

Building bridges to protect health

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This paper describes work under a Fellowship in Public Policy centred on enhanced partnerships among human, animal, and ecosystem health sectors in New Zealand.¹ The outcome of the project is a guide to help protect the health of New Zealand's people, production animals, wildlife, and environment by urging and guiding transdisciplinary interactions (Harvey 2010a).²

Setting the context for connected health³

The *One World, One Health* paradigm is a global initiative that acknowledges the health interdependence of humans, animals, and ecosystems (Food and Agriculture Organisation of the United Nations, FAO; World Organisation for Animal Health, OIE; World Health Organisation, WHO; UN System Influenza Coordination; United Nations Children's Fund, UNICEF; World Bank 2008).⁴ Despite the interdependence of human, animal, and ecosystem health, communication shortfalls between disciplines have led to unnecessary health, environmental, and economic burdens. The organisations designed to protect health within each discipline often fail to communicate with one another about threats that are shared across disciplines. Cohesive policies that weave together veterinary, human, and ecosystem health efforts are urgently needed as demographic changes and altered land-use practices further stress ecosystems and introduce opportunities for communicable diseases and other threats to emerge. For such partnerships to occur, the context must be set for connected health.

Zoonotic diseases

Infectious diseases account for a substantial health burden worldwide, causing approximately one-quarter of all deaths according to WHO estimates (WHO 2008). The burden is substantially attributable to established infectious diseases such as common respiratory infections, diarrhoeal diseases, HIV/AIDS, tuberculosis, and malaria.

In addition to diseases that are well-established, new or previously under-control infectious diseases emerge to cause illness in humans. These include SARS, 2009 H1N1 influenza, and

antimicrobial-resistant pathogens. A 2008 *Nature* paper estimated that 335 new infectious diseases emerged in humans between the years of 1940 and 2004 (Jones *et al.* 2008). If adequate surveillance or control mechanisms are not in place to detect and mitigate new infectious diseases, these emerging infectious diseases become established. We have observed this scenario with HIV in our lifetimes and are watching this unfold with the increasing spread of antimicrobial resistant pathogens.

Zoonotic pathogens—organisms that transmit from animals and cause disease in humans—account for three-quarters of emerging infectious diseases in humans (Jones *et al.* 2008). In addition to SARS, influenza, and HIV, other examples include Ebola, Q-fever, Nipah virus, and *E. coli* O157:H7. The list continues.

A 2008 National Academies' workshop analysed the forces that contribute to zoonotic disease emergence (Institute of Medicine & National Research Council 2008). These include human population growth; human development that encroaches on natural habitats; erosion and other stresses on soil, air, and waterways; changes in land use; intensification of agricultural production systems; increased international travel, trade, and transport; changing weather and temperature patterns; and adaptation of microbes and their associated vectors. Of note, many of these factors underpin anthropogenic climate change. Not only do these factors contribute to emerging infectious

¹ The Ian Axford (New Zealand) Fellowships in Public Policy were established by the New Zealand Government in 1995 to encourage the exchange of policy ideas and experience between New Zealand and the USA (<http://www.fulbright.org.nz/awards/am-ian-axford.html>)

² For the purposes of this review, 'transdisciplinary' describes an integrated, holistic approach that crosses disciplinary boundaries. Transdisciplinary is distinct from multi-disciplinary and cross-disciplinary in that the boundaries between disciplines are diffuse while expertise is engaged, and the approach is dependent upon frequent communication and efficient and aligned execution of a common goal.

³ Herein, health is interpreted in the broader sense to include human, animal, and ecosystem health.

⁴ The phrase *One World, One Health* is trademarked by the Wildlife Conservation Society. Herein, the term *One Health* is used to describe the interdependence of human, animal, and ecosystem health.

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Hillery earned her PhD in microbiology in 2000 after which she worked for several years at a major vaccine company. Her work in infectious diseases sparked a personal interest in the interdependence of animals, humans, and the environment and the inherent links among the health of all three. This interest led to Hillery's Axford project, which seeks to increase communication and partnerships among animal, human, and ecosystem health disciplines.

In 2010 Hillery worked for seven months at the Ministry of Agriculture and Forestry, Biosecurity, where she focused on how the global *One Health* initiative – an international paradigm that recognises the relatedness of human, animal, and environmental health – might improve prevention and response to communicable diseases and ecosystem threats in New Zealand and the USA.

diseases, they contribute to additional shared health risks such as pests, toxins, pollutants, and other strains on the environment. These factors directly impact the health and balance of overall ecosystems.

