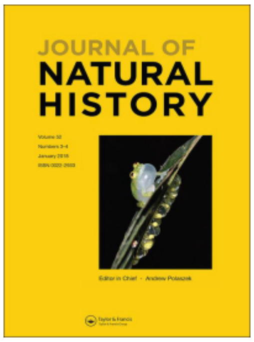

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Current knowledge of helminth parasites in Australian Anatidae species

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ABSTRACT

Research on parasites in Australian birds is limited. This study aimed to identify patterns of parasite burdens and their distribution across Australia in Anatidae species. Data were gathered from databases and the Australian Helminth Collection, then analysed using a Microsoft Excel spreadsheet. The findings reveal that platyhelminths were more frequently reported than nematodes, while acanthocephalans were the least abundant and least diverse parasites. At least 119 parasitic helminth taxa were recorded in Australian Anatidae (22 species from 16 genera), based on 271 records from 44 published articles and five museum/research institution collections. Specifically, 76 cases of nematode infection (33 taxa) were found among 20 Anatidae species, 102 cases of trematode infection (42 taxa) among 22 species, and 90 cases of cestode infection (40 taxa) among 16 species. The high prevalence of platyhelminths may be due to the host diet and the parasites' ability to multiply asexually in various larval stages among trematodes, increasing the likelihood of exposure and infection. The study also highlights the challenges in accurately identifying parasites due to many records being identified only at higher taxonomic levels. This issue is exacerbated by a scarcity of taxonomists and insufficient investment in capacity building in the country. Moreover, the available knowledge about the geographical distribution of Anatidae parasites in Australia is biased by the location of research institutions rather than the actual distribution of parasites. The introduction of non-native parasites through bird movement and introduced domestic waterfowls across borders poses a significant risk to native wildlife, potentially leading to new disease outbreaks or exacerbating existing health issues.

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Helminth parasites; Anatidae; waterfowl; Australia; natural history museum; zoo

Introduction

The family Anatidae includes a variety of waterfowl such as geese, ducks and swans, known for their global distribution, inhabiting every continent except Antarctica (Backues 2015). These birds are well adapted to aquatic life, capable of swimming, floating and sometimes diving in shallow waters. Beyond their natural habitats, many waterfowl

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species are also raised in captivity for their meat and eggs, and they are commonly found in both zoological and private collections (Routh and Sanderson 2009).

Australia hosts 19 native Anatidae species, along with four migratory species that visit the continent annually (Johnsgard 1965; Christidis and Boles 2008; BirdLife International 2024). Of the 13 genera present in Australia, six – *Anseranas*, *Cereopsis*, *Chenonetta*, *Biziura*, *Malacorhynchus* and *Stictonetta* – are monotypic and primarily confined to this region (Johnsgard 1965).

The distinctiveness of Australian waterfowl is a testament not only to their unique evolutionary history but also to their ecological adaptations. Bird species that use both aquatic and terrestrial habitats for survival are of great interest as they are exposed to both aquatic and terrestrial diseases and parasites, and are able to spread parasites to new locations/environments due to their migratory habits (Gregory 1990; Tracey *et al*. 2004; Gutiérrez *et al*. 2017). Many Anatidae species migrate annually for breeding or feeding purposes. In Australia, water systems influence the movement of Anatidae species, in particular during El Niño events when more dry years than wet ones are expected. As waterways dry up, these waterfowl follow on to other water sources for survival (Bino *et al*. 2015).

The current knowledge of helminth diversity in Australian native bird species is insufficient, with very little known about the parasites of Anatidae species in Australia. The last major research on parasites of birds was conducted in the 1980s (eg Mawson *et al*. 1986). This earlier research relied heavily on incidental findings rather than systematic, long-term studies. Thus, understanding the parasites present in these species can enhance our knowledge on parasitic life cycles, as well as understanding their potential impacts on agriculture, environment and human health (Tracey *et al*. 2004; Olsen 2009).

This study aimed to provide a review of the current knowledge of helminth parasites in Australian Anatidae species, a field that has significant implications for the health and conservation of these birds. Understanding the diversity and impact of helminth parasites on Australian waterfowl can offer insights into their ecology, behaviour and overall well-being.

Materials and methods

The review was conducted to provide information about the species of helminths, and geographical locations of the parasites' occurrence, in Australia. The systematic approach employed to search, collect and analyse reports of parasites in Anatidae species within Australia is outlined below. A combination of specific keywords and a range of scientific databases and search engines were used to compile a comprehensive dataset, ensuring a robust and thorough examination of the topic. The subsequent analysis focused on the taxonomy of reported parasites, the bird species parasitised, and the geographical distribution of these reports.

Literature search strategy

A comprehensive literature search was conducted to compile the reports of parasites from wild and domestic waterfowl (Anatidae species) in Australia. The search strategy involved the use of specific keyword combinations to ensure a thorough and targeted search. The primary combination of keywords used was 'Anatidae AND Parasite'. This was followed by searches for each species of Anatidae reported in Australia (Atlas of Living Australia 2024), combined with the keyword 'parasite' (Table 1).

Databases and search engines

The following English-language scientific databases and search engines were utilised for the literature search: Australian Helminthological Collection (accessed via the South Australian Museum website), the PRIMO university online library search engine, Web of Science, Scopus, PubMed, Science Direct, and Google Scholar.

Data management

During the data collection process, any reports that were categorised under broad or ambiguous terms such as 'unidentifiable', 'unidentified' or 'undetermined' were uniformly recorded as 'Unidentified' in the spreadsheet, but were not included in the analyses.

Inclusion and exclusion criteria

The inclusion and exclusion criteria for the literature search are detailed in the PRISMA 2009 flow diagram (Figure 1). These criteria were rigorously applied to ensure the relevance and quality of the data collected.

Data analysis

The data collection was finalised on 1 May 2024. Following the completion of data collection, the analysis was conducted using Microsoft Excel. This analysis involved organising, categorising, and summarising the data to derive meaningful insights and conclusions regarding the parasitic infections in Anatidae species in Australia.

Analysis of parasite reports

In articles with two or more reported helminths, each parasite was counted separately and is referred to as a 'reported case' throughout the article. The first part of the analysis focused on the parasites reported, summarising the data based on different taxonomic levels. This included creating a general table with the scientific and common names of birds reported to have helminth parasites, along with the total number of parasite reports for each bird. Summary tables were then created for each individual bird species included in the study. Each table listed the parasites reported to their lowest taxonomic rank.

