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Lymnaeid snails hosts of *Fasciola hepatica* and *Fasciola gigantica* (Trematoda: Digenea): a worldwide review

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Abstract

Fasciolosis is a snail-borne disease, causing serious public and veterinary health problems worldwide. This disease is produced by infection with *Fasciola hepatica* or *Fasciola gigantica* through the consumption of vegetables or water contaminated with the parasite's metacercarial cysts. Both species of liver flukes are transmitted worldwide by small freshwater snails of the family Lymnaeidae. A global account on the species that are actually or may act as potential hosts of *Fasciola* spp., compiling particular research on their geographical distribution and susceptibility, is needed as a helpful tool in the understanding of fasciolosis transmission, and therefore in the control and prevention programmes of the disease. We have gathered here a comprehensive review of those lymnaeid species that are known to transmit the parasites in the field or that have been experimentally tested. We aim to bring forward the main intermediate hosts by regions in order to facilitate the understanding of worldwide transmission.

Keywords

Lymnaeidae, *Fasciola hepatica*, *Fasciola gigantica*, Fasciolosis, Snail transmission

Review Methodology

We searched the following databases: Scopus, PubMed, Google Scholar, JSTOR, SciELO and SpringerLink. Most common keywords used in database search were: lymnaeid snails, *Fasciola hepatica*, *Fasciola gigantica*, natural prevalence, experimental infection, liver fluke transmission, fasciolosis. Relevant ancient and recent articles related to the snail species reported as hosts of *Fasciola hepatica* and/or *Fasciola gigantica* were included. We used articles written in English, French and Spanish. Up to 160 references were included from all continents. References of local studies that were included in larger scale studies were disregarded to avoid over citing. The names of species referenced in ancient studies are cited here using the latest nomenclature available for each species after recent molecular studies.

Background

One of the key aspects in the epidemiology of infectious diseases is acquiring a comprehensive view of their potential extension and their means of transmission. It is particularly complicated when a pathogen includes several organisms to complete its life cycle, making it more difficult to manage and prevent. This is especially the case of vector-borne diseases. The understanding of these diseases necessarily involves a knowledge of their chains of transmission and vector species or hosts. Usually, intermediate hosts and vectors are ultimately the target of control programmes because they represent the weakest link in the transmission chain. To accomplish this goal, having an up-to-date understanding of the distribution and actual role of the species involved in transmission is fundamental to prevent and control vector-borne diseases.

Fasciolosis: A Snail-Borne Disease

Fasciolosis is a snail-borne disease causing serious public health problems worldwide, especially in low-income nations [1]. However, it remains as an unsolved problem in both developing and developed countries at veterinary level [2, 3]. Additionally, fasciolosis is considered as one of the most globally spread parasitic diseases, which extends widely across a large variety of habitats in different geographic regions [4]. The disease is mostly caused by the hermaphroditic parasites *Fasciola hepatica* Linnaeus, 1758 and *Fasciola gigantica* Cobbold, 1855 (Platyhelminthes: Trematoda: Digenea). Fasciolosis affects more than 17 million people with nearly 180 million at risk of infection worldwide [5].

However, according to the World Health Organization (WHO), fasciolosis remains a neglected tropical disease [6]. Furthermore, *Fasciola* species are placed in a particular group known as the most 'neglected' among the neglected worms where all the main food-borne trematode infections also stand [7].

Both *Fasciola* species are capable of infecting a very wide spectrum of mammalian definitive hosts, including humans, [8] where parasites reproduce sexually producing thousands of eggs at a daily basis (see Figure 1 for a detailed description of the life cycle). Noteworthy, while ruminants are commonly described as the most infected definitive hosts (for which the disease asserts the highest economic losses), several smaller mammals (rodents, lagomorphs, etc.) may have an important role as reservoirs and disseminators of the parasite in the wild [9].

Lymnaeid snails (Gastropoda: Lymnaeidae) act as the intermediate hosts of *F. hepatica* where asexual reproduction of the parasite occurs and a clonal expansion from a single infective larva increases the probability of transmission. The family Lymnaeidae Rafinesque, 1815 is believed to comprise nearly 100 species of small aquatic and amphibious snails [10]. However, about 1200 species have been described worldwide [11]. Lymnaeid snails have a right coiled shell and are known to extend from tropical to temperate regions; some of them occur at very cold latitudes [12–14]. In general, the great ecological plasticity of lymnaeid snails allows them to inhabit a large range of ecosystems which is actually one of the key aspects of the successful extend of fasciolosis.