Ecosystems

Ecosystems⁵ have been described as the planet's life support system. We depend on ecosystem services like food, fresh water, timber, fibre, and fuel. Ecosystem health intertwines with human and animal health. A 2005 World Health Organisation publication based on the United Nations Millennium Ecosystem Assessment captures this complex interdependence (WHO 2005). Human activity contributes to environmental changes and ecosystem impairment. Examples cited in the report include climate change, ozone depletion, forest clearance, land use changes and degradation, loss of wetlands and biodiversity, freshwater depletion and contamination, impacts of urbanisation, and damage to coastal reefs and ecosystems. Some of these impacts are irreversible. The challenges of preservation and prevention are exacerbated because often the effects are deferred in time from the actual cause—so the links are not straightforward.

Such ecosystem impairments in turn lead to human health impacts. The WHO describes these impacts in three levels: direct, ecosystem-mediated, and indirect or deferred (WHO 2005). Direct impacts include floods, heat waves, water shortages, landslides, and exposure to pollutants. Ecosystem-mediated health impacts encompass altered infectious disease risks, malnutrition due to reduced food yields, and mental health, aesthetic, social, and cultural impacts. Indirect and deferred health impacts include loss of livelihood, population displacement, and conflict.

Visual conceptualisation of the links between human, animal, and ecosystem health can be useful. Figure 1a portrays the intersection of the three disciplines (adapted from Aguirre *et al.* 2002). The minor overlap in the illustration does not reflect the true degree of interdependence. Conceptualising the ecosystem as it encompasses or upholds human/animal health presents a more accurate view. Figure 1b portrays the more realistic viewpoint that: the overall ecosystem *includes* humans and animals, and a healthy ecosystem is the necessary foundation upon which healthy animals and humans depend (adapted from Rabinowitz & Conti 2010).

Of note, underpinning the bidirectional impacts of human and ecosystem health, the Millennium Ecosystem Assessment (MA), launched by the UN Secretary-General in 2001, found that:

...human actions are depleting Earth's natural capital, putting such strain on the environment that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted. (Millennium Ecosystem Assessment 2005a)

⁵ *Ecosystem: A dynamic complex of plant, animal, and microorganism communities and their nonliving environment interacting as a functional unit.*

Ecosystem health: A measure of the stability and sustainability of ecosystem functioning or ecosystem services that depends on an ecosystem being active and maintaining its organisation, autonomy, and resilience over time. Ecosystem health contributes to human well-being through sustainable ecosystem services and conditions for human health. (Millennium Ecosystem Assessment 2005b)

The interdependence described in the WHO report on the Millennium Ecosystem Assessment underscores how ecosystems affect human health and, notably, vice versa (WHO 2005). Human activity impacts ecosystems and conversely, human and animal health depends upon ecosystems. Consider that few natural ecosystems will exist in the future that are not in some way modified or degraded by anthropogenic climate change or direct human activity. A more realistic conceptualisation of the interdependent circles is illustrated in Figure 1c, which drives home the necessity of a holistic, upstream approach to ecosystem health and its direct impact on human and animal health. Solutions to the challenges ahead are unknown but will certainly require transdisciplinary expertise. With this in mind, shared human, animal, and ecosystem health risks should not be approached as if they are separate problems.

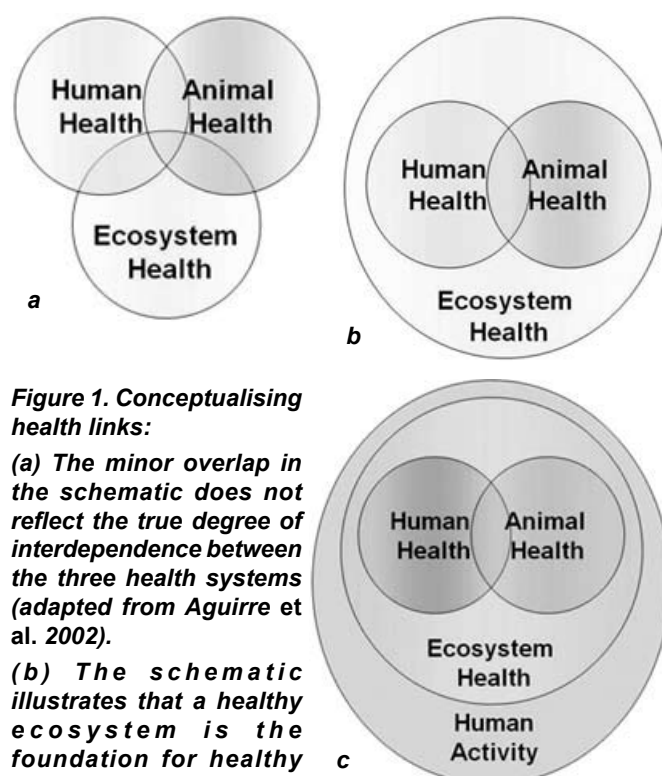


Figure 1. Conceptualising health links:

(a) The minor overlap in the schematic does not reflect the true degree of interdependence between the three health systems (adapted from Aguirre *et al.* 2002).

