Symbionts and diseases associated with invasive apple snails

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Abstract

This contribution summarizes knowledge of organisms associated with apple snails, mainly *Pomacea* spp., either in a facultative or obligate manner, paying special attention to diseases transmitted via these snails to humans. A wide spectrum of epibionts on the shell and operculum of snails are discussed. Among them algae, ciliates, rotifers, nematodes, flatworms, oligochaetes, dipterans, bryozoans and leeches are facultative, benefitting from the provision of substrate, transport, access to food and protection. Among obligate symbionts, five turbellarian species of the genus *Temnocephala* are known from the branchial cavity, with *T. iheringi* the most common and abundant. The leech *Helobdella ampullariae* also spends its entire life cycle inside the branchial cavity; two copepod species and one mite are found in different sites inside the snails. Details of the nature of the relationships of these specific obligate symbionts are poorly known. Also, extensive studies of an intracellular endosymbiosis are summarized. Apple snails are the first or second hosts of several digenean species, including some bird parasites. A number of human diseases are transmitted by apple snails, angiostrongyliasis being the most important because of the potential seriousness of the disease.

Introduction

The term “apple snail” refers to a number of species of freshwater snails belonging to the family Ampullariidae (Caenogastropoda) inhabiting tropical and subtropical regions (Hayes et al., 2015). Some species have invaded parts of the world to which they are not native, altering ecosystems and becoming problematic for a range of human activities.

Because of their morphology (e.g. shape and size of the shell, possession of a mantle cavity), behaviour and peculiar amphibious life habit, apple snails are a suitable habitat for species that associate and interact among themselves and with the snails, whether negatively or positively and including facultative or obligate associations (Fig. 1). Several studies have been carried out in their native ranges on the interactions of these snails with associated species. However, studies dealing with the detailed nature and significance of these relationships are few.

This contribution summarizes current knowledge of organisms associated with apple snails, mainly *Pomacea* spp., either in a facultative or obligate manner. Special attention is paid to diseases transmitted via these snails to humans.

The word symbiosis is used here as a comprehensive concept, setting aside the role played by the two species and the benefits and/or costs derived from their relationships. Symbionts can be specific, associated with one or a few host species, or generalist, associated with a wide range of species (Buckland-Nicks et al., 2013). Facultative symbionts (epibionts) temporarily or opportunistically associated with the host species can be easily distinguished from obligate symbionts (parasites, commensals, mutualists) that depend on their host species to live. One instance involves endocytobiosis, i.e. intracellular endosymbiosis (Vega et al., 2006).

**Facultative symbionts (epibionts)**

Epibionts are organisms associated facultatively with the surface of living substrates, in this case the shell and operculum of the snails (Fig. 1). Epibionts such as algae, ciliates and other sessile organisms settle on apple snail shells. This epibiont community could have various effects on the host, including camouflage, increased resistance to water and modification of predator attraction. Epibiosis may be advantageous for epibionts because of host behaviour (e.g. transport of epibionts to more favourable areas, facilitation of access to food, provision of permanent substrate). Other aspects of behaviour can be
Fig. 1. The main taxonomic groups associated with various parts of the body and shell of apple snails.
Fig. 2. Epibionts of *Pomacea canaliculata*. A, B: general view of the shell of *P. canaliculata* with ciliates and eggs of *Temnocephala iheringi*. C-E: ciliates, Peritrichida (*Epistylis* sp.). F: Chlorophyceae, Chaetophorales. Scale bars: A, B: 1 cm; C-F: 100 µm.
disadvantageous for epibionts (e.g. burial during unfavourable periods or air exposure due to amphibious habits) (Dias et al., 2008).

Observations in different environments in the Río de la Plata River Basin (South America) revealed that in some Pomacea canaliculata populations, epibionts cover the shell surface thickly and uniformly while in others the epibiont community is sparse (Fig. 2). When the population density of P. canaliculata is high and/or the environment is poor in food, the snails are frequently found grazing on each other’s shells.

