹⁸ intensely connected with each other, and also with the University of Malaysia (Malaysia). The University of Malaysia and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) make the link between groups (disks) A and B. The third group (disk C) consists of Singaporean organisations only. Contrary to the 'Australian group' (B), the Singaporean group (C) has no intermediary or knowledge broker. Most of these Singaporean organisations (disk C) also are directly connected to an organisation from the central network (disk A). It is worth noticing the central position of the CDC, while only a few organisations from the United States (US) appear in this network. The CDC seems to have occupied a strategic position of coordinator of the whole network and mainly with actors from low and middle income countries.

5.1.2. 2003-2007

In this collaboration network of 102 organisations (out of a total of 235), there is no longer a separation between organisations in the centre and in the periphery (see Figure 5.1). Instead, the network was divided into roughly three different levels (D; E and F). The first level is the centre of the network (D). It contains the most important collaborators (large size nodes). Again it was found that the CDC (23 collaborators) and the Australian Animal Health Laboratory (31) were among the largest collaborators. The third organisation that collaborates the most is the Pasteur Institute, with 15 partners. This Institute did not appear among the main collaborating organisations during the first period of analysis and represents, therefore, a new European connection in the global network of Nipah virus research. A second level of major players (see E, Figure 5.1) included the University of Malaya, present in the earlier collaboration network, and a new important actor: the International Centre for Diarrhoeal Disease Research (ICDDR) of Dhaka, Bangladesh. Two communities appear at the margin of the network (third level: F), linked to the core (D) by only one or two nodes. They encompass organisations mainly from high income countries (with an important presence of the US) linked with the core of the network by knowledge brokers. The knowledge brokers are organisations that ensure the link between 'external' groups and the core by having a moderate to high degree of centrality. Contrary to the groups identified in the network of the first period, networks in the second period included countries from different continents, which is a sign of collaboration by overcoming geographical, and, probably, cultural distances.

5.1.3. 2008-2011

The collaboration network grew to 212 nodes out of a total of 272 organisations publishing on Nipah (see Figure 5.1). Looking at this last period, we can easily infer that organisations publishing about Nipah virus tended to do so in cooperation with others. The increase of collaboration is seen by the increase in size of the collaboration network involving a greater number of organisations. In addition to getting larger, the network became less dense over time¹⁹ but displayed chaotic links. These results are not surprising since, in a network which contains a greater number of nodes, the probability for the actors to link with each other is lower. Large networks usually appear less dense, which is the case here. Moreover, there is no longer a separation between central nodes and a periphery of the network. Instead, the network appears as a dense web of organisations with a core composed of highly collaborative organisations (large sized nodes) surrounded by a cloud of less and less collaborative nodes when going away from the centre.

¹⁸ Plus one organisation from Papua New Guinea.

¹⁹ The measure of density for the three periods is 0.09 for 1999-2002, 0.05 for 2003-2007 and 0.03 for 2008-2011.

5.1.4. Evolution of degree centrality

The degree of centrality reflects the number of organisational partners within the main networks. The average degree centrality²⁰ was 6.1 for the period of 1999-2002, 4.4 for the period 2003-2007 and 7.0 for the period 2008-2011. The number of collaborators thus decreased and then increased. This is consistent with the observed presence of small isolated networks during the second period of time (not shown here because they not part of what was called the collaboration network). Indeed, there was a trend toward isolated relationships in the second period. By contrast, in the last period, scientists favoured collaboration with well-connected individuals.

