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An Investment in Human and Animal Health: Parasitology in Australia

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For the Australian Society for Parasitology

Dedicated to Dr Alan Bird in recognition of a life devoted to science, education and parasitology

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Forword

The pressures and the pace of today's world mean that the long-term view is often ignored. The urgent takes precedence over the merely important, at a time when everyone is expected to do more with fewer resources and the ease of electronic mail creates its own demon - the demand for instant answers.

Science is essentially of the long-term world. Experiments need to be validated, theories tested over time. It takes fifteen years to bring a new pharmaceutical to market, and decades to establish whether remedial action in severe environmental cases is working. Science has its own methodical pace, its own process for putting forward and testing ideas.

In the world of the short-term, science is being damaged. This damage exposes Australia to significant potential dangers. Unless we maintain a baseline capacity in science Australia will find it hard to respond to new issues, or benefit from new advances, or react to national crises.

Worldwide, about two billion people are infected with parasites; the problems of human parasitic disease are growing, as personal mobility increases and parasites evolve. Add to this the burden to agriculture from parasitic infections in domestic animals and it is clear that we still face a massive task in dealing with the age-old scourge of parasitic disease. In the past century, parasitology - the scientific study of parasites and how to combat them - has contributed enormously to the health and welfare of Australia's people, and to our economy.

The Australian Society for Parasitology has catalogued the decline in research resources and the problems facing their particular area. The problems of parasitology are symptomatic of the majority of science disciplines. The decline is research resources is science-wide, shared by universities and national research organisations such as CSIRO.

Australia is simply investing too little in science and research. Our current level indicates that about 1.4 per cent of GDP is invested in research and development, compared to the average OECD national investment of 2.1 per cent. To reach the OECD average, Australia would need to invest another $13 billion over the next five years.

The possibilities for advancement and the potential pitfalls described by the Australian Society for Parasitology are echoed in most other areas of science in Australia. If these possibilities are to be taken up and the dangers averted, it will require a conscious change in national priorities, and a focussing on long-term priorities by Government, industry and the community.

Chris Fell
President, Federation of Australian Scientific and Technological Societies (FASTS)

Executive summary

Parasitology has allowed Australia to enjoy a 'First World' quality of life in a continent that is plagued with climatic extremes and biological hazards more often associated with the 'Third World'. These medical and veterinary achievements have been built upon a foundation of excellence in research and education over many years. But in concert with many areas of science, there is now a worrying decline in the science of parasitology in Australia at a time when threats from parasitic disease are exacerbated by global warming and the effects of increasing globalisation of trade.

This paper discusses some of these emerging problems - both Australian and global - their causes, and possible solutions. It is to be hoped that, with sufficient determination and resources, the next one hundred years will see research in parasitology continue to protect us, our agriculture, our native fauna, and our environment.

Key findings

- **Increased risk of disease**

Changing climatic conditions in Australia as a result of global warming will cause changes in the distribution of parasites, increased numbers of parasites in neighbouring regions may result in the introduction to Australia of previously absent parasitic diseases.

- **Increased need for quarantine and surveillance strategies**

The potential for new parasites to invade Australia is enhanced by the flow of goods and services across international boundaries. Continuing vigilance and research is necessary to ensure the country's safety. To protect Australia from threats such as malaria, surra and the vector-borne arbovirus diseases, it is vital to monitor livestock movements, maintain effective quarantine barriers and early warning systems, and develop risk containment strategies.

- **Increasing difficulty with disease control**

The growing resistance of parasites to drug therapy is a serious threat to Australia's grazing industry as well as to the control of human diseases such as malaria. We may soon be faced with a range of 'old' diseases for which we have no available drugs! Resources and expertise are needed to promote research, develop new drugs and therapies and to implement targetted control strategies. Technology transfer from parasitologists to industry is also vital if we are to profit from Australian research.

- **Threats to the provision of safe food and water**

Costs to food production because of parasitic disease are escalating. The broad scale use of chemicals to control disease is limited because of toxicity and pollution problems. Water supplies and foodstuffs, both plant and animal, need to be free of parasites that can cause human disease as well as residues of the drugs used to control the parasites.

In summary

The pressures from old and new parasitic diseases are increasing in Australia, as are the number of emerging and exotic threats in the region. However, the resources available to science and science infrastructure to deal with these threats have decreased. Facilities in the CSIRO and Universities have been downsized or closed, and there are fewer expert clinicians, diagnosticians and researchers. This decline will affect the ability of Australian science to provide answers to Australian problems and to maintain our international competitiveness.

Australia has been at the forefront of bio-control research, vaccine development, gene technology and biodiversity research. Unless governments take urgent action to reverse the decline in job opportunities, encourage research funding and industry investment, parasitology will continue to decline. As a result, those parts of the economy reliant on agriculture will be less profitable and public health will be at greater risk.

Introduction

Parasites live on or in a host organism and cause it damage. Parasites are very varied, ranging from single-celled organisms to complex animals. Familiar examples include many worms, ticks and types of biting insect. The study of parasites is called parasitology[1]. Parasitic organisms are thought to account for more than half of the life forms on Earth.