(b) The schematic illustrates that a healthy ecosystem is the foundation for healthy animals and humans (adapted from Rabinowitz & Conti 2010).

(c) Human and animal health depends upon healthy ecosystems. Conversely, ecosystem health depends upon human activity.

Project goals and methods

The project objective is an improved interface between human, animal, and ecosystem health sectors that encompasses multiple levels including policy, research, community, and education.

Project methodology was straightforward. I interviewed New Zealand experts on subject matter ranging across human, animal, and ecosystem health disciplines to: evaluate the need for improved transdisciplinary coordination; study past examples of successes and existing coordination; understand roles and responsibilities; and identify barriers and future opportunities for improved partnerships. I gained valuable input and perspectives from policy-makers, policy implementers, scientific researchers, educators, and members of the community, industry, and professional organisations across human, animal, and ecosystem health disciplines.

I participated in events and activities across all three disciplines. I attended meetings and symposia. I presented my project to diverse audiences and collected feedback at every opportunity. I facilitated collaborations between disciplines and contributed to *One Health*-focused publications (Rawdon *et al.* 2010a,b; Harvey 2010b,c). I also was given the opportunity to lead discussions focusing on the *One Health* paradigm.

This theme stated in the *One World, One Health* strategic framework underpinned the project:

Only by breaking down the barriers among agencies, individuals, specialties and sectors can we unleash the innovation and expertise needed to meet the many serious challenges to the health of people, domestic animals, and wildlife and to the integrity of ecosystems (FAO, OIE, WHO, UN System Influenza Coordination, UNICEF, World Bank 2008).

Emergent themes

Throughout the interviews and discussions with key stakeholders and subject-matter experts, important themes emerged:

- New Zealand expert consensus indicates that a need exists for improved partnerships among human, animal and ecosystem health disciplines.
- The current political climate is right to expand transdisciplinary coordination; without exception, individuals who contributed to the project were enthusiastic to engage their counterparts in other health disciplines.
- Skilled transdisciplinary leadership is crucial. Transdisciplinary leaders should have knowledge and/or experience across all three disciplines and be able to articulate and act on these links. These are people who see the whole picture, beyond their individual discipline or agency mandate, and who can lead by sharing this vision and connecting ‘the purposes and work of very different organisations’ (Marcus *et al.* 2006).
- A dual top-down, bottom-up approach is needed for integrated health: policy-makers need to drive the change; educators must teach the importance of health interdependence to tomorrow’s professionals; and researchers and community practitioners must collaborate and take advantage of the expertise of their counterparts in other disciplines.
- The importance of ecosystem health must be mainstreamed. Considering the context for connected health discussed above, policy-makers need public support to advance transdisciplinary health policy. For that support to exist, the public must understand the links and interdependence of human health to ecosystem health.

- Anthropogenic boundaries between health disciplines must be diffused by collectively addressing health threats according to disease pathway (see final section of this review).

Transdisciplinary health success in New Zealand

Lessons can be learned from examining past efforts. In New Zealand, actions against specific health threats have demonstrated that using complementary skills, interests, and resources to address cross-cutting health issues is crucial to success. Coordinated transdisciplinary actions have resulted in striking achievements in the control of bovine brucellosis, bovine tuberculosis, and echinococcosis. More recently, transdisciplinary health research and response efforts have successfully reduced campylobacteriosis cases, addressed pandemic influenza, and eradicated the southern saltmarsh mosquito (see timeline in Figure 2).

Bovine brucellosis

New Zealand successfully eliminated bovine brucellosis (*Brucella abortus*) from cattle in the late 1980s (Davidson 2002; Mackereth 2003).

The WHO considers brucellosis, which is globally distributed, a major zoonosis involving livestock. Like other zoonoses, the most rational approach for prevention involves coordination of control activities between public health and animal health sectors. Control measures include immediate public health authority notification, joint investigations, public education, pasteurisation of dairy products, and occupational hygiene. Control measures in areas with high prevalence include surveillance, culling, and vaccination (WHO 2010).