5.1.5: Evolution of knowledge brokerage

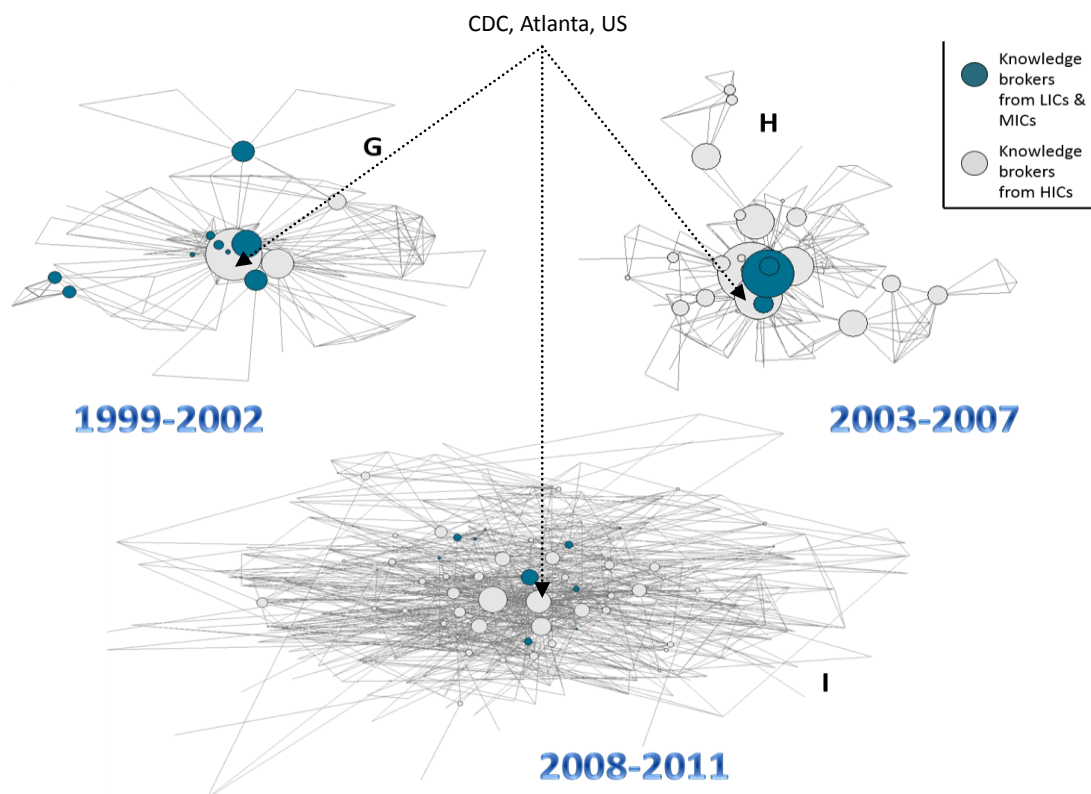


Figure 5.2: Visualisation of knowledge brokers in the collaboration networks of the three periods studied

On the graphs of Figure 5.2, the organisations with a value of betweenness centrality different from 0 (positive) appear as bigger nodes and are considered as knowledge brokers. We see an increase of the number of knowledge brokers (over the overall number of organisations) along with an increase in the number of organisations involved in the network over time. The proportion of knowledge brokers in the network also increased between 1999 and 2011: from 19 per cent during the first period, to 27 per cent during the second, and 34 per cent during the third. This indicates greater links between groups within the collaboration network over time. Note that the Centre for Diseases Control (Atlanta) occupied a very central position in all the three periods. Besides having a high degree of centrality, the CDC appeared also as a major knowledge broker (see Figure 5.2). These two characteristics mean that the CDC was collaborating with many partners to produce knowledge on Nipah, while linking together groups working on Nipah, the two functions appearing as essential for the application of One Health. Knowledge brokers became more abundant over time which made the

²⁰ Equal to the overall average of the number of links by organisation (sum of the number of links for each organisation divided by the number of organisations) that is to say the number of collaborators by organisation.

individual importance of each broker reduced over time. That is to say, the power of knowledge brokerage became divided among a greater number of actors, making the network less dependent on a few knowledge brokering organisations.

As seen on Figure 5.2, fewer developing countries (represented by low income countries (LICs) and middle income countries (MICs)) played the role of knowledge brokers over time. Because of the emergence of Nipah virus in Malaysia, Malaysian universities and Government agencies were acting as knowledge brokers during the first period of publication (darker nodes) on Figure 5.2 - G). However, from 2003 on many fewer organisations from LICs and MICs maintained such positions in the network in the second and third periods (networks H and I). The proportion of developing countries involved in knowledge brokerage decreased over time (13 per cent in 1999–2002, 4 per cent in 2003–2007 and 6 per cent in 2008–2011). Note that the ICCDR was one of the last organisations from the low and middle income countries remaining as an important knowledge broker.

5.2. Evolution of the network composition

5.2.1. Evolution of scientific collaborations by field

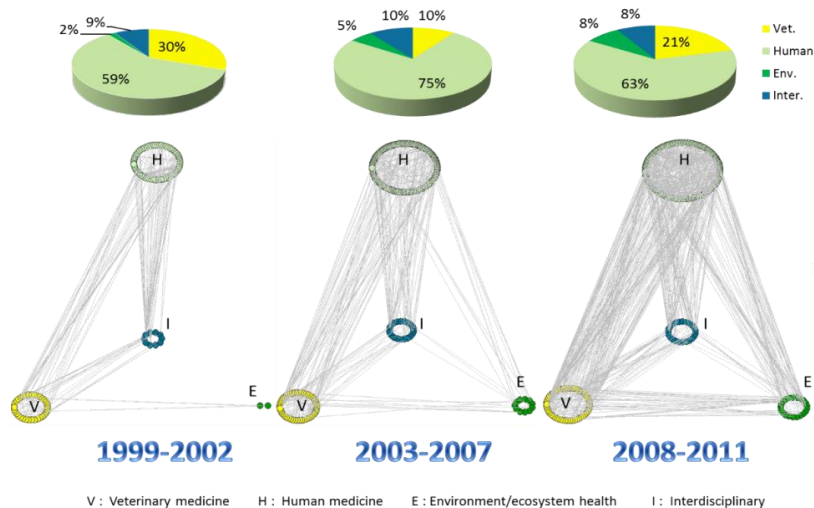


Figure 5.3: Polar representation of networks according to field

The evolution of the structure of polar graphs for the three time periods (Figure 5.3) indicates an increase over time of the level of cooperation between each of the three research field categories since the number of links is greater for the second and third periods. An increase of the collaboration among organisations belonging to the same field category is especially visible within the animal and human medicine areas. The absence of links between the medical and environmental poles when researching on Nipah began (1999–2002), indicates a lack of cooperation between those two scientific fields. Nevertheless, this cooperation slightly improved during the period 2003-2007 and was strengthened during the last period (2008–2011). Each of the field categories witnessed an increase in the total number of organisations active in Nipah research publication. It can be noted that the central category of interdisciplinary research grew in parallel with the other field categories (animal, human or environmental health) and in parallel with the recruitment of new organisations. This is the case notably for the EcoHealth Alliance (United States), the Queensland Centre for Emerging Infectious Diseases (Australia) and the Research Group for Emerging Zoonoses (Germany).

These organisations displayed a clear willingness to integrate several disciplines into their research work but still represent a small number of organisations.