Parasites cause human diseases such as malaria, sleeping sickness, toxoplasmosis, giardiasis, cryptosporidiosis, amoebiasis, fascioliosis, hookworm, hydatids, and filariasis all of which can be fatal. External parasites, such as lice, scabies, and ticks can cause serious disease either directly or by carrying bacteria and viruses. Mosquitoes and some other blood-sucking insects are particularly important as vectors (carriers) of both parasitic and viral diseases.

About two billion people in the world are infected with parasites to an extent sufficient to cause clinical symptoms. Domestic animals suffer a range of diseases that cause serious economic loss in agricultural and veterinary systems. Imported parasitic diseases have the potential to wipe out Australian wildlife. Some parasites can be transmitted from animals to humans causing zoonotic diseases. Few can forget the hysteria and alarmist coverage that accompanied the costly 1999 Sydney water crisis. Yet with proper research and education in parasitology this need not have happened.

The challenges presented by parasites have forged a long and proud history of parasitological research and scholarship in Australia. The Bancrofts and Mackerrases pioneered tropical parasitology; sheep parasite research in Australia also rests on a long and distinguished tradition. The old Australian $50 note featured Sir Ian Clunies Ross, the first President of the International Wool Secretariat and a veterinary parasitologist. It also featured a parasite in the lower right hand corner, the Australian sheep blowfly.

Australian parasitology has built on these excellent beginnings and today is a world leader in research into malaria, drug resistance in nematodes, tapeworm and tick vaccines, mosquito borne viruses, the control of coccidian parasites and parasite ecology. However, parasites evolve and adapt and so must our efforts to understand and control them. All the parasites present in our animals and ourselves at the beginning of the 20th century are still here, and most are still able to cause as much sickness and mortality as they did a hundred years ago. This is not because of a lack of effort on the part of science: a century of research has led to improvements in control and in the level of our knowledge of the organisms and the diseases they cause. However, the rise of drug resistance means that our current controls are under real threat while the research and knowledge base is in decline with a continuing loss in the number of the scientists who study parasites - parasitologists.

The recent Government Innovation statement may begin to address some of the issues raised in this paper - particularly the need for more research funds for ARC and NH&MRC - but there will be few positive outcomes without a continuing effort to improve training, education and research and to develop fully the technologies that come from scientific endeavour .

In the following paper, we[2] address several areas where parasitology is important for the future health of Australians, for our economy (including agriculture and tourism), and for the education and training of parasitologists.

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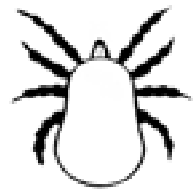
[1] Parasites such as viruses and many bacteria, which are smaller than single cells, are called microorganisms and are studied by microbiologists.
[2] See Page 19 for a list of contributors.

Forecasting changes in parasite disease incidence

Global Warming



The enhanced greenhouse effect – global warming due to human-induced changes to the atmosphere - will have both positive and negative effects on environmental conditions. Final results are predictable only in general terms; a summary follows of the possible effects on parasite abundance and distribution.

Temperature – Both the maximum and minimum temperatures will increase, the latter by a higher amount due to increases in cloud cover.

The impacts of these changes on most parasites will include:

- Accelerated development rates, meaning changed seasonal patterns of abundance and more generations in the same time period. This will make parasites appear earlier in the season and each generation will appear earlier throughout the year.
- Longer growing seasons will enable more generations to be completed in a year, with the greatest proportional effects being experienced by species such as ticks, mosquitoes and flies.
- More parasites surviving the winter in temperate zones, because it will be shorter and milder. This is especially significant for buffalo flies and cattle ticks.
- Changed geographical distributions of most parasites, with tropical species such as buffalo flies, cattle ticks and mosquitoes expanding their ranges southwards and temperate species, such as some lice species, experiencing a contraction in their distribution.

Moisture – Heavier, less frequent rainfall, with higher evaporation from intensification of the hydrological cycle.

The impacts will include:

- Greater extremes of wetness and dryness leading to more variable numbers of parasites, such as worms, cattle ticks and flies.
- Potential for greater nutritional stress of livestock with consequent reduced resistance to parasites of all types.

Carbon dioxide -Increased water use efficiency in plants

The impacts will include:

- Increased leaf area providing more shelter for free-living stages of parasites, such as worms and ticks.
- Extended length of plant growing seasons. Plants can provide suitable micro-climates for sheltering worms and ticks; if plant cover is available for longer each year, the parasites species could benefit.

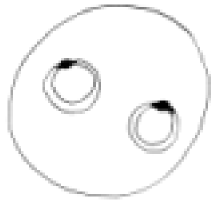
Wind – changed synoptic weather patterns

Impacts include:

- Altered migration or dispersal patterns of flying insects. Examples likely to be affected are sheep blowflies, mosquitoes and the exotic, but nearby, screw-worm fly - one of the largest threats to livestock in Australia.

Exotic parasites

Malaria



Malaria is caused by a single-celled parasite that is transmitted from one human to another by a mosquito vector. According to WHO reports, there are 300-500 million clinical cases per year and over 1 million deaths, mostly African children less than 5 years of age. Almost half the world's population lives in the shadow of this terrible disease and the economic impact in terms of health care and lost labour is hard to overstate. By far the greatest burden is borne by developing countries, although small outbreaks have been reported in some countries of the developed world.