Bovine brucellosis was first reported in New Zealand during the late 19th century and was a major cause of loss of production and herds for dairy and beef farmers. A 1907 New Zealand Department of Agriculture report estimated that ‘the disease caused greater loss to dairy farmers than all other diseases put together’ (Davidson 2002). In the mid-1960s, annual incidence of human *Brucella abortus* infections was estimated at 110 cases, costing an estimated NZ\$350,000 annually (Shepherd *et al.* 1979).

Complete eradication was achieved through several decades of vaccination and careful surveillance and culling affected herds, and New Zealand has been free of the disease since 1989, when the last sero-positive herds were destroyed (Davidson 2002). The success of the eradication programme resulted in both economic gains, due to increased productivity and overseas marketability, and public health gains. Only 12 human brucellosis notifications have occurred in New Zealand since 1997, and these infections are believed to have been acquired outside

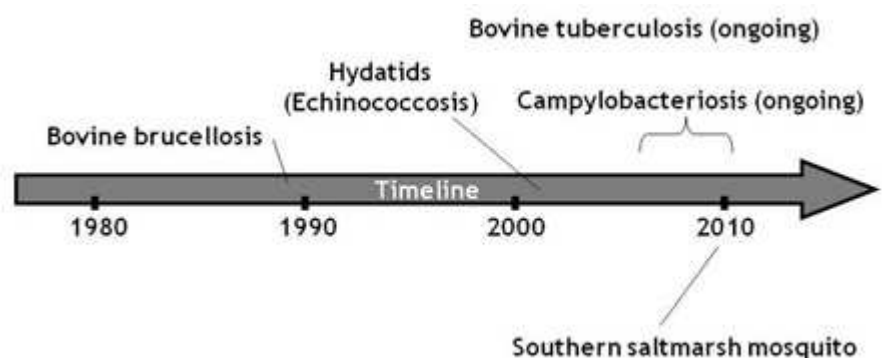


Figure 2. Selected examples of transdisciplinary health success in New Zealand.

New Zealand (ESR 2010). The Ministry of Agriculture and Forestry (MAF) continues to work with public health authorities to monitor infection-sources of suspect cases.

Given the high distribution of the disease prior to the programme, its eradication represents a remarkable achievement for New Zealand and reflects the value of good collaborative efforts among government personnel, farmers, veterinarians, and laboratory workers in animal and public health sectors (Davidson 2002; Adlam 1978).

Bovine tuberculosis

Understanding disease transmission links between production animals and the wildlife reservoir underpins New Zealand's ongoing success in reducing bovine tuberculosis (Tb).

Though infection in humans in New Zealand is rare, bovine Tb is present in domestic animals and wildlife. The New Zealand Animal Health Board calls bovine Tb 'one of New Zealand's most serious animal health problems, affecting domestic cattle and deer herds throughout the country' (Animal Health Board 2010a).

In New Zealand, bovine Tb was first recognised by the veterinary community in the 1880s. Unsustained efforts toward eradication consisted of voluntary 'test and removal' beginning in the late 19th century. Until the 1940s, policy targeted reducing public health risk through milk testing and mandatory pasteurisation.

Concerns about international marketability of dairy and beef products and public health led to a national eradication plan. The plan incrementally introduced compulsory cattle herd testing and slaughter programmes, beginning in the 1950s, with all herds being tested by 1977. Voluntary testing and slaughter of domestic deer herds began in 1985 and became mandatory in 1990 (Davidson 2002).

Despite an extensive national mandatory test-and-slaughter programme – which was proving highly successful against brucellosis during this time – bovine Tb persisted.

The answer to this mystery lay in understanding the disease epidemiology, transmission pathways, and most importantly the role of wildlife hosts who share the environment with production animals. Possums are the reservoir host for *M. bovis* and transmit infection to cattle, and can also transmit infection to deer (Davidson 2002). Once their role in maintenance of bovine Tb in New Zealand was recognised, strong focus was applied to their control. Incidence of the disease has fallen steadily, with the current management scheme directed at 'Tb free status' by 2013 (Animal Health Board 2010b).

Bovine Tb eradication efforts demonstrate lessons learned about the importance of an integrated approach among sectors for successful management of a disease that infects wildlife, domestic animals, and humans. Like many other zoonoses, bovine Tb underscores the importance of understanding the emergence of disease from wildlife.

Hydatids

Early this decade, New Zealand gained provisional freedom from hydatids. Also called echinococcosis, hydatids is a zoonotic infection caused by parasitic tapeworms of the genus *Echinococcus*.

Similarly to other zoonotic disease transmission cycles, hydatids first take advantage of overlapping production and companion animal environments. They cross over to humans through overlapping human and companion animal environments.

Echinococcus granulosus is distributed globally. Today, prevalence ranges from sporadic to high within endemic areas of North and South America, Europe, Asia, Africa, and Australia (WHO 2001).