However, if we look at the proportions of organisations engaged in Nipah research by field category, there is no linear evolution. As a matter of fact, the human medicine category was largely predominant during all 13 years but varied from 59 per cent of the total of participating organisations in the first period, 75 per cent in the second and 63 per cent in the third. In parallel to this, the field category of veterinary medicine followed the exact inverse pattern: from 30 per cent during the first period to only 10 per cent during the second and 21 per cent during the third. The environmental health research category followed a different pattern, increasing progressively across the years (2 per cent → 5 per cent → 8 per cent). Finally, the proportion of participating organisations in the interdisciplinary category did not vary much compared to the other field categories, staying between 8 per cent and 10 per cent.

5.2.2. Evolution of scientific collaborations by economic status

Figure 5.4 shows that the proportion of participation by low and middle income countries decreased from 1999 to 2007 (from 36 per cent to 24 per cent) and stabilised until 2011 (24–25 per cent). This means that HICs became more important in the network over time. Also, organisations from LICs only published in association with HICs. Similarly, most organisations from MICs depended on high income countries to publish. We can note that organisations from Cameroon, Madagascar and Cambodia were connected with each other and with actors in France during the period 2003–2007. All three are former French colonies and partially French-speaking countries. By contrast, Ghana (when entering the network in 2008–2011) was collaborating with English-speaking countries such as the US, UK and Australia.

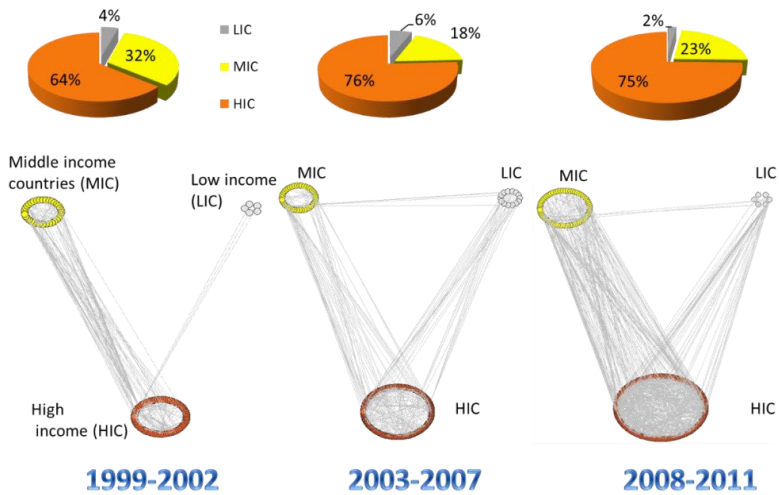


Figure 5.4: Polar representation of networks according to economic status

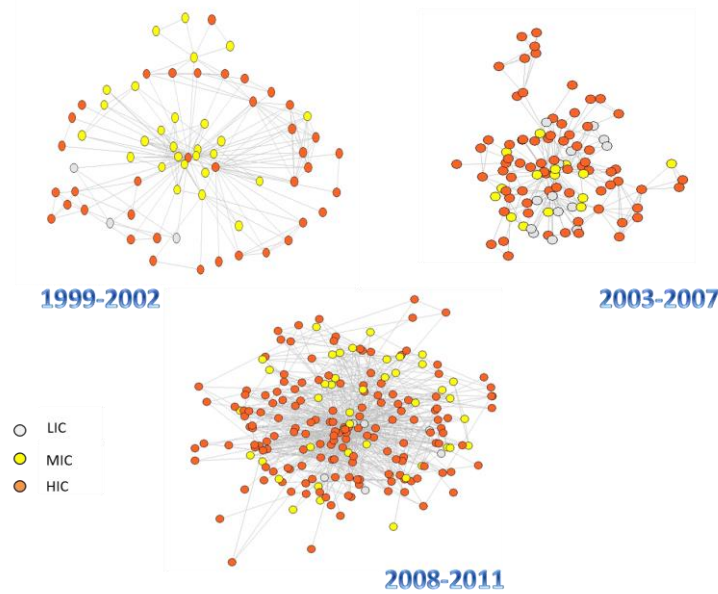


Figure 5.5: Collaboration networks of organisations publishing on Nipah differentiated according to their country's economic status: high, middle or low income

On the graphics in Figure 5.5 we see that, in 2008–2011, LICs and MICs appeared far more at the edge of the main network than in previous periods/years, which indicates that they no longer occupied a central position in the network in the third period. On the polar graphs, we see that the organisations from LICs did not publish in collaboration with the middle income countries during the first period of analysis. Then, a few links appear in 2003–2007 but diminished in 2008–2011, whereas the cooperation between organisations from HICs with the other two categories was strengthened over time. To sum up, actors from LICs and MICs tended to be dependent on those from HICs for publications, and this explains a poor level of cooperation amongst themselves.

5.2.3: Evolution of scientific collaborations by type of organisation

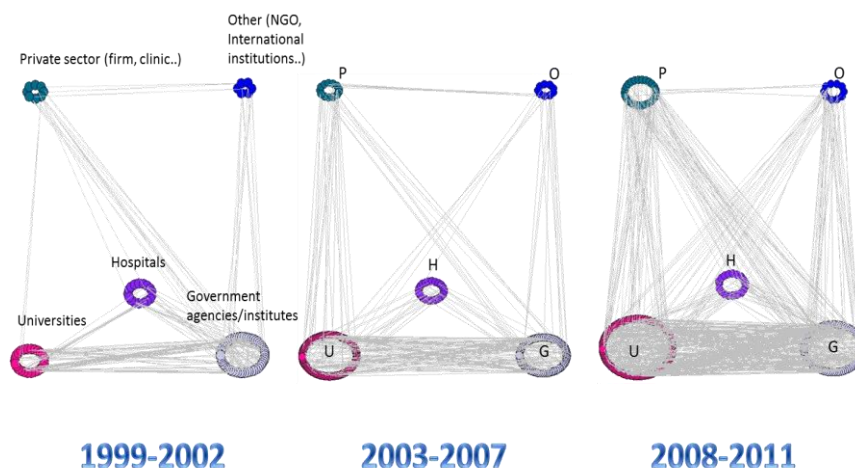


Figure 5.6: Polar representation of networks according to type of publishing organisation