Malaria, was a significant problem in Australia's tropical areas before it was eradicated in the 1960's, however, some 700-800 returning Australian travellers are diagnosed with malaria each year. As travel and tourism becomes more accessible the number of Australians afflicted with malaria will rise. Furthermore, as a consequence of global warming malaria will threaten an increased proportion of the world's population and, possibly, could become re-established on the Australian mainland, as it was until the 1960's.

Malaria is endemic in many countries in Asia and the Western Pacific, including our nearest northern neighbours, Papua New Guinea, Indonesia and East Timor. The recent success of Australia's role in the multinational peacekeeping force in East Timor has been widely commented on and justly acclaimed. However, a recent paper by Scott Kitchenor and colleagues at the Army Malaria Institute in Queensland revealed that 267 INTERFET soldiers developed symptoms of malaria, despite being provided with the anti-malarial drug, doxycyclin.

Worryingly, many soldiers had relapses after treatment with primaquine. Ever-increasing drug resistance and the lack of an effective vaccine means that modern medicine is still not able to offer effective protection against malaria. The humanitarian, social and economic impacts of endemic malaria in neighbouring countries need to be addressed and this is an issue that cannot be ignored by Australia at this time when there is an increased focus on our neighbours in the Asia/Pacific region.

The rapid spread of parasites resistant to cheap and safe anti-malarials like chloroquine and the emergence of insecticide-resistant mosquito vectors highlights the importance of research into new drugs and vaccines which could supplement existing control measures. Australia scientists have, for many years, played leading roles in the research effort aimed at developing new measures to control the spread and development of malaria parasites and in understanding the pathogenesis of the disease they cause.

Important fundamental studies into the molecular structure and evolutionary biology of malaria parasites have been carried out in Australia. Major contributions with direct practical implications have included unravelling the mechanisms responsible for drug resistance and the development of new treatment regimes.

Australian research has also contributed in a major way towards the development of a malaria vaccine. Research at The Walter and Eliza Hall Institute and the Queensland Institute of Medical Research, now conducted within the Cooperative Research Centre for Vaccine Technology, has resulted in the identification and characterisation of a large number of parasite antigens, several of which are now considered to be potential components of a malaria vaccine. This large research program, which is now two decades old, has received significant funding from various

Commonwealth Government programs. Support from the Tropical Diseases Research Program of World Health Organisation and collaborations with numerous overseas research organisations have also been important to the progress that has been achieved. Extensive preclinical evaluation of vaccine candidates has been carried out and collaborations with Australian biotechnology companies have led to the production of experimental vaccines for testing in human volunteers.

Initial trials have been carried out at the Royal Brisbane Brisbane Hospital in malaria-naïve Australians and subsequent trials in Papua New Guineans living in an endemic setting have been conducted by the Papua New Guinea Institute of Medical Research. Although an effective vaccine against malaria is not yet a reality encouraging results have been obtained from early clinical trials in Papua New Guinea and continued input of Australian expertise into malaria research is required if the progress to date is to be fully exploited.

Surra

As already discussed in the malaria section, there are many threatening parasitic diseases outside Australia which have the potential to invade. If they gain entry, these 'exotic' diseases could have devastating effects. One of the most worrying is a disease called Surra. This is caused by a single-celled organism, *Trypanosoma evansi*, which is related to the causative agents of sleeping sickness in Africa. However, unlike sleeping sickness, *T. evansi* does not need a tse tse fly for transmission and can be spread mechanically on the mouthparts of many biting flies, such as the tabanids.

This group of insects is widely distributed in Australia. Surra is an immediate threat to Australia because it is endemic in Indonesia and possibly Papua New Guinea. Furthermore, *T. evansi* has a wide host range including dogs, domestic livestock and horses. Infection can cause mortality or reduced productivity. In addition, feral animals such as pigs, camels and horses are susceptible and could act as reservoirs.

Recent research has confirmed the susceptibility of our native fauna to infection with *T. evansi*. Fortunately, the Australian Quarantine Inspection Service (AQIS) is monitoring the situation and is supported by Australian parasitologists who are developing more effective diagnostic tools and better drugs for treating affected animals. However, time is not on our side and current surveillance and research activities are limited by available funding.

Mosquitoes and arboviruses

As external parasites, mosquitoes are simply a nuisance - they don't take enough blood to cause us harm. But as carriers (or vectors) of a huge range of diseases they constitute a significant and growing threat to our health and economy. Malaria has already been mentioned as a major mosquito-borne disease. In addition, mosquitoes and other biting insects can carry a suite of viruses, called arboviruses, which are responsible for human and domestic animal diseases. Arboviruses and malaria will have a growing impact on health and welfare in Australia and our near neighbours over the next few decades.

The arboviruses are a group of about 500 viruses which reproduce in blood-sucking parasites (mosquitoes, ticks, mites) and in vertebrate hosts, including humans. Each year, Ross River virus causes around 5000 human infections in Australia and about 200 infections in horses in Victoria alone. Worldwide, dengue viruses cause 40-60 million human infections annually. In 1993 dengue haemorrhagic fever had escalated to the point where the World Health Assembly recognised a global crisis. This is complicated by rapid jet travel that can transport an infective individual from Singapore to north Queensland within hours. The mosquito that transmits dengue fever is present in Queensland, which has suffered dengue cases since 1981. Potential annual losses due to a severe epidemic of dengue fever in Queensland have been estimated at $500 million.