The family of Lymnaeidae has been the target of several taxonomic revisions in the last two decades due to its importance in the transmission of fasciolosis [15–17]. Vinarski [17] presents the Lymnaeidae divided into two subfamilies, Lymnaeinae (16 genera) and Radicinae (ten genera). Some genera are known to be best suited for a particular species of *Fasciola*, where *F. hepatica* appears to be mainly transmitted by the group of *Galba* whereas *F. gigantica* is commonly related with the *Radix* group [15]. However, different snail habitat preferences (e.g. ponds, ditches, flooded crops), rather than phylogenetic affinity, may better explain the patterns of host specificity by *Fasciola* spp. in different regions [18]. Interestingly, not all lymnaeid species act as intermediate hosts of *Fasciola* spp., and among those that host the parasites, there is a strong variation in the potential of transmission. Indeed, different patterns of susceptibility, host–parasite compatibility and even immunological resistance have been described in this host–parasite system [19–21].

The knowledge of which particular snail species inhabits a risk area for fasciolosis transmission can be used to trigger control campaigns or mapping risks [22]. The understanding of fasciolosis transmission worldwide requires a global account on the snail species that are vectors or that may act as potential hosts of *Fasciola* spp. The compilation of specific research on their geographical distribution and susceptibility is needed as a helpful tool that may serve in the control and prevention programmes of the disease. In the following sections, we present a review of the global distribution of lymnaeid snails with a known role in *Fasciola* spp. transmission according to the latest systematics published for this family. We will only consider those species which have experimentally proved to be susceptible to infection or that have been described as natural vectors of the parasite in the field (see Table 1).

Brief Overview of *Fasciola* spp. Distribution

Fasciola hepatica and *F. gigantica* (known as liver flukes), are the main aetiological agents of fasciolosis worldwide (Figure 2). The large diversity of hosts of *F. hepatica* (i.e. many lymnaeid snails and mammal species act as intermediate and definitive hosts, respectively) determine a major role for this species in the global burden of the disease. This species is reported in all continents except Antarctica and it is present in many oceanic islands. Contrastingly, given that *F. gigantica* is usually restricted to the tropical and subtropical region of Asia and Africa, it has a lesser global impact in public and veterinary health [4]. In any case, fasciolosis is a serious problem for public health in some endemic regions such as the Bolivian Altiplano, Peru, Egypt, Iran and southeast Asia where prevalence in the human populations is particularly high [4, 5]. From a veterinary point of view, there are reports of *F. hepatica* infecting over 300 million bovines and nearly 250 million ovine worldwide; together with *F. gigantica* the economic losses ascend up to 3000 million dollars [1, 5]. The localities where fasciolosis reaches the highest prevalence are known for having: (a) high infection rates and intensities in either human and livestock populations, (b) available surface water for compatible lymnaeid snail populations to settle in most of the year and (c) adequate temperature and humidity for the development and survival of each parasite stage in and out of the hosts [5].

Lymnaeid Distribution

The family of Lymnaeidae has a worldwide distribution [11] (Figure 3). Although this review focuses only in its role in fasciolosis transmission, it is important to note that several lymnaeid species also serve as hosts of a major number of trematode families, causing diseases in wildlife and domestic fauna as well as humans [68, 69].

Transmission in the Americas

The American lymnaeid species display a vast distribution ranging from north Canada to south of Patagonia as well as through the Caribbean Islands. However, the transmission is not as thoroughly reported in every region.

North American Lymnaeidae

In North America, studies depicting the diversity of Lymnaeidae accumulated in the past but have not been so abundant in the last decades. In the USA, *Galba cubensis* and *Pseudosuccinea columella* were identified as the main vectors of fasciolosis but only after a series of experimental infection trials [29]. However, in Florida (USA), Kaplan et al. [70] presented *G. cubensis* as the main host for *F. hepatica*, owing to its broad distribution and to its ability to transmit the parasite throughout the year after presented recovered field prevalence data. Still in the USA, *Galba bulimoides* from Wisconsin was experimentally infected with successful retrieval of metacercariae [46] and *Galba modicella* from Montana was found naturally infected in a goat farm with transmission occurring between spring and summer [33]. Also, in Montana, Knapp et al. [45] described the transmission of *F. hepatica* by *Hinkleyia caperata*, which is supposed to occur from the east to the west coasts of North America up north to Alberta [71, 72]. Another related species, *Stagnicola palustris* has been reported infected in eastern Washington [66] with a distribution range from south Alaska to New Mexico [73]. In Canada, although fasciolosis is recognized to occur within dairy cows in Quebec [74], the lymnaeid species implicated are not well studied. However, Hubendick [11] admitted *Galba truncatula*, *S. palustris* and probably *Galba humilis* to reach Canada. In Mexico, *G. humilis* and *G. bulimoides* are known to transmit *F. hepatica* [32] from late summer to early winter mostly in warm and damp sites [75].

