Journal of Helminthology (2005) **79,** 1–14 DOI: 10.1079/JOH2004266

Review Article

Parasitic zoonoses in Papua New Guinea

I.L. Owen*

C/o National Veterinary Laboratory, National Agriculture and Quarantine Inspection Authority, Port Moresby, Papua New Guinea†

Abstract

Relatively few species of zoonotic parasites have been recorded in humans in Papua New Guinea. A greater number of potentially zoonotic species, mostly nematodes, occur in animals but are yet to be reported from humans. Protozoa is the best represented group of those infecting man, with *Giardia duodenalis*, *Cryptosporidium parvum*, *Cyclospora cayetanesis*, *Toxoplasma gondii*, *Sarcocystis* spp., *Entamoeba polecki*, *Balantidium coli* and, possibly, *Blastocystis hominis*. The only zoonotic helminths infecting humans include the trematode *Paragonimus westermani*, the cestodes *Hymenolepis nana*, *H. diminuta* and the sparganum larva of *Spirometra erinacea*, and the nematodes *Trichinella papuae* and *Angiostrongylus cantonensis* and, possibly, *Ascaris suum*. Other groups represented are Acanthocephala (*Macracanthorhynchus hirudinaceus*)), insects (*Chrysomya bezziana*, *Cimex* sp., *Ctenocephalides* spp.), and mites (*Leptotrombidium* spp. and, possibly *Sarcoptes scabiei*, and *Demodex* sp.). One leech (*Phytobdella lineata*) may also be considered as being zoonotic. The paucity of zoonotic parasite species can be attributed to long historical isolation of the island of New Guinea and its people, and the absence until recent times of large placental mammals other than pig and dog. Some zoonotic helminths have entered the country with recent importation of domestic animals, in spite of quarantine regulations, and a few more (two cestodes, one nematode and one tick) are poised to enter from neighbouring countries, given the opportunity. Improvement in water supplies, human hygiene and sanitation would reduce the prevalence of many of these parasites, and thorough cooking of meat would lessen the risk of infection by some others.

Introduction

Zoonosis, as defined by WHO (1979), covers disease and infection that are 'naturally transmitted between vertebrate animals and man'. While zoonosis is probably as old as man himself, there is no doubt that the domestication of animals, by bringing man and beast into closer contact than had previously occurred, facilitated the process of zoonosis and may have given opportunities for new zoonoses to evolve.

Southwood (1987) states that the largest number of shared diseases are those common to man and dog, the smallest number to man and poultry. He remarks that 'the number of shared parasites seems proportional to the length of time since domestication' – amongst mammals, the dog having the longest time history of domestication and the horse the shortest, *c.* 15,000 and *c.* 6000 years respectively, according to Clutton-Brock (1999).

The zoonotic parasites present in Papua New Guinea (PNG) when European exploration first began late in the 19th century, are likely to have been here a long time. Two or more waves of human immigrants are believed to have entered the island of New Guinea (NG)[1], the first possibly

*E-mail: iowen@datec.net.pg
†Present address: PO Box 5539, Boroko, Papua New Guinea

[1]The island of New Guinea is divided into two political entities, PNG, an independent state, in the eastern half and West Papua, a province of Indonesia, in the western half.

50,000 years ago and the last about 5000 years ago (Bulmer, 1982; Main *et al.*, 2001).

Following the last wave of migrants, NG appears to have been in a virtual state of quarantine up to the 19th century as, for several reasons, there was little or no contact with the outside world over this long period. The land link between southern NG and northern Australia, which had been there for millennia, disappeared 6000–8000 years ago when melting glacial ice caused sea levels to rise. NG became an island, situated beyond the world known to ancient civilizations and therefore isolated from their activities.

Later, during the second half of the last millennium, when European countries sent ships to explore, what were for them, unknown parts of the world, the inhospitable nature of the land of NG, as seen from ships, together with the belligerent and less than welcoming attitudes of the people to intruders, discouraged early European exploration. Thus, for thousands of years, the likely contact the people of NG had with the outside world was restricted to shipwrecked seamen and, for coastal people of the western end of the island, some trading with people of the Indonesian islands to the west.

This long isolation meant that there was little opportunity for new zoonotic parasites to enter. It is unlikely to be a coincidence that the only zoonotic helminth parasites found in humans when the first parasite surveys were done in the 20th century, were two tapeworms whose natural hosts are rats. Rats and bats were the only placental land mammals present in NG when man first arrived (Flannery, 1995). The parasites of the other mammals on the island, monotremes and marsupials, apparently, find man an unsuitable host. Humans probably acquired no new zoonotic parasites after arrival until domestic animals were brought in; pigs probably about 5000 years ago, and dogs 2000–3000 years ago, while all other domestic livestock arrived within the last 100 or so years. In spite of quarantine regulations, some zoonotic parasites have entered PNG with imported livestock but it remains a country with a restricted range of zoonotic parasites (Barnish & Ashford, 1989).

The zoonotic parasites recorded in PNG can be placed into one of two categories; those found infecting humans, and those present in PNG animals but not yet recovered from humans. In a separate category are zoonotic parasites that occur in neighbouring countries and with a distinct potential for entering PNG (table 1).

Protozoa

Ashford & Atkinson (1992) comment on the abundance of intestinal protozoan fauna found in humans in PNG. Some, such as *Dientamoeba fragilis*, *Entamoeba hartmanni*, *E. dispar* and the pathogenic *E. histolytica* are known only from man or other primates. Transmission in these species is person to person (anthroponotic) and not zoonotic. The focus in this account is on parasites with zoonotic transmission.

Potentially zoonotic commensal protozoa

A variety of protozoa inhabit the human gut in PNG that are, strictly speaking, not parasites but commensals as they are considered to do no harm to the host. They (or identical forms) can be found infecting certain other mammalian hosts; *Entamoeba coli*, *Iodamoeba butschlii*, *Chilomastix mesnili* have been recorded in pigs, and *Endolimax nana*, *Enteromonas hominis* and *Pentatrichomonas* (= *Trichomonas*) *hominis* occur in rodents. These organisms are commonly recorded in human surveys, sometimes with high incidence (Kelly & Gar Avusi, 1974; Kelly, 1975; Desowitz & Barnish, 1986; Ashford & Atkinson, 1992), which prompts the question if their prevalence is associated with zoonotic as well as the normal person to person transmission. The ubiquitous pig, and also rodents, are an integral part of most village environments in PNG.

Giardia

Giardia duodenale is common in dogs and cats (Thompson, 1998) but there are no records of infection in these or other animals in PNG.

Human infection has been recorded in several surveys in the country (Avery, 1946; Bearup & Lawrence, 1950; Kelly & Gar Avusi, 1974; Hornabrook *et al.*, 1975; Kelly, 1975; Desowitz & Barnish, 1986; Ashford & Atkinson, 1992). Young children were the most frequently infected and usually had the highest infection rate. Crouch (1982) noted that the importance of *Giardia* as a causative agent in diarrhoea in PNG has not been assessed.

Bukenya (1991) recorded a higher prevalence in non-diarrhoeic than in diarrhoeic infants in a PNG coastal settlement survey.

Cryptosporidium

The only published report of human infection with *Cryptosporidium parvum* is in a group of children in Goroka (Groves *et al.*, 1994) with an infection rate of 24%, while Barnish (1992) also mentions its diagnosis in patients in Goroka. Ashford & Atkinson (1992) did not detect oocysts in a survey in nearby Asaro valley but, from observations, considered the parasite to occur in the area. It is probably a common but overlooked parasite in the country, although Bukenya (1991) found a maximum prevalence of only 2.1% in diarrhoeic infants under 5 years of age in a survey of a Port Moresby coastal settlement.

As there are no reports of infection in PNG animals, the epidemiological role animals may have in PNG has not been investigated.

Cyclospora

Ashford (1979) reported an unidentified coccidian parasite of man in PNG, later named *Cyclospora cayetanensis* when discovered in a population of children in Peru (Ortega *et al.*, 1994). It has been recorded elsewhere in non-human primates (Ashford *et al.*, 1993; Smith *et al.*, 1996) as well as in chickens, rodents and dogs (Scherchand & Cross, 2001). It is not known if animals are infected in PNG.

Toxoplasma

The domestic cat, being the sole member of the cat family in NG, is the only definitive host of

Table 1. Zoonotic and potential zoonotic parasites in Papua New Guinea (PNG) and in neighbouring countries.