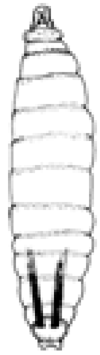
In 1995, Japanese encephalitis, widespread throughout Asia, arrived in the Torres Strait causing two deaths and, in April 1998, one non-fatal case in Cape York. Research on vectors and the range of hosts - eg. marsupials - is vital to the design of control programs and to risk assessment. Murray Valley encephalitis has occurred sporadically over mainland Australia to South Australia and Victoria. During the 1974 epidemic there were 13 deaths, tourism plummeted and farmers in the Murray Valley had problems hiring fruit pickers. Japanese encephalitis is far more lethal.

In Australia, 7800 Ross River and 850 Barmah Forest virus notifications were recorded in 1996. The diseases leave a legacy of intermittent fever, rash and sporadic arthritis in the limb joints lasting for months. The 1983-84 epidemic of Ross River virus in the Riverina of New South Wales was estimated to cost $10 million, and $6 million is spent annually on diagnosis. Of all of these viruses, a vaccine exists only for Japanese encephalitis. Control of the rest depends on controlling the blood-sucking vectors. Unfortunately, little is known of these in Australia. We need to clarify the species involved, investigate their biology, and formulate and apply appropriate controls.

A range of animal viruses are also carried by mosquitoes and biting flies. For example, bluetongue viruses affect sheep. When bluetongue was discovered in Australia in 1977, our export markets were severely compromised. Of the eight strains known in Australia, four are highly pathogenic but, because of current climatic conditions, their vectors are separated from our national herd. Global warming may change the distribution of such vectors. Bovine Ephemeral Fever, also associated with mosquitoes, is particularly serious in stud bulls. Akabane virus is associated with abortion of pregnant cows while Wallal and Warrego viruses may cause blindness in kangaroos.

The Northern Australian Quarantine Strategy now extends via cooperative agreements to Indonesia and Papua New Guinea. Integral to this monitoring process is a firm understanding of the epidemiology of the arboviruses, their blood-sucking vectors and control strategies for epidemics.

Flesh flies and other invaders



Maggots of various fly species can invade the living tissues of their hosts causing local trauma and sometimes death. Among the most threatening species are the Sheep Blowfly, a major killer of sheep in Australia; and the Old World Screw Worm Fly, common in New Guinea and the Oriental Region, which attacks a wide variety of hosts including people. The establishment of this fly in Australia could devastate the cattle industry. Other screw worm or bot fly species occasionally arrive on travellers returning from South America or South Africa. Not surprisingly, many medical practitioners do not recognise wounds of the New World Screw Worm Fly, the Human Bot Fly or the Tumbu Fly.

Australia's animal industries suffer losses of over $300 million annually because of the sheep blowfly, the sheep nasal bot fly, the stomach bots of horses and the buffalo fly. In Queensland and northern coastal NSW the buffalo fly causes irritation of cattle, and necessitates repeated insecticidal intervention throughout the warm months of the year.

Other insect parasites with significant effects on animal and human health include lice and fleas. Fleas already cause major problems in dogs and cats with flea hypersensitivity. Fleas affecting humans are not a current problem, although the increase in tourism and travel does expose us to threats such as the Jigger Flea of South America and South Africa. (Females of this species attach permanently to the skin of humans or other animals, forming localised wounds.) There can be no doubt that this flea would survive in Australia if accidentally introduced.

Australia has already imported a number of louse species. There are three species attacking humans in Australia. Parents of school-age children will know the anguish and difficulties of dealing with head lice in their children's hair. Despite increased awareness of this problem, there are more cases now than in the 1960s. Indeed, head lice were the third most 'communicable' condition recorded among children in Western Sydney child care centres in 1992.

The most recently arrived louse is the biting louse of alpacas. This louse feeds on the skin of alpacas and llamas, causing irritation and rubbing by the host. From a handful of infested animals brought into Australia in the early 1990s, this pest is now widespread in the industry and necessitates insecticide intervention. The exclusion of this pest would have provided Australian growers with the market advantage of being pesticide-free, as no other insect pests need to be treated in this industry.

As with most parasites and pests, resistance to the drugs and insecticides used to control flesh flies, lice and fleas is building. It is already well established in the sheep blowfly, buffalo fly and various lice. Clearly Australia must continue to improve its system of quarantine and health surveillance and encourage research and development into new controls for these parasites. We have led the world in both these areas of parasite control through the 20th Century, and must maintain this lead in the 21st.

Intestinal worms and the grazing industry

Intestinal worms remain the number one cause of serious sheep disease in Australia. Anthelmintics are the drugs used to control worm (helminth) parasites. Along with other antiparasitic drugs, anthelmintics constitute the majority of animal health remedies sold in Australia and are the cornerstones of parasite control. Unfortunately, the worms of sheep have become resistant to these compounds and few of these treatments control infections.

Worms currently cost the sheep industry $220 million per year; if the problem of anthelmintic resistance runs its course, worm control is expected to cost 4 to 5 times that amount within 10 years. The levels of resistance are such that, none of the current drugs are likely to be effective against the major intestinal worms. As a consequence, sheep production would no longer be economic in the northern half of the current geographic range.

