Chapter 9
Macroparasites in Antarctic Penguins

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9.1 Introduction

Parasites are the majority of species on Earth (Windsor 1998). The total number of parasite species is likely to be huge, because practically all free-living metazoan species harbor at least one parasite species and almost every individual of every species is parasitized by at least one parasite during its life cycle (Poulin and Morand 2004). The number of parasite species has been estimated as a range from 30 to 71 %

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of the living species (Price 1980; de Meeus and Renaud 2002). Therefore, parasites can be considered a selective pressure affecting different aspects of the host life which can modulate host populations (Morand and Deter 2009). Moreover, parasite diversity provides insights into the history and biogeography of other organisms, into the structure of ecosystems, and into the processes behind the diversification of life (Poulin and Morand 2004).

Helminths and ectoparasites are the main macroparasites of birds. Helminth is a Greek word that means "worm" and is a conventional name, but not a taxon of animal classification (Miyazaki 1991). Among helminth parasites are included those metazoan "worms" that in any stage of their life cycle live in or on other metazoan species (host). Helminths living inside bird hosts are represented by the major groups, Digenea, Cestoda, Nematoda, and Acanthocephala.

Helminths occupy diverse sites within the host including the gastrointestinal, respiratory, and urinary systems and in organs and tissue spaces of their host. Depending on the parasitic species, their intensity of infection, the host immune status, and the environmental conditions, their presence might not lead to obvious clinical manifestations, or it may manifest itself in terms of individual morbidity and mortality or produce more subtle negative effects on host fitness (Hoberg 2005).

Ectoparasites include arthropod parasites such as ticks, mites (Acari), lice, bugs, fleas, and flies (Insecta). The effects of ectoparasites may include anemia (Gauthier-Clerc et al. 1998; Mangin et al. 2003), feather damage (Barbosa et al. 2002), transmission of pathogens (Allison et al. 1978; Morgan et al. 1981; Siers et al. 2010; Yabsley et al. 2012), and, in the case of some ticks, injection of neurotoxins (Gothe et al. 1979). The consequences of these infestations can vary greatly depending on their intensity and on host health and immune status, and can include negative impacts in terms of mortality, breeding success, and behavior (Gauthier-Clerc et al. 1998; Mangin et al. 2003).

Animals living in Antarctica including penguins are also affected by parasites; however, there is limited knowledge available on their presence, their distribution, epidemiology, life cycles, and health effects on the host in Antarctic fauna (Barbosa and Palacios 2009; Kerry and Riddle 2009). Among Antarctic vertebrates, penguins represent more than 90 % of the terrestrial biomass and are the most studied group on this matter. However, available information is sparse and fragmented. In this chapter, we examine the published information on macroparasites of Antarctic penguins, using these species as a model to understand the broader picture on the parasitology of Antarctic birds.

9.2 Diversity and Richness of Helminth Parasites

Former Antarctic expeditions, such as the ones led by James Clark Ross (1839–1843), Jean-Baptiste Charcot (1903–1905), and Robert Falcon Scott (1910–1913), among others, already collected parasites and left us a valuable source of information. One of the most thorough publications on helminths from that time was the one written by Johnston in 1937–1938, dealing with parasites collected during the 1911–1914 Australian Antarctic expedition. He not only supplied descriptions and drawings of helminths, but also included the review and history of each one of them. In general, former published surveys on helminths parasitizing Antarctic penguins often provided only a list of hosts and the parasites collected from them and with few cases reporting on the proportion of infected hosts (Johnston and Mawson 1945; Mawson 1953). Nevertheless, data about their prevalence, intensity, or abundance are scarce, and have only started to be provided in the last decades (Fonteneau et al. 2011; Vidal et al. 2012; Diaz et al. 2013, 2016). Despite this apparent gap, there is a sufficient number of publications that, when compiled and compared, allow as a fairly comprehensive assessment of the richness of helminths present in Antarctic penguins.

Antarctic and Sub-Antarctic penguins act as definitive host of only 13 recognized helminth species (Table 9.1). The core component of the helminth fauna of Antarctic penguins are cestodes, mainly *Parorchites zederi* (Dilepididae). This species is the only cyclophyllidean present in pelagic birds and is widely distributed among Antarctic penguins, including the three pygoscelid species and the Emperor penguin (Cielecka et al. 1992; Vidal et al. 2012; Diaz et al. 2013, 2016; Kleinertz et al. 2014). The presence of Cyclophyllidea eggs has also been demonstrated in the feces of Adélie penguins (Fredes et al. 2008), and it is reasonable to presume these were *P. zederi*.

Members of the Tetrabothriidea are also important components of the helminth communities of Antarctic penguins (Baer 1954). *Tetrabothrius pauliani* Joyeux and Baer 1954 was registered parasitizing all pygoscelid species and also the King penguin, *Tetrabothrius joubini* Railliet and Henry, 1912 was only reported in the Chinstrap penguin (Prudhoe 1969; Cielecka et al. 1992; Georgiev et al. 1996), and *Tetrabothrius wrighti* Leiper and Atkinson 1914 was registered in Adélie, King, and Emperor penguins (Leiper and Atkinson 1914; Johnston 1937; Prudhoe 1969; Fonteneau et al. 2011).