One of the earliest contributions to knowledge of the diversity of epibionts living on three native species of Pomacea commonly inhabiting the Río de la Plata River Basin was by Di Persia & Radici de Cura (1973), who mentioned the presence of a large suite of taxa (Table 1) including many different groups (algae, ciliates, rotifers, nematodes, flatworms, oligochaetes, dipterans, bryozoans, etc.), some of them very common and abundant, others sporadic. In Brasil, Dias et al. (2006, 2008, 2010) studied the ciliates adhering to the shell surface of two species of Pomacea and Gorni & Alves (2006) studied the oligochaetes inhabiting the umbilicus of Pomacea bridgesii (probably correctly identified as P. diffusa; R.H. Cowie, pers. comm.). Four species of leeches in the family Glossiphoniidae have been recorded in the umbilicus of P. canaliculata and occasionally in the mantle cavity (Damborenea & Gullo, 1996), and in the mantle cavity, foot and on the shell of P. diffusa (De-Carli et al., 2014). These species benefit from shelter and food provided by the snail during their reproductive period, but they ordinarily live free in the environment and thus form a facultative association with the apple snail.

Table 1 summarizes the main epibiont taxa mentioned as being associated with various species of Pomacea.

### Commensal symbionts

Temnocephalids (Platyhelminthes: Temnocephalidae) are commensal symbionts frequently associated with apple snails, with which they form an obligate association. Five species of temnocephalids have been described in association with different species of ampullariids, i.e. Temnocephala colombiensis, T. iheringi, T. haswelli, T. rochensis and T. lamothei (Damborenea & Cannon, 2001; Damborenea & Brusa, 2008; Garcés et al., 2013). Among these, Temnocephala iheringi has the widest distribution (Table 2). These temnocephalid species have a close and permanent relation with their ampullariid hosts, but no information is available regarding its functional significance. They are found in the
mantle cavity and lung sac (Fig. 3), near the gill and by the opening of the lung sac, all year round. They do not live on the shell, but deposit their egg capsules on it, especially in the umbilicus and where the channelled suture meets the aperture. Temnocephalids feed on algae or small animals entering the mantle cavity in the breathing currents generated by the host snail.

There are a number of studies on populations of *Temnocephala iheringi*, especially in the Río de la Plata River Basin and southern Buenos Aires Province (Damborenea, 1996, 1998; Martín *et al.*, 2005). During a study of the symbiotic species assemblages associated with *Pomacea canaliculata* in streams connected with the Rio de la Plata, Damborenea *et al.* (2006) found a high prevalence of temnocephalids (80-100 % of the snails) in most sampling stations, with average abundance varying among localities, and with the maximum number of temnocephalids within a snail being 167. The distribution

<table>
<thead>
<tr>
<th>Epibiont taxon</th>
<th>Host</th>
<th>Country</th>
<th>References</th>
<th>Location</th>
</tr>
</thead>
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<td><strong>Chlorophyta</strong></td>
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<td><em>Stigeoclonium</em> sp.</td>
<td><em>P. canaliculata</em></td>
<td>Argentina</td>
<td>Di Persia &amp; Radici de Cura, 1973</td>
<td>shell</td>
</tr>
<tr>
<td><em>Oedogonium</em> sp.</td>
<td><em>P. maculata</em></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td><em>P. scalaris</em></td>
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</tr>
<tr>
<td><strong>Chrysophyta</strong></td>
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</tr>
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<td></td>
<td><em>P. maculata</em></td>
<td></td>
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<td></td>
<td><em>P. scalaris</em></td>
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</tr>
<tr>
<td>Oscilatoriales</td>
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<td>Di Persia &amp; Radici de Cura, 1973</td>
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</tr>
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<td></td>
<td><em>P. maculata</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>P. scalaris</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ciliophora - Peritrichia</strong></td>
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<tr>
<td><em>Carchesium polypinum</em></td>
<td><em>P. figulina</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2008, 2010</td>
<td>shell</td>
</tr>
<tr>
<td><em>Carchesium</em> sp.</td>
<td><em>P. lineata</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2006</td>
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</tr>
<tr>
<td><em>Epistylis plicatilis</em></td>
<td><em>P. figulina</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>Utz, 2007</td>
<td></td>
</tr>
<tr>
<td><em>Epistylis</em> sp.</td>
<td><em>P. canaliculata</em></td>
<td>Argentina</td>
<td>this work</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>P. lineata</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2006</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>P. figulina</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2008</td>
<td></td>
</tr>
<tr>
<td><strong>Opercularia</strong> sp.</td>
<td><em>P. figulina</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2008</td>
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<tr>
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<td><em>P. lineata</em></td>
<td>Brasil</td>
<td>Dias <em>et al.</em>, 2006</td>
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</tr>
<tr>
<td><strong>Vaginicola</strong> sp.</td>
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<td>Brasil</td>
<td>Dias <em>et al.</em>, 2006</td>
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<tr>
<td><strong>Vorticella microstoma</strong></td>
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<td>Brasil</td>
<td>Dias <em>et al.</em>, 2008</td>
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<td><strong>Vorticella campanula</strong></td>
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<td>Dias <em>et al.</em>, 2008</td>
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<tr>
<td><strong>Vorticella</strong> sp.</td>
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<td>Dias <em>et al.</em>, 2006</td>
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Ciliophora - Suctoria