Table 1. List of helminths reported from Anatidae species in Australia. Abbreviations include AHC: Australian Helminthological Collection, at present housed in the South Australian Museum, Adelaide, South Australia; CSIRO: Division of Wildlife and Rangelands Research (name of the institution as referred to by Mawson *et al*. 1986), Canberra, Australian Capital Territory; UMSVS: University of Melbourne, Victoria, School of Veterinary Science; CIH: Commonwealth Institute of Health, University of Sydney, New South Wales; BM: British Museum (Natural History), London, England; AM: Australian Museum, Sydney, NSW; Bass Str.; Bass Strait. 'Unidentified' refers to records where the parasite was only classified as Cestoda, Trematoda, Nematoda, or Acanthocephala.

Bird scientific name	Common name	Parasite	Locality	Reference/source
*Anas castanea***	Chestnut teal	**N**:	Tas	AHC
		Capillaria sp.		
		Echinuria uncinata	Tas	AHC
		Epomidiostomum sp.	Tas	AHC
		Tetrameres fissispina	Tas	AHC
		C:	NSW	Johnston (1912b)
		Cloacotaenia megalops (syn. *Hymenolepis megalops*)		
		Diorchis sp.	NSW	CSIRO
		Diorchis flavescens	NSW	Johnston (1912c)
		Diploposthe laevis	NSW	Johnston (1912c)
		Fimbriaria fasciolaris (syn. *Taenia pediformis*)	NSW	Krefft (1871); Johnston (1912b)
		Microsomacanthus collaris (syn. *Hymenolepis collaris*)	NSW	Johnston (1912a)
		Cestoda gen. sp.	Vic	AHC
		T:	NSW	AHC
		Hypoderaeum sp.		
		Hypoderaeum conoideum	Tas	AHC
		Levinseniella tasmaniae (syn. *Microphallus tasmaniae*)	Tas	Smith (1973)
		Maritrema calvertense	Tas	Smith (1973)
Anas gracilis[d] reported as *Anas gibberifrons*	Grey teal	**N**:	SA	Mawson (1981)
		Amidostomum acutum		
		Capillaria sp.	NSW; NT	CSIRO; AHC
		Echinuria sp.	NSW	CSIRO
		Echinuria uncinata (syn. *E. querquedulae*)	NT; SA	AHC; Johnston and Mawson (1942)
		Epomidiostomum sp.	NSW	AHC
		Epomidiostomum uncinatum	SA; Vic	Johnston and Mawson (1942); UMSVS
		Streptocara sp.	SA; NSW	Johnston and Mawson (1942); CSIRO
		Strongyloides sp.	NSW	CSIRO
		Tetrameres sp.	SA; NSW	Johnston and Mawson (1942); CSIRO
		C:	NSW	CSIRO
		? *Cloacotaenia megalops*		
		Diorchis flavescens	Qld; NSW	Baylis (1934); CSIRO
		Gastrotaenia sp.	NSW	CSIRO
		Haploparaxis veitchi	Qld	Baylis (1934)
		Hymenolepis robertsi	Qld	Baylis (1934)
		Staphylepis lamellata	SA	AHC
		Cestoda gen. sp.	Vic; SA; NT	UMSVS; AHC;
		T:	NSW	AHC
		Cyclocoelidae gen. sp.		
		Echinostoma sp.	NT	AHC
		Echinostomatidae gen. sp.	NSW	AHC
		Echinostomatinae gen. sp.	SA	AHC
		Hypoderaeum sp.	SA	AHC
		Notocotylidae gen. sp.	SA	AHC

(*Continued*)

Table 1. (Continued).

Bird scientific name	Common name	Parasite	Locality	Reference/source
		Schistosomatidae gen. sp.	NSW; Qld; Vic	Blair and Ottesen (1979)
		Trichobilharzia sp.	NSW	Bearup (1957)
		Trichobilharzia parocellata	NT	Islam and Copeman (1986)
		Typhlocoelum sp.	SA	AHC
		Trematoda gen. sp.	NSW	AHC
Anas superciliosa[d]	Pacific black duck	**N**: *Amidostomum* sp.	NSW	CSIRO
		Amidostomum acutum	Tas; SA	Mawson (1981)
		Capillaria sp.	NSW	Cleland (1922)
		Contracaecum microcephalum	NSW	Johnston and Mawson (1941b)
		Echinuria sp.	NSW	CSIRO
		Epomidiostomum sp.	NSW; Tas; SA; NT	CSIRO; AHC
		Physaloptera sp.	NSW	Johnston and Mawson (1941a)
		Porrocaecum crassum	Tas	AHC
		N: *Streptocara crassicauda*	Vic; Tas	Mason (1988)
		Tetrameres fissispina	SA; Tas; NT	Johnston and Mawson (1949)
		C: *Cloacotaenia megalops* (syn. *Hymenolepis megalops*)	Qld; NSW; WA	CIH; CSIRO; BM; Johnston (1912a)
		Cloacotaenia megalops (syn. *Taenia cylindrica*)	NSW	Krefft (1871)
		Diorchis flavescens	Qld; NSW;	Johnston (1912b); CIH; CSIRO; AHC
		Diorchis flavescens (syn. *Taenia flavescens*)	EA	Krefft (1871)
		Diploposthe laevis	NSW	Johnston (1912c)
		Drepanidotaenia lanceolata	Qld	BM
		Fimbriaria sp.	SA	AHC
		Fimbriaria fasciolaris	NSW	Johnston (1912a)
		Fimbriaria fasciolaris (syn. *Taenia pediformis*)	EA	Krefft (1871)
		Gastrotaenia sp.	NSW	CSIRO
		Hymenolepis sp.	NSW; Qld; SA	Johnston (1912a); AHC
		Microsomacanthus collaris (syn. *Hymenolepis collaris*)	NSW	Johnston (1912a)
		Microsomacanthus collaris (syn. *Taenia bairdii*)	EA	Krefft (1871)
		Cestoda gen. sp.	NSW; Tas; Qld; SA; Vic; NT	Cleland (1922); Munday and Green (1972); AHC; UMSVS
		T: ? *Prosthogonimus* sp.	SA	AHC
		Apatemon gracilis	Tas	Smith and Hickman (1983)
		Cotylurini[b]	Qld; SA	AHC
		Diplostomatidae gen. sp.	SA	AHC
		Echinostoma revolutum	Qld; NSW; SA; Tas	Johnston (1912a), Johnston and Mawson (1941b); Johnston (1913a); AHC
		Echinostomatinae gen. sp.	Qld; SA;	AHC
		Hypoderaeum sp.	Qld; SA	AHC
		Levinseniella tasmaniae (syn. *Microphallus tasmaniae*)	SA	Smith (1982)
		Maritrema calvertense	Tas	Smith (1982)
		Notocotylidae gen. sp.	Qld; SA	AHC
		Notocotylus attenuatus	Qld	Nicoll (1914)
		Paramonostomum bursae	Tas	Smith and Hickman (1983a)
		Paramonostomum caeci	Tas	Smith and Hickman (1983a)
		Patagifer sp.	NSW	AHC

(*Continued*)

Table 1. (Continued).