Table 9.1 Summary of macroparasites recorded in Antarctic penguins

	Emperor *Aptenodytes forsteri*	King *Aptenodytes patagonicus*	Adélie *Pygoscelis adeliae*	Chinstrap *Pygoscelis antarctica*	Gentoo *Pygoscelis papua*	Macaroni *Eudyptes chrysolophus*	Southern Rockhopper *Eudyptes chrysocome*	Royal *Eudyptes schlegeli*
Breeding distribution	Antarctic	***Sub-Antarctic	Antarctic	Antarctic/Sub-Antarctic	Antarctic/Sub-Antarctic	Sub-Antarctic	Sub-Antarctic	Sub-Antarctic
Diet (% by weight)								
Fishes	96.8	68.7–99.8	67.3–100	0.1–38.8	0.2–70.0	2.0–25.0	1.9–28.3	45.8
Crustaceans	0.4	0.1	54.6–99.6	55.1–99.9	30.0–99.8	75.0–98.3	45.1–99.7	51.4
Cephalopods	2.7	0.2–31.3	0–0.4	0	0.5–2.1	0.1–2.2	0.3–53.0	2.8
Cestoda								
Parorchites zederi	X (1, 2)		X (1, 18, 19)	X (18, 24, 25)	X (18, 26, 29, 34)			
Tetrabothrius joubini				X (18, 23, 24)				
Tetrabothrius pauliani		X (1)	X (18)	X (18, 25, 26, 27)	X (1)			
Tetrabothrius wrightii	X (1)	X (8)						
Tetrabothrius sp.	X (2)		X (19, 21)	X (31, 32)		X (27)		
Diphyllobotrhium sp.	X (2)				X (34)			
Nematodes								
Stegophorus macronectes			X (19, 20)	X (25)	X (7, 29)	X (7)	X (7)	
Stegophorus adeliae					X (34)			
Tetrameres wetzeli		X (8)			X (29)			
Tetrameres sp.			X (19)					
Contracaecum heardi		X (8)			X (7)	X (7)		
Contracaecum sp.		X (7)			X (31, 32)		X (7)	
Terranova piscium								X (7)[a]
Streptocara sp.			X (21)		X (31)			

Stomachus = *Anisakis* sp.					X (7)[a]			X (7)[a]
Acanthocephalans								
Corynosoma shackletoni					X (29, 33, 34)			
Corynosoma hamanni					X (29)[a]			
Corynosoma bullosum					X (29)[a]			
Corynosoma pseudohamanni				X (28)[a]				
Corynosoma sp.				X (25)				
Chewing lice								
Austragonioides antarcticus			X (3, 4, 5, 10)					
A. brevipes		X (4, 5, 9, 10)						
A. bicornutus						X (4, 5, 10)		
A. bifasciatus			X (4, 5)					
A. concii						X (4, 5)	X (5, 10)	
A. cristati						X (3, 4, 5, 10, 11)	X (3, 4, 5, 10, 11)	X (4, 5, 10)
A. demersus						X (4)		
A. gressitti				X (3, 4, 5, 10)	X (3, 4, 5, 10, 34)	X (4)		
A. keleri					X (4, 5)	X (3, 4, 5, 10	X (3, 4, 5)	
A. macquariensis				X (4, 5)	X (4, 5)	X (3, 4, 5, 10, 11)	X (3, 4, 5, 9, 10, 11)	X (10)
A. strutheus								X (4, 5)
A. mawsoni	X (3, 4, 5)							

(continued)

Table 9.1 (continued)

	Emperor *Aptenodytes forsteri*	King *Aptenodytes patagonicus*	Adélie *Pygoscelis adeliae*	Chinstrap *Pygoscelis antarctica*	Gentoo *Pygoscelis papua*	Macaroni *Eudyptes chrysolophus*	Southern Rockhopper *Eudyptes chrysocome*	Royal *Eudyptes schlegeli*
A. hamiltoni						X (11)	X (4, 5, 10, 11)	X (4, 5, 9, 10)
Nesiotinus demersus		X (11)						
Naubates prioni					X (11)			
Ticks								
Ixodes uriae		X (10, 12, 13, 14, 15, 16, 17)	X (10, 23)	X (23)	X (10, 23, 34)	X (10, 12, 15, 38, 40)	X (10, 12, 38, 39)	X (10)
Mites *Rhinonyssus scheili*			X (22)					
Ayersacarus tilbrooki					X (36)			
Gamasellus antarcticus					X (37)			
Gamasolaelaps arenosus					X (36)			
Fleas *Parapsyllus heardi*						X (10)	X (10)	
Parapsyllus longicornis					X (35)		X (10)	
Parapsyllus magellanicus							X (10, 12)	

Diet from Williams (Williams 1995)