Parasite group	Zoonotic parasites infecting humans in PNG	Potential zoonotic parasites present in PNG	Important zoonotic parasites in neighbouring countries
Protozoa	*Giardia duodenalis* *Cryptosporidium parvum* *Cyclospora cayetanensis* *Toxoplasma gondii* *Sarcocystis* spp. **Blastocystis hominis* *Balantidium coli* *Entamoeba polecki*		
Trematodes	*? Paragonimus westermani*	*Fasciola hepatica*	
Cestodes	*Hymenolepis nana* *H. diminuta* *Spirometra erinacei* (sparganum)	*Dipylidium caninum* *Taenia taeniaeformis* *T. hydatigena*	*Taenia solium* *Echinococcus granulosus* (hydatid)
Nematodes	**Ascaris suum* *Trichinella papuae* *Angiostrongylus cantonensis*	*Ancylostoma* spp. *Toxocara* spp. *Trichostrongylus* spp. *Strongyloides* spp. *Trichuris* spp. *Gnathostoma doloresi* *Dirofilaria immitis* *Spirocerca lupi* *Cheilospirura hamulosa* *Anisakis simplex* *Eustrongylides* sp. *Mammomonogamus laryngeus*	*Capillaria philippinensis*
Acanthocephala	*Macracanthorhynchus hirudinaceus*	*Moniliformis* spp.	
Annelids: Leeches	*Phytobdella lineata*		
Arthropods: Insects	*Chrysomya bezziana* *Cimex* spp. *Ctenocephalides* spp.	*Chrysomya* spp. *Xenopsylla* spp.	
Ticks			*Ixodes holocyclus*
Mites	**Sarcoptes scabiei* **Demodex* sp. *Leptotrombidium* spp.	*Dermanyssus gallinae* *Ornithonyssus* spp.	

Note: ? denotes uncertainty as to a parasite's continued presence in PNG; and * indicates uncertainty as to a parasite's zoonotic status.

Toxoplasma gondii. Cats, and presumably *T. gondii*, first arrived on the island probably early in the colonial period but there are no reports of any being examined for infection, and there are very few records of other animals acting as intermediate hosts. De Roever-Bonnet *et al.* (1964) reported 64% infection in pigs and 6 and 7% respectively in dogs and cattle in West Papua. These data, however, may not be typical of NG animals as the pigs and cattle were periurban and the dogs were European owned. In PNG, Ewers (1973) recorded *Toxoplasma* sp. in a pigeon (*Ducula concinna*).

Reports of human infection are more numerous. De Roever-Bonnet *et al.* (1964), Cross *et al.* (1977) and Wallace *et al.* (1974) reported varying prevalence rates in various communities on the island of New Guinea, which the latter authors attribute to the presence or absence of cats in the environment. Zigas (1976), on the other hand, considered there were strong indications linking infection amongst four communities in East New Britain Province, PNG, to factors other than the presence of cats, such as consumption of undercooked infected meat.

Sera collected recently from five rural villages in Western Province had prevalence rates of more than 85% in men and 72% in women (unpublished data). A few cats are present in the villages, but the very high prevalence suggests that they are not the sole source of infection. Serological evidence of toxoplasmosis in some species of deer has been recorded overseas (Watson & Charleston, 1985), and 2% prevalence has been reported in agile wallabies (*Macropus agilis*) in northern Australia (Speare *et al.*, 1983) and severe outbreaks have occurred in captive wallabies in New Zealand (Duignan *et al.*, 2004). As rusa deer (*Cervus timorensis*), agile wallabies and wild pigs form a regular part of the diet of the village people in the area, undercooked meat could be a major source of infection. Screening of a group of high school students and teachers from a school near Port Moresby on the other hand, showed a seroprevalence of 18% (unpublished data). This is the same rate of infection that Klufio *et al.* (1993) found in pregnant women attending antenatal clinic in Port Moresby General Hospital. One can speculate that the village and urban groups have different sources of infection, linked to different eating habits, although Dubey (1998a) notes that it is very difficult to determine a source of infection.

Clinical toxoplasmosis, as distinct from detection of *Toxoplasma* by serodiagnosis, has been recorded in NG only by De Roever-Bonnet *et al.* (1964) who reported a

case of congenital infection of a stillborn child and a case of an adult with ocular anomalies, probably produced by toxoplasmosis, both in West Papua.

Sarcocystis

Man acts as the definitive host for two zoonotic species, *Sarcocystis hominis* and *S. suihomini* and can be an accidental (dead-end) intermediate host for several unidentified species of sarcocysts that infect livestock and wild animals (Dubey, 1998b).

Munday *et al.* (1977) reported 45% of free-range chickens tested in PNG had sarcocysts in their muscles; dogs were considered to be the definitive hosts. Examination of pig tissues from various parts of PNG (mostly commercially grown pigs) at the National Veterinary Laboratory over 11 years, found only 1.4% to be infected and an infection rate of 0.5% was recorded in cattle tissues over the same period (unpublished data). Barnish & Ashford (1989), on the other hand, state that village pigs in PNG are commonly infected with *Sarcocystis* sp., and found the scarcity of records of human infection surprising in view of the importance pig meat has in the traditional diet of many people. It is not known if the sarcocysts seen in tissues of pigs and cattle are zoonotic species, or cysts of other species that can occur in pigs and cattle for which the dog and/or cat act as definitive hosts (Dubey, 1998b).

Blastocystis

Ashford & Atkinson, (1992) found *Blastocystis hominis* to be the most abundant gut parasite of people in the Asaro valley in the highlands of PNG, while Bangs *et al.* (1996) report infection as infrequent to rare in people of the Oksibil valley in the highlands of West Papua. It is not known if *Blastocystis* is present in animals in PNG, therefore, it remains to be discovered what role, if any, animals have in its epidemiology.

Entamoeba

There are sporadic reports in some countries of human infection with the uninucleated cyst-producing *Entamoeba polecki* (which Verweij *et al.* (2001) suggest should be referred to as '*E. polecki*-like' pending clarification of genetic variation), but foci of infection occur in SE Asia and in PNG (Lloyd, 1998a). McMillan & Kelly (1970) report that Heydon was the first to record *E. polecki* in PNG in a 1933 human survey in the highlands. Subsequent surveys, (Vines & Kelly, 1966; Kelly & Gar Avusi, 1974; Kelly, 1975; Desowitz & Barnish, 1986; Ashford & Atkinson, 1992) have shown it is a common intestinal parasite, sometimes being the predominant protozoan species of the gut fauna (Kelly, 1975; Desowitz & Barnish, 1986). Muller *et al.* (1987) refer to its common occurrence in a highlands survey in West Papua.

In PNG *E. polecki* occurs usually as one of many intestinal species of protozoa, including the pathogenic *E. histolytica* with which it may be confused as both the trophozoite and cyst stages of the two species are very similar (Martinez-Palomo & Espinosa Cantellano, 1998). Consequently, although infection with *E. polecki* is generally considered to be asymptomatic in humans, if it generates any ill-effects, they may be masked by, or attributed to, those produced by *E. histolytica*.

There is no information about the prevalence of *E. polecki* in pigs in PNG but it is likely to be widespread as human infection elsewhere is often found where there is close association between humans and pigs, as occurs in many societies in the country.

Balantidium

Human infection with *Balantidium coli* is uncommon while infection in pigs is said to be extremely common (Zaman, 1998). Various surveys conducted in NG indicate that human infection with *B. coli* can be common in one locality but rare or absent from another a short distance away (Couvée & Rijpstra, 1961). These authors, working in the highlands of West Papua, postulate that high prevalence may be linked to a high population of pigs and their need in a cold, high altitude environment for warmth and shelter which they find under or within their owner's house, ensuring close contact between pigs and people and conducive for the possibility of zoonotic infection to occur.

The highest prevalences of human infection reported in NG are 28% (Couvée & Rijpstra, 1961) and 20% (Van Der Hoeven & Rijpstra, 1957) in highland communities in West Papua. Heydon, as quoted by Ewers & Jeffrey (1971), recorded the highest prevalence found in PNG of 11% in people in the Mt Hagen area in 1933. More than 30 years later, Vines & Kelly (1966) reported an infection rate of only 1.7% in the highland provinces, and Kelly (1975) found infection in only three villages of more than 60 surveyed in eight provinces.

Reports of clinical cases of balantidiasis in PNG are rare; Radford (1973) described four, and one fatal case is mentioned by Barnish & Ashford (1989).

There are very few published accounts of infection of pigs with *Balantidium* in NG, but there is a general perception that infection is common in village pigs, especially in mountainous localities. Van der Hoeven & Rijpstra (1957) and Couvee & Rijpstra (1961) found infection in every village pig tested in one highland valley in West Papua, while infection was much less prevalent in coastal village pigs (Van der Hoeven & Rijpstra, 1962). Although no surveys of village pigs for *B. coli* have been done in PNG, isolated testing indicates a general presence especially in the highlands. Unpublished data show that infection can occur also in commercial piggeries both in the highlands and lowlands. There is a potential risk of infection, therefore, not only for villagers but also for staff of piggeries and abattoirs.

Trematodes

It would appear there were no trematodes infecting man in PNG before recent immigrants and their animals began arriving in late 19th century. The situation today is only slightly different, with one fluke (*Fasciola hepatica*) definitely and one (*Paragonimus westermani*) possibly established in the country.

Although a number of other trematodes have been suggested to be present in PNG, the evidence is not

compelling as it is based on isolated findings of one or more eggs in human faeces. Positive identification of helminth eggs in faeces can be difficult as some worms belonging to different genera, and even classes, produce eggs of similar appearance and size. The difficulties are greater when determination is dependent on recognition of eggs in histological sections, as Prociv (1989) points out, with reference to a claim by Murthy *et al.* (1989) of possible schistosomiasis in a man from Enga Province, based on seeing eggs in sections of liver. Both Prociv (1989) and Walker (1989) consider this case was probably one of misidentification.