Bird scientific name	Common name	Parasite	Locality	Reference/source
		Psilochasmus sp.	Qld	AHC
		Psilochasmus oxyurus	Tas	Smith (1982)
		Schistosomatidae gen. sp.	Qld; NSW; Vic	Blair and Ottesen (1979)
		Trichobilharzia sp.	Qld	Blair and Ottesen (1979)
		Trichobilharzia australis	Qld	Blair and Islam (1983)
		Trichobilharzia parocellata	NT	Islam and Copeman (1986)
		Typhlocoelum sp.	Qld; vic; SA	AHC
Not stated	Domestic duck	**N**: *Streptocara crassicauda*	Vic; Tas	Harrigan (1981), Mason (1988)
Not stated	Cayuga duck	**N**: *Streptocara crassicauda*	Vic; Tas	Mason (1988)
Anseranas[d] *semipalmata*	Magpie goose	**N**: *Amidostomum anseris*	Vic	UMSVS
		Epomidiostomum sp.	NT	AHC
		Heterakis sp.	Vic	UMSVS
		Streptocara crassicauda	Vic	UMSVS; Harrigan (1981)
		Tetrameres anseranas	NT; Vic	UMSVS; Mawson (1979)
		C: *Angularella australis*	Aust	BM
		Biuterina sp.	Aust	BM
		Cloacotaenia megalops (syn. *Hymenolepis megalops*)	Qld	Johnston (1913a)
		Passerilepis stylosa	Aust	BM
		Sobolevicanthus terraereginae (syn. *Hymenolepis terraereginae*)	Qld	Johnston (1913a)
		Cestoda gen. sp.	Qld; Vic; Nt	AHC
		T: *Echinostoma revolutum sensu lato*	Qld	Nicoll (1914); AHC
		Notocotylus attenuatus	Qld; NT	Nicoll (1914); AHC
		Schistosomatidae gen. sp.	Qld	Blair and Ottesen (1979)
		Typlocoelum reticulare	Qld; NT	Johnston (1913b); AHC
Aythya australis[d]	Hardhead	**N**: *Capillaria* sp.	SA	AHC
		Epomidiostomum sp.	NSW	WLRR
		Streptocara sp.	Tas	Munday and Green (1972)
		Streptocara crassicauda	Tas	AHC
		C: ? *Sobolevicanthus* sp.	NSW	WLRR
		Cloacotaenia sp.	NSW	WLRR
		Diorchis flavescens	NSW	Johnston (1912c)
		Diplogynia sp.	NSW	WLRR
		Diplogynia oligorchis	Qld	CIH
		Diploposthe laevis (syn. *Taenia tuberculata*)	Qld; NSW;	Johnston (1912c); BM; Maplestone (1922); Krefft (1871)
		Fimbriaria sp.	NSW; SA	WLRR; Mawson *et al.* (1986)
		Gastrotaenia sp.	NSW	WLRR
		Cestoda gen. sp.	Qld; SA; NT; Vic; Qld	Johnston (1912c); CIH; AHC; UMSVS
		T: Cyclocoelidae gen. sp.	NSW; SA	AHC
		Echinostomatidae gen. sp.	NSW; SA; Qld; NSW	AHC; Blair and Ottesen (1979)
Biziura lobata[d]	Musk duck	**A**: *Polymorphus biziurae*	SA; NSW	AHC; Johnston (1948)
		N: *Amidostomum* sp.	NSW	CSIRO

(*Continued*)

Table 1. (Continued).

Bird scientific name	Common name	Parasite	Locality	Reference/source
		Amidostomum biziurae	SA; NSW	Johnston and Mawson (1947), Mawson (1981); Mawson (1959)
		Capillaria sp.	NSW	CSIRO
		Streptocara formosensis	NSW	AHC
		Streptocara recta	SA	AHC
		Tetrameres biziurae	SA; NSW	AHC; Johnston and Mawson (1941a)
		C: ? *Cloacotaenia megalops*	NSW	CSIRO
		Cyclophyllidea gen. sp.	SA	AHC
		Gastrotaenia sp.	NSW	CSIRO
		Sobolevicanthus sp.	NSW	CSIRO
		Taenia moschata[a]	NSW	Krefft (1871)
		Cestoda gen. sp.	Qld; NSW; Tas; SA	AHC
		T: *Apatemon vitelliresiduus*	Qld; SA	Dubois and Angel (1972)
		Echinoparyphium ellisi	SA	Johnston and Mawson (1949)
		Echinostoma revolutum	Qld; SA	Johnston and Mawson (1941b)
		Echinostomatidae gen. sp.	NSW;	AHC
		Echinostomatinae gen. sp.	Qld; SA	AHC
		Notocotylidae gen. sp.	NSW; SA	AHC
		Psilochasmus sp.	SA	AHC
		Trematoda gen. sp.	NSW	AHC
Cairina moschata	Muscovy duck	**N**: *Streptocara crassicauda*	Vic; Tas	Mason (1988)
		T: *Sphaeridiotrema globulus*	NSW	Campbell and Jackson (1977)
		Trichobilharzia arcuata	NT	Islam (1986)
Cereopsis novaehollandiae[d]	Cape barren goose	**N**: *Amidostomum anseris*	Tas	Mawson (1981)
		Heterakis chenonettae	Tas	AHC
		Heterakis dispar	Bass Str	BM
		Heterakis vesicularis	SA	AHC
		C: *Sobolevicanthus* sp.	SA	AHC
		T: *Psilochasmus* sp.	Tas	AHC
Chenonetta jubata[d]	Maned duck	**N**: *Amidostomum* sp.	Qld; NSW	WLRR
		Epomidiostomum sp.	NSW	WLRR
		Heterakis chenonettae	NSW	Johnston (1912b); Johnston and Mawson (1941b)
		T: Echinostomatidae gen. sp.	NSW	AHC
		Schistosomatidae gen. sp.	Qld	Blair and Ottesen (1979)
Cygnus atratus[d]	Black swan	**A**: *Corynosoma* sp.	SA	AHC
		Polymorphus sp.	SA	AHC
		N: *Amidostomum* sp.	NSW; Vic	CSIRO; AHC
		Amidostomum cygni	SA; Tas	Johnston and Mawson (1945), Mawson (1981); AHC
		Capillaria ellisi	SA	(Johnston and Mawson 1945)
		Echinuria uncinata	Vic; Tas; SA	UMSVS; AHC
		Pseudamidostom sp.	NSW	CSIRO
		Tetrameres australis	SA	Johnston and Mawson (1941a); AHC

(*Continued*)

Table 1. (Continued).