Numbers in brackets refers to references in the table notes

[a] Denotes immature individuals

References: (1) Prudhoe (1969), (2) Kleinertz et al. (2014), (3) Clay and Moreby (1967), (4) Clay and Moreby (1970), (5) Clay (1967), (7) Mawson (1953), (8) Fonteneau et al. (2011), (9) Banks et al. (2006), (10) Murray et al. (1991), (11) Palma and Horning (2002), (12) Murray and Vestjens (1967), (13) Gauthier-Clerc et al. (1998), (14), Gauthier-Clerc et al. (1999), (15) Frenot et al. (2001), (16) Gauthier-Clerc et al. (2003), (17) Mangin et al. (2003), (18) Cielecka et al. (1992), (19) Diaz et al. (2016), (20) Zdzitowiecki and Drózdz (1980), (21) Fredes et al. (2008), (22) Wilson (1967), (23) Barbosa et al. (2011), (24) Ippen et al. (1981), (25) Vidal et al. (2012), (26) Georgiev et al. (1996), (27) Andersen and Lysfjord (1982), (28) Dimitrova et al. (1996), (29) Diaz et al. (2013), (31) Fredes et al. (2006), (32) Fredes et al. (2007), (33) Hoberg (1986), (34) Gonzalez-Acuña et al. (2013), (35) De Meillon (1952), (36) Hunter (1970), (37) Tragardh (1908), (38) Brooke (1985), (39) Schultz and Petersen (2003), (40) Bergstrom et al. (1999)

Undetermined species of *Tetrabothrius* were also mentioned in Antarctic and Sub-Antarctic regions (Barbosa and Palacios 2009; Kleinertz et al. 2014).

Eggs of *Diphyllobothrium* sp. have been documented in fecal samples of Emperor (Kleinertz et al. 2014) and only in one Gentoo penguin specimen (Gonzalez-Acuña et al. 2013). Recently, some mature and gravid specimens identified as *Diphyllobothrium* sp. were recovered from different colonies of the three pygocelid species (Fusaro and Diaz unpublished data), and in some instances these parasites can be found on the penguin nests (Barbosa unpublished data). Diphyllobothriidae is a very common group in Antarctic marine mammals but does not seem as common in seabirds. It is worth noting that even though *Diphillobotrium scoticum* (see Meggitt 1924; Markowski 1952) has been registered as parasites of pygoscelid penguins (Adélie and Chinstrap), this finding was later denied by Johnston (1937).

Spirurid nematodes occur in the esophagus and stomach of seabirds and are one of the more abundant components in the helminth communities of penguins. *Stegophorus macronectes* (Johnston and Mawson 1942) (Acuariidae) is the best represented species. This acuarid nematode has a wide host and geographical distribution, having been reported in all pygoscelid species (Vidal et al. 2012; Diaz et al. 2013, 2016) and in the Rockhopper and Macaroni penguins in Sub-Antarctic regions (Johnston and Mawson 1945; Mawson 1953; Zdzitowiecki and Drózdz 1980). The taxonomical and nomenclatural history of this species is complex, and different synonyms were employed in the past including *Stegophorus adeliae* Johnston and Mawson 1945 and *Stegophorus paradelia* Johnston, 1938 sensu Petter, 1959 (see Vidal et al. 2016).

In addition to acuarids, nematodes of the genus *Tetrameres* (Spirurida, Tetrameriidae) parasitized the proventricular glands in Antarctic penguins (Schmidt 1965). *Tetrameres wetzeli* (Schmidt 1965) is the only species on the genus described parasitizing penguin hosts, Rockhopper, King, and Gentoo penguins (Schmidt 1965; Fontaneau et al. 2011; Diaz et al. 2013). Undetermined species of *Tetrameres* were also found in Adélie penguins (Diaz et al. 2016).

Contracaecum ascaridoid nematodes are commonly found in the stomach of piscivorous birds (Garbin et al. 2007, 2008; Diaz et al. 2010). *Contracaecum heardi* Johnston and Mawson 1942 is the species best documented among Sub-Antarctic penguins infecting King, Macaroni, and Gentoo penguins (Mawson 1953; Fonteneau et al. 2011).

Other nematode species have been found in Antarctic and Sub-Antarctic penguins. However, most of these reports were based on eggs, few, immature, or fragmented specimens, or corresponded to fish or mammal parasites, so their identification was not possible or is doubtful (e.g., *Contracaecum* spp., *Stomachus* = *Anisakis* sp., *Streptocara* sp., *Terranova* sp., *Capillaria* sp., among others (Mawson 1953; Fredes et al. 2006, 2007, 2008).

Acanthocephalans are not common in pelagic birds. Only *Corynosoma shackletoni* Zdzitowiecki 1978 has been found at the adult stage in Gentoo penguins (Hoberg 1986; Diaz et al. 2013). Other *Corynosoma* species were registered in pygoscelid penguins (e.g., *Corynosoma bullosum*, *Corynosoma hamanni*, and *Corynosoma pseudohamanni*). However, all those reports correspond to immature specimens (see Zdzitowiecki 1991; Dimitrova et al. 1996; Vidal et al. 2012; Diaz et al. 2013), and it is thought that these parasites only reach maturity in cetaceans or pinnipeds with penguin infections being accidental (Holloway and Bier 1967; Hoberg 2005).