Blackburn & Ma (1971) obtained positive reactions with intradermal tests of *Schistosoma mansoni* antigen in people of the Baiyer River area, Western Highlands Province, but the authors themselves acknowledge it could be a case of cross-reaction with other helminths as there is no clinical or laboratory evidence of human schistosomiasis in NG.

Papua New Guinea, therefore, remains a country in which diseases caused by flukes are not a problem for human health but there is need for constant vigilance as, with the ever increasing movement of people, the risk of one or more of the many species of trematodes endemic in the S.E. Asian region entering the country is greater than ever. The molluscan fauna of the country is largely unknown as, consequently, is the role they could play as intermediate hosts of exotic trematodes

Fasciola

The first known arrival of *Fasciola hepatica* in PNG was in the immediate years after World War II. Sheep from Australia were placed at Nondugl, Western Highlands Province, a site where the aquatic snail *Lymnaea viridis* occurs. *Lymnaea viridis* is the only intermediate host in PNG and is present above 550–650 m in some but not all river systems. *Fasciola* is now a common parasite of sheep and cattle in Eastern Highland Province, with foci of infection in ruminants in some highland sites of other mainland provinces.

Human fascioliasis due to *F. hepatica* is said to be uncommon (Macpherson *et al.*, 2000).

Watercress (*Nasturtium officinale*) is the plant most commonly reported as the source of human infection in many countries where it is eaten as a fresh salad vegetable. Watercress is an introduced plant in PNG and people prefer eating it as a cooked vegetable. The heating process kills any larvae present, which may explain why no human infection has been reported as yet in PNG. Nevertheless, with the high prevalence of infection in sheep and cattle in parts of the highlands, and the common human habit of chewing on blades of grass, it would be surprising if there has been no zoonotic transmission in the country.

A seasonality of infection is usually seen in animals in PNG, coinciding with or following a wet period when flooding of pasture allows snails to migrate from permanent water courses and contaminate surrounding vegetation with larvae. Low level infection can occur throughout the year where there are seepages or conditions are permanently swampy (Owen, 1989).

Paragonimus

The only case of paragonimiasis recorded in PNG is by Cilento & Backhouse (1927) who found a pair of adult *Paragonimus westermani* at post mortem in the lungs of a man from coastal East New Britain Province. The infected person came from a village that had had practically no contact with overseas people and where crabs (potential second intermediate hosts) were a very popular item of food. Taking these facts into consideration, the authors felt the disease was endemic in the locality. The lack of reported sighting of *Paragonimus* in people from the area in subsequent years suggests it has failed to survive or is maintaining itself at a low prevalence with human incidence too low to elicit pathognomonic symptoms. According to Barnish & Ashford (1989), Anon. (1927) refers to *Paragonimus* being occasionally seen in Chinese in the country. It is not known which snail in PNG can serve as the intermediate host.

There are no records of dogs, cats or rats, the other potential definitive hosts of *P. westermani*, being infected in the locality.

Cestodes

Although PNG has a number of zoonotic tapeworms, none pose a serious threat to human health. However, two other cestodes (*Taenia solium* and *Echinococcus granulosus*) present in neighbouring countries, would lead to serious consequences for human health if they became established in the country.

Hymenolepis

From data recorded in various surveys, *Hymenolepis nana* is a rare parasite of humans in PNG. It was not seen, for example, by Bearup & Lawrence (1950), McMillan *et al.* (1971), Kelly (1975) and Hornabrook *et al.* (1975), while Shield *et al.* (1980, 1981, 1984) reported infection of only one person in each of the three surveys. The only record of rodent infection in PNG is of a massive infection of a mouse belonging to the National Veterinary Laboratory mouse colony (unpublished data), which suggests it can be locally common.

While *H. nana* is the most frequently encountered human tapeworm in the world (Lloyd, 1998b) but uncommon in PNG, *H. diminuta* is a much more common parasite of man in the country although it is a relatively rare human parasite elsewhere (Bisseru, 1967). *Hymenolepis diminuta* has been reported in the highlands, mostly from children, by Vines & Kelly (1966), McMillan *et al.* (1971), and Kelly (1975), with infection percentages up to 3%. There are no records, it seems, of the worm occurring in people living at low altitudes. The reason cannot be linked to adverse effect of higher environmental temperatures as *H. diminuta* eggs have greater heat tolerance than that of its beetle intermediate host (Pappas *et al.*, 1999) and *H. diminuta* has been identified from various species of rats at lowland sites in Central, Western and East Sepik provinces as well as from Goroka in the highlands.

Dipylidium

Dipylidium caninum is a very common tapeworm of dogs in PNG, particularly in urban centres (Hamir &

Wernery, 1987), and sometimes of cats. Infection is characterized by white segments resembling rice grains in the host's faeces. Infection of humans is said to be rare and almost all in young children. There are no reports of human infection in PNG.

Spirometra (sparganum)

Adult *Spirometra erinacei* tapeworms have been found on several occasions in urban dogs and cats in Port Moresby, Lae and Goroka. Its prevalence in rural animals is not known.

The only recorded case of human sparganosis in PNG is of a young man with the larval sparganum worm contained in a nodule in an orbit (Ashford *et al.*, 1978). Instances of sparganosis in animals have been recorded in reptiles only in PNG, found either between muscles or in the serous membranes of the body cavity. The crocodile is the most commonly infected animal and infection has been seen also in one species of goanna and two species of snakes. In Australia, wild pigs can be infected (Stevenson & Hughes, 1988) as well as species of bandicoot, dunnart and echidna (Spratt *et al.*, 1991), animals that also occur in PNG. Echidnas are said to be affected more severely than other secondary intermediate hosts (Booth, 1994); they are greatly prized by hunters in PNG (Flannery, 1995).

Taenia

The tapeworms *Taenia taeniaeformis* and *T. hydatigena* have, on rare occasions, been found infecting man, and both have been recorded in animals in PNG (Egerton & Rothwell, 1964; Talbot, 1968/69). Adult *T. taeniaeformis* has been recorded a few times in cats and the larval stage recovered from the liver of the large rat (*Mallomys rothschildi*) on three occasions (unpublished data). Adult *T. hydatigena* tapeworm has been recorded in dogs but is not common. The larval bladder stage has been recovered from sheep, almost solely from imports that have been kept under permanent quarantine conditions so as to prevent infection of dogs through scavenging of offal.

No human cases of infection with the larval stages of *T. taeniaeformis* or *T. hydatigena* have been recorded in PNG.

Taenia solium has particular significance for PNG as it is present in West Papua. It was unknown in NG until it was introduced in pigs imported from western Indonesia into the Paniai Lakes area of highland West Papua in 1971 (Gajdusek, 1978). Its rapid spread eastwards to within a relatively short distance of the PNG border indicates the likely scenario that would occur in PNG if the tapeworm became established here before authorities were aware of its presence and were able to initiate a control or eradication programme.

Pigs have an equally important role in the social and economic life of village people on both sides of the border. Also similar is the customary way of cooking pig meat in a *mumu* (earth oven) with the meat sometimes eaten when inadequately cooked (Wandra *et al.*, 2000; Owen *et al.*, 2001). Other important factors are poor personal hygiene, leading to contamination of food, while indiscriminant defaecation can lead to fly-borne transfer of eggs from faeces to food as well as allowing pigs, both village and wild, to become sanitary cleaners and thereby becoming infected with cysticerci (Lloyd, 1998c). Village dogs also serve as refuse cleaners and, being highly susceptible to infection with cysticerci, can act as intermediate hosts and be a source of human infection where dog-meat is eaten (Ito, 2002). Education and quarantine vigilance will have vital roles in a control or eradication programme.

According to recent surveys, human and porcine cysticercosis continues to be a major health problem in West Papua (Subahar *et al.*, 2001). Wandra *et al.* (2000) report a sudden increase in cases of epilepsy and burns associated with cysticercosis in the Baliem Valley north-west of Wamena in the early 1990s, while Subahar *et al.* (2001), working in the same district in 1999–2000, found 70.4% of village pigs and 50.6% of people to be seropositive. These latter authors comment on the traditional movement of people for trading and social reasons across the land border with PNG and the risk this presents for the introduction of the disease into this country.

So far, the only published record of the presence of *T. solium* in PNG is of a West Papuan refugee, originally from the Paniai Lakes area, who was seropositive but who showed no clinical signs and whose faeces had no eggs or proglottids (Fritzsche *et al.*, 1990). Barnish & Ashford (1989) also refer to unpublished data on seropositivity of four West Papuan immigrants and six PNG nationals in 1985. Recent screening of people in Western Province at the southern end of the border revealed no positive reactors (Owen *et al.*, 2001).

Echinococcus (hydatid)

Papua New Guinea is one of the few countries in the world free of hydatid disease. The application of strict quarantine regulations with respect to importation of dogs has prevented the entry of the adult worm of *Echinococcus granulosus* into the country, although Alto & Nettleton (1989) cite the presence of cysts in two cattle thought to have been born in PNG, as indicating illegal entry of infected dogs had occurred. An extensive programme of purging dogs in the locality yielded no tapeworms and there has been no evidence in subsequent years that *E. granulosus* is cycling in PNG, but the risk of entry is always present.