Following introduction by sheep imported from the UK in the 19th century, hydatid disease remained highly prevalent in sheep and dogs in New Zealand until the middle of the 20th century. Echinococcosis was also a public health problem in humans.

At the turn of the 20th century, community medical and veterinary practitioners aimed control efforts at encouraging farmers to change the way dogs were fed in order to disrupt transmission cycles, i.e. not feeding dogs uncooked offal.

A national control effort became mandatory in 1959, when an estimated 80% of adult sheep and 10% of dogs carried *E. granulosus* (Kasper 1990). The control effort instituted requirements to diagnose and treat infected dogs, change feeding practices, regulate slaughter procedures on farms, conduct post-mortem surveillance in slaughterhouses and follow up infection sources, as well as to educate dog owners about hydatids, and regulate the movement of animals from infected farms.

Local health practitioners (human and veterinary), willing slaughterhouse management, and cooperative dog owners successfully contributed to New Zealand's provisional freedom from hydatids. Rural communities endured the heaviest echinococcosis burden, and were willing and effective partners in its control. MAF, aware of the risk of reintroduction, maintains vigilance through continued slaughterhouse surveillance, treatment of imported dogs, and the continued ban on feeding dogs offal (Davidson 2002; Pharo 2002).

Southern saltmarsh mosquito

New Zealand's eradication of *Aedes camptorhynchus*, the southern saltmarsh mosquito (SSM), is possibly the first time a country has eradicated this mosquito species. This notable achievement was made through effective collaborations among public health professionals, ecologists, local government officials, and staff across New Zealand government agencies, including MAF, the Ministry of Health (MOH), and the Department of Conservation.

SSM is the primary vector for Ross River virus, endemic to Australia and other parts of the South Pacific, which causes a usually non-fatal but debilitating chronic arthritic infection in humans. The virus also infects livestock, fruit bats, and possums. Epidemics are associated with high temperatures and heavy rainfall (Kuhn *et al.* 2005). SSM also transmits Murray Valley encephalitis virus and other arboviruses.⁶

The SSM was found for the first time in New Zealand in 1998 in Napier following complaints about mosquitoes with particularly vicious bites. Concern that the mosquitoes might

⁶ *Arbovirus* is a term used to refer to a group of viruses that are transmitted by arthropod vectors (Editor)

spread Ross River virus spurred New Zealand public health officials to launch efforts to eradicate them before they became well-established.

Following identification of the mosquito, response and eradication required sound understanding of vector ecology, and entailed environmental monitoring to gain information about aquatic habitats and breeding habits (MOH 1999; Mackereth & Hearnden 2001).

The eradication programme included identification and surveillance of potential habitats and targeted application of pesticide as well as a national surveillance programme outside of the eradication zones, and public education about how to avoid mosquito bites continues.

The Minister of Health and the Minister of Agriculture and Forestry jointly announced successful eradication of SSM on 1 July 2010 (Minister of Health & Minister of Agriculture and Forestry 2010).

Vector-borne diseases have been recognised as an important infectious disease threat confronting New Zealand (Crump *et al.* 2001; Derraik *et al.* 2009). Of interest, *Aedes aegypti*, an important mosquito vector for dengue and yellow fever, both globally significant arbovirus diseases, is well-established in Australia, but although suitable habitat and climate exist in New Zealand, this particular mosquito vector has not been detected here. However, the threat of *A. aegypti* introduction requires similar vigilance to that shown toward *A. camptorhynchus* (Derraik 2004; Derraik *et al.* 2009). A clear understanding of this threat contributed to efforts behind recent successful efforts to eradicate the SSM, and should future mosquito incursions occur, this programme will undoubtedly be used as a model for eradication efforts.

Campylobacteriosis

The recent successful coordination of research, surveillance, and public health efforts aimed at reducing campylobacteriosis in New Zealand demonstrates the value of facilitating transdisciplinary collaboration.

Campylobacteriosis, caused by *Campylobacter* bacteria, is the most common human bacteria-related diarrhoeal illness in developed and developing countries. Although seldom disease-causing in animals, *Campylobacter* infects most warm-blooded wild and domestic animals. Humans become infected through ingestion of contaminated unpasteurised milk, water, or undercooked meat – especially poultry (US Centers for Disease Control and Prevention 2009).

Human *Campylobacter* infections have been increasing in developed countries although reasons remain unclear (Olson *et al.* 2008). Infection rates in New Zealand, steadily increasing since 1980, peaked in 2006 at over 15000 notifications (Baker *et al.* 2007a). The disturbing upward trend prompted researchers and the New Zealand Government to take action.