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<th>Location</th>
<th>Notes</th>
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<tr>
<td>Acineta sp.</td>
<td><em>P. lineata</em></td>
<td>Brasil</td>
<td>Dias et al., 2006</td>
<td>Brasil</td>
<td>shell</td>
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<tr>
<td>Tokophrya fasciculata</td>
<td><em>P. figulina</em></td>
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<td>Dias et al., 2008</td>
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<tr>
<td>Tokophrya sp.</td>
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<td>Dias et al., 2006</td>
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Annelida - Oligochaeta

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<th>Notes</th>
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</thead>
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<tr>
<td>Aelosoma sp.</td>
<td><em>P. canaliculata</em></td>
<td>Argentina</td>
<td>Di Persia &amp; Radici de Cura, 1973</td>
<td>Argentina</td>
<td>shell</td>
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<tr>
<td>Chaetogaster sp.</td>
<td><em>P. maculata</em></td>
<td>Argentina</td>
<td>Di Persia &amp; Radici de Cura, 1973</td>
<td>Argentina</td>
<td>umbilicus of the shell</td>
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<td>Naididae (several species)</td>
<td><em>P. bridgesii</em> (probably <em>P. diffusa</em>)</td>
<td>Brasil</td>
<td>Gorni &amp; Alves, 2006</td>
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Annelida - Hirudinea - Glossiphoniidae

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<tr>
<td>Gloiobdella michaelseni</td>
<td><em>P. canaliculata</em></td>
<td>Argentina</td>
<td>Damborenea &amp; Gullo, 1996</td>
<td>Argentina</td>
<td>shell, especially in the umbilicus; sometimes inside the mantle cavity</td>
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<td>Helobdella adiastola</td>
<td><em>P. canaliculata</em></td>
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<td>H. simplex</td>
<td><em>P. canaliculata</em></td>
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<td>De Carli et al., 2014</td>
<td>Brasil</td>
<td>shell, mantle cavity, foot</td>
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<tr>
<td>H. triserialis lineata</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>De Carli et al., 2014</td>
<td>Brasil</td>
<td>shell, mantle cavity, foot</td>
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<tr>
<td>H. triserialis nigricans</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>De Carli et al., 2014</td>
<td>Brasil</td>
<td>shell, mantle cavity, foot</td>
</tr>
<tr>
<td>H. triserialis</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>De Carli et al., 2014</td>
<td>Brasil</td>
<td>shell, mantle cavity, foot</td>
</tr>
<tr>
<td>H. triserialis diffusa</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>De Carli et al., 2014</td>
<td>Brasil</td>
<td>shell, mantle cavity, foot</td>
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Bryozoa

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<th>Location</th>
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<td>Hyalinella vahiriae</td>
<td><em>P. canaliculata</em></td>
<td>Argentina</td>
<td>Cazzaniga, 1988</td>
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Mollusca - Bivalvia

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<th>Notes</th>
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<tr>
<td>Limnoperna fortunei</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>Darrigran &amp; Damborenea, 2005</td>
<td>Brasil</td>
<td>shell (Fig. 5)</td>
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Nematoda

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<th>Notes</th>
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<td>Actinolaimus sp.</td>
<td><em>P. canaliculata</em></td>
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<td>Di Persia &amp; Radici de Cura, 1973</td>
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<td>among algae growing on the shell</td>
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<td><em>P. maculata</em></td>
<td></td>
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<tr>
<td></td>
<td><em>P. scalaris</em></td>
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</table>

**Fig. 5.** Pomacea canaliculata with Limnoperna fortunei attached to the umbilicus. Scale bar: 2 cm. (Photos: Gustavo Darrigran)
Table 2. Symbiont species (commensals and parasites) associated with *Pomacea canaliculata* and other ampullariid species.