Finding hydatid cysts in imported sheep and cattle in PNG is not surprising as the disease is present in parts of Australia and New Zealand, the only countries from which these animals are sourced. About 90% of cysts in cattle are sterile, but more than 90% are fertile in sheep (Stevenson & Hughes, 1988), which is the main reason why all sheep imported into PNG are kept in life-long quarantine. Maintenance of strict import and quarantine regulations and vigilance of meat inspection at abattoirs should continue, to prevent this zoonotic parasite from becoming established in PNG.

Nematodes

The number of nematode worms in PNG that are zoonotic or potentially zoonotic is relatively high and, with the occasional discovery of new or exotic species, the list is growing.

Ascaris

Both *Ascaris lunbricoides* and *A. suum*, parasites of man and pig respectively, are very common in parts of PNG. The issue of whether or not *A. suum* has a zoonotic role in this and other countries remains unresolved.

Ancylostoma

The four species of zoonotic hookworms belonging to the genus *Ancylostoma* that can cause health problems for humans are *A. caninum* (of dogs), *A. tubaeforme* (of cats) and *A. braziliense* and *A. ceylanicum* (of dogs and cats). Each species causes distinct clinical problems in humans, affecting the skin, intestine or blood (Prociv, 1998). All can enter the body via the mouth or the skin but not all produce cutaneous lesions (larva migrans) or attain adulthood in the human gut.

The only published report (Hamilton & Ferguson 1927), of cutaneous larva migrans in PNG that may have been caused by *Ancylostoma* (or *Strongyloides*) involved a Caucasian child with lesions resembling those caused by *A. braziliense*.

Both *A. caninum* and *A. braziliense* have been recorded in dogs and cats in PNG (Egerton & Rothwell, 1964; Talbot, 1968/69), *A. caninum* being the more widespread, especially in dogs. *Ancylostoma tubaeforme* occurs in cats, while *A. ceylanicum* is not known in PNG but heavy enteric infections with the species (described then as *A. braziliense*) were recorded in Dutch servicemen in West Papua (Anten & Zuidema, 1964).

Toxocara

Three species of *Toxocara* occur in PNG and can be of importance to human health, *T. canis* (of dogs), *T. cati* (of cats) and *T. vitulorum* (of cattle and buffalo), but no human infection with a *Toxocara* sp. has been documented. None of these worms can mature in man, but following ingestion of eggs, larvae pass from the gut to the liver and lungs and from there to other tissues and organs producing the syndrome, visceral larva migrans.

Trichostrongylus and related worms

A number of trichostrongylid worms, normally parasites of ruminants, are potentially zoonotic in PNG. The most likely culprits belong to the genus *Trichostrongylus*. *Trichostrongylus axei* and *T. colubriformis* are very common parasites of sheep and goats in PNG. Others present, and occasionally reported in humans elsewhere, include *Haemonchus contortus* and *Mecistocirrus digitatus*. Barnish & Ashford (1989) reported eggs resembling those of *Trichostongylus* in man, but the eggs of all these nematodes are virtually indistinguishable from each other; diagnosis requires culturing of faeces to identify the larvae.

Strongyloides

The threadworm *Strongyloides stercoralis* has a worldwide distribution in humans although Barnish & Ashford (1989) note that it is 'surprisingly infrequent' in PNG. It also naturally parasitizes dogs, but zoonotic transmission and pathogenicity is said to vary geographically with different strains.

Strongyloides stercoralis has not been recorded in dogs in PNG and is uncommon in Australia, but as the worm is difficult to see grossly in *post mortem* (it has a length of 2.0 to 2.8 mm), and larvae, not eggs, are passed in the faeces, it may have been overlooked. It is not known, therefore, if dogs have a zoonotic role in infecting humans here. The other human species present, *S. fuelleborni kellyi*, is known only from man (Ashford & Crewe, 1998); its geographical isolation from *S. f. fuelleborni* in Africa remains an unexplained mystery (Viney *et al.*, 1991).

Other species of *Strongyloides* occur in animals in PNG: *S. papillosus* in cattle and sheep, *S. ransomi* in pigs and *S. westeri* in horses. The infective larvae of all these species are able to penetrate human skin but are unable to develop into adult worms (Muller, 2002).

Capillaria

No species of *Capillaria* has been reported in man in PNG but Bangs *et al.* (1994) found evidence of indigenous infection of a child with an unidentified species of *Capillaria* in a remote part of West Papua near the PNG border. The pathogenic *C. philippinensis* occurs in parts of the Philippines and some SE Asian countries and, therefore, is a potential exotic zoonosis.

A number of different species of *Capillaria* have been recorded in chickens and pigeons (Egerton & Rothwell, 1964; Talbot, 1968/69) and in ruminants in PNG, and Mackerras (1957) described an unidentified species in the spleen of a rat (*Rattus rattus*) from Port Moresby. *Capillaria papuensis* is an endemic species common here in domestic (Copland, 1975) and wild (unpublished data) pigs. It is unlikely that any of these animal species are zoonotic, otherwise eggs would have been detected in the many human surveys carried out in PNG.

Trichuris

Trichuris suis of pigs, which morphologically resembles closely the human whipworm *T. trichiura*, has a widespread distribution in the country and, together with the less common *T. vulpis* of dogs, is potentially zoonotic, but neither species has been recorded in man in PNG.

Trichinella

No species of *Trichinella* was known in NG until, in 1988, a few village pigs and about 8% of wild pigs in the Bensbach area of Western Province, were found to be parasitized (Owen *et al.*, 2000). Pigs in the area had been monitored periodically before for *Trichinella* but none had been detected. The species discovered in 1988 proved to be new, *T. papuae* (Pozio *et al.*, 1999), and, because it is non-encapsulated, detection with the compression method used earlier would have been difficult. This means there is no certainty how long *T. papuae* has been present in Bensbach pigs and we have no knowledge as to where it came from as the situation on the West Papua side of the border is not known. Recently, commercially farmed crocodiles, originating from the Kikori area of Gulf

Province, were found to be infected with *T. papuae* (Pozio *et al.*, 2004).

People living in the Bensbach villages were tested and 28.9% were serologically positive for *T. papuae* (Owen *et al.*, 2001), while lower prevalence rates were found in some villages further away from the focal area. No one, so far, has been found to be clinically ill from trichinellosis but, as some of the symptoms, such as fever, myalgia, fatigue, eosinophilia, diarrhoea, etc. are non-specific, it is difficult to know to what extent infection affects the well-being of people.

People become infected by eating uncooked or undercooked infected pig meat. Infection rate amongst the Bensbach people is higher in men than in women and this is attributed to the male custom of eating tidbits of raw or undercooked pig meat when out hunting. The general source of infection for people is linked to the method of cooking meat in a *mumu* (earth oven). The area does not have normal river stones, used for *mumu* elsewhere in PNG, and people make use of substitute materials, such as small rough stones, pieces of termite mounds, balls of dried clay and, when available, pieces of metal. These do not retain heat adequately to thoroughly cook all meat so that infection may follow. There is still much to learn about this new zoonosis in PNG.

Gnathostoma

Miyazaki (1968) reported that the species of *Gnathostoma* found in PNG pigs was *G. doloresi* and not *G. hispidum* as previously believed. *Gnathostoma doloresi* is one of several species of the genus that can cause both cutaneous and visceral larva migrans in humans. It has widespread distribution in village pigs in PNG as well as in wild pigs. Talbot (1972) recorded a prevalence of 55% in a survey of village pigs. As yet, there are no cases of human gnathosomiasis reported in PNG but, with the increase in foreign travel and an inclination to try ethnic food, infection may be acquired by travellers while overseas.

Spirocerca and *Cheilospirura*

Spirocerca lupi and *Cheilospirura hamulosa* are two nematodes that on rare occasions have infected humans; they are common parasites of their natural hosts in PNG.

No human case involving *Spirocerca lupi* has been reported in PNG but, as Hamir & Wernery (1987) recorded 70% prevalence in dogs in Port Moresby, it must be viewed as a potential human parasite in the country. Faust *et al.* (1970) found it surprising that more cases had not been observed in enzootic areas.

Humphrey (1979) recorded a prevalence of up to 10% *Cheilospirura hamulosa* in free-range and semi-intensively kept chickens in PNG, being somewhat more common in lowland than highland locations. It has been recovered once from a nodule on the conjunctiva of a man in the Philippines (Muller, 2002); there are no human cases recorded in PNG.

Angiostrongylus (Parastrongylus)

Scrimgeour (1984) showed that *Angiostrongylus cantonensis* is well established in three species of rats and in the snail *Achatina fulica* in Port Moresby, Lae and Rabaul and various other lowland sites in PNG, but not in Goroka. He reported a case of eosinophilic meningoencephalitis due to *A. cantonensis* (Scrimgeour & Burke, 1979) as well as a probable case of ocular angiostrongyliasis (Scrimgeour *et al.*, 1982), both in East New Britain Province.