Digenea parasites have not been recorded in Antarctic or Sub-Antarctic penguins. This likely occurs due to the limitation of their life cycle, the focal nature of transmission near island systems, and the dilution effect of the marine costal environment, which diminishes their ability to thrive in this kind of hosts (Hoberg 2005).

It is well established that pelagic birds generally support a depauperate parasite fauna, with a much lower diversity than that of birds inhabiting in neritic and littoral waters (Hoberg 2005). A noticeable pattern that emerges by comparing the community of helminths present in Antarctic penguins to that of seabirds from other continents is that the helminth community of penguins is remarkably less diverse. For instance, seabirds of the Alcidae family there are reported in more than 40 helminth species (Muzaffar and Jones 2004), while Antarctic penguin species are parasitized by a total of 10 species (Barbosa and Palacios 2009). Nevertheless, such comparison should be taken with caution as the different number host species might allow more parasite species; in addition, differences in research effort could also affect the comparison. Within penguins, differences in helminths richness between Antarctic and non-Antarctic penguins are similar. Non-Antarctic penguins harbor 12 helminth species, while Antarctic penguins present eight recognized species and seven species parasitize penguin species distributed in the Sub-Antarctic region (Clarke and Kerry 2000; Barbosa and Palacios 2009). Moreover, penguins included in the genus *Spheniscus* (non-Antarctic) have helminth communities richer than those of *Pygoscelis* genus (Clarke and Kerry 2000; Barbosa and Palacios 2009; Brandão et al. 2014). Infracommunities of three pygoscelid species present in the Antarctic Peninsula harbor between one or three helminth species, while those of the Magellanic penguins in Patagonia harbor up to five species (Diaz et al. 2010, 2013, 2016; Vidal et al. 2012). In general, the low number of helminths found in pygoscelid penguins can be explained by the narrow range of variety of prey present in their diet which is form mainly by krill and some few species of squid and fishes (Williams 1995). A wider diet and/or foraging plasticity facilitate the exposure to a high number of parasite species through the ingestion of a high number of intermediate hosts (Hoberg 1996).

9.3 Life Cycles and Source of Infection of Helminths

Most helminths that infect seabirds have indirect life cycles, involving a definitive host, the bird in which adults develop and sexual reproduction occurs, and one or more intermediate/paratenic hosts (invertebrates, fishes) carrying the larval stages. As a result, infestations by helminths are strongly influenced by the trophic relationships of the hosts (Hoberg 1996). Specialized foragers, such as some Antarctic penguins, can therefore be expected to be infested by fewer parasites than more generalist species.

The trophic webs of the Southern Ocean have macrozooplankton such as euphausiids (krill) playing a key role as an intermediate between primary producers and top predators. Krill (especially *Euphausia* spp.) are the main prey item for most Antarctic penguins (Cherel and Kooyman 1998) and are therefore plausible intermediate hosts for their helminths (Hoberg 2005; Bush et al. 2012).

Larval stages of penguin cestodes use a variety of prey crustaceans/fishes as intermediate hosts (Hoberg 2005). *Parorchites zederi* is probably widely distributed among Antarctic penguins due to a broad oceanic distribution of euphausiids (Hoberg 2005; Vidal et al. 2012; Diaz et al. 2013).

The complete life cycle of *Tetrabothrius* species remains unclear and further investigations are needed. It has been suggested that the first intermediate host of tetrabothriidean cestodes are marine crustaceans and second intermediate or paratenic host could be cephalopods or fishes (Baer 1954; Hoberg 1987). Larval stages identified as Tetrabothriidae were found in nototheniid fishes in Sub-Antarctic waters (Rocka 2003). Presence of tetrabothrids could therefore be higher in penguin species that include cephalopods or fishes in their diets (Diaz et al. 2016).

Acuarid and tetramerid nematodes that parasitize aquatic vertebrates are known to develop to the third infective stage in the hemocoel of crustaceans (Anderson 2000). The high prevalence of *S. macronectes* in Antarctic penguins could thus be a consequence of the broad oceanic distribution of euphausiids and their key role in the Southern Ocean trophic web, since they likely serve as suitable intermediate/paratenic hosts. This is corroborated by the observation of a third stage nematode larva in a krill specimen during a survey from Punta Stranger (Diaz pers. obs.). Morphological features observed in that case (Fig. 9.1) are consistent with those of an Acuariidae third stage larva (see Anderson 2000).

However, considering that this larva was the only parasite specimen found after having dissected hundreds of krill individuals (Vidal and Barbosa unpublished data) prevalence of helminth larvae in krill is likely very low. In fact, it is striking that Kagei et al. (1978) found no helminth stages in two large samples of more than 35000 and 55000 Antarctic krill (*E. superba*) each one.