Fortunately, Australia leads the world in research into anthelmintic resistance. This lead was built on the expertise and pre-eminence of veterinary parasitology in Australia in the 1930s, and it has been maintained since. In the areas of pharmacology, methods of diagnosis, mathematical modelling and genetics of anthelmintic resistance we dominate research worldwide. We have also been successful in the extension of this research into the farming community. This has resulted in the design of control schemes (promulgated locally and promoted by Government Departments of Agriculture) and the commercialisation of diagnostic kits that are marketed internationally.

Ironically, the appearance of anthelmintic resistance in worms infecting sheep has stimulated other avenues of research that traded on our expertise. Resistance has emerged as a serious problem in the small red worms (cyathostomes) of horses, and information gained from research on sheep has been extended to this problem. Methods of diagnosing anthelmintic resistance in horse parasites are being developed and will be sold to the world. We are also well placed to take advantage of our expertise in the world cattle industry, which is also facing the problems of anthelmintic resistance. The WHO and pharmaceutical companies, support several researchers in Australia because it is feared that resistance will soon occur in human nematode parasites such as *Onchocerca volvulus*, the cause of river blindness in Africa. While recent success in controlling hookworm disease in Aboriginal communities in northern Australia is now threatened by the spectre of drug resistance.

The problems of anthelmintic resistance have spawned research into alternative methods for the control of these parasites. The first recombinant DNA vaccine against a parasite was developed in Australia against tapeworms in sheep. The second such vaccine was also produced here against the cattle tick, and is now in commercial production. Worm-resistant sheep too were first developed here by genetic selection.

However, much of this research into alternatives to drugs is now occurring overseas as Australian research lacks the funds and personnel to capitalise on our own innovation. Examples are readily found including:

- The greatest concentration of research into worm-resistant sheep now occurs in New Zealand, while the USA leads the way with research into control of cattle parasites.
- Recombinant parasite vaccines are being developed in the USA and many countries in Europe while funding for this research in Australia has virtually ceased.

That such a situation should have developed at the very time when drug resistance is reaching its peak is appalling and necessitates immediate remedial action.

Current problems in plant nematology in australia

Nematode worms infect plants as well as animals. In Australia, the two major plant-infecting nematodes, root-knot nematode and cereal cyst nematode, are thought to cause 8 per cent and 10-20 per cent reductions in yield, respectively. This translates into annual losses of A$100-200 million for root-knot and A$50-70 million for cereal cyst nematodes. Other, less damaging, plant parasitic nematodes - including root-infecting nematodes such as root lesion nematode - cause smaller annual losses on a wide variety of crops although these also run into millions of dollars.

In Australian pastures, a seed gall causing nematode-bacterium complex gives rise to a toxic disease of sheep and cattle that can cause losses of up to $10 million per annum. Overall, it has been estimated that nematodes in Australia cause agricultural losses of $300-450 million per year.

Many serious nematode pests have spread more widely over the years and new nematode problems have appeared in Australia. Nematodes such as the soybean cyst nematode and the pine wood nematode are potential threats that require an ever-vigilant quarantine service.

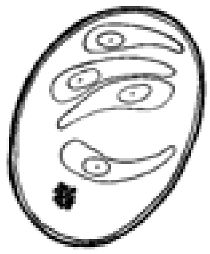
There have been three main methods of managing plant parasitic nematodes: chemical nematicides, crop rotation and host resistance. Most nematicides have now been removed from the market because of toxicity and environmental pollution. When methyl bromide is removed from the market, growers will be left with no viable alternative. Crop rotation has proved to be quite effective in cases where the nematode pathogen has a restricted host range but not in other situations.

The most promising method of control has been breeding for host resistance. Coupled with crop rotation, this has proved to be effective in the control of cereal cyst nematode. However, traditional plant breeding may take more than 10 years to develop suitable cultivars for growers and there is always the danger of resistance-breaking biotypes.

In order to provide growers with solutions to the imminent loss of nematode control agents, strategic research should be encouraged in the following fields:

- genetic engineering of resistant plants
- research into new biological control strategies especially considering soil microbiology
- studies of nematode physiology to find novel targets for drug control; and
- encouragement of postgraduate programs in nematode biology and control.

Provision of safe drinking water



A wide range of worms and single-celled parasites may be transmitted to vertebrate hosts through contaminated drinking water. Various management and treatments for the provision of safe drinking water have been developed and enshrined in legislation. Most practices have been based on data relevant to bacterial contaminants and not to viruses or parasites. Indeed, the parasites *Giardia* and *Cryptosporidium* have recently gained worldwide notoriety following their detection in public water supplies in association with focal outbreaks of diarrhoeal disease (eg. the Milwaukee outbreak affecting some 400,000 people).

Since then, water sampling and testing technologies have improved significantly and parasites are now being found with alarming frequency in both raw and treated water supplies (eg. the recent Sydney water scare). Australia must establish reliable and competent water testing protocols through parasitological education and training programs.

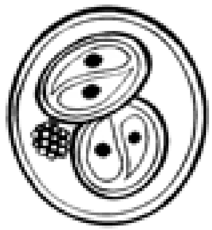
Studies have shown that most contemporary purification (filtration) and disinfection (chlorination) techniques are limited in their ability to remove or kill parasitic cysts. More reliable and effective treatment procedures are urgently required to render water safe for human consumption. Applied research must be conducted on alternative treatment procedures to address community and industry needs. Realistically, the cost of providing safe water must be balanced against the relative risk of transmitting infections.