How and when *A. cantonensis* came to PNG is not known, but it has apparently accompanied the spread of *Achatina fulica* from the latter's point of entry in Rabaul during World War II to many other locations in the country. Land snails are not normally eaten by people in PNG but they may be ingested accidentally, or human infection may follow eating salad vegetables contaminated with larvae from slime of snails. Paratenic hosts, such as the coconut crab, freshwater crayfish can be sources of infection, or even standing barefoot on an infected snail, allowing larvae to enter through an abrasion (Scrimgeour & Welch, 1984).

Dirofilaria

Dirofilaria immitis, canine heartworm, is a common parasite of dogs in PNG, particularly in urban areas (Hamir & Wernery, 1987) and, occasionally, of cats. Humans are accidental and unsatisfactory hosts in the dog–mosquito–dog cycle. There are no documented reports of human infection in PNG but it may be a mistake to assume that none occurs here as, human populations in other endemic areas have seroprevalences approaching those corresponding to canine populations (Simon Martin & Genchi, 2000).

Anisakis

Infective larvae of *Anisakis simplex* have been found in skipjack tuna (*Katsuwonus pelamis*) in waters of the southern coast of PNG. They have been recovered here also on several occasions in foreign canned mackerel and, although no longer infective, they may elicit allergic responses in susceptible people (Audicana *et al.*, 2002).

Eustrongylides

Eustrongyloides larvae of unknown species have been recovered from three species of freshwater fish and from two species of crocodiles in PNG. There are no reports of human infection in the country but there is a potential risk of infection if freshwater fish or crocodile meat are eaten raw or in an inadequately cooked state. The growing international trend of eating uncooked fish and other meat dishes increases the risk of infection.

Mammomonogamus

In 2001, *Mammomonogamus laryngeus*, previously unknown in PNG, was found in the larynx of a bovine at slaughter (unpublished data); more cases have subsequently been found from the same locality. The source of the worms is not known and there are no reports of human infection.

Acanthocephala

Macracanthorhynchus and *Moniliformis*

Infection of village and wild pigs with *Macroacanthorhynchus hirudinaceus* in PNG is common. It is not surprising that a 3-year-old child was found infected (Barnish & Misch, 1987) as it is the nature of young children to put objects in their mouths and often they indulge in geophagy (Lloyd, 1998d).

Two species of *Moniliformis*, *M. moniliformis* and *M. dubius*, that are sporadic human parasites, are present in rats in PNG. They both use cockroaches or beetles as intermediate hosts. As Miyazaki (1991) remarks, it is impossible to envisage humans directly eating cockroaches but infection may be possible through unwittingly swallowing a larva in the debris of a cockroach. No case of human infection has been reported in PNG.

Hirudinea

Although leeches are not usually considered as zoonotic parasites, in one locality in PNG significant parasitism of man by a land leech, *Phytobdella lineata*, is linked to heavy infestation of domestic cattle. Leeches, apparently, were no more of a problem in the Pimaga area of Southern Highlands Province than in other humid parts of the country prior to the introduction of cattle by a mission in the 1960s to alleviate local malnutrition. The locality is at an altitude of about 610 m and surrounded by sago swamps.

The arrival of cattle led to a leech population increase that, in years with above average rainfall (>5000 mm), can reach plague levels. Under these conditions, cattle become anaemic, debilitated and, reportedly, sometimes die as a result of leech infestation. There are no reports of human health being directly affected by the leeches but, in the words of a member of the mission staff, they 'make life untenable for man and beast'. Control measures, other than removal of the cattle, are restricted to temporary remedies such as spraying pasture with concentrated salt solution and topical application of lemon juice, as potentially more effective, long-term remedies involve chemicals that can be hazardous for humans and the environment.

Insects

Chrysomya

Chrysomya bezziana, the Old World screw-worm fly, that can infest any warm-blooded animal, occurs all over PNG except on Buka and Bougainville islands (Spradbery, 1991). Zumpt (1965) refers to two cases of human myiasis infection in New Ireland Province, and Barnish & Richens (1989) describe three cases in the highlands, affecting an eye socket, nose and ear. Animal 'strikes', particularly of cattle and sheep, are common.

Three other *Chrysomya* species widespread in the country, *C. megacephala*, *C. rufifacies* and *C. saffranea*, unlike *C. bezziana*, are not obligatory parasites but can be involved in myiasis, usually as secondary agents (Kurahashi, 1987; Spradbery, 1991). There are no reports of human infestation in PNG, but myiasis by the first two species has been observed on several occasions in sheep (unpublished data).

Cimex

The bed bug, *Cimex lectularius*, normally feeds on man but it also can be found associated with laying birds in chicken houses in PNG, which may serve as sources of infestation for humans.

Ctenocephalides and other fleas

The cat flea (*Ctenocephalides felis*) and the dog flea (*C. canis*) can transfer to man for short periods, especially when the normal host is not available. This often happens in PNG when a house, which had a cat or dog, stands empty for a period before being reoccupied. Vibrations caused by human movement liberate adult fleas from pupae hidden in cracks leading to attacks by hungry fleas. Pigs housed near human dwellings can be a source of *C. felis* and, also, of the human flea, *Pulex irritans* (Beesley, 1974), so that infestation in piggeries may be a problem for workers (Stevenson & Hughes, 1988). *Ctenocephalides felis*, *C. canis* and *P. irritans* serve as intermediate hosts for the tapeworm, *Dipylidium caninum*.

Traub *et al.* (1970) record the presence of the flea *Xenopsylla cheopis* on rats in the Bulolo area, and *X. vexabilis* on rats in Bulolo and Port Moresby environs. *Xenopsylla vexabilis* has been found also in Western Province. In the absence of their rat hosts, they will readily infest man. The significance of these fleas is that they, and also *P. irritans*, are vectors of plague, and *X. cheopis* transmits murine typhus. Although neither disease exists in PNG, their vectors are of special interest to health authorities.

Acarines

Sarcoptes

Sarcoptes scabiei, the mite that causes the skin condition known locally as 'kaskas', is, apparently, less common in man in PNG now than it used to be (Ewers & Jeffrey, 1971), but the mite is a widespread parasite of pigs (Talbot, 1972) and dogs (Hamir & Wernery, 1987). It is uncertain if *Sarcoptes* of animal origin is zoonotic as Beesley (1998) comments that it seems poorly adapted to live on man.

Dermanyssus and *Ornithonyssus*

Dermanyssus gallinae, *Ornithonyssus bursa* of chickens and other hosts, and *O. bacoti* of rats are all blood-feeding mites and can transfer quite easily to man, although people only become temporarily infested. All three mites are recorded in PNG (Egerton & Rothwell, 1964; Talbot, 1968/69).

Demodex

Demodectic mange is a serious skin disorder in some animals in PNG, especially dogs, cattle and goats. The forms parasitizing animals are believed to only rarely

infest man, while the human *Demodex folliculorum* is probably a common occupant of the human skin and not considered a medical problem (Beesley, 1998).

Trombiculid mites

Two species present in PNG, *Leptotrombidium akamushi* and *L. deliense* (Traub *et al.*, 1970), are of particular medical importance as vectors of the scrub typhus organism *Orientia* (syn. *Rickettsia) tsutsugamushi*. The larvae, known as 'mokkas' in PNG or chiggers, normally parasitize rodents, insectivores and birds; in man, ankles, groin and around the waist are sites of choice. Scrub typhus foci are associated with areas where forest has been cleared for gardening and then left to secondary growth, an environment in which both rats and mites flourish (Beesley, 1998). A particularly virulent strain of the rickettsia, which led to the death of two army personnel on Bat Island, Manus Province, during World War II, was transmitted by *L. deliense* (Philip & Kohls, 1945).

Ticks

There are no ticks that normally parasitize man in PNG. Very occasionally a tick of animal origin is reported, for example, *Amblyomma cyprium cyprium* (of pigs) or *Haemaphysalis novaeguineae* (of marsupials and some domestic animals), but they are of no importance to human health. However, *Ixodes holocyclus*, the paralysis tick, that is widespread on a range of hosts in coastal eastern Australia, would be of concern to PNG if it entered the country.

Prevention and control

Improvement in sanitation and especially personal hygiene would reduce transmission of many zoonotic parasites as all the intestinal protozoan fauna and many of the gut helminths of man in PNG use the faecal–oral route to enter the host.

Having pigs roaming free in PNG villages acting as scavengers of human waste, as described by Jenkins (1995), may 'keep the concentration of human faeces low' but is not the answer to zoonotic parasites. Eggs of some human parasites pass unaltered through the gut of a pig (Jones, 1976), and pigs act as intermediate hosts for others (e.g. *Taenia solium*). Also, some of the pig's own parasites may be infective to people (e.g. *Ascaris suum, Balantidium coli)*. Dogs, like pigs, can act as disseminators and environmental contaminators of some human parasites (*Ascaris lumbricoides*, and possibly *Trichuris trichiura* and *Isospora belli*) (Traub *et al.*, 2002), as well as being mechanical transmitters of *Toxoplasma gondii* and intermediate hosts of *Taenia solium*.