Figure 5.6 presents the polar view of networks of organisations sorted by type (government, university, private sector and others) over time. During the first period, there was an important

involvement of government agencies, which published mainly with universities and hospitals. There were only a few links between the private sector and universities, as well as between the private sector and other types of organisations, whereas private organisations had more connections with government agencies. Notice that there are no collaborations between organisations classified as 'other' type (which includes international organisations for public health, NGOs and military departments) with universities nor with hospitals during the first period of time, nor with hospitals during the three periods.

By 2003, all types were connected with each other. There was a much greater relationship between the private sector and universities, the latter still intensely involved in cooperation with government institutes. The number of links increased over time, with more governmental organisations and universities involved (larger circles U and G from the period 2008–2011 in Figure 5.6). In the same way, the number of private organisations working on Nipah was higher during the last period of time, whereas the number of hospitals (H) and 'other' (O) types of organisations showed little increase in collaborative publishing.

5.3. Nature of collaborations and related needs and opportunities for future improvements

Interviews with participating scientists provided insightful narratives about the nature of national and international scientific collaborations among researchers publishing on Nipah virus. By combining these stories with the analysis of network structure strengths and gaps in the past and current collaborations on Nipah virus considering the framework of One Health have been identified.

5.3.1. Nature of collaborative relationships

One of the questions raised during the interviews was: 'What makes researchers collaborate with each other?' 'Breakthroughs come when mixing disciplines, as we do here for physics and biology,' said a biochemistry engineer working at the School for Global Animal Health, Washington State University. He added that, considering research in general is highly specialised nowadays, collaboration is indispensable in order to mix disciplines. The necessity of joining various understandings and domains of expertise if researchers are going to produce new knowledge about novel pathogens has been pointed out. Similarly, and across interviews, it appeared that international collaborations are essentially initiated by following person-to-person meetings, usually established through professional gatherings (at international conferences for instance) or through existing personal friendships.

'Working in collaboration requires being open minded and creative', said a study participant. The quality of communication between experts from different fields is said to be much lower than is the case between people sharing the same speciality. Despite the fact that interdisciplinary cooperation requires time dedicated to understanding different professional languages and framings, it appeared to the interviewees to be also challenging for their career and 'quite exciting'. In addition to their willingness to create new knowledge for the benefit of the public, interviewees declared gaining intellectual development and happiness out of collaborative experiences.

The facilitating role of modern information and communication technologies was raised several times during the interviews. It facilitates finding experts but also maintaining relationships across spatial distance. Interviewees mentioned that regular paper co-writing and peer-reviews without any direct verbal contact was possible. Nevertheless, relationships based on person-to-person and informal contacts were considered crucial for building trust and long-term fulfilling cooperation. Ease of travelling to any part of the world was also acknowledged as being very important, especially for attending conferences abroad.

5.3.2. Barriers to international collaboration

The process of entering into and developing collaborative relationships has a cost, as seen in the previous paragraph. Beside the time and energy it can require, the interviews revealed that associated disincentives can actually prevent researchers from getting involved in knowledge sharing with others, especially with those who are distant geographically or in different scientific disciplines. The risk of conflicts around authorship involving mainly scientists from HICs was raised by the interviewees in this study. 'Some people are scared that they will not get credit for collaboration', suggested a participant.

A bad collaborative experience in the past can also strongly affect a scientist's willingness to put trust in foreign researchers in the future. This typically used to happen when 'Western' organisations travelled to developing countries to take virus strains from local laboratories back to their own labs. No benefit was perceived by local scientists, who somehow felt abused. Another disincentive to engage in collaborations concerns scientists who are at an early stage in their careers and in new positions. According to an American researcher at Washington State University, being new in an organisation limits a scientist's capacity to collaborate with academics from different fields. A participant mentioned:

Even if I would like to work more with epidemiologists or economists, as an assistant professor, I need to stay focused on what I am stronger at, because promotions, publications and grants all depend on me being productive.

The same participant pointed out that possible collaborations could make him spread out his efforts, preventing him from becoming productive in his own specific area, and not being rewarded for that work. Finally, sometimes, even within a given organisation, co-workers may know each other in an informal way and cultivate friendships but nonetheless be quite ignorant of their colleagues' skills and work interests. Seemingly easy opportunities for collaboration like those can be blocked due to a lack of communication and encouragement within the work place.

The importance of hierarchy in some countries also has been identified as a barrier to international cooperation. In Bangladesh, for instance, it was highlighted that government employees tend to focus on their own ministries in order to get rewarded and promoted. 'It was a big challenge to get the Ministry of Fisheries, Livestock and Forests, and the Ministry of Health to collaborate at the time the country was experiencing avian influenza in 2007', said an interviewee. Since then, programs have been put in place to reinforce communication between ministries in Bangladesh and a recent field epidemiology training programme for outbreak investigations gathered trainees from the Health Ministry as well as the Livestock Ministry in order to build personal relationships, so that collaboration becomes a reflex during future outbreak investigations. In Ghana, the very hierarchical government structure has caused communication issues, missed opportunities for international research support and some hostility from officials towards local scientists collaborating with 'Western' research organisations.