Regrettably, results from *in vitro* (culture) and *in vivo* (animal) experiments have revealed that most criteria used to assess parasite viability are flawed, and therefore we cannot even reliably tell whether any parasites present are alive or dead. Comprehensive basic research on parasite cell biology is required so that we can readily assess parasite viability and, ultimately, provide reliable public health risk assessments.

At present, there is considerable confusion as to how many parasite species exist, and what hosts they might infect. Genetic characterisation studies have shown that some parasite genotypes are limited to humans whereas others occur in humans, domestic animals and possibly some wild animals. Both human and animal effluent must therefore be considered as potential sources of contamination; this has costly implications when devising appropriate water resource management strategies and effluent disposal practices. Further genotyping of clinical and environmental isolates is required to determine the routes and comparative risks of infection.

While previous epidemiological studies have indicated marked differences in host susceptibility to infection and clinical disease (young children and immunocompromised individuals being at greater risk), recent studies have shown that the parasites themselves may vary in their pathogenic potential (some strains being highly pathogenic and others non-pathogenic). We therefore need to find genetic markers for pathogenicity and other biological traits of clinical significance, such as infectivity and period of viability in various environments outside the host. Clearly, there is much that parasitologists must do to maintain public health and to ensure that most basic need of civilised society, a safe drinking water supply.

Coccidians - threats to humans and animals



Coccidian parasites are microscopic single-celled organisms that infect nearly all animals. There are hundreds of species, and a single host animal may have 10 or more different species at one time. Coccidians cause disease and death in humans and domestic animals and are some of the most common parasites known. *Cryptosporidium* has already been discussed as a water-borne threat; the following three species further illustrate the impact of this diverse and costly group.

Toxoplasma gondii is transmitted by the domestic cat, with the infective stage of the parasite passed in the cat's faeces. Humans can either contract the disease directly, by swallowing the parasites after contact with cat droppings, or indirectly, via infected sheep meat or pork. If sheep or pigs eat the parasite it can form cysts in their muscles. Humans can then become infected by eating this meat if it is undercooked.

Toxoplasma is very common in most human populations. It has been cultured from our local meat supply and about 30 per cent of the adult Australian population show evidence of past exposure to the parasite. If first contracted during pregnancy, *Toxoplasma* can cause stillbirth or foetal abnormalities. In Australia about 0.2-0.5 per cent of women of child-bearing age show evidence of acute toxoplasmosis. Of congenitally infected neonates without symptoms at birth, three-quarters will later develop mental retardation and/or hearing defects and as many as 90 per cent will suffer eye problems as they grow older. Toxoplasmosis can be fatal in AIDS patients and other immunocompromised individuals, although if diagnosed early it can be treated.

As well as the loss and reduction in quality of human life, toxoplasmosis causes great financial loss in the agricultural industry, as it is the primary cause of abortion and stillbirth in sheep flocks in Britain, Australia and New Zealand. Toxoplasmosis has also been identified as a cause of abortion in Angora goats and is very common in Australian wildlife. However, the impact of *Toxoplasma* on domestic species and wildlife in Australia is unknown, a situation common to many parasites of Australia's unique fauna.

Neospora caninum has become the focus of significant international concern because of the recent connection of this coccidian with abortion and congenital infection in cattle populations around the world. Indeed *Neospora* is now believed to be responsible for about 30 per cent of all cattle abortions, particularly on dairy farms. *Neospora* is closely related to *Toxoplasma gondii* and serological evidence for human infection by *Neospora* has recently been established.

Abortion resulting from *Neospora* infection is a major cause of economic loss to both the dairy and beef industries in Australia. In NSW, where the problem has been most extensively studied, the rate of abortion due to *N. caninum* is estimated at 1-5 per cent annually on most dairy farms but occasionally reaches as high as 20 per cent. Annual losses to the Australian economy from a reduction in calf and milk production have been valued at a minimum of $100 million. In dogs the main clinical signs are neuromuscular disease, leading to paralysis of the hind limbs, especially in young puppies.

Control measures for *Neospora* include protecting feed from dogs (in order to reduce faecal contamination), eliminating the practice of feeding raw offal from slaughtered cows or calves to dogs, and preventing or limiting access of dogs to cattle-grazing areas. Although a wide range of diagnostic tests for detecting exposure to *Neospora* are available, it is not yet possible to predict the risk of *Neospora*-induced abortion. A test that could identify at-risk cows early in pregnancy would help; this would allow timely veterinary intervention to save foetuses that would otherwise have been aborted.

Vaccines for the control of *Neospora* are not available. Infections in dogs (if caught early enough) may be treated with drugs, but this is not considered practical for cattle herds. No studies on vaccine development for *Neospora* have yet been commissioned in Australia. Other *Neospora* species have been associated with abortion in horses and humans but no work has been carried out in Australia. *Neospora* is an excellent example of a lack of knowledge about potentially damaging parasites even in domestic species - a situation that is still too frequent.