Fishes serve as paratenic hosts for the infective third stage larvae of Anisakidae nematods, which mature after being ingested by the definitive hosts. Species of Nototheniidae have been registered as intermediate hosts of *Contracaecum* larvae in the Antarctic region (Kloser et al. 1992; Rocka 2004). The diet of Antarctic penguins includes varying proportion of nototheniid fish, particularly like *Pleuragramma antarcticum* in different proportions (Adams and Klages 1989; Pütz 1995; Ainley et al. 1998; Lescröel et al. 2004), and it is reasonable to speculate that these species may be involved in the transmission of *Contracaecum* to penguins. However, considering that Antarctic penguins generally do not have a strictly piscivorous diet, reports of Anisakidae are very scarce.

Acanthocephalans appear to be almost absent from pelagic birds (Anderson 2000). *Corynosoma* matures in the gut of mammals and birds, whereas fishes and

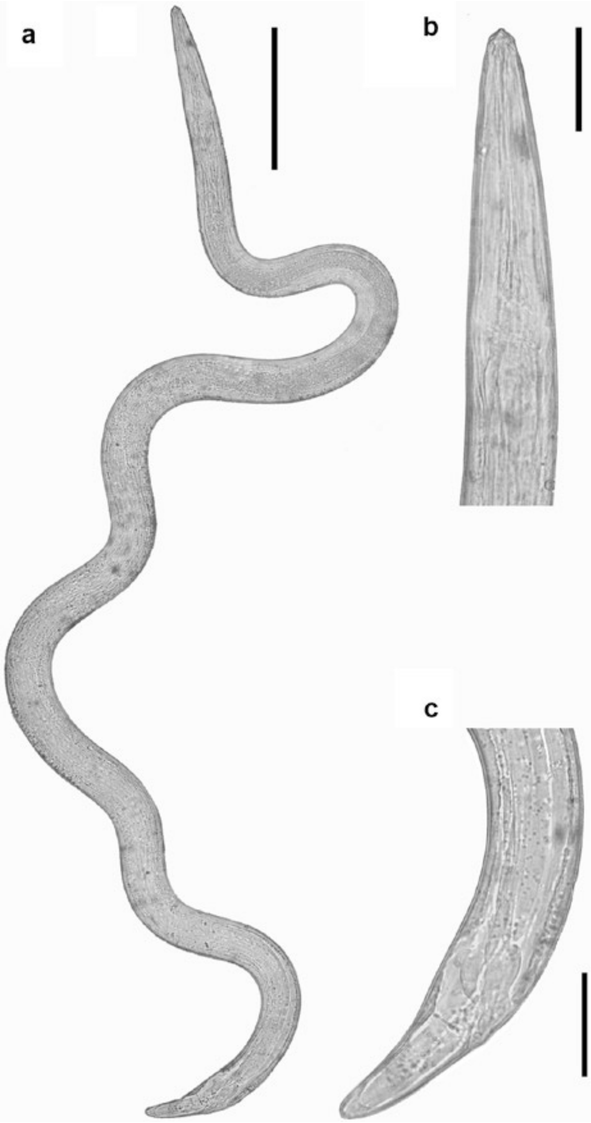

Fig. 9.1 Acuariidae third stage larvae found in the hemocoele of *E. superba*. (**a**) Complete specimen. (**b**) Detail of anterior end. (**c**) Detail of posterior end. Scale bards: (a) 500 µ; (b, c) 100 µ

aquatic invertebrates serve as intermediate hosts. However, since euphausiids are not part of the life cycle of *Corynosoma*, infestation rates are low in krill-dependent species like penguins (Muzaffar and Jones 2004). Notothenid fishes such as *Notothenia coriiceps* have been reported harboring cystacanths of *C. shackletoni* in the studied area (Laskowski and Zdzitowiecki 2005; Laskowski et al. 2012), and therefore are likely to play a role in the transmission of *Corynosoma* spp. to penguins in the Antarctic.

Finally, it should be noted that many helminth species that were reported parasitizing Antarctic penguins only develop to maturity on mammal definitive hosts.

However, taking account that some marine mammals (i.e., pinnipeds, cetaceans) and penguins feed on the same prey items, several larvae or immature stages could appear in the intestinal tract of the birds (e.g., *C. bullosum*, *C. hammani*, and *C. pseudohammani* (Mawson 1953; Zdzitowiecki 1991).

9.4 Ectoparasites

Due to the harsh conditions in Antarctica, the number of species of ectoparasites present in Antarctic penguins is relatively small and limited to ticks, fleas, and chewing lice (Barbosa and Palacios 2009) (Table 9.1). There is only one tick species (*Ixodes uriae*) which is distributed in both Sub-Antarctic (Gauthier-Clerc et al. 1998) and Antarctic regions (Barbosa et al. 2011). Flea species of Antarctic penguins (*Parapsyllus heardi*, *P. longicornis*, *P. magellanicus*) are only present in Sub-Antarctic islands (De Meillon 1952; Murray and Vestjens 1967; Murray et al. 1991). Finally, chewing lice species are the more diverse group of ectoparasites with 17 species (*Austrogoniodes antarcticus, A. bicornutus, A. bisfasciatus, A. brevipes, A. chrysolophus, A. concii, A. cristati, A. gressitti, A. hamiltoni, A. keleri, A. mawsoni, A. macquiariensis, A. strutheus, A. vanalphenae, A. watersoni, Naubates prioni, Nesiotinus demersus*) only five of which occur in the Antarctic continent and adjacent islands (*Austrogoniodes antarcticus, A. bifasciatus, A. chrysolophus, A. gressitti, A. mawsoni*) (Clay 1967; Clay and Moreby 1967, 1970; Murray et al. 1991; Palma and Horning 2002; Banks et al. 2006).