5.3.3. Collaboration: downsides and pay-offs

Once established, maintaining partnerships represents a big challenge, as the engaged people want to meet in order to benefit from their investments. This is especially the case for 'North-South' collaborations, which often bring together people with different resources, cultures and interests. What appears in the analysis of network structures is also reflected in interviews with researchers from Ghana and Malaysia. International funding can slip from local scientists' grasp in low and middle income countries, and so is seen as monopolised by HIC organisations. A danger of this is that international collaboration indirectly leaves aside LICs and MICs' priority needs because research would only be framed by HICs' views.

Two cases from the interviews are instructive. The first is the case of Bangladesh, where human infections with Nipah virus were first recognised in 2001, and where the local institutions have contributed importantly to research projects. Even so, 85 per cent of the research budget has come from US government funds and only 15 per cent from Bangladeshi authorities. It is important to note that the Bangladeshi Government led outbreak investigations since the beginning²¹. Thus, while not being part of research budgets, Bangladeshi teams have provided substantial workforce and infrastructure to make investigations possible. Bangladeshi authorities, as well as the general public, needed to understand what was happening and what agent was responsible for the disease and that is why they were involved in the research process. Americans (mainly from the CDC) came as helpers to face this quite new danger by gathering resources (staff and money) in order to react early and limit the number of casualties.

In Ghana, in contrast, no outbreak of Nipah virus has ever occurred and therefore Nipah infections do not constitute a priority for government agencies, scientists or farmers. Local organisations nonetheless facilitate and actively support foreign research teams investigating the presence of the virus in different species of animals in Ghana. However, for Ghana, current neglected infectious diseases like 'peste des petits ruminants' which cause losses in livestock constitute higher research priorities for animal health. Thus, the priorities of HICs (emerging viruses like Nipah) and of Ghana (tropical livestock production) are not aligned and this makes collaboration difficult.

The discovery of new Nipah virus strains in a new geographic region constitutes a good opportunity for funding and academic achievement for Ghana's own scientific community. Yet, this kind of work is almost exclusively carried out in Ghana by scientists from HICs. As a consequence, the synthesis of complex products such as new therapeutics or vaccines also is occurring mainly in 'Western' laboratories, preventing LICs and MICs from benefitting commercially from the research on health issues occurring in their country.

Interviewees' narratives also revealed information about the real advantages for the parties engaged in collaborations, even if the outcomes often do not appear immediately but rather in the long run. For example, Ghanaian scientists are said to have accumulated knowledge and skills from years of international cooperation around emerging zoonoses like Nipah. While Ghana would probably not be able fully to manage or control human outbreaks by itself, intra-national actors who are already linked to international organisations would know who to contact to ask for help in crisis time and before the spread of disease. On-going partners would provide assistance immediately, cutting across the time-consuming processes of formal international requests and partnership building. Western organisations also believe in helping researchers from low and middle income countries to value their profession, which may be relatively underestimated in their own country's institutional system.

²¹ Since 2005, the samples are no longer sent to US laboratories and the diagnostic work is carried out in Bangladesh.

5. Discussion – conclusion

6.1. Support for initial hypotheses

First, this study has shown an increase of the level of social capital over time, since between 1999 and 2011 the number of collaborators by organisation (measured by the degree centrality) has increased. Although this augmentation was not linear (with a decrease in the period 2003–2007), the evolution of research networks on Nipah has allowed scientists to accumulate social capital, though unevenly as between HICs and LMICs. In addition, the observed increase of the number of knowledge brokers, along with the growth of the network, shows that more scientists were connecting with otherwise isolated groups of researchers in 2011 than at the beginning of Nipah virus research in 1999.

Second, the involvement of interdisciplinary organisations increased slightly in this period and was coupled to greater cooperation between organisations belonging to different field categories over time, which was identified as crucial by interviewed researchers to advance knowledge on Nipah and emerging zoonoses in general.

The third hypothesis, a greater involvement of developing countries, has been refuted by the results. In fact, despite the overall augmentation of organisations from LICs and MICs, the latter became less important in proportion to the HICs over time, and difficulties in integrating networks are also reflected in the qualitative data.

With regard to the fourth hypothesis, this study has shown increased cooperation between organisations of different types since 1999. Despite the persistence of a weak relationship between international or non-governmental organisations and the private sector, there is evidence of more public-public and public-private partnerships.

Finally, according to the selection of actors' narratives, there has been an accumulation of intellectual capital through local capacity building, though only in some places like Bangladesh, where research appeared as an immediate necessity. However, the extent to which it occurred could not be assessed by this study and would need further research. Less evidence of real capacity building has been shown in other places, such as Ghana, where no outbreak has been diagnosed yet and therefore Nipah did not represent a priority for research.

6.2. Evolution of Nipah virus research networks: General features and their alignment with One Health

This network study, offering both quantitative and qualitative analyses combined with deeper qualitative enquiry, brings insightful conclusions about research on Nipah and its consistency with the One Health concept (summarized in Table 6.1). The study also raised more general questions about network construction patterns and the evolution of scientists' social capital. It also facilitated discussions about such networks' future regarding the One Health framework.

6.2.1. Network development

The place where Nipah virus emerged was a major feature determining the construction of networks around the pathogen. As observed in this study, Malaysia initially occupied a key position in the network. In addition to being very central in the network, Malaysian organisations were knowledge brokers who created the links between other scientific organisations before 2011. Notably, the University of Malaya was one of the last organisations from LICs or MICs that remained an important knowledge broker. Associated with the fact that low and middle income countries were progressively displaced from the centre of the network, they appeared always very dependent on high income

countries to publish. This finding was already raised by Safahieh *et al.* (2013) when they noted that developing countries were not publishing massively, but when they did they collaborated a lot. These observations raise concerns about the potential exclusion of LIC and MIC from knowledge flows on Nipah, even if quite important amounts of research are still carried out in these regions.