Identifying the infection source(s) was the first challenge before effective control measures could be implemented. The complex *Campylobacter jejuni* transmission pathway involves animal, human, and environmental components. The challenge lies in identifying the exact infection route in humans, which can originate from multiple sources.

The human health impact combined with the range of animal hosts and exposure pathways demanded a transdisciplinary approach to identify the primary infection source and to develop and implement subsequent control efforts.

In 2005 the veterinary research and public health sectors collaborated to enhance surveillance to understand the primary source of infection. The study determined that *Campylobacter* infections were primarily food-borne, rather than from water or other environmental sources, and that the main implicated source, causing up to 80% of human cases, was poultry (French 2008; Mullner *et al.* 2009a,b).

In 2006 and 2007 public health researchers called for increased regulatory action (Baker *et al.* 2006, 2007a,b). Media reports on the researchers' findings helped catalyse public support for government control efforts.

By 2007 the New Zealand Food Safety Authority and poultry industry had collaborated to improve poultry production and processing, with the aim of reducing *Campylobacter* contamination levels in poultry meat (Sears, personal communication 2010).

A substantial decline in human campylobacteriosis notifications was observed during 2007/08 (Institute of Environmental Science & Research 2010).

Despite the striking success of the collaborative effort, public health researchers urge caution and sustained vigilance to ensure a continued decline in campylobacteriosis on par with other developed nations such as Australia and the USA (Baker *et al.* 2007a). Although the surveillance study identified poultry as the primary source of human disease, it also found that other animal sources such as sheep and cows account for disease transmission, probably due to environmental and occupational exposures (French 2008, 2010; Mullner *et al.* 2009a,b).

New Zealand campylobacteriosis efforts show how an integrated *One Health* approach likely contributed to successful reduction of this important food-borne zoonotic disease. The effort encompassed human and animal health disciplines across academic research, national and community government, and industry. Partnerships reached across the areas of research, surveillance, response, and communications.

The collective *Campylobacter* effort could serve as a model to address other diseases that arise from the intersection of humans, animals, and the environment.

Transdisciplinary health organisations in New Zealand

In addition to the examples of successful zoonotic disease eradication or control discussed above, several state-of-the-art New Zealand organisations already conduct their work, teaching and research under the paradigm that transdisciplinary collaboration is the fastest path to success. These include the New Zealand Centre for Conservation Medicine (2009), the Massey University EpiCentre (2010), the National Centre for Biosecurity and Infectious Diseases (2010). The work approaches these organisations uphold offer models for coordinated actions against health threats.

Towards an integrated approach

As mentioned above, the same factors that impact communicable disease risk also influence other broad health threats including pests, toxins, and impaired ecosystems.

Despite this, shared health risks are generally handled separately, through respective disciplines. A recent Chatham House paper about control of zoonotic diseases captures the situation in most countries, including the USA and New Zealand:

Today, responsibility for human health is mostly under the sole purview of ministries of health/public health, while that for livestock and poultry and international trade lies with ministries of agriculture in the public sector, and increasingly with agricultural companies in the private sector. Ministries of natural resources/environment/interior are responsible for wildlife and environmental health and ecotourism. These sectors and agencies are guided by different missions. However, the drivers of zoonotic disease emergence and actions required to effectively prevent, detect or control them cross over the mandates of these and often other ministries. Over the last several decades, these entities, in virtually all countries, have been unable to undertake, integrate and/or coordinate their efforts effectively to prevent, detect and control emerging zoonotic infections early, either in animal or human populations. (Pappaioanou 2010)

As the examples noted above demonstrate, transdisciplinary health partnerships do occur. However, these interactions are not necessarily strategically mandated or supported. The interactions can be *ad hoc* rather than routine; costly gaps, inefficiencies, and duplications can be introduced; and important stakeholders can be excluded, or not included in a timely manner. As an alternative, an integrated transdisciplinary approach to health, driven by joint collectively executed strategy is proactive, cohesive, more robust and efficient, potentially reduces downstream costs, and takes advantage of the expertise, experience, and perspectives of multiple disciplines.

New Zealand is uniquely placed to address emerging zoonotic infections and health at the human-animal-ecosystem interface for multiple reasons. New Zealand is:

- dependent on its agricultural base
- dependent on its reputation for environmental integrity
- a developed country
- internationally respected for its biosecurity systems
- strongly linked to the international agencies leading *One Health*
- small, with manageable public health and research communities conducive to communication and the exchange of ideas.

New Zealand has an opportunity to serve as a model to guide other nations in a transdisciplinary approach to health.