A retrospective interview survey (unpublished) indicates that pit toilets are widely, if not universally, present in PNG villages, mostly associated with individual dwellings but sometimes shared or used as a communal facility. In general, it is only in some coastal villages, where use is made of the sea, and in low-lying locations where the water table is high, that pit latrines are not found. Their usefulness in reducing the risk of infection with zoonotic parasites is lessened, however, by improper usage and lack of maintenance.

Improvement in personal hygiene is closely linked with availability of water, specifically, access to running water, as hand-washing is of particular importance. When water has to be carried long distances, as is often the case in villages, frequent washing of hands is likely to be an unacceptable luxury. However, installation of water supply systems in rural communities in PNG, as Jenkins (1995) points out, has not been without its problems, many of them linked to insensitivity on the part of the facilitators to social and cultural factors.

Gorter *et al.* (1991), in a study of diarrhoea disease in rural Nicaraguan children less than five years of age, found that those from homes located more than 500 m from a water supply had diarrhoeal incidence 34% higher than children from homes with their own water supply. This is likely to be the case whether the infective agent is microbial or protozoan. Curtis & Cairncross (2003) report that by using soap with water for hand-washing, benefits extend not only to reduction in enteric diseases but also to some other infectious diseases.

Water quality in rural communities can be affected by contamination with faecal matter and, other than boiling water, ensuring contamination-free water usually requires a communal effort in controlling pigs and indiscriminate human defaecation. The general custom in PNG of eating cooked rather than raw leaf vegetables reduces the risk of infection from garden plants watered with contaminated water.

Care is not always taken in PNG, particularly at feasts, that meat is properly cooked when eaten and this leads to the risk of infection by such food-transmitted parasites as *Taenia solium*, *Trichinella*, *Capillaria*, *Gnathostoma*, *Anisakis, Eustrongylides*, *Paragonimus*, *Toxoplasma* and *Sarcocystis*. Cooking, however, may not help those individuals susceptible to *Anisakis* allergens.

Most cysts, eggs and larvae are susceptible to desiccation, so allowing sunlight on to damp ground is a way of reducing survival time of these soil-transmitted stages.

Food, such as flour and cereal grains need to be protected from flour beetles and rodents that serve as intermediate and final hosts respectively of *Hymenolepis* spp.

Conclusions

The number of what might be called 'active' zoonotic parasites in PNG is relatively small in comparison with many other tropical countries, but a significant number of potential zoonotic forms are present that either have not yet succeeded in infecting man, or infection is so low or sporadic that, so far, they have escaped detection.

A further number of zoonotic organisms are on PNG's doorsteps, and will present considerable danger to health if they enter and become established here. The warm, humid, tropical environment is conducive for the survival of free living stages, although there may be uncertainty in some instances, for example with trematodes, if suitable intermediate hosts are present to perpetuate a life cycle.

With the increasing movement overseas of Papua New Guineans on academic or lengthy training courses, it is not only foreign visitors or workers entering PNG that may bring exotic zoonotic parasites into the country. While adequate sanitation may prevent the establishment

of these parasites in urban centres, conditions in rural settings such as logging camps could be different. It calls for vigilance on the part of health workers in the field and of those in diagnostic laboratories.

While health education is a key factor in combating zoonotic infections, experience in various countries has shown that for successful implementation of control measures, it is necessary, as Hughes (1992) points out, to have formal and informal cooperation between medical and veterinary interests at all levels of government, and with the community.

Acknowledgements

I thank Edoardo Pozio and his coworkers of the Istituto Superiore di Sanita, Rome, for the data on seroprevalence of *Toxoplasma* in PNG; David Gibson, Rod Bray and Eileen Harris of the Parasitic Worms Section, The Natural History Museum, London, for helminth identifications; Simon Reid, Murdoch University, Perth, for assistance with three references; and an anonymous reviewer who helped make the manuscript more presentable.

References

Alto, W.A. & Nettleton, L.B. (1989) Hydatid disease: the threat within Papua New Guinea. *Papua New Guinea Medical Journal* **32**, 139–142.

Anten, J.F.G. & Zuidema, P.J. (1964) Hookworm infection in Dutch servicemen returning from West New Guinea. *Tropical and Geographical Medicine* **16**, 216–224.

Ashford, R.W. (1979) Occurrence of an undescribed coccidian in man in Papua New Guinea. *Annals of Tropical Medicine and Parasitology* **73**, 497–500.

Ashford, R.W. & Atkinson, E.A. (1992) Epidemiology of *Blastocystis hominis* infection in Papua New Guinea: age-prevalence and association with other parasites. *Annals of Tropical Medicine and Parasitology* **86**, 129–136.

Ashford, R.W. & Crewe, W. (1998) *The parasites of* Homo sapiens. 128 pp. Liverpool School of Tropical Medicine, Trowbridge, Cromwell Press.

Ashford, R.W., Murthy, D.P. & Parsons, G.A. (1978) A case of sparganosis in Papua New Guinea. *Papua New Guinea Medical Journal* **21**, 347–348.

Ashford, R.W., Warhurst, D.C. & Reid, G.D.F. (1993) Human infection with cyanobacterium-like bodies. *Lancet* **341**, 1034.

Audicana, M.T., Ansotegui, I.J., Corres, L.F. de & Kennedy, M.W. (2002) *Anisakis simplex*: dangerous dead and alive? *Trends in Parasitology* **18**, 20–25.

Avery, J.L. (1946) Parasite infections among natives of the Samarai District, Papua, New Guinea. *Journal of Parasitology* **32**, 25–29.

Bangs, M.J., Purnomo & Andersen, E.M. (1994) A case of capillariasis in a highland community of Irian Jaya, Indonesia. *Annals of Tropical Medicine and Parasitology* **88**, 685–687.

Bangs, M.J., Purnomo, Andersen, E.M. & Anthony, R.L. (1996) Intestinal parasites of humans in a highland community of Irian Jaya, Indonesia. *Annals of Tropical Medicine and Parasitology* **90**, 49–53.

Barnish, G. (1992) The epidemiology of intestinal parasites in Papua New Guinea. pp. 345–354 *in* Attenborough, R.D. & Alpers, M.P. (*Eds*) *Human biology in Papua New Guinea: the small cosmos*. Oxford, Oxford Science Publications, Clarendon Press.

Barnish, G. & Ashford, R.W. (1989) Occasional parasitic infections of man in Papua New Guinea and Irian Jaya (New Guinea). *Annals of Tropical Medicine and Parasitology* **83**, 121–135.

Barnish, G. & Misch, K.A. (1987) Unusual cases of parasitic infections in Papua New Guinea. *American Journal of Tropical Medicine and Hygiene* **37**, 585–587.

Barnish, G. & Richens, J. (1989) Myiasis in the highlands of Papua New Guinea. *Papua New Guinea Medical Journal* **32**, 63–64.

Bearup, A.J. & Lawrence, J.J. (1950) A parasitological survey of five New Guinea villages. *Medical Journal of Australia* **1**, 724–732.

Beesley, W.N. (1974) Arthropods – Oestridae, myiasis and acarines. pp. 349–368 *in* Soulsby, E.J.L. (*Ed.*) *Parasitic zoonoses: clinical and experimental studies*. London, Academic Press.

Beesley, W.N. (1998) Scabies and other mite infestations. pp. 859–872 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Bisseru, B. (1967) *Diseases of man acquired from his pets*. 482 pp. London, William Heinemann Medical Books Ltd.

Blackburn, C.R.B. & Ma, M.H. (1971) Skin reactions of natives in the Western Highlands of New Guinea to a *Schistosoma mansoni* antigen. *Tropical and Geographical Medicine* **23**, 278–281.

Booth, R. (1994) Medicine and husbandry: monotremes, wombats and bandicoots. pp. 395–420 in *The T.G. Hungerford Refresher Course for Veterinarians*, Proceedings 233, *Wildlife*. Post Graduate Committee in Veterinary Science, University of Sydney, Australia.

Bukenya, G.B. (1991) *The epidemiology of under-five childhood diarrhoeas in a peri-urban population of Papua New Guinea*. 259 pp. PhD thesis, University of Queensland.

Bulmer, S. (1982) Human ecology and cultural variation in prehistoric New Guinea. pp. 169–206 *in* Gressitt, J.L. (*Ed.*) *Biogeography and ecology of New Guinea*, Vol. **1**. The Hague, W. Junk Publishers.

Cilento, R.W. & Backhouse, T.C. (1927) Paragonimiasis: its first recorded occurrence in the Territory of New Guinea. *Medical Journal of Australia* **1**, 79–81.

Clutton-Brock, J. (1999) *A natural history of domesticated mammals*, 2nd edn. 238 pp. Cambridge, Cambridge University Press.

Copland, J.W. (1975) *Capillaria* infections of pigs: description of *C. papuensis* sp.n. and the pathology of natural infections. *Journal of Helminthology* **49**, 187–190.

Couvée, L.M.J. & Rijpstra, A.C. (1961) The prevalence of *Balantidium coli* in the central highlands of Western New Guinea. *Tropical and Geographical Medicine* **13**, 284–286.

Cross, J.H., Irving, G.S., Anderson, K.E., Gunawan, S. & Saroso, J.S. (1977) Biomedical survey in Irian Jaya (West Irian) Indonesia. *Southeast Asian Journal of Tropical Medicine and Public Health* **8**, 532–536.