Table 6.1: Main features that characterises Nipah virus scientific cooperation networks from 1999 to 2011 relevant to the application of One Health

Network features that favour One Health approaches	Network features that impede One Health approaches
<ul style="list-style-type: none"> • Internationalisation of communities of practice over time • Increase in cooperation between fields • Increase in cooperation between types • Increase in cooperation between countries of different economic statuses (especially between MIC and HIC) • Decrease in network density over time (evidence of openness to new norms and ideas) • LIC and MIC in which outbreaks occur are central in networks 	<ul style="list-style-type: none"> • The rate of interdisciplinary publications does not increase • The Environmental Health field still weakly involved in cooperation • Over time, developing countries were pushed away from central positions in knowledge flows; research followers more than leaders (lack of access to research grants) • Communities of practice are mainly linked by HIC which control the passage of knowledge (brokers) • Very little cooperation within and between LIC and MIC

What if the disease had emerged in a high income country? Would it mean that the network would encompass almost exclusively organisations from HICs? Based on my analysis, this seems possible. Yet, it would not mean that the risk would not also be present in LICs and MICs and that research would be needed in these regions as well. The gap in economic resources between countries like the USA or Australia and the LICs is enormous and emerged as a key barrier to research in LICs during the interviews. This resource gap impacts hugely on the capacity of LICs and MICs to react to the emergence of a disease. In the case of Nipah, organisations coming from these two high income countries were present at the beginning to help investigate the unknown pathogen in Malaysia and Singapore.

The central and knowledge broker positions that the HICs quickly come to occupy in networks of response to emerging pathogens also implies a great responsibility to ensure the establishment of solid networks. These western organisations can and should be the guarantors of the wide dissemination and sharing of new knowledge about emerging pathogens across the world where it could be needed. They should also accept their responsibility to encourage interdisciplinary contacts. Keusch *et al.* (2009) support this idea by advocating that the US Government:

[...] has a considerable stake in preventing the emergence and limiting the spread of zoonotic diseases, it should lead efforts to coordinate a globally integrated and sustainable zoonotic disease surveillance system.

But this responsibility might not be taken, especially after outbreaks are contained in a certain part of the world. The very important role of the CDC (Atlanta), for example, was highlighted by this study. This organisation is responsible for public health within the US Government and has a particularly

important position regarding emerging zoonoses. The CDC publishes the peer-reviewed journal 'Emerging Infectious Diseases' which is a monthly open access journal incorporating international authors and reviewers. This journal confers a valuable power for the CDC to link with scholars around the world.

The presence of national clusters at the birth of the research on Nipah (1999-2002) is an interesting point to analyse. Clustering of communities can have different implications for knowledge management of a zoonosis soon after its emergence. Clustering can provide assets as well as drawbacks. In his reflection on social and intellectual capital, Coleman (1988) considered the role of 'closure'²², which characterises a group of highly clustered nodes. He pointed out that closure can induce the 'enforcement of prescribed behaviour' by coordinating sanctions against actors who deviate from the social norms prevailing within the cluster. This implies a hindrance to acceptance of new ideas and innovations. As a result, for example, information about what happens in some regions of the world might not reach the other parts. This goes against the principle of global sharing of knowledge, as required by One Health. Moreover, the inability to be open to new norms throws into question of the possibility of cooperating with research organisations from different cultures and regions, which is also a challenge to One Health. Nonetheless, this type of closed social group allows efficient spread of information among its internal actors. In other words, closure brings advantages as well as disadvantages. There are direct implications for zoonosis emergence research in this consideration of closure. The ability of closed communities to circulate information rapidly and efficiently is indubitably an asset for interdisciplinary cooperation and the dialogue with policy makers within a country, but it also represents a barrier for international cooperation. In the case of Nipah, network maturity opened up national clusters that allowed international expansion.

6.2.2. Evolution of social capital and diversity of collaborators

The results of my analysis indicate that social capital evolved in parallel with the development of positive collaborations. First, researchers became integrated in small networks involving a few organisations, which did not allow them to increase their social capital but did allow them to create strong relationships which can be considered as forming communities of practice. These small networks progressively joined others to form bigger networks. The augmentation of the number of knowledge brokers allowed the augmentation of the links between communities of practice along with the recruitment of new organisations over time. This implies a better circulation of knowledge among scientists in the more recent years. Moreover, results of this study indicates that these improved knowledge flows became distributed more widely across countries by 2011, as shown by national clusters being transformed into international communities over time. This means knowledge on Nipah was shared with countries not directly involved with the epidemics and therefore made accessible to researchers in different regions of the world. In addition, a decrease of density over time meant less closure of networks, potentially better acceptance of new ideas and cultural differences, and facilitation of integration of new actors, all this potentially leading to innovative initiatives in research on Nipah. One could assume that the quality of research on Nipah increased due to the involvement of diverse actors across the world, as it is supported by One Health advocates.