Eimeria tenalla is one of seven species of coccidian that cause serious disease and losses to the poultry meat industry, at a worldwide cost of more than $1 billion per year. *Eimeria* causes diarrhoea and rapid body wasting, leading to death. It is highly infective under intensive rearing conditions used for efficient poultry meat production. *Eimeria* has developed resistance to drugs in current use and no new drugs are under development. The changes in the egg production industry from factory cages to barn and free-range systems may increase the incidence and costs of *Eimeria* infections.

For these reasons, the development of a vaccine against coccidiosis, to replace the currently used drugs, is a priority of Australian parasitological research. Vaccines have several advantages over chemical control regimens:

- the vaccines leave no residues in the meat, satisfying increasing consumer demand for chemical-free agricultural products;
- the vaccines are totally non-toxic to the chicks and other animals;
- the administration of the vaccines presents no hazards to chicken house personnel;
- injection of the chicks, which can distress them, is not necessary to administer these vaccines.

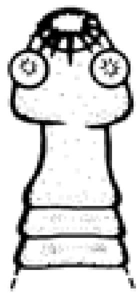
The development of these vaccines has been one of several positive stories in the recent history of parasitology in Australia. The research has attracted back and kept some promising younger researchers in the country, who have received support from their institutions and funding agencies. This research also illustrates the fact that Australia can very successfully compete in parasitological research at an international level.

Pets and parasites

Australia has the highest incidence of pet ownership in the world. The pet care industry is one of the largest in the country, contributing an estimated $3 billion to the Australian economy annually. Most dog owners in Australia will be familiar with the problems associated with flea infestation, particularly allergic dermatitis, and the difficulties and costs of trying to control fleas. None of the available 'anti-flea' products are totally effective and there is a continuing need for new remedies.

Gut-dwelling hookworm - an important pathogen of dogs in warmer part of Australia - is easier to control than fleas. Interestingly, it was Australian expertise that first demonstrated that dog hookworm could also cause a painful intestinal disease in humans, a syndrome which has now also been reported in the USA.

Pets also harbour many other parasites of public health significance that can be transmitted to people and cause disease. Such infections are called zoonoses, and Australian parasitologists have contributed much to their control. The hydatid tapeworm *Echinococcus granulosus*, which can be transmitted from infected dogs to people, gives rise to massive cysts in the internal organs of its human host. The only sure way to cure hydatid disease in humans is by major surgery.

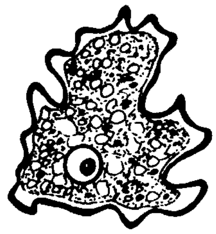


Australia is often referred to as the home of hydatid research because of the pioneering work of Harold Dew in the 1920s and of Desmond Smyth in the 1960s and 1970s, as well as the success of the Tasmanian hydatid eradication campaign (THEC). The THEC served as a model for similar hydatid control programs throughout the world. These will be enhanced with the introduction of a recombinant hydatid vaccine recently developed at the University of Melbourne.

Pets also carry other parasite zoonoses such as *Toxocara* and *Toxoplasma.* Fortunately, awareness of these parasites is high because Australian veterinary parasitologists have played a continuing role in educating the public about them. The role of pets in carrying parasites of public health significance was recently highlighted during the Sydney water crisis with the potential dangers of *Giardia* and *Cryptosporidium*. The significance of dead dogs found near a water supply and the possibility they could have been a source of *Giardia* was widely publicised.

Australian parasitologists have recently developed molecular genotyping tools which could have determined whether the *Giardia* in the dogs was a 'strain' potentially infective to humans, and readily discriminated between algae and *Cryptosporidium* in water samples, thereby helping to determine the source of *Cryptosporidium* in the water.

Biodiversity and the invisible component



In the most significant analysis to date - "*The State of the Environment: Australia*" report in 1996 - one million species (including microorganisms) was given as an estimate of Australia's biodiversity. However, only 15 per cent of these have been formally described. Because Australian plants and animals have evolved in isolation over the last 50 million years, these one million species represent a rich biodiversity of unique life forms - for example, some 85 per cent of our mammals are found nowhere else in the world. As this example attests, most of the large organisms (plants and vertebrates) have been described and, in some cases, studied in detail.

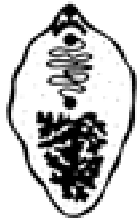
However, almost nothing is known about the estimated 225 000 invertebrate species inhabiting this land, less that half of which have been described. This vast and less visible world is intimately involved with the critical processes that maintain a healthy ecosystem and a healthy environment. An even less visible but equally essential component not mentioned at all in the SOE report are those organisms which have taken up a parasitic life style; they represent more than 50 per cent of the world's biodiversity.

Parasites are known to have a dual but conflicting significance. Pathogenic parasites present threats to humans, livestock and wildlife. On the other hand, parasites can and do control host populations, help maintain genetic diversity and play a significant role in the structure of vertebrate and invertebrate communities. Furthermore, parasites 'tell stories' about themselves and their hosts, and can inform us about host ecology, behaviour and trophic interactions.

An attempt to balance the international biodiversity research effort is the Species 2000 Program, which has been established by the international scientific unions IUBS, CODATA and IUMS, and is associated with the UN convention on Biological diversity and endorsed by UNEP. Australia has a representative on the project team but has given no formal support. Species 2000 has the goal of producing a uniform and validated index to the world's known species. Whilst this is a very worthwhile effort, it serves only to make present knowledge more accessible rather than finding out new knowledge.