Bird scientific name	Common name	Parasite	Locality	Reference/source
		C: *Armadoskrjabinia globosa* (syn. *Hymenolepis globosa*)	Aust; Qld;	BM; Szpotanska (1931)
		Australiolepis southwelli (syn. *Echinorhynchotaenia nanu*)	Qld; Aust	Szpotanska (1931); Maplestone and Southwell (1922)
		Cyclophyllidae gen. sp.	SA	AHC
		Diorchis spiralis	Aust	Szpotanska (1931)
		Drepanidotaenia lanceolata	Aust; Qld; NSW; Vic; SA	BM; WLRR; AHC; Szpotanska (1931)
		Drepanidotaenia lanceolata (syn. *Hymenolepis lanceolate*)	Qld	Maplestone and Southwell (1922)
		Drepanidotaenia sp.	SA	AHC
		Gastrotaenia sp.	SA	AHC
		Hymenolepis sp.	Qld	BM
		Hymenolepis chenopis	Vic	Palmer (1981)
		Hymenolepis variabilis	Qld	CIH
		Monosaccanthes sp.	SA	AHC
		Monosaccanthes curiosa	Aust	Szpotanska (1931)
		Monosaccanthes curiosa (syn. *Hymenolepis curiosa*)	Qld	BM
		Monosaccanthes kazachstanica	Vic	Palmer (1981)
		Nematoparataenia paradoxa	Qld; Vic; SA; Aust	Maplestone and Southwell (1922); AHC; BM
		Parabisaccanthes bisacculina	Vic; Qld; SA	Palmer (1981); BM; AHC
		Parabisaccanthes bisacculina (syn. *Drepanidotaenia bisacculina*)	Aust	Szpotanska (1931)
		Cestoda gen. sp.	NSW; Aust; Qld; NSW; Tas; SA; Vic	Cleland (1922); AHC; AM; CIH; UMSVS
		T: *Apatemon intermedius*	SA	Johnston (1948)
		Apatemon intermedius(syn. *Hemistomum intermedium*)	NSW	Johnston (1904)
		Cotylurus magniacetabulus	SA	Dubois and Angel (1972)
		Cyclocoelidae gen. sp.	NSW; Vic; SA	AHC
		Cylindroirema cygni	SA	Angel (1973)
		Echinoparyphium ellisi	SA; Qld	Johnston and Mawson (1949); Verma (1936b)
		Echinoparyphium gizzardai	?Qld	Johnston and Mawson (1949); Verma (1936b)
		Echinostoma sp.	Tas	AHC
		Echinostoma revolutum	Qld; SA	Johnston and Mawson (1941b); Nicoll (1914)
		Echinostomatidae gen. sp.	NSW	AHC
		Echinostomatinae gen. sp.	SA	AHC
		Hyptiasmus magnus	Vic	Johnston (1916)
		Hyptiasmus magnus (syn. *Monostomum* sp.)	Vic	Johnston (1948)
		Notocotylidae gen. sp.	Qld; Tas; NSW; SA	Smith (1982); AHC
		Notocotylus attenuatus	Qld	Nicoll (1914)
		Notocotylus sp.	Tas; SA	AHC
		Paramonostomum caeci	Tas	Smith and Hickman (1983a)
		Psilochasmus oxyurus	Tas	Smith (1982)

(*Continued*)

Table 1. (Continued).

Bird scientific name	Common name	Parasite	Locality	Reference/source
		Psilostomum spp.[c]	SA; Tas	AHC; Smith (1982)
		Trichobilharzia sp.	SA	Johnston (1941)
		Trematoda gen. sp.	NSW	AHC
Dendrocygna arcuata[d]	Wandering whistling-duck	**C**: ? *Passerilepis zosteropis*	Aust	BM
		Cloacotaenia megalops	Qld	CIH
		Diorchis flavescens	Qld	Maplestone (1922)
		Diplogynia oligorchis (syn. *Coturnia oligorchis*)	Qld	Maplestone (1922)
		Diplogynia oligorchis (syn. *Diplopostha laevis*)	Qld	Johnston (1913a)
		Hymenolepis ibidis	Qld	CIH
		Ophiotaenia hylae	Qld	Maplestone (1922)
		Cestoda gen. sp.	Qld	AHC
		T: Echinostomatinae gen. sp.	Qld	AHC
		Notocotylidae gen. sp.	Qld	AHC
		Schistosomatidae gen. sp.	Qld	Blair and Ottesen (1979)
		Trichobilharzia arcuata	NT	Islam (1986)
Dendrocygna eytoni[d]	Plumed whistling-duck	**N**: *Streptocara crassicauda*	Tas	Mason (1988)
		T: Schistosomatidae gen. sp.	Qld	Blair and Ottesen (1979)
Malacorhynchus membranaceus[d]	Pink-eared duck	**N**: Acuariidae gen. sp.	SA	AHC
		Capillaria sp.	SA	AHC
		C: Cestoda gen. sp.	Vic; SA	AHC
		T: ? Microphallidae gen. sp.	SA	AHC
		Cyclocoelum sp.	Vic	AHC
		Echinostoma sp.	Vic	AHC
		Notocotylidae gen. sp.	Vic; SA	AHC
		Paramonostomum sp.	SA	AHC
		Trematoda	Vic	AHC
Nettapus coromand-elianus[d]	Cotton pygmy-goose	**T**: *Cyclocoelum* sp.	Qld	AHC
Nettapus pulchellus[d]	Green pygmy-goose	**N**: *Echinuria uncinata*	NT	AHC
		C: Cestoda gen. sp.	NSW	AHC
		T: *Echinostoma revolutum*	Qld	Nicoll (1914)
		Notocotylus attenuatus	Qld	Nicoll (1914)
Oxyura australis[d]	Blue-billed duck	**A**: Acanthocephala gen. sp.	Tas	Mawson *et al.* (1986)
		N: *Capillaria* sp.	SA	AHC
		Epomidiostomum sp.	Tas	AHC
		Streptocara crassicauda	Tas	AHC
		C: Cestoda gen. sp.	Tas; SA	Munday and Green (1972); AHC
		T: *Apatemon intermedius*	SA	Dubois and Angel (1972)
		Echinostomatinae gen. sp.	SA	AHC
		Notocotylidae gen. sp.	Tas; SA	AHC

(*Continued*)

Table 1. (Continued).