Looking at the participation of different fields also informed how research on Nipah was done in the respect of taking the direction of One Health. The growth in the human medicine field category coupled with a decrease in the veterinary field category certainly was linked with the fact that Bangladesh faced human cases involving person-to-person transmission starting in 2001. Subsequently, the search for the virus outside Asia and in wild species (especially bats) led to a greater involvement of environmental and veterinary field categories. Nonetheless, the medical field category was and remained the dominant player in Nipah virus research. This too may have

²² Network closure means a particular configuration of network in which all actors are connected 'such that no one can escape the notice of others' (Burt 2001).

implications for implementation of the One Health concept. Some authors writing about One Health note that physicians often are less motivated than veterinarians and ecologists to cooperate with other disciplines (Leboeuf 2011). The absence of significant growth in the 'interdisciplinary' field category will be disappointing to those wishing to implement One Health practices. This result indicates that more efforts are needed to persuade experts from different fields to collaborate. The fact that the private sector did not play a big role in the research networks on Nipah also is disappointing since a greater enrolment of multiple actors such as private clinics and industries is also central to One Health (Leboeuf 2011).

6.2.3. Long term future of Nipah networks

As noted above, the knowledge broker position within networks of some particular organisations confers on them a certain power to control knowledge distribution (Burt 1992 and 2001). This paper suggests that this might impose particular norms and values, and condition international policy making, in the public health domain. As it is argued in Chapter 4, this becomes a problem in equitable knowledge sharing and policy making when low and middle income countries find themselves excluded from these key positions. This probably happens because of the lack of interest by scientists in HICs to collaborate with organisations with limited scientific capacities or their staff with a limited expertise, as could be the case for organisations in LICs and MICs, and this despite the motivation showed during interviews with researchers from LMICs. This can represent a risk that the established norms of scientific practice and public health policy, dominated by the priorities of HICs (namely acute infectious of pandemic potential), will not match the needs of the developing regions (Kickbusch 2002; Ollila 2005).

This concern is also linked with the idea of redundancy, another cause of network failure in addition to closure. The term redundancy here is used to qualify a network which links only organisations already sharing the same views or cultural background. Reagans and Zuckerman (2008) show that a network strategy based on redundancy implies avoidable social distance within a network and is not a good strategy for actors to benefit in participating to the network. A redundant network loses capacity to create new knowledge outside of its areas of commonality. Redundancy pushes networks toward disciplinarity and geographic isolation, and perhaps, thus, toward failure with respect to responding to emerging diseases in a manner consistent with One Health.

Capacity development, where needed in LICs and MICs, is crucial in order to retain them in networks. Also, as suggested unanimously by the scientists interviewed, a better allocation of international funding directly to local research organisations might lead to the creation of 'south-south' partnerships and give a real comparative advantage²³ to LIC and MIC research and therefore reduce their dependence to HICs. Actions like the support of the scientific independence of low and middle countries can contribute to orienting the research agenda toward the priorities of these countries. NGOs such as 'Planet Earth Institute' (PEI), which is claiming a leading role in scientific research and technology development in Africa for low and middle income countries, are already taking this step. PEI gives major importance to building research capabilities in LICs and MICs within its international collaborations. This work has highlighted the importance of the epidemiological and ecological features of the pathogen (from the network analysis) as well as the pre-existing social links between individuals (from the interviews) to explain networking processes. The complexity of these two parameters (pathogen biology, human social) makes their interactions in the evolution of scientific networks impossible to predict in detail. Nobody knows where the next outbreak of Nipah will occur and, depending on location (UK versus Ghana, for example), different countries will play important early roles leading to completely different network configurations. Thus, predicting the future evolution of social Nipah science networks is difficult. Nonetheless, from the analysis presented here,

²³ A term employed in economics for a specific capability of an agent to produce a good efficiently which makes it attractive to commercial partners.

the key actors, such as knowledge-brokers, have been identified and a pattern of network evolution over time has been discerned. Furthermore, positive and negative outcomes with respect to the effective application of One Health principles can be attributed to certain characteristics of scientific knowledge networks by cautious extrapolation from this study of Nipah. This opens up possibilities for international health management organisations (WHO, FAO, OIE) to adopt policies and procedures for management of future responses to new emerging disease outbreaks that are informed by such social network analysis. This also favours One Health-friendly characteristics in scientific networks that evolve around emerging disease issues. Policies might include capacity development and funding of research in LICs and MICs local institutions as high priorities. On another level, it is reasonable to predict, based on current biological knowledge, that Nipah will be recognised as a pathogen of people in Africa. Based on experience in Malaysia, Singapore and Bangladesh, we can expect new African actors involved in Nipah networks, since Old World fruit bats, the wild reservoir of the virus, are present in all of sub-Saharan Africa. The initial Nipah network existing already in Ghana because of exploratory research may point to additional opportunities to build capacity and networks in Africa in reasonable anticipation of the emergence there of Nipah and other emerging human pathogens such as Ebola.

6.3. Supporting international collaboration networks to address emerging zoonoses

The findings of this research suggest that, to improve global capacity to respond to emerging diseases, the international community should encourage scientific collaboration. One of the big challenges, to international and interdisciplinary cooperation, identified thanks to the interviews, is the individualistic reward system of academia and research in general. Researchers are trained to become good specialists but are not encouraged to spend time and energy on a broader interdisciplinary view. Building social capital and communities of practice requires individuals to embrace collective approaches based on mutualism or solidarity and not individualism as it is seen in societies with a modern economic system based on capitalism and individual interests (Lomas 1998; Hislop 2013). However, everyone cannot form partnerships with everyone else, especially if trust is needed to maintain the relationship. Some connections might be easier to sustain than others, as this network analysis showed by discerning the influence of common cultural background (such as language or historical links) on the establishment of partnerships.