9.5 Prevalence and Parasitism Intensity

Information on the prevalence or infection intensity of helminths and ectoparasites of Antarctic penguins is scarce, with only 12 out of 33 published studies examined in this chapter providing information on prevalence (Table 9.2). Prevalence of metazoan parasites can differ considerably among parasites species, host species, regions, years and season. As a result, the interpretation of the prevalence data herein compiled should be cautious, especially because most of the information is based on relatively small simple sizes.

A remarkable trend is that penguin helminths tend to occur at higher prevalence than ectoparasites, with a maximum prevalence in several worm species (*P. zederi, T. pauliani, S. macronectes*). Current data indicate that *P. zederi* has the widest distribution of prevalence information, from East Antarctica showing the lowest prevalence in the Emperor penguin to Avian Island and Deception Island with the highest prevalence in both Adélie and Chinstrap penguins. Among penguin species, *P. zederi* parasitizing Gentoo penguin seems to be more prevalent in the South Shetlands than in more Southern locations although the opposite is shown in Adélie penguin with the higher prevalence in the more Southern location in Avian Island than in the Northern populations. *Stegophorus macronectes* does not show any clear geographical pattern

Table 9.2 Parasite prevalences in Antarctic penguins

Host species	Location	*N*	Parasite	*P* %	Reference
Eudyptes chrysolophus	Sub-Antarctic ±		*Ixodes uriae*	6	Bergstrom et al. (1999)
	Antarctic Peninsula	13	*Tetrabothrius* sp.	23	Andersen and Lysfjord (1982)
Aptenodytes patagonicus	Crozet ± Archipelago	41	*Tetrabothrius wrighti* *Tetrameres wetzeli* *Contracaecum heardi*	100 41.5 14.6	Fonteneau et al. (2011)
			Ixodes uriae	15	Gauthier-Clerc et al. (1999)
Aptenodytes forsteri	East Antarctica	50f	*Parorchites zederi* *Tetrabothrius* sp. *Diphyllobothrium* sp.	2 24 2	Kleinertz et al. (2014)
Pygoscelis adeliae	Hope Bay	7C	*Stegophorus macronectes* *Tetrameres* sp.	50 33	Diaz et al. (2016)
	Avian Is.	2	*Parorchites zederi* *Tetrabothrius* sp.	100 50	
	25 de Mayo/King George Is.	7/19C	*Parochites zederi* *Stegophorus macronectes* *Tetrameres* sp.	29/16C 14/21C 14	
		3	*Parochites zederi* *Tetrabothrius pauliani*	33 33	Cielecka et al. (1992)
			Ixodes uriae	9*	Barbosa et al. (2011)
Pygoscelis antarctica	Bouvet Is.	9	*Tetrabothrius pauliani*	88	Andersen and Lysfjord (1982)
	Deception Is.	4/61C	*Parorchites zederi* *Tetrabothrius pauliani* *Stegophorus macronectes*	100/26C 100/13C 67/72C	Vidal et al. (2012)
			Ixodes uriae	26*	Barbosa et al. (2011)
	Ronge Is.		*Ixodes uriae*	2*	
	Livingston Is.		*Ixodes uriae*	10*	
		3	*Tetrabothrius joubini* *Tetrabothrius pauliani*	66 33	Georgiev et al. (1996)
	25 de Mayo/King George Is.	3	*Parorchites zederi* *Tetrabothrius pauliani*	100 100	Cielecka et al. (1992)
			Tetrabothrius joubini	100	

Table 9.2 (continued)

Host species	Location	*N*	Parasite	*P* %	Reference
Pygoscelis papua	Paradise Bay	5/100e	*Parorchites zederi*	20	Gonzalez-Acuña et al. (2013)
			Stegophorus adeliae	40	
			Corynosoma shackletoni	40	
			Ixodes uriae	5	
			Austrogonioides gressitti	4	
	Antarctic Peninsula	6/100e	*Parorchites zederi*	33	
			Stegophorus adeliae	16	
			Corynosoma shackletoni	33	
			Austrogonioides gressitti	1	
	Ardley Is.	3/100e	*Diphyllobothrium* sp.	100	
			Stegophorus adeliae	33	
			Austrogonioides gressitti	1	
	25 de Mayo/	3/8C	*Parorchites zederi*	100/0C	Cielecka et al. (1992)
	King George Is.	1	*Parorchites zederi*	100	Georgiev et al. (1996)
		37	*Parorchites zederi*	54	Diaz et al. (2013)
			Stegophorus macronectes	48.6	
			Tetrameres wetzeli	5.4	
			Corynosoma shackletoni	13.5	
			Ixodes uriae	9*	Barbosa et al. (2011)
	Livingston Is.		*Ixodes uriae*	8–10*	
	Ronge Is.		*Ixodes uriae*	2*	