Bird scientific name	Common name	Parasite	Locality	Reference/source
Spatula rhynchotis reported as *Anas rhynchotis*[d]	Australasian shoveler	**N**: Acuariidae gen. sp.	NSW	UMSVS
		Amidostomum acutum	NSW	UMSVS
		Capillaria sp.	SA	AHC
		Streptocara crassicauda	Aust	AHC
		Streptocara sp.	NSW	UMSVS
		Tetrameres sp.	SA	AHC
		C: ? *Cloacotaenia megalops*	NSW	CSIRO
		Diorchis flavescens (syn. *Taenia flavescens*)	NSW	Krefft (1871)
		Gastrotaenia sp.	NSW	CSIRO
		Cestoda gen. sp.	NSW; SA	UMSVS; AHC
		T: *Echinostoma revolutum*	SA	Johnston and Mawson (1941b)
		Echinostomatidae gen. sp.	NSW	AHC
		Echinostomatinae gen. sp.	SA	AHC
		Schistosomatidae gen. sp.	NSW	Blair and Ottesen (1979)
Stictonetta naevosa[d]	Freckled duck	**N**: *Amidostomum* 'sp. 6'	NSW	CSIRO
		Amidostomum acutum	SA	Mawson (1981)
		synhimantus sp.	SA	AHC
		Tetrameres sp.	SA	AHC
		C: *Cloacotaenia* sp.	NSW	CSIRO
		Diorchis sp.	NSW	CSIRO
		Cestoda gen. sp.	SA	AHC
		T: *Echinoparyphium* sp.	SA	AHC
		Notocotylidae gen. sp.	SA	AHC
		Psilochasmus sp.	SA	AHC
Tadorna radjah[d]	Radjah shelduck	**N**: *Amidostomum acutum*	NT	Mawson (1981)
Tadorna tadornoides[d]	Australasian shelduck	**N**: *Echinuria uncinata*	Vic	AHC
		Epomidiostomum sp.	NSW	AHC
		Streptocara crassicauda	Vic	AHC
		Tetrameres sp.	Vic	AHC
		C: *Hymenolepis* sp.	Vic	AHC
		Cestoda gen. sp.	NSW; SA; Vic	AHC
		T: *Echinoparyphium* sp.	SA	AHC
		Echinoparyphium revolutum	SA	AHC
		Echinoparyphium revolutum sensu lato (syn. 'echinostome larvae')	NSW	Bradley (1927)

[a]According to Johnston (1912c), the name is no longer valid as the type specimens were lost and the original description is too poor to allow a specific identification.

[b]This is a tribe, not a taxon.

The '?' next to some taxon names was included as it appeared in the original records. This notation likely indicates that the authors/curators believed the identification of these species was dubious.

[c]There were two unidentified species.

[d]Native Australian Anatidae species. Note that *Anseranas semipalmata* is under the family Anseranatidae. Both Anseranatidae and Anatidae are familes under Anseriformes. Since they are the only birds of this family in Australia, they have been included in this study.

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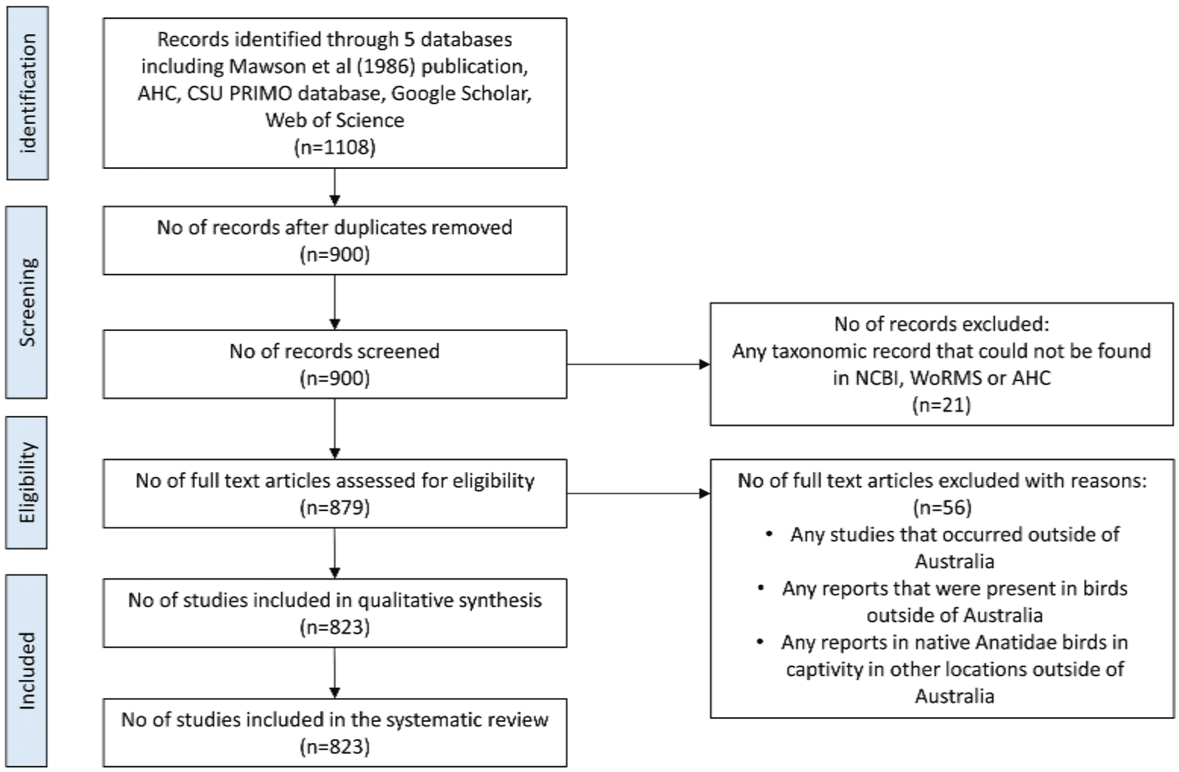

Figure 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2009 flow diagram of the systematic review process used for this study detailing the selection process of parasite reports in Anatidae (Moher *et al*. 2009). Abbreviations: National Center for Biotechnology Information (NCBI), World Register of Marine Species (WoRMS), Australian Helminthological Collection (AHC).