<table>
<thead>
<tr>
<th>Symbiont taxon</th>
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<th>Country</th>
<th>References</th>
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<td>Pila globosa</td>
<td>India</td>
<td>Bathia, 1936</td>
<td>rectum</td>
<td>parasites or commensals?</td>
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<td>Parasicuophora ampullarium</td>
<td><em>Pomacea canaliculata</em></td>
<td>Uruguay</td>
<td>Gascón, 1975</td>
<td>digestive tract</td>
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<td>Parasicuophora corderoi</td>
<td><em>Pomacea canaliculata</em></td>
<td>Uruguay</td>
<td>Gascón, 1975</td>
<td>digestive tract</td>
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<td>Colombia</td>
<td>Garcés et al., 2013</td>
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<td>Temnocephala haswelli</td>
<td><em>P. canaliculata</em></td>
<td>Uruguay</td>
<td>Ponce de León, 1989</td>
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<td>Temnocephala haswelli</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>Seixas et al., 2010a</td>
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<td>Temnocephala iheringi</td>
<td><em>P. canaliculata</em></td>
<td>Argentina</td>
<td>Di Persia &amp; Radici de Cura, 1973; Damborenea, 1992, 1996; Martin et al., 2005</td>
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<td>Temnocephala iheringi</td>
<td><em>P. canaliculata</em></td>
<td>Brasil</td>
<td>Seixas et al., 2010b</td>
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<td>Temnocephala iheringi</td>
<td><em>P. canaliculata</em></td>
<td>Uruguay</td>
<td>Dion, 1967; Ponce de León, 1979</td>
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<td><em>Pomacea lineata</em></td>
<td>Brasil</td>
<td>Pereira &amp; Cucuolo, 1941</td>
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<td>Pomella megastoma</td>
<td>Argentina</td>
<td>Damborenea et al., 1997</td>
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<td>Pomella megastoma</td>
<td>Argentina</td>
<td>Damborenea &amp; Brusa, 2008</td>
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<td><em>Cercaria unidentified (1 species)</em></td>
<td><em>Pomacea canaliculata</em></td>
<td>Argentina</td>
<td>Ostrowski de Nuñez, 1979</td>
<td>parasites</td>
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<td>Argentina</td>
<td>Damborenea et al., 2006</td>
<td>digestive gland</td>
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<td>Venezuela</td>
<td>Uribe, 1925</td>
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<td>Venezuela</td>
<td>Nasir, 1971</td>
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<td>Brasil</td>
<td>Pinto et al., 2015</td>
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<td>Echinostoma parcespinosum</td>
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**SYMBIONTS AND DISEASES ASSOCIATED WITH INVASIVE APPLE SNAILS**
of temnocephalids in the host snail did not differ between host sexes. There is an increase in abundance whenever temperature rises and the snails become more active. The life cycle of the host and the commensal temnocephalids are synchronized in order to enhance reproduction and colonization of new hosts.

Martin et al. (2005) studied the factors affecting the distribution and abundance of T. iheringi among populations of P. canaliculata in southern Buenos Aires Province (Argentina), which is the southern boundary of the snail’s native range. They found that only 23% of the apple snail populations inhabiting streams harboured temnocephalids, but higher frequencies (71%) were observed in lentic localities. The commensals were found in localities with bicarbonate concentrations below 6.6 meq l\(^{-1}\) and could tolerate low water temperatures (4-5 °C in winter).

In addition to the aforementioned epibiont hirudinean species, there is an additional species, Helobdella ampullariae (Fig. 3), that inhabits the mantle cavity of ampullariid snails, establishing an obligatory association (Ringuelet, 1945, 1949; Di Persia & Radici de Cura, 1973). A seventeen-month study of a population of apple snails from Bagliardi Beach, Buenos Aires, Argentina (Damborenea & Gullo, 1996) showed that H. ampullariae is associated with the host all year round and completes its life-cycle entirely in this association. Juveniles, adults, adults with cocoons and brooding adults are found inside the mantle cavity of the snails. The reproductive period of the leech is long (December to June), beyond the season in which their hosts are buried. Ringuelet (1945) considered this species as a parasite feeding on the snail, but in fact there is no knowledge of the feeding habits of the leeches.

Two species of copepods are known as symbionts of ampullariids, i.e. Ozmana haemophila in the haemocoel of Pomacea maculata in the Amazon basin, Brasil (Ho & Thatcher, 1989), and Ozmana huarpium in the haemocoel, mantle cavity, ctenidium and penis-sheath groove of P. canaliculata in Palermo Park, Buenos Aires city, Argentina, where prevalence of the symbiont is 100% in both sexes (Gamarra-Luques et al., 2004).
Di Persia & Radici de Cura (1973) recorded larvae, nymphs and adults in the mantle cavity and under the mantle of the snails.