Crouch, P.R. (1982) A review of intestinal parasitism and nutrition. *Papua New Guinea Medical Journal* **25**, 43–49.

Curtis, V. & Cairncross, S. (2003) Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. *Lancet Infectious Diseases* **3**, 275–281.

De Roever-Bonnet, H., Molenaar, J.C., Folkers, C. & Terpstra, C. (1964) Toxoplasmosis in West New Guinea. *Tropical and Geographical Medicine* **16**, 82–87.

Desowitz, R.S. & Barnish, G. (1986) *Entamoeba polecki* and other intestinal protozoa in Papua New Guinea highland children. *Annals of Tropical Medicine and Parasitology* **80**, 399–402.

Dubey, J.P. (1998a) Toxoplasmosis. pp. 303–318 *in* Cox, F.E.G., Kreier, J.P. & Wakelin, D. (*Eds*) Topley and Wilson's *Microbiology and microbial infections*, 9th edn. Vol. **5**, *Parasitology*, London, Arnold.

Dubey, J.P. (1998b) *Sarcocystis*, *Isospora* and *Cyclospora*. pp. 319–327 *in* Cox, F.E.G., Kreier, J.P. & Wakelin, D. (*Eds*) Topley and Wilson's *Microbiology and microbial infections*, 9th edn. Vol. **5**, *Parasitology*, London, Arnold.

Duignan, P.J., Norman, R.L., O'Keefe, J. & Horner, G. (2004) Health assessment of wallabies from Kawau Island. *Surveillance* **31**, 16–18.

Egerton, J.R., Rothwell, T.L.W. (1964) *The distribution of infectious and parasitic diseases of animals in Papua and New Guinea.* 30 pp. DASF Research Bulletin No. 1 (Veterinary Science Series), Port Moresby.

Ewers, W.H. (1973) A host–parasite list of the protozoan and helminth parasites of New Guinea animals. *International Journal for Parasitology* **3**, 89–110.

Ewers, W.H. & Jeffrey, W.T. (1971) *Parasites of man in Niugini*. 275 pp. Milton, Queensland, The Jacaranda Press.

Faust, E.C., Russell, P.F. & Jung, R.C. (1970) Craig and Faust's *Clinical parasitology*. 890 pp. 8th edn. Philadelphia, Lea and Febiger.

Flannery, T. (1995) *Mammals of New Guinea*. 568 pp. New edn. Chatswood, NSW Australia, Reed Books.

Fritzsche, M., Gottstein, B., Wigglesworth, M.C. & Eckert, J. (1990) Serological survey of human cysticercosis in Irianese refugee camps in Papua New Guinea. *Acta Tropica* **47**, 69–77.

Gajdusek, D.C. (1978) Introduction of *Taenia solium* into West New Guinea with a note on an epidemic of burns from cysticercus epilepsy in the Ekari people of the Wissel Lakes area. *Papua New Guinea Medical Journal* **21**, 329–342.

Gorter, A.C., Sandiford, P., Smith, G.D. & Pauw, J.P. (1991) Water supply, sanitation and diarrhoeal disease in Nicaragua: results from a case-control study. *International Journal of Epidemiology* **20**, 527–533.

Groves, V.J., Lehmann, D. & Gilbert, G.L. (1994) Seroepidemiology of cryptosporidiosis in children in Papua New Guinea and Australia. *Epidemiological Infections* **113**, 491–499.

Hamilton, G.R. & Ferguson, E.W. (1927) Larva migrans in Australia. *Medical Journal of Australia* **2**, 875–878.

Hamir, A.N. & Wernery, U. (1987) Diseases of dogs in Papua New Guinea. *Tropical Veterinarian* **5**, 205–208.

Hornabrook, R.W., Kelly, A. & McMillan, B. (1975) Parasitic infection of man on KarKar Island, New Guinea. *American Journal Tropical Medicine and Hygiene* **24**, 590–595.

Hughes, K.L. (1992) The impact of zoonotic diseases on the workforce and the community. pp. 301–313 *in* *Zoonoses*. Proceedings 194, Post Graduate Committee in Veterinary Science, University of Sydney.

Humphrey, J.D. (1979) Helminths of the alimentary tract of the domestic fowl in Papua New Guinea. *Australian Veterinary Journal* **55**, 205–207.

Ito, A. (2002) Serologic and molecular diagnosis of zoonotic larval cestode infections. *Parasitology International* **51**, 221–235.

Jenkins, C. (1995) Changing hygiene behaviour in Papua New Guinea. *Papua New Guinea Medical Journal* **38**, 320–324.

Jones, H.I. (1976) The role of pigs in the dissemination of *Ascaris* and hookworm infections in Papua New Guinea. *Papua New Guinea Medical Journal* **19**, 153–155.

Kelly, A. (1975) *Alimentary parasites of man in Papua New Guinea*. 56 pp. Papua New Guinea Institute of Medical Research, Goroka.

Kelly, A. & Gar Avusi, M. (1974) A parasitological survey of a village in a mountain district of Papua. *Tropical and Geographical Medicine* **26**, 178–181.

Klufio, C.A., Delamare, O., Amoa, A.B. & Kariwiga, G. (1993) The prevalence of toxoplasma antibodies in pregnant patients attending the Port Moresby General Hospital antenatal clinic: a seroepidemiological survey. *Papua New Guinea Medical Journal* **36**, 4–9.

Kurahashi, H. (1987) *The blow flies of New Guinea, Bismarck Archipelago and Bougainville Island (Diptera: Calliphoridae)*. 99 pp. Occasional Paper no. 1, Entomological Society of Japan, Tokyo.

Lloyd, S. (1998a) Occasional and miscellaneous zoonoses and opportunistic infections. pp. 921–933 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Lloyd, S. (1998b) Other cestode infections hymenolepiosis, diphyllobothriosis, coenurosis, and other adult and larval cestodes. pp. 651–663 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Lloyd, S. (1998c) Cysticercosis and taeniosis *Taenia saginata*, *Taenia solium*, and Asian *Taenia*. pp. 635–649 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Lloyd, S. (1998d) Toxocarosis. pp. 841–854 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Mackerras, M.J. (1957) *Capillaria* in the spleen of a rat (Nematoda: Trichiuroidea). *Australian Journal of Science* **19**, 230.

Macpherson, C.N.L., Gottstein, B. & Geerts, S. (2000) Parasitic food-borne and water-borne zoonoses. *Office International des Epizooties, Scientific and Technical Review* **19**, 240–258.

Main, P., Attenborough, R., Chelvanayagam, G. & Gao, X. (2001) The peopling of New Guinea: evidence from class 1 human leukocyte antigen. *Human Biology* **73**, 365–383.

Martinez-Palomo, A. & Espinosa Cantellano, M. (1998) Intestinal amoebae. pp. 157–177 *in* Cox, F.E.G., Kreier, J.P. & Wakelin, D. (*Eds*) Topley and Wilson's *Microbiology and microbial infections*, 9th edn. Vol. **5**, *Parasitology*, London, Arnold.

McMillan, B. & Kelly, A. (1970) *Entamoeba polecki* von Prowazek, 1912 in New Guinea. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **64**, 792–793.

McMillan, B., Kelly, A. & Walker, J.C. (1971) Prevalence of *Hymenolepis diminuta* infection in man in the New

Guinea highlands. *Tropical and Geographical Medicine* **23**, 390–392.

Miyazaki, I. (1968) *Gnathostoma doloresi* Tubangui, 1925 from pigs in New Guinea. *Journal of Parasitology* **54**, 186–187.

Miyazaki, I. (1991) *Helminthic zoonoses*. 494 pp. SEAMIC Publication No. 62, Tokyo, International Medical Foundation of Japan.

Muller, R. (2002) *Worms and human disease*. 300 pp. 2nd edn. Wallingford, Oxon, CABI Publishing.

Muller, R., Lillywhite, J., Bending, J.J. & Catford, J.C. (1987) Human cysticercosis and intestinal parasitism amongst the Ekari people of Irian Jaya. *Journal of Tropical Medicine and Hygiene* **90**, 291–296.

Munday, B.L., Humphrey, J.D. & Kila, V. (1977) Pathology produced by, prevalence of, and probable life cycle of a species of *Sarcocystis* in the domestic fowl. *Avian Diseases* **21**, 697–703.

Murthy, D.P., Igo, J.D., Latz, S.A. & Cooke, R.A. (1989) A probable endemic case of schistosomiasis from Papua New Guinea. *Medical Journal of Australia* **150**, 162.

Ortega, Y.R., Gilman, R.H. & Sterling, C.R. (1994) A new coccidian parasite (Apicomplexa: Eimeriidae) from humans. *Journal of Parasitology* **80**, 625–629.

Owen, I.L. (1989) The epidemiology of fasciolosis in Papua New Guinea. *Australian Veterinary Journal* **66**, 58–60.

Owen, I.L., Sims, L.D., Wigglesworth, M.C. & Puana, I. (2000) Trichinellosis in Papua New Guinea. *Australian Veterinary Journal* **78**, 698–701.