Only were considered those papers in which prevalences were provided or they were possible to be calculated, and those parasites that only reach maturity in birds

N *n*umber of birds examined, *P* prevalence, ± Sub-Antarctic Regions, *f* fecal samples, *C* chicks, * collected under stones, *e* external examination

in prevalence although seems to be more prevalent in chicks in Deception Island, while the remaining locations show prevalences around 50 %. As was mentioned above, *P. zederi* and *S. macronectes* are the most prevalent and frequent helminth species among Antarctic and Sub- Antarctic penguins, which could be due to the potential role played by euphausiids, the mean prey item in this system, as intermediate hosts.

The prevalence of *Tetrabothrius* infections in Antarctic penguins varies greatly even at the species level, with higher prevalence being recorded in the Sub-Antarctic region and South Shetlands islands whereas more austral populations have less prevalence. Data from *Tetrameres* indicate that *T. wetzeli* is more prevalent in the Sub-Antarctic region (King penguins at Crozet Island) than in the South Shetlands

(Gentoo penguins at 25 de Mayo/King George Island). Finally, *Corynosoma* species show higher prevalence in the Southern locations than in the North.

Information on the prevalence of ectoparasites is even scarcer than for helminths. Ticks are present in both Sub-Antarctic and Antarctica regions, but they present different behavior that precludes any comparisons. In Sub-Antarctic islands, ticks are found on the penguins (Gauthier-Clerc et al. 1999), while in the Antarctic Peninsula they are much less common and are usually found under the stones close to the penguin colonies (Barbosa et al. 2011). Nevertheless, data from the Antarctic Peninsula indicates a North-South decrease in the abundance and prevalence of ticks present under the stones at the penguin rookeries (Barbosa et al. 2011). However, such pattern is not coherent with a hypothesis of tick colonization from North to South because genetic studies showed that there is no latitudinal genetic cline; on the contrary, results have shown two different genetic populations of ticks in these regions (McCoy et al. 2013).

In general, the data seem to indicate a broader trend of decreased macroparasite prevalence towards more southerly localities; however, this conclusion should be considered judiciously due to the small number of studies and in some cases their small sample size. With regard to age, prevalence appears to be generally higher in adults than in chicks that could be explained due to the longer time of exposure to the parasites in adult individuals and the shorter period of time for parasite development in chicks, but again caution should be taken with this conclusion due to the small sample size in the case of adults. In fact, the opposite patterns can also be found which is explained by the less development of the immune system in the case of chicks.

Information on parasite intensity is even scarcer than prevalence information. There are only four studies giving such information from Crozet archipelago in King Penguin (mean intensity (MI) = 178.6) (Fonteneau et al. 2011), 25 de Mayo/King George Island in Gentoo penguin (MI = 22.02) (Diaz et al. 2013), Deception Island in Chinstrap penguin (MI = 23.21) (Vidal et al. 2012), and 25 de Mayo/King Gorge Island, Bahia Esperanza/Hope Bay, and Avian Island in Adélie penguin (MI = 26) (Diaz et al. 2016). These studies are generally consistent with the interpretation that the mean intensity of infection is higher in penguins inhabiting the Sub-Antarctic region than those on the South Shetland Islands or at the Antarctic Peninsula. A similar result was found comparing the mean intensity between Antarctic and non-Antarctic penguin species with higher values for the latter (D'Amico et al. 2014).

9.6 Parasite Effects on Antarctic Penguins

The effect of macroparasites on the health and fitness of Antarctic penguins is a topic that barely has been addressed, with only a few studies dealing with ticks infecting penguins living in Sub-Antarctic islands and others investigating the potential effects of helminths in the South Shetlands Islands. Reported effects of ticks on penguins include mortality due to hyperinfestation (Gauthier-Clerc et al. 1998), reduced breeding success (Mangin et al. 2003), and transmission of tick-borne diseases such as borreliosis (Olsen et al. 1995; Schramm et al. 2014; Barbosa et al. unpublished data) and babesiosis (Earle et al. 1993; Montero et al. 2016).

Helminth effects on Antarctic penguin have been reported at the level of the tissue damage, specifically, Martin et al. (2016) described lesions companied by hemorrhage, edema, degeneration, and necrosis of the intestine. More generally, using an experimental approach by means of the administration of anti-helminthic drugs, Palacios et al. (2012) estimated the effect of helminth parasites as a loss of 6% of the body mass in infected chicks of Chinstrap penguins. Body mass loss has been also reported in Gentoo penguin chicks in a similar experiment (Palacios et al. unpublished data). Effects on the immune system of Antarctic penguins have also been demonstrated in terms of an increased foot-web swelling response to phytohemagglutinin and a decreased concentration of eosinophils and monocytes in the blood of individuals treated with anti-helminthic drugs (Bertellotti et al. 2016).