Epithelium cells of the midgut gland of some species of ampullariids carry two kinds of pigmented endosymbiont prokaryote corpuscles belonging to the same organism (Castro-Vazquez et al., 2002; Koch et al., 2006). Corpuscles are also found in faeces and sediment, indicating a life-cycle alternating endosymbiotic and free phases. These endosymbionts have been extensively studied in *P. canaliculata*, although they have also been found in other species, including *P. maculata*, *P. scalaris*, *Asolene pulchella* and *Marisa cornuarietis* (no faeces were found in the latter) (Vega et al., 2006). Bacterial

Gamarra-Luques et al. (2004) made numerous biological observations on *O. huarpium*, including showing in experiments that it is transmitted to parasite-free hosts during copulation.

A species of unionicolid mite, *Unionicola (Ampullariatax) ampullariae*, also lives in the mantle cavity of *Pomacea canaliculata* and *P. maculata* (Di Persia & Radici de Cura, 1973; Rosso de Ferradás & Fernández, 2005), *P. maculata* now being the senior synonym of *P. insularum*, which was the name used by these authors (see Hayes et al., 2012).
DNA attributed to 16S rRNA demonstrated a close relationship of the corpuscles with representatives of the orders Chroococcales or Pleurocapsales (Cyanobacteria) (Vega et al., 2005, 2006). Koch et al. (2003) demonstrated that transmission was vertical from mother to offspring.

Godoy et al. (2013) identified proteases in the digestive system of *P. canaliculata*. Protease 30kDa was found in the mid-gut and in the endosymbiotic corpuscles, where activity was detected. Endosymbionts are liberated into the stomach vestibule via the ducts of the mid-gut gland. This suggests protease secretion is a possible function, in addition to detoxification, as suggested by the accumulation of various metals in the corpuscles, which are later liberated in the faeces (Vega et al., 2012).

### Parasitic symbionts

Three species of heterotrichid ciliates have been found in the digestive system of apple snails, i.e. *Parasicuophora ampullariarum* and *P. corderoi* both inhabiting the gut of *Pomacea canaliculata* from Uruguay (Gascón, 1975), and *Plagiotoma kempi* in the rectum of *Pila globosa* from India (Zeliff, 1933). These observations did not establish the nature of the relationship.

Several trematode larvae have been noted associated with apple snails (Fig. 4), but adults of only one species were found in them, i.e. *Catadiscus pomaceae* (Paramphistomidae) in the intestine of *Pomacea canaliculata* (Hamann, 1992). The life cycle of this species remains unknown. Probably, *P. canaliculata* may become

![Fig. 4](image-url)

**Fig. 4.** Microphotographs of metacercariae found in the mantle cavity of *Pomacea canaliculata*. A: encysted metacercariae. B: metacercariae extracted from cyst. Scale bars: 200 µm.
infected by ingesting metacercariae encysted in plants and other substrata, as for other Paramphistomidae (Vega et al., 2006).

A large number of trematode larvae have been mentioned associated with apple snails (Table 2). Two redia generations of *Echinostoma parcespinosum* have been found in the digestive gland and gonad of *P. canaliculata* and encysted metacercariae were observed in the mantle cavity and hepatopancreas (Martorelli, 1987). The definitive hosts of this parasite are rails (in the birds’ intestines). The apple snail, which is the first intermediate host, can also be the second intermediate host (among other freshwater snails). In the latter case, the life cycle of *E. parcespinosum* may be shortened without the need for another host, as cercariae have been recorded encysted within rediae (Martorelli, 1987). This peculiarity was also observed in Brasil in *Pomacea lineata* (Machado & Sampaio, 1980). Metacercariae of *Dietziella egregia* have been observed in the renal cavity of *P. canaliculata* from Argentina (M.C. Digiani & M. Ostrowski de Núñez, unpublished).