Analysis of bird species data

The next set of data summarised and analysed was that of the bird species included in the project. A general table was created listing the scientific and common names of birds reported to have helminth parasites, along with the total number of parasite reports for each bird. From this, summary tables were created for each individual bird species, detailing the parasites reported to their lowest taxonomic level.

Analysis of location data

The first table produced detailed the number of parasite reports for every location. The locations used in the report were: South Australia (SA), New South Wales (NSW), Australian Capital Territory (ACT), Western Australia (WA), Northern Territory (NT), Queensland (Qld), Victoria (Vic), Tasmania (Tas) Australia (no specific state) (Aust), Eastern Australia (no specific state) (EA).

Results

There were at least 119 parasitic helminth taxa present in Anatidae species included in this study (Table 1). A total of 22 Anatidae species (out of 30 reported species in Australia) belonging to 16 genera were reported with parasitic helminths (Figure 2). A total of 271

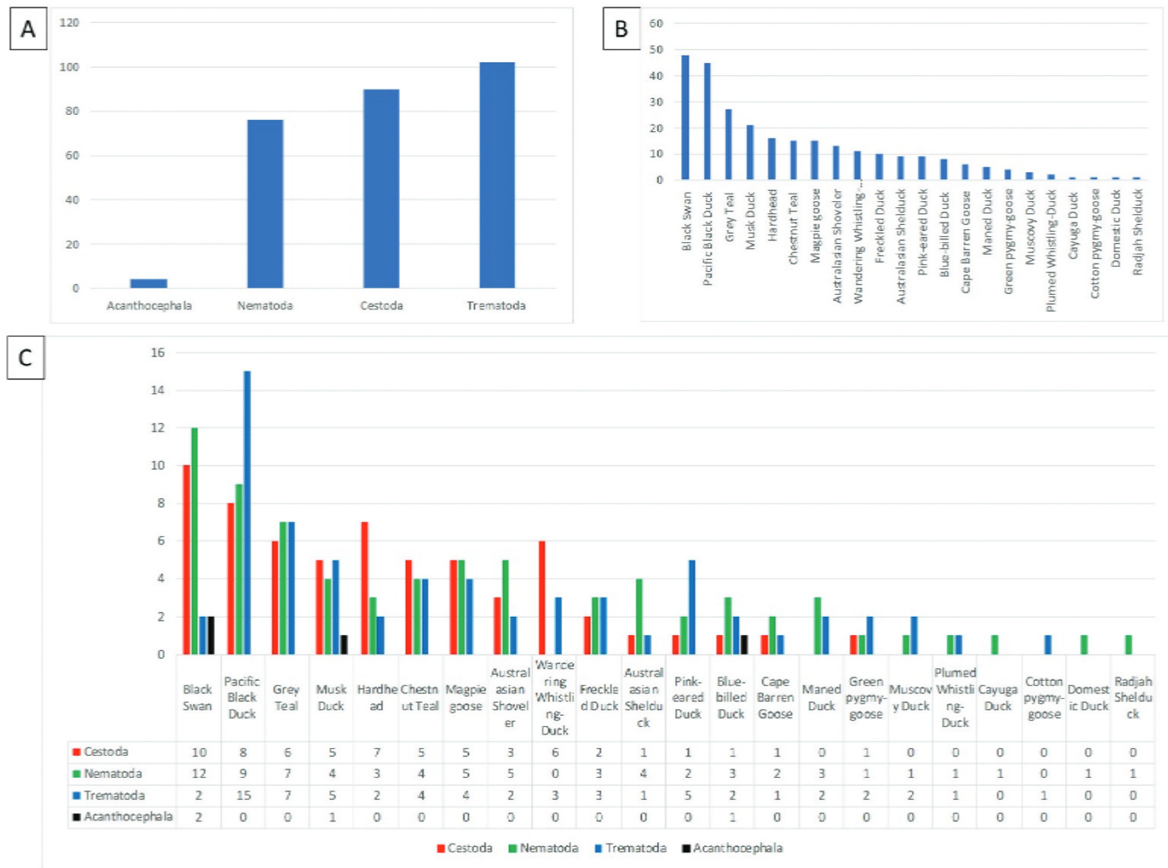

Figure 2. (A) Number of taxa of major parasitic helminths in the present study; (B) number of records for each Anatidae species in the present study; (C) number of recorded genera of parasitic helminths per major helminth group for each Anatidae species. Note: To avoid doubling the existing records, unidentified taxa were excluded from panel C unless they were the only available records.

cases of parasitic helminth occurrence from 44 published articles and five parasite collections in museums/research institutions were found.

Acanthocephala had the lowest number of taxa reported from Anatidae species. Altogether, four cases of infection with Acanthocephala were found among three species of Australian Anatidae – *Biziura lobata* (musk duck), *Cygnus atratus* (black swan) and *Oxyura australis* (blue-billed duck) – with distribution in SA, NSW and Tas.

A total of 76 cases of infection with Nematoda caused by 33 nematode taxa were found among 20 species of Anatidae. With 10 and 9 reported cases, respectively, *Anas superciliosa* (Pacific black duck) and *Anas gracilis* (grey teal) had the highest reported cases of infection with Nematoda, followed by Australasian shoveler *B. lobata* and *C. atratus* (6 each).

A total of 102 cases of infection with Trematoda caused by 42 taxa were found among 22 species of Anatidae. With 21 and 11 reported cases, respectively, *A. superciliosa* and *A. gracilis* had the highest reported cases of infection with trematodes, followed by other Anatidae species having 1–4 cases each. Members of the family Echinostomatidae were the most common reported trematodes, followed by Notocotylidae and Schistosomatidae. There were four reports of infection in which no identification was provided for the Trematoda.

A total of 90 cases of infection with Cestoda caused by 40 taxa were found among 16 species of Anatidae. *Cygnus atratus* had the highest reported cases of infection with Cestoda (19 cases), followed by *A. superciliosa* (Pacific black duck) (14) and *Aythya australis* (hardhead) (10). There were 14 reports where authors did not provide any identification details for the tapeworms found in the examined birds (Table 1).