Furthermore, research networks should be enhanced only if there is a benefit for the community. That is to say, the cost of forming networks must be lower than the value of the benefits it provides. Social network analysts have shown through models that, beyond their own immediate links, actors can experience benefits as their linked neighbours form more links, or even if other indirectly connected actors form more links (see Jackson 2008: 208). This theory suggests a form of positive externality in networks as individuals can benefit from the fact that other individuals have connections. Individual actors in a network usually do not account for the indirect benefits that their connections bring to their neighbours. In this sense, incentives for selfish behaviour can lead to inefficient networks. That is to say, an individual considers whether his or her payoffs will increase when forming a network link but does not really pay attention to whether or not the link would increase the payoffs of other actors in the network.

The case of co-authorship networks offers a good illustration of this concept. Jackson and Wolinsky (1996) created a model of network payoffs called the 'co-author model' which introduced the notion of negative externalities due to links. It relied on the fact that a given individual would rather that his or her neighbours have fewer connections than more connections. In collaborating on a research project, individuals benefit by having the other player interacting with others. Beyond the benefit of having the partner dedicate time into the project, there is also a form of synergy, proportional to the amount of time the two researchers devote to the project. The time that researchers spend on a given project depends on the number of projects in which they are involved. Consequently, the more

projects each has, the less synergy is obtained through each project. Based on this model, the scientific community concerned by emerging zoonoses should be organised in networks that allow researchers to be linked with only a few key partners and in ways that build solid and long-term relationships, exchanging tacit knowledge and building specific capacities where needed.

6.4. Study limitations

Scopus generated an abundance of bibliometric information that required a large amount of work in sorting and cleaning the data. Due to the lack of time, interviews had to proceed in parallel with the network analysis. It would have been better to have analysed the networks prior to conducting the interviews in order to identify more precisely the information needed to better understand the observed network relationships. A greater number of interviews would have brought more insights in this regard.

No assumption could be made about the translation of the knowledge embedded in the networks analysed in this study into actual policy because the data analysed did not include the flow of knowledge from research to policy.

There may have been a bias in the selection of interviewees as, in retrospect, the scientists interviewed probably were the ones who publish the most with co-authors from low and middle income countries. In addition, due to snowball sampling, the participants might have been biased in the sense that they already collaborated with international scholars. Separate categorisation and analysis of papers aiming to contribute to fundamental research compared to applied/policy-oriented research that might have brought insights on the role of particular countries, regions or organisations was omitted from the current analysis. However, such categorisation would have required detailed reading of the articles included in this analysis, which was not possible within the study timeframe.

6.5. Future directions

In the context of emerging zoonoses, the separation between scientific research and policy making may in fact be quite thin. In health crises, response actions must be taken before there is time to launch research projects that need long preparation and many resources. Disease outbreaks need to be quickly identified and prevented from spreading. Therefore during a health crisis, scientists and policy makers can find themselves brought together very quickly. That is why one can consider the study of emergent zoonosis research networks also as a study of real 'governance networks'. Torfing (2005) synthesized the literature on governance network theory and provided a condensed definition of governance networks. According to him, governance networks involve

[...]relatively stable horizontal articulations of interdependent, but operationally autonomous, actors who interact with one another through negotiations which take place within a regulative, normative, cognitive and imaginary framework that is self-regulating within limits set by external forces and which contributes to the production of public purpose.

(Torfing 2005)

Governance networks imply that 'no single actor can exercise their power to exert hierarchical control over anyone else.' (Torfing 2005: 307) Instead, the members of the network interact through negotiations combining elements of bargaining and deliberation that facilitate trust creation, knowledge exchange and common understanding.

It is fair to question the practical reality of the principles inherent to these governance networks with respect to management of emerging zoonoses. According to the One Health concept, instead of many sparse COPs, it would be ideal to have an international one, in which people share knowledge on a

large scale. But, in the opinion of the author, this goal is unrealistic since even the concept of COPs involves informal interactions between people who know each other. In 2008, Schmoch and Schubert wrote:

The successful organisation of an international cooperation is more demanding than that of a purely national one. This substantial investment may only be undertaken if a high payoff is expected.

Instead of a unique worldwide community, we can support the development of localised communities of practice with their own values on how to apply One Health. These communities would differ according to different cultural and historical background and politico-economic contexts. However, if properly connected with each other, it would not prevent them engaging in a coherent global action. So, links need to be encouraged. But it is not only about increasing the level of social capital, it is also about identifying communities of practice and linking them in an appropriate way. A study now underway of how policies are framed in a country according to various social influences (corresponding to various communities) may help understand a potential lack of coordination internationally in the management of emerging zoonoses. Another important aspect that has to be considered is the actual knowledge transfer and transformation of social capital into intellectual capital/local capabilities for countries which lack economic capital.

Finally, scholars talk about social capital as a useful resource in a world where strong economic inequalities remain. Indeed, in order to prevent a pathogen infecting new susceptible species or spreading geographically, countries have to reach high levels of permanent awareness of the circulation of pathogens. Besides, as this study shows, social capital can also be determinant for mobilising international partners in response to an outbreak. We should thus invest in social capital which might, in that regard, offer opportunities for improvements in preparedness and appropriate rapid responses without the large pulses of financial resources usually required for reacting to an outbreak. This view implies, in my opinion, a considerable opportunity for low and middle income countries, in which economic resources are few but social links are usually strong and tight (Valeix 2012). This point is consistent with the fact that researchers from LICs and MICs published mainly in large teams of collaborators (Safahieh *et al.* 2013). If scientists from LICs and MICs have more connections with other scientists around the world, they can serve as knowledge brokers needed by the whole scientific community.

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