In order to describe and explore as many species as possible, two basic parameters must be met. The first is that suitably trained graduates must be available to carry out the work and the second is that research must be encouraged in the biodiversity of Australian parasites.

Education in parasitology– the biggest problem?



The discipline of parasitology plays a significant role in various aspects of human and animal health, primary industries and in basic biological research. Hence there is a well-established need for trained parasitologists with a wide range of parasitological skills. Training in parasitology can be divided into four main areas: medical, veterinary and agricultural parasitology and fundamental parasite biology.

Medical schools in Australia currently train almost no parasitologists. Parasitology is treated as a minor adjunct to microbiology and the greatest emphasis is given to diseases such as malaria. As a consequence, there are few medical graduates in Australia with post-graduate qualifications in parasitology. Given the importance of parasitic diseases in South-East Asia, this lack of training is surprising. However, it is likely to worsen rather than improve in the foreseeable future, with changes in medical curricula and a move away from the comprehensive coverage of disciplines to case-based learning.

Veterinary schools in Australia have parasitology as a core subject and would be unlikely to be able to retain their certification if parasitology ceased to be a core subject. There are currently six academic positions in Veterinary Parasitology in the country compared with nine such positions five years ago. Although all undergraduate veterinary students are required to study parasitology, very few undertake postgraduate studies and, as a consequence, it has become difficult to fill veterinary parasitology positions in universities and government departments. Of the various schools of agricultural science, only one offers a course in parasitic diseases of livestock. Faculties of agriculture have in the past run courses in nematology, which deal with parasites of crop plants, but the last academics with expertise in this field retired a few years ago.

Therefore the possibility of training new research students in parasitology is limited. In spite of the importance of parasites to crops and the livestock industries, the opportunities for postgraduate training have diminished substantially.

The major source of post-graduate training in parasitology has been through departments of biological science in universities and certain medical institutes. In the past, the most prominent centres have been the Universities of Adelaide, Queensland, New England, James Cook University, the Australian National University, the Walter and Eliza Hall Institute and the Queensland Institute of Medical Research. The formal teaching of parasitology at the University of Adelaide ceased in 1991 and the programs at James Cook, New England and ANU have diminished significantly. The WEHI malaria program has been reduced in size but is still training postgraduates, and QIMR is also still active. The only Department of Parasitology remaining was that at the University of Queensland but it was merged into the Department of Microbiology and the name has now been lost, though the people remain.

Parasitology is undergoing a decline in Australia. One of the effects is the increasing numbers of graduates undertaking research in parasitology who have never undertaken a course in the discipline, often because there are no such courses to undertake. The decline in parasitology teaching reflects the ignorance of university and government administrations and the lack of any policy for maintaining the supply of suitably trained graduates despite a demonstrated need.

The numbers of trained parasitologists will continue to decline on current trends. Universities and governments are as yet oblivious to the issue, while potential employers are beginning to appreciate some of the problems.

Recommendations

The parasitological issues summarised in this paper point to a number of problems that are generic to science as well as more specific concerns to infectious disease research and parasitology in particular. It is clear that these problems and concerns can only be solved by a concerted approach at all levels of government, as well as involvement by industry and educational institutions.

The costs of an outbreak of parasitic and other infectious disease can far exceed the simple cost of control. Current illustrations of this principle abound, the Sydney water crisis being a local parasitological example. Our lack of knowledge about the causes of infectious diseases such as parasites, and their potential biosecurity threat to Australia's health and economy will only be overcome by research and education.

Specific measures, such as CRCs and targeted grants, will help improve the situation but only a culture of research and development will significantly protect us against major problems such as caused by BSE and Foot and Mouth Disease in Britain. These epidemics are classic cases of too little research and a lack of timely action leading to catastrophic medical and veterinary problems which might easily occur with parasitic species or other diseases in Australia.

Local examples of our lack of knowledge include the recent finding of the Hendra and Lyssaviruses in bats in Australia both potentially lethal to humans and animals. While parasite examples include finding the worm *Trichinella* in Tasmanian Devils which caused some disquiet until it was determined to be natural to the devil and not apparently zoonotic, whereas new findings of the protozoan disease Surra's encroachment to our shores could devastate Australian livestock and wildlife.

This report makes the following recommendations:

1. Develop a coordinated strategy for the prediction, surveillance and control of infectious diseases.
This strategy would be based on the establishment of interdisciplinary research leading to the detection and control of diseases with the potential for harming Australia. It would draw upon and coordinate parasitology work carried out through institutions such as AQIS, ACIAR, BRS, NH&MRC, ARC, CSIRO and the Universities.

2. Combat drug resistance and design better anti-parasitic drugs
Australian research has led the world in defining the forms of resistance and methods for extending the life of current chemicals, and there is local expertise in drug targeting and drug development. The coordinated strategy should encourage research and industry to work together on drug resistance problems, and the design of new drugs.

3. Increase the national capacity in parasitology education and research training
Australia needs a strategic national approach to training and education, to ensure a steady supply of students, graduates, researchers and teachers. This would involve revitalising existing courses, encouraging universities and other research institutions to develop critical mass, and encouraging postgraduate work in parasitology.

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