9.7 Potential Effects of Climate Change

Climate change can affect the distribution, abundance, and/or virulence of parasites (Sutherst 2001). Antarctica, however, is a region where the effects of climate change are complex and sometimes even contradictory. While the Antarctic Peninsula is one of the parts of the Earth where the temperatures have increased more rapidly in recent decades (Meredith and King 2005) and as a consequence a substantial reduction in sea ice extent has been detected (Stammerjohn et al. 2008; Fan et al. 2014), the Eastern continental region has shown an opposite trend of gradual decrease in land air temperatures and increase in sea ice extent (Fan et al. 2014). As a result, the expected effects of climate on the Antarctic fauna, including penguins and their parasites, will certainly differ between these regions.

Climate change in the Antarctic Peninsula is producing profound environmental changes affecting the trophic web from the bottom to the top through a significant reduction in the primary production (Montes-Hugo et al. 2009). With the consequent reduction in krill abundance (Atkinson et al. 2004; Flores et al. 2012), top predators such as penguins are changing their population trends (Carlini et al. 2009; Trivelpiece et al. 2011; Barbosa et al. 2012). However, not all species inhabiting the same areas have responded similarly, as is notoriously the case of the ice-intolerant Gentoo penguins, which have often benefitted from climate change, whereas the ice-dependent Adélie penguins in the same areas have experienced sharp population decreases (Forcada et al. 2006; Forcada and Trathan 2009). Dietary changes as a response to climate change could be predicted based on changes occurred during past climate changes in which penguins change their diet from krill to squid during warm periods (Emslie et al. 1998). Such changes would certainly affect not only the overall nutritional and health status of these seabirds, but it would also affect the rate of ingestion of parasite cysts/larvae and of exposure to new parasites. Similarly, because the life cycles of ectoparasites are greatly influenced by ambient temperature, it is expected that the increase of temperatures affect these parasites. For instance, there are already data to suggest that warmer years produce an increase in the abundance of ticks in the Antarctic Peninsula (Benoit et al. 2009).

9.8 Conclusions and Future Prospective

Although Antarctic penguins have been far more studied than other Antarctic seabirds, the scarce and fragmented nature of the available information has limited our broader understanding on the pathogens and disease that affect them and how they may impact their ecology, conservation, and evolution (Barbosa and Palacios 2009).

Published information is based on a geographically uneven sampling area, with few areas (e.g., South Shetland Islands) having been the subject of extensive research whereas virtually no information is available for the most of the continent (e.g., Ross Sea). As a consequence, there is not enough information yet to allow us to establish biogeographical patterns of presence and abundance of parasites. An additional complicating factor is that the information has often been collected during relatively short and discontinuous periods of time and long-term studies or surveillance of the temporal variation of prevalence or parasitism intensity is nonexistent. Such information is crucial to evaluate how environmental changes affect the ecology of these parasites and their impacts to the health of penguins.

Another challenge faced in health studies of Antarctic penguins is the difficulty of obtaining high quality data that faithfully reflect the occurrence of pathogens and disease, often due to the logistical limitations that are inherent to the continent or to application of diagnostic methods that were not specifically designed or validated to be used for these species. For instance, an important limitation that may influence data quality is the difficulty to obtain information of helminth parasites from live penguins through coprological studies because of the high probability of false negative results (Vidal et al. 2012). This, along with the ethical and legal restrictions and the endangered status of many species, restricts the study of endoparasites to the postmortem examination of naturally deceased individuals. As a result, quantitative information on the epidemiology of these parasites (prevalence, intensity of infection, etc.) are likely to be heavily biased and might allow for an adequate interpretation of their ecology and health effects. To solve this problem, the application of molecular techniques could help in improving the applicability and reliability of helminthological studies to living animals (Vidal et al. 2016).

Another important gap in our knowledge on the parasites of Antarctic penguins is the generalized insufficiency of information about their life cycles. This implies that we do not know which could be the intermediate hosts and, as a result, it is not possible to evaluate the risk of infection or how environmental factors affect the epidemiological dynamics.

Finally, from an ecological standpoint, the mechanisms and extent to which parasites affect their hosts is a critical gap in our understanding of Antarctic penguin parasites. Parasites can play a key role in the population dynamics of their hosts by affecting fitness traits such as survival, breeding success, or behavioral performance (Morand and Deter 2009). This can produce decline in host populations or affect host in different subtle ways through resources consumption and affecting metabolic rate, territorial behavior, phenology, intra- and interspecific interactions, mating and foraging success, etc. (Moller 1997). In addition, hosts can also adjust their behavior in order to avoid or reduce the effects of parasites (Perrot-Minnot and Cézilly 2009). The study of all these aspects has been virtually absent in Antarctica for decades, and only recently some studies have been published on this topic (see above).

It is therefore clear that an urgent effort is needed to obtain high quality data through long-term and geographically representative sampling effort, investigating not only the occurrence of parasites and pathogens but also deeper aspects of their ecology, life cycle, epidemiology, and health impacts. This will be a challenge not only for Antarctic researchers individually, but also reflects the need for broader instruments and policies by international and national Antarctic research programs to incorporate fauna health and pathogen studies as core components of scientific research in the Antarctic.

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