Discussion

The present study revealed that acanthocephalans were the least common helminth parasite reported in Australian Anatidae. This observation aligns with findings from a study on Australian freshwater fish by Smales *et al*. (2018), which reported a depauperate acanthocephalan fauna in the country. The scarcity of acanthocephalans in these hosts may indicate broader ecological or environmental factors that limit their presence in Australian freshwater ecosystems. However, it should be noted that in other regions, ducks also inhabit marine environments where Acanthocephala are more commonly found (Barton and Smales 2015; Smales and Weaver 2015; Shamsi and Suthar 2016). The absence of reports of marine Acanthocephala infecting ducks in Australia does not necessarily rule out the possibility of such infections occurring. It may simply indicate a lack of research on this subject. While host specificity likely plays a role, meaning marine Acanthocephala may primarily infect fish or other marine animals, further research is needed to fully understand the interactions between these parasites and ducks in marine systems.

In contrast to Acanthocephala, our results showed that platyhelminths were the most frequently reported parasites in Australian Anatidae, consistent with findings from other parts of the world. For instance, Padilla-Aguilar *et al*. (2020) reported that platyhelminths were the predominant phylum in Anatidae from Mexico, with their prevalence being 2.7 times higher than nematodes and six times higher than acanthocephalans. This similar pattern suggests that certain ecological or biological factors may favour the success of platyhelminths over other helminth parasites such as Acanthocephala in Anatidae.

Most platyhelminths reported in the present study were gastrointestinal parasites, as previously found (eg, in Johnston, 1910). However, it should be noted that most dissection efforts and necropsies focus on the digestive system, potentially overlooking parasites present in other organs, such as the cardiovascular system, liver or kidney. Nevertheless, the presence, abundance and richness of gastrointestinal helminths in birds, such as those in the family Anatidae, can often be attributed to the diet of the host. Anatidae typically consume a diverse array of seeds, roots, tubers, invertebrates – including annelids, crustaceans (eg copepods, water fleas and ostracods), snails, insects (eg beetles, flies, butterflies and dragonflies) – and occasionally small amphibians (Swanson *et al*. 1985; Combs and Fredrickson 1996). These diverse dietary items include some of the most common intermediate hosts harbouring infective stages of parasites listed in the present study. For example, infective stages of *Echinostoma* have been found in molluscs and small fish commonly eaten by Anatidae in New South Wales (Shamsi *et al*. 2021, 2024).

It is also important to note that both platyhelminths and acanthocephalans have complex life cycles that require multiple intermediate hosts. However, a key difference is that platyhelminths, including Trematoda and some Cestoda, can continue to reproduce asexually within their intermediate hosts, whereas acanthocephalans cannot (Moore 1981; Lawson and Gemmell 1983; Hoberg 1986; Islam 1986; Negm-Eldin and Davies 2002). This reproductive strategy (Poulin and Lagrue 2015) likely contributes to the higher infection rates consistently observed for the abovementioned platyhelminths in Anatidae worldwide (Padilla-Aguilar *et al*. 2020). The ability of most platyhelminths to multiply asexually in their intermediate hosts may enhance their transmission efficiency and prevalence in definitive hosts like Anatidae by increasing the likelihood of exposure to as well as the quantity of the parasite.

Nematodes reported in Australian Anatidae include both monoxenic species, such as *Amidostomum* spp., and heteroxenic species, such as capillariid nematodes. However, the limited number of records and available information precludes drawing robust conclusions about species richness of Nematoda in Australian Anatidae.

As our findings suggest, at least 19 helminth taxa were identified only to higher taxonomic levels (ie Acanthocephala, Trematoda or Cestoda) and many more (116 records) to family or genus levels. Even for those reported to the species level, further examination is often required due to unclear taxonomic statuses at the time of identification. For example, taxa belonging to the genus *Echinostoma* require further scrutiny because their taxonomy remains poorly understood, with limited and sometimes conflicting molecular data leading to frequent changes in genus and species names (Ray *et al*. 2024). Another example is taxa identified as capillariid nematodes, which is one of the most challenging groups of helminths from a taxonomic and systematic viewpoint. Although Moravec (1982) provided a review of these taxa, the exact identity of the specimens found in Australia requires further investigation. This underscores the need for caution when considering the specific identity of taxa reported in Australian Anatidae, especially given that many records are outdated and do not meet current species identification standards.

Accurate and reliable parasite identification in Australian wildlife remains a significant challenge (Spratt and Beveridge 2019). The country faces a high rate of taxonomic deprivation (Weaver 2017; Shamsi and Sheorey 2018; Bradbury *et al*. 2022), with few active taxonomists working on terrestrial and freshwater parasites of wildlife. This lack of expertise and research attention has resulted in a paucity of recent findings, further complicating efforts to understand parasite biodiversity in the region.

In addition to their ecological roles, parasites are important for causing disease and death in their hosts (Shamsi *et al*. 2013; Sutherland *et al*. 2018). Several parasites identified in this study hold significant veterinary importance. For instance, Mason (1988) documented multiple cases of laryngeal streptocariasis caused by *Streptocara* spp., which led to death by asphyxiation in both farmed and wild Anatidae. Similarly, in Canada, Wojcinski *et al*. (1987) reported an outbreak of schistosomiasis in Atlantic brant geese (*Branta bernicla hrota*), caused by schistosomes of the genera *Trichobilharzia* and *Dendritobilharzia*. Schistosomes have also been found to cause proliferation of medial smooth muscle fibres leading to venous hypertrophy in whooper swans (*Cygnus cygnus*) in Japan (Akagami *et al*. 2010).

Additionally, several potentially zoonotic parasites were identified in this study, including *Echinostoma* spp., *Corynosoma* sp. and *Trichobilharzia* spp. (Hurley *et al*. 1994; Chai *et al*. 2009; Fujita *et al*. 2016). However, Anatidae primarily serve as definitive hosts for these parasites, where the parasites complete their life cycles, rather than as reservoirs for their infective stages for humans. Their role as definitive host is crucial in the transmission dynamics of zoonotic parasites, highlighting the importance of monitoring and managing these host–parasite interactions to mitigate zoonotic risks. A notable instance is avian schistosomes, which are known to cause cercarial dermatitis, also known as swimmer's itch. This is now considered an emerging disease, responsible for the majority of reported dermatitis outbreaks around the world (Horák *et al*. 2015).