In any case, the actual distribution of the lymnaeid species, and particularly those able to transmit *F. hepatica*, in the northern region of North America is poorly known. An ancient species report made by Sterki [76] in eastern North America informed of 13 species of Lymnaeidae including *Lymnaea stagnalis*, *P. columella*, *G. modicella*, *G. humilis*, *Ladislavella elodes* and *Radix auricularia*. However, the systematics of this family in this region should be viewed cautiously due to the lack of molecular studies that would help to clarify the identity of the species described. Given that many lymnaeid species have a large phenotypic variability and are quite difficult to differentiate by shell morphology, the numbers might be overestimated. A more recent list made by Johnson et al. [77] on the freshwater snails from Canada and the USA includes 61 species of Lymnaeidae. Among them, 21 correspond to the group of the small-shelled *Galba*. Here again, these numbers are perhaps overestimated due to possible systematic confusions in the absence of molecular studies. In the arctic region, lymnaeid snails are known to occur but are related to the transmission of *Fascioloides magna* parasitizing caribou populations as it

has been demonstrated by the observation of parasite stages overwintering in the snails. However, the snail species are not outlined [78]. A recent study carried out by Vinarski et al. [79] suggests that the endemic lymnaeid from Greenland, former *Lymnaea vahlii* should be considered as a form of the North American *Ladislavella catascopium* which is known to transmit the liver fluke [15]. In any case, transmission of *F. hepatica* in these high latitudes remains unknown.

Caribbean Lymnaeidae

In the Caribbean basin, the situation is much less complicated with three species occurring. In Cuba, Vázquez et al. [21] infected several populations of *G. cubensis* and *P. columella* with different isolates of *F. hepatica* and reported, according to the levels of susceptibility and compatibility, the former as the main host in the island. *Galba cubensis* is described from Cuba and has an extended distribution in the country while *P. columella* is found only from the west to the central region [80]. Field studies have reported natural prevalences in *G. cubensis* ranging from 0 to 11% [27] and 0 to 34% [28] in localities reported as transmission foci. In Cuba, *P. columella* might play a secondary role in the transmission [21] and has been only recently reported naturally infected by for the first time in the Caribbean region with a prevalence of 1% [52]. Transmission in Cuba is therefore supposed to occur by both species with several human outbreaks and important economic losses due to high cattle infection [3]. Interestingly, at least six natural populations of *P. columella* from Cuba have been found to display an active resistance against *F. hepatica* miracidia infection [20, 21]. Resistant populations can be phenotypically distinguished by a different mantle pigmentation pattern consisting of a number of small well-defined spots in a belt-like shape in the centre [81]. These resistant populations, although frequently rare, are an interesting model to tackle fasciolosis transmission. The mechanisms of resistance are not yet well known.

Both *G. cubensis* and *P. columella* are also described in some Lesser Antilles where transmission of *F. hepatica* had never been reported, like Martinique [82] and Guadeloupe [83]. Both lymnaeid species are also reported in some other Caribbean countries such as the Dominican Republic [84]. In Puerto Rico [85] and Jamaica [86], *G. cubensis* is responsible for *F. hepatica* transmission. Recently, a third species, *Galba schirazensis*, has been reported in the Dominican Republic [87] but it seems that it does not act in fasciolosis transmission. There is a previous report of *Galba viator* from the Dominican Republic [88] but its identification is questionable given the lack of molecular tools at that time. The fact that it is rather the distribution range of *G. cubensis* and that both species are very difficult to separate morphologically, it would probably correspond to the latter.

South American Lymnaeidae

As in North America, the South American scenario becomes again ravelled with a diversity of very morphologically similar species able to transmit the liver fluke. In northern South America, the genus *Galba* is probably mainly responsible for transmission. Several species such as *Galba cousini*, *G. cubensis*, *G. schirazensis* and *G. truncatula* are all reported in this region and most have been found regularly infected with *F. hepatica* [34, 89]. The species *G. cousini* has been found in Venezuela, Colombia and Ecuador [24, 90, 91]. Its role in the transmission in these countries seems restricted to altitudes lying between 2000 and 4000 m [90]. In the last years, *G. schirazensis* was discovered in many types of habitats from Venezuela, Colombia and Ecuador [92] and its role in the transmission of *F. hepatica* remains under discussion. In Venezuela and Colombia, this snail was the only species of lymnaeid found in several active foci, and although not found infected during sampling, it is highly probable that it is responsible for the transmission of *F. hepatica*. In any case, experimental infections carried out with an isolate of *F. hepatica* and a strain of *G. schirazensis* from Colombia showed that seven snails out of 400 harboured several rediae and two contained free cercariae on day 50 post-exposure [19]. In addition, in Ecuador, a 6% natural prevalence was detected in *G. schirazensis* using molecular techniques [93]. However, the actual role of this snail species in a sustained transmission should be confirmed with cercarial shedding and effective metacercarial infectivity. Apart from *Galba* spp., *P. columella* is