Although the life cycle of this digenean is not fully known, the white-faced ibis (*Plegadis chihi*) could be the definitive host. Encysted metacercariae of *Edietziana malacophilum*, an intestinal parasite of the snail kite, *Rostrhamus sociabilis*, have been found in the hepatopancreas of *Pomacea paludosa* in Cuba (Pérez Vigueras, 1944). Other metacercariae were found in *Pomacea canaliculata* (Keawjam et al., 1993) in Southeast Asia (Table 2). Nasir & Diaz (1968a, b) described new species of Echinostomatidae in *Pomacea glauca*, i.e. *Echinochasmus zubedakhaname* (parasitizing a small passerine bird, *Fluvinicola pica*) and *Stephanoprora heteroglandula*. The snail also carried many cercariae of different morphological types (Table 2).

**Diseases associated with apple snails**

*Derma titis*

Schistosome dermatitis occurs when a person becomes the accidental host of cercariae of non-human schistosome trematodes. The cercariae penetrate the skin where they soon die, causing a hypersensitive reaction of the skin (Hoeffler, 1974). Leedom & Short (1981) reported dermatitis caused by furcocercous cercariae from *Pomacea paludosa* in Florida (United States).
**Echinostomiasis**

This is a disease caused by infections by flukes of the family Echinostomatidae (echinostomes) via oral intake of undercooked infected snails and clams. Twenty species belonging to eight genera of this family are known to infect humans worldwide (Chai, 2009). The main clinical symptoms involve diarrhoea, abdominal pain, anaemia and eosinophilia (Mehlhorn, 2008). In cases with heavy loads of echinostomes mortality is caused by intestinal perforation or marked malnutrition and anaemia. *Echinostoma ilocanum* was discovered in the Philippines at the beginning of the twentieth century. Bonne *et al.* (1953) found it infecting humans in Malaysia, with *Pila scutata* as one of the first intermediate hosts, among other snails. Human infections with *E. ilocanum* were later reported in Indonesia, China, Thailand, India and Cambodia. The main cause of these infections was the consumption of raw or undercooked flesh of *Pila scutata* (Sohn *et al.*, 2011). [Note that the name *Pila luzonica* as used by Sohn *et al.* (2011) is now considered a junior synonym of *Pila conica*, and *Pila conica* as used by Bonne *et al.* (1953) is considered a junior synonym of *Pila scutata*; see Cowie (2015)].

**Gnathostomiasis**

This is an unusual human infection by larvae of the nematode *Gnathostoma spinigerum*, a parasite of felines and canids. It is acquired by eating raw or undercooked flesh of infected intermediate hosts (fish, amphibians, reptiles, birds). The larvae in the intermediate hosts enter human tissue and may migrate through many tissues causing intermittent subcutaneous swellings and (often) intestinal nodules, and an inflammatory reaction associated with production of many eosinophils. The larvae are especially destructive when they die in the brain or eye. *Pomacea canaliculata* and *Pila ampullacea* are suitable paratenic hosts for third stage larvae of *G. spinigerum* (Komalamisra *et al.*, 2009).

**Angiostrongyliasis**

Angiostrongyliasis is caused by two species of nematodes of the genus *Angiostrongylus* (Secernentea, Metastrongyloidea). *Angiostrongylus cantonensis* causes eosinophilic meningitis and meningoencephalitis, and the disease is sometimes referred to
as neuroangiostrongyliasis, while *A. costaricensis* causes abdominal angiostrongyliasis, a gastrointestinal syndrome (Mehlhorn, 2008; Murphy & Johnson, 2013).

*Angiostrongylus cantonensis* was discovered by Chen (1935) in the pulmonary arteries and hearts of domestic rats in China, and therefore became known as the rat lungworm. It is endemic in South Asia, the Pacific islands, Australia and the Caribbean islands. Its life cycle involves rats as definitive hosts, snails and slugs as intermediate hosts, and various other animals, including crustaceans (prawns and land crabs), land planarians, frogs and monitor lizards, as paratenic (transfer or transport) hosts (Cowie, 2013b). Humans acquire *A. cantonensis* by eating raw or undercooked intermediate or paratenic hosts that contain the infective third larval stage of the worm, or inadvertently by eating vegetables contaminated with infected snails. When infective larvae are ingested, they penetrate the intestinal wall and reach the circulatory system, and finally reach the brain where the third stage larvae develop to a sub-adult stage. These worms are not able to leave the brain and they generally die. The immune reaction causes inflammation, and the meninges and cerebral vessels are infiltrated with lymphocytes, plasma cells and eosinophils (Wang et al., 2008). Also, physical brain lesions, and even in the spinal cord, are caused especially by the movements of live worms (Chotmongkol & Sawanyawisuth, 2002; Cowie, 2013a). The larvae can also move to the eyes and cause ocular angiostrongyliasis, resulting in visual disturbance (Sawanyawisuth et al., 2006).