In the present study, it was observed that the Pacific black duck (*A. superciliosa*) and black swan (*C. atratus*) host a greater number of helminth species compared to other examined host species. Several factors may contribute to this higher diversity of helminth species in these two bird species. Firstly, the ecology of the Pacific black duck and black swan might play a significant role. Both species are highly adaptable and occupy a wide range of habitats, including freshwater lakes, rivers and wetlands, which are rich in intermediate hosts for various helminth parasites (Pizzey and Knight 2014). Their diverse and opportunistic feeding habits, which include consuming a variety of invertebrates, plants and small vertebrates, could increase their exposure to different parasitic species. Secondly, the wide distribution of these species across Australia and beyond could also contribute to their higher parasite diversity. A broader geographical range often correlates with exposure to a wider variety of parasitic organisms, as the birds encounter different ecosystems and intermediate host species throughout their range (Poulin 1996). Thirdly, the level of research interest and sampling effort directed towards these species may influence the recorded number of helminth species. Both are prominent and well-studied species within Australian avifauna, potentially leading to more intensive and extensive parasitological studies. This increased research effort can result in the identification of a greater number of helminth species compared to less studied host species.

Our results indicate that both native and introduced host species included in the present study share common parasites (see Table 1).

A review of parasites reported in native Australian Anatidae species housed in zoos abroad revealed that only a few parasites typically restricted to Australia were present. However, several parasites not found in Australia, such as *Tetrameres fissispina* and *Hymenolepis micrancristrota*, were frequently observed in these ducks, suggesting exposure to non-native parasites in foreign environments. This observation highlights a broader concern: if biosecurity measures within Australia are not strictly enforced, native ducks could become infected with introduced parasites, posing a significant threat to local ecosystems. These parasites may have no natural predators or controls in Australia, potentially leading to severe consequences for wildlife health and biodiversity. The implications of this knowledge extend beyond research and conservation, playing a crucial role in the training and education of biosecurity officers and others responsible for animal health and ecological safety. Biosecurity officers must be well versed in identifying potential parasite risks and understanding the pathways through which exotic parasites can enter and spread in Australia.

Furthermore, an examination of parasites reported in native Australian Anatidae kept in zoos in other countries revealed the presence of only a few parasites typically restricted to Australia (Table 2). Additionally, several parasites that have not been found in Australia were common in those ducks (eg *Tetrameres fissispina* and *Hymenolepis micrancristrota*). This suggests the potential for parasite spillover and spillback events in Australia due to introducing Anatidae species. Although spillover and spillback events are known to occur

Table 2. Examples of reports of parasites from native Australian Anatidae kept in other countries.

Bird scientific name	Common name	Parasite	Locality	Reference
Anas castanea	Chestnut teal	**N:** *Capillaria anatis*	United Kingdom	Wakelin (1965)
Anseranas semipalmata	Magpie goose	*Tetrameres fissispina*	Philadelphia Zoo (origin of the bird was from Tasmania)	Canavan (1931)
Cereopsis novaehollandiae	Cape barren goose	**N:** *Heterakis vesicularis* (syn. *Heterakis caudata*)	Calcutta Zoo	Maplestone (1932)
		C: *Fimbriarioides intermedia* (syn. *Fimbriaria intermedia*)	Calcutta	Meggitt (1933)
Cygnus atratus	Black swan	**N:** *Baruscapillaria obsignata* (syn. *Capillaria obsignata*)	England	Wakelin (1963)
		Baruscapillaria obsignata (syn. *Capillaria obsignata* (syn. *C. anatis*))	England	Wakelin (1963)
		Heterakis circumvallata	Germany	Linstow (1906)
		Heterakis vesicularis (syn. *H. papillosa*)	Berlin Zoo	Schneider and Schneider (1866)
		Trichostrongylus tenuis	England	Wakelin (1963)
		C: *Cloacotaenia megalops*	Warsaw; Qld; NSW; SA; Vic	AHC; CSIRO; BM; CIH; Kotechi (1970)
		Dicranotaenia coronula	Warsaw	Kotechi (1970)
		Diorchis stefanski	Warsaw	Kotechi (1970)
		Hymenolepis sp.	Bengal; Qld	BM; Southwell (1916)
		Hymenolepis liophallos	Europe	Krabbe (1869)
		Hymenolepis micrancristrota (syn. *Taenia micrancristrota*)	Hungary	Wedl (1855)
		Tscherlkovilepis krabbei	Warsaw	Kotechi (1970)
		T: *Vermatrema longitestis*	Calcutta	Srivastava (1974)
		Vermatrema longitestis (syn. *Euparyphium longitestis*)	Calcutta	Verma (1936a); Johnston and Mawson (1949)
Tadorna tadornoides	Australasian shelduck	**C:** *Staphylepis lamellata* (syn. *Hymenolepis lamellata*)	London Zoo	Woodland (1930)

for parasites of importance to livestock (Kelly *et al*. 2009; Thompson 2013; Miller *et al*. 2018), little is known about the involvement of other hosts in these events (Shamsi *et al*. 2019, 2020). Therefore, future targeted research should explore these dynamics further to understand their implications for wildlife and ecosystem health.

Lastly, the data derived from museum collections have been fundamental to this study. Parasite collections in museums are integral to advancing our understanding of biodiversity, host–parasite relationships, and the evolution of parasitic organisms (Galbreath *et al*. 2019; Thompson *et al*. 2021). This study underscores their crucial role. These collections provide a historical record of parasite diversity and distribution, allowing researchers to study changes in parasite populations and the impacts of environmental changes over time (Wood and Vanhove 2022). With many parasite species still undescribed or poorly understood, museum specimens serve as reference points for identifying new species and re-evaluating existing classifications (Wood and Vanhove 2022). This is particularly important in regions like Australia, where there is a high rate of taxonomic deprivation and limited expertise in parasitology. The identification of helminths in Australian Anatidae, often only to higher taxonomic levels, reflects the challenges and the necessity of these collections for improving taxonomic resolution. Our findings show that there were at least 135 records of parasite specimens, mostly in museum collections, identified to family and genus levels or higher taxonomic levels, that still remain unidentified over 40 years after Mawson's articles (Mawson 1959, 1981).

In conclusion, this study provides baseline data on the helminth parasites of Australian Anatidae, highlighting the need for updated research in this area. These findings underscore the importance of investing in capacity building and training to enhance the identification and study of parasites in Australian wildlife. This is also crucial for strengthening biosecurity measures, because preventing the introduction of non-native parasites that could threaten avian health, subsequently leading to zoonotic disease outbreaks, relies on accurate and reliable identification of disease agents including parasites. By addressing these gaps, we can better protect the health of Australian Anatidae and maintain the integrity of their ecosystems.

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