Owen, I.L., Pozio, E., Tamburrini, A., Danaya, R.T., Bruschi, F. & Gomez Morales, M.A. (2001) Focus of human trichinellosis in Papua New Guinea. *American Journal of Tropical Medicine and Hygiene* **65**, 553–557.

Pappas, P.W., Rutherford, K.H. & Barley, A.J. (1999) Thermal tolerance of *Hymenolepis diminuta* eggs does not limit the parasite's distribution. *Journal of Helminthology* **73**, 85–86.

Philip, C.B. & Kohls, G.M. (1945) Studies on tsutsugamushi disease (scrub typhus, mite-borne typhus) in New Guinea and adjacent islands. *American Journal of Hygiene* **42**, 195–203.

Pozio, E., Owen, I.L., LaRosa, G., Sacchi, L., Rossi, P. & Corona, S. (1999) *Trichinella papuae* n. sp. (Nematoda), a new non-encapsulated species from domestic and sylvatic swine of Papua New Guinea. *International Journal for Parasitology* **29**, 1825–1839.

Pozio, E., Owen, I.L., Marucci, G. & La Rosa, G. (2004) *Trichinella papuae* in saltwater crocodiles (*Crocodylus porosus*) of Papua New Guinea. *Emerging Infectious Diseases* **10**, 1507–1509.

Prociv, P. (1989) All that deposits eggs in tissues is not *Schistosoma*. *Medical Journal of Australia* **150**, 411–412.

Prociv, P. (1998) Zoonotic hookworm infections (ancylostomatosis). pp. 803–822 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Radford, A.J. (1973) Balantidiasis in Papua New Guinea. *Medical Journal of Australia* **1**, 238–241.

Scrimgeour, E.M. (1984) Distribution of *Angiostrongylus cantonensis* in Papua New Guinea. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **78**, 776–779.

Scrimgeour, E.M. & Burke, W.J. (1979) Angiostrongyliasis cantonensis. *Australia and New Zealand Journal of Medicine* **9**, 75–77.

Scrimgeour, E.M. & Welch, J.S. (1984) *Angiostrongylus cantonensis* in East New Britain, Papua New Guinea. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **78**, 774–775.

Scrimgeour, E.M., Chambers, B.R. & Kaven, J. (1982) A probable case of ocular angiostrongyliasis in New Britain, Papua New Guinea. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **76**, 538–540.

Sherchand, J.B. & Cross, J.H. (2001) Emerging pathogen *Cyclospora cayetanensis* infection in Nepal. *South East Asian Journal of Tropical Medicine and Public Health* **32** (Suppl 2), 143–150.

Shield, J.M., Scrimgeour, E.M. & Vaterlaws, A.L. (1980) Intestinal helminths in an adult hospital population in the Eastern Highlands of Papua New Guinea: relationship with anaemia, eosinophilia and asthma. *Papua New Guinea Medical Journal* **23**, 157–164.

Shield, J.M., Smith, D. & Heywood, P. (1981) The prevalence of alimentary helminthiasis and its association with nutritional status in children under five years old in the highlands of Papua New Guinea. *Papua New Guinea Medical Journal* **24**, 40–44.

Shield, J., Anian, G., Ostwald, R. & Arnhold, R. (1984) Reinfection with intestinal helminths after treatment with mebendazole and fluctuations in individual *Ascaris lumbricoides* infections with time. *Papua New Guinea Medical Journal* **27**, 89–94.

Simon Martin, F. & Genchi, C. (2000) Dirofilariasis and other zoonotic filariases: an emerging public health problem in developed countries. *Research and Reviews in Parasitology* **60**, 1–16.

Smith, H.V., Paton, C.A., Girdwood, R.W.A. & Mtambo, M.M.A. (1996) *Cyclospora* in non-human primates in Gombe, Tanzania. *Veterinary Record* **138**, 528.

Southwood, T.R.E. (1987) Species-time relationships in human parasites. *Evolutionary Ecology* **1**, 245–246.

Speare, R., Beveridge, I., Johnson, P.M. & Corner, L.A. (1983) Parasites of the agile wallaby, *Macropus agilis* (Marsupialia). *Australian Wildlife Research* **10**, 89–96.

Spradbery, J.P. (1991) *A manual for the diagnosis of screw-worm fly.* 62 pp. Canberra, Commonwealth of Australia, CSIRO Division of Entomology.

Spratt, D.M., Beveridge, I. & Walter, E.L. (1991) A catalogue of Australasian monotremes and marsupials and their recorded helminth parasites. *Records of the South Australian Museum*, Monogr Ser. No. 1, 1–105.

Stevenson, W.J. & Hughes, K.L. (1988) *Synopsis of zoonoses in Australia*. 260 pp. 2nd edn. Commonwealth Department of Community Services and Health, Canberra, Australian Government Publishing Service.

Subahar, R., Hamid, A., Purba, W., Wandra, T., Karma, C., Sako, Y., Margono, S.S., Craig, P.S. & Ito, A. (2001) *Taenia solium* infection in Irian Jaya (West Papua), Indonesia: a pilot serological survey of human and porcine cysticercosis in Jayawijaya District. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **95**, 388–390.

Talbot, N.T. (1968/69) New recordings of animal parasites in Papua and New Guinea. *Papua and New Guinea Agricultural Journal* **20**, 89–94.

Talbot, N.T. (1972) Incidence and distribution of helminth and arthropod parasites of indigenous owned pigs in Papua New Guinea. *Tropical Animal Health and Production* **4**, 182–190.

Thompson, R.C.A. (1998) *Giardia* infections. pp. 545–561 *in* Palmer, S.R., Lord Soulsby & Simpson, D.I.H. (*Eds*) *Zoonoses*. Oxford, Oxford University Press.

Traub, R., Mirza, A.B., Nadchatram, M. & Mann, E.B. (1970) Survey of Bulolo fleas and trombiculid mites. *Papua and New Guinea Medical Journal* **13**, 62–64.

Traub, R.J., Robertson, I.D., Irwin, P., Mencke, N. & Thompson, R.C.A. (2002) The role of dogs in transmission of gastrointestinal parasites in a remote tea-growing community in northeastern India. *American Journal of Tropical Medicine and Hygiene* **67**, 539–545.

Van Der Hoeven, J.A. & Rijpstra, A.C. (1957) Intestinal parasites in the central mountain district of Netherlands New-Guinea. *Documenta de Medicina Geographica et Tropica* **9**, 225–228.

Van Der Hoeven, J.A. & Rijpstra, A.C. (1962) Animal parasites prevalent in the human intestine in central south New Guinea. *Tropical and Geographical Medicine* **14**, 350–354.

Verweij, J.J., Polderman, A.M. & Clark, C.G. (2001) Genetic variation among human isolates of uninucleated cyst-producing *Entamoeba* species. *Journal of Clinical Microbiology* **39**, 1644–1646.

Vines, A.P. & Kelly, A. (1966) Highlands region survey of intestinal parasites. *Medical Journal of Australia* **2**, 635–640.

Viney, M.E., Ashford, R.W. & Barnish, G. (1991) A taxonomic study of *Strongyloides* Grassi, 1879 (Nematoda) with special reference to *Strongyloides fuelleborni* von Linstow, 1905 in man in Papua New Guinea and the description of a new subspecies. *Systematic Parasitology* **18**, 95–109.

Walker, J.C. (1989) Schistosomiasis in Papua New Guinea? *Medical Journal of Australia* **150**, 606.

Wallace, G.D., Zigas, V. & Gajdusek, D.C. (1974) Toxoplasmosis and cats in New Guinea. *American Journal of Tropical Medicine and Hygiene* **23**, 8–14.

Wandra, T., Subahar, R., Simanjuntak, G.M., Margono, S.S., Suroso, T., Okamoto, M., Nakao, M., Sako, Y., Nakaya, K., Schantz, P.M. & Ito, A. (2000) Resurgence of cases of epileptic seizures and burns associated with cysticercosis in Assologaima, Jayawijaya, Irian Jaya, Indonesia, 1991–95. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **94**, 46–50.

Watson, T.G. & Charleston, W.A.G. (1985) The significance of parasites in farmed deer. pp. 105–117 *in* Fennessy, P.F. & Drew, K.R. (*Eds*) *Biology of deer production*. Bulletin **22**, The Royal Society of New Zealand, Wellington.

World Health Organization. (1979) *Parasitic zoonoses*. Report of a WHO Expert Committee with participation of FAO. Tech Rep Ser No. 637, Geneva, WHO.

Zaman, V. (1998) *Balantidium coli*. pp. 445–450 *in* Cox, F.E.G., Kreier, J.P. & Wakelin, D. (*Eds*) Topley and Wilson's *Microbiology and microbial infections*, 9th edn. Vol. **5**, *Parasitology*, London, Arnold.

Zigas, V. (1976) Prevalence of *Toxoplasma* antibodies in New Britain, Papua New Guinea. *Papua New Guinea Medical Journal* **19**, 225–230.

Zumpt, F. (1965) *Myiasis in man and animals in the Old World*. 267 pp. London, Butterworths.

(Accepted 20 July 2004)