The first human case of angiostrongyliasis was reported in Taiwan in 1945 (Beaver & Rosen, 1964). Since then, several outbreaks of the disease have been reported in the Pacific islands and other endemic regions. In Taiwan many cases of angiostrongyliasis have been reported, mainly in children, with *Achatina fulica* and *Pomacea canaliculata* the most frequent intermediate hosts (Tseng et al., 2011). *Angiostrongylus cantonensis* has been reported from 13 provinces in China, where the spread of the invasive species *P. canaliculata* would facilitate expansion of the disease (Lv et al., 2011). Unfortunately, *P. canaliculata* is very susceptible to *A. cantonensis* and has become an important intermediate host in these regions (Wang et al., 2008).

Several *Pila* spp. (*P. scutata*, *P. gracilis*, *P. virescens* and *P. ampullacea*) have been found infected with *A. cantonensis* in Malaysia and Thailand (Harinasuta et al., 1965). These species are used as a food resource and thus could cause human infection. *Pomacea paludosa* infected by *A. cantonensis* was found in Cuba (Aguiar et al., 1981). *Pomacea paludosa* was also reported to be infected in the Hawaiian Islands (Wallace & Rosen, 1969a, b) but this may have been a misidentification as this species is not known...
to have ever been present in the wild in the Hawaiian Islands (Cowie et al., 2007). However, other non-native apple snails are present in Hawaii and are used for human consumption and as aquarium pets (Cowie et al., 2007), and *Pomacea canaliculata* is reported to be infected (Kim et al., 2014). *Angiostrongylus cantonensis* has recently been found in *Pomacea maculata* introduced in the southeastern United States (Louisiana). This introduced snail is currently spreading rapidly across this region, triggering concerns about establishment of the parasite (Teem et al., 2013).

The first cases of human infection by *Angiostrongylus costaricensis* were diagnosed mainly in children. They are characterized by the formation of granulomas with heavy eosinophilic infiltration in the abdominal cavity (Morera & Céspedes, 1971). Rodents are the final hosts. The larvae leave the intestine in the faeces. Intermediate hosts (slugs or snails) feed on these larvae, which develop into the infectious third stage larvae. Humans are accidentally infected when in contact with the molluscs. The adult worms are localized in the mesenteric arteries of the definitive host, where inflammatory reactions are common. Many of the arterioles containing adults become thrombosed after the worms die, causing intestinal obstruction (Mehlhorn, 2008). Abdominal angiostrongyliasis has been recorded from the southern United States to northern Argentina. Up to 500 human cases are reported annually in Costa Rica. In Brasil, cases have been reported mainly in the southern states (Thiengo et al., 2013).

The main intermediate hosts of *A. costaricensis* are slugs. However, apple snails are potential hosts. *Pomacea flagellata* was introduced to Costa Rica for human consumption and has been successfully infected experimentally (Briceño Lobo, 1986).

**Salmonellosis**

Various outbreaks of food-borne illnesses such as salmonellosis have been associated with snail consumption. Salmonellosis is a disease caused by the bacterium *Salmonella*. Most people have diarrhoea, fever and stomach pains. Consumption of apple snails, known locally as *kuhol*, as a fish and meat substitute has become popular in the Philippines. The main concern about this culinary culture is undercooking the snails. *Salmonella* serotype *typhimurium* populations survive at 60 °C, while the sharpest drop in the counts of these bacteria is observed at 90 °C (Gabriel & Ubana, 2007).

Bartlett & Trust (1976) isolated different serotypes of *Salmonella* and other potential pathogens in apple snails from aquaria in North America. Their study revealed a
formerly unreported zoonotic reservoir of salmonellae. There is a reason to believe that this association of salmonellae with apple snails could explain some cases of human salmonellosis, as other aquarium species have already been shown to contribute towards many cases of this infectious disease (Bartlett & Trust, 1976).

Acknowledgments

Thanks to Ravindra Joshi for inviting us to participate in this book, to Robert Cowie for his important comments on the manuscript, to Gabriela Kuppers for identification of the ciliates associated with *Pomacea canaliculata* and to Gustavo Darrigran for permission to use the photographs of *Pomacea canaliculata* with *Limnoperna fortunei* in the umbilicus.

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