Recommendations towards a convergent path

The numerous individuals who contributed to this project included policy-makers, researchers, educators and community members and practitioners, ranging in expertise across human, animal, and ecosystem health. The recommendations fall across several levels: community, education, research, and policy. Ad-

ditional details and examples, more recommendations, and a list of barriers identified (Table 1) are available in the full project report (Harvey 2010a).

Community

Strengthen links between practitioners of human and animal health

As an example, veterinarians and general medical practitioners could routinely meet to discuss cross-over issues such as appropriate use of antibiotics and antimicrobial resistance. Regional Council members could be engaged when cross-over issues have an environmental component.

Incorporate transdisciplinary approaches into daily practice

One example of this could be a veterinarian discussing zoonotic disease risks with their human clients, e.g., what symptoms to watch for if their animals have or are at risk of a zoonotic infection. Conversely, general practitioners could increase their awareness of patients' potential zoonotic disease exposures. Part of the challenge with human infections like psittacosis or leptospirosis is delayed diagnosis because early clinical symptoms often mimic more common ailments such as influenza. In turn, under-reporting of such diseases challenges understanding of actual disease burden and hinders control measures.

Engage community members in integrated, reciprocal communication

Human behaviour significantly influences zoonotic disease management and often environmental factors play a role in transmission. Veterinary personnel and Regional Council experts could liaise with their human health counterparts for planning and communicating information and risks to the public, and conversely, jointly address public questions and concerns.

Education

Develop transdisciplinary leaders

Experts from the Harvard School of Public Health and US Centers for Disease Control and Prevention recently published a model to guide government connectivity called meta-leadership, a strategy to 'overcome traditional silo thinking' and that 'connects the purposes and work of different organisations' (Marcus *et al.* 2006). They describe meta-leaders as individuals who are able to 'provide guidance, direction, and momentum across organisational lines that develop into a shared course of action and a commonality of purpose among people and agencies that are doing very different work' (Marcus *et al.* 2006). In this vein, support professional development of individuals who have the leadership skills to articulate, engage, and lead across health disciplines.

Provide integrated courses to undergraduates, graduate trainees, and career professionals

These courses could present, to students or mid-career professionals, health case studies that require integration of human, animal, and ecosystem issues to arrive at a solution.

Provide interdisciplinary scholarship opportunities and mentoring programmes for graduate students

For example, graduate students could be eligible for funding or scholarships if their projects cross disciplines. A graduate student with such a project may have a primary mentor within their main area of focus, and a secondary mentor in the cross-over discipline. These interactions will facilitate cross-training as well as collaborations.

Table 1. Barriers to transdisciplinary health coordination.

Through discussions with key stakeholders and subject experts, the project identified the following barriers to transdisciplinary health coordination. The barriers identified are not unique to New Zealand, but are common across many countries and organisations trying to achieve more integrated One Health approaches.

1. Lack of awareness of important links to other disciplines: lack of understanding the value of others' input and getting beyond 'patch protection', ignorance and egos to engage expertise and perspective.
2. Inadequate common diagnostic platforms and tools for monitoring and detecting health threats.
3. Inadequate risk assessment of emerging threats. Improved methods are needed to adequately evaluate the consequences of changes in climate, farming, and land use practices.
4. Insufficient information-sharing mechanisms and capacity. Improved methods are needed for routine information sharing between agencies. More resources are needed to publish important findings.
5. Legislative impediments.
6. High personnel turnover, leading to the loss of institutional knowledge and breakdown of relationships across agencies.
7. Unclear understanding of agency roles and responsibilities. Defining agency roles must be in the interest of efficiency and collaboration, rather than territory protection or reluctance to take on new responsibility.
8. Inconsistent jargon. Different disciplines have alternative meanings for the same words – for example, 'risk', 'endemic', 'conservation health'.
9. Lack of concisely stated answers to the question: 'What does the environment do for public health?'
10. Insufficient mutual acknowledgement of others' input and contributions.
11. Potential conflicts between industry and public health, animal welfare, and ecosystem health and economic health interests.
12. Weak relationships between government agencies and academic research: agencies should engage researchers early on for science-driven policy decisions (see successful *Campylobacter* effort).
13. Inadequate engagement of ecology perspective.
14. Inaccurate assumption that 'all the necessary information or data must exist before action can be taken': In an urgent or evolving situation, acknowledge information gaps and move forward with action using best available information while continuing to collect data; actions can then be refined as necessary based on new data.
15. Reluctance to share data that needs publishing for continued funding and concerns about misinterpretation or misuse of data.
16. Insufficient ability to communicate science to inform policy. Scientists need to understand the dynamics of how decisions get made and communicate their findings accordingly.
17. Public perceptions of risks. Community attitudes can alter health threat control efforts.
18. Inconsistent analysis methods among disciplines. For example, human surveillance data is often lower throughput with large amounts of background data, whereas animal surveillance data may have higher sample numbers, with less background data.
19. Lack of mandated support for transdisciplinary groups at policy level and research level, i.e. lack of consensus to move toward integrated approach.
20. Policy tendency toward reactive retrospective response, as opposed to proactive prospective actions. Moving toward proactive position requires different competencies and skills and ways of working than traditional reactive approaches.
21. Lack of integration of health outcomes into discussions of environmental and agricultural interests.
22. Need for leadership with transdisciplinary expertise – for example individuals with training background and experience in human health, animal health, and ecosystem health.
23. Inadequate research funding.
24. Insufficient epidemiology. Better baseline prevalence data could improve understanding of disease pathways and epidemiology.

Research

Establish a zoonotic disease research steering committee

The former Enteric Zoonotic Diseases Research Steering Committee's successful coordination of research, surveillance, and public health efforts aimed at reducing campylobacteriosis in New Zealand demonstrates the value of such a committee. This committee comprised representatives from MOH, MAF, New Zealand Food Safety Authority, Crown research institutes, universities, and the dairy and poultry industry. Despite its success and praise by multiple members, the steering committee was recently disbanded. Re-establishing this committee or its equivalent could help address other health threats to New Zealand. The new committee could expand its mandate beyond enteric and food-safety-related diseases, and provide a platform to address other shared health risks including pests and toxins, and as before, could provide expert technical transdisciplinary input for science-driven policy.

Direct funding opportunities toward collaborative projects

If transdisciplinary projects are regarded favourably by funding decision-makers, this would encourage a culture of collaboration rather than competition. Deliberate effort should be made to avoid partitioning-off competitive groups through funding decisions. Increase opportunities such as those afforded by the 'Cross Departmental Research Pool' (Ministry of Science & Innovation, formerly Ministry of Research, Science, and Technology 2010).

Coordinate interdisciplinary research and training

New Zealand boasts multiple centres or organisations that conduct state-of-the-art research on zoonotic diseases and other shared health threats. Leading and creating a network of these centres of excellence could facilitate collaborations and, just as importantly, broaden awareness of non-collaborative activities to increase efficiency and reduce potential research gaps.

Policy

Establish high-level interagency governance group

The primary function of this group would be to develop and orchestrate collaborative strategies for managing health threats. The governance group would comprise high-level representatives from key stakeholder agencies and institutes. A chairperson capable of leading across disciplines would head the group. The governance group would define agency roles and responsibilities, prioritise activities, generate a collective strategy, and oversee execution.

Conduct cost analysis of integrated health approaches

Conventional wisdom suggests prevention and early intervention strategies are a far cheaper way to address broad-impact health threats. A true cost analysis would lend credence to transdisciplinary approaches.

Strengthen international ties

Leverage support and expertise of international organisations including the FAO, WHO, and OIE, all of whom have committees or liaisons for integrated, transdisciplinary, *One Health* approaches. In addition resources can be tapped from agencies in other countries that have put forward *One Health* recommendations, e.g. the Public Health Agency of Canada (2009).

Mainstream ecosystem health

Adding to ecosystem health challenges is the task of educating policy-makers and the general public about the interdependence

of human, animal, and ecosystem health. Increased awareness will improve support for prevention efforts that in time will reduce the need for more costly and potentially unsuccessful response efforts. Experts need to communicate the bi-directionality of ecosystem and environmental health with human and animal health. The importance of sustainable use and the value of ecosystem services—clean air, safe water for drinking, fishing, and recreation, food, natural energy and fuel, fibre, land, and forest products—needs to be clearly communicated and understood by the mainstream public.

Broad brush strokes

The overarching recommendation is to manage broad impact health issues according to biology, rather than according to government mandates, legislation, or lines drawn on a map. Whereas government agencies are bound by administrative authority, pests and pathogens are restricted only by the laws of nature. Health issues cross disciplines. Human health determinants often sit outside the human health sector's traditional jurisdiction. The same is true for animal and ecosystem health. Consider antimicrobial resistance, food safety and security, water systems, disease ecology, and the effects of climate change and agricultural production systems on soil, air, and waterways. Consider erosion, loss of natural habitats, invasive plants and animals, increased development, population growth, and emerging infectious diseases.

Current and future threats require coordinated transdisciplinary action. An approach to health as collective and interdependent as the ecosystem itself would improve the health of each component. The context is set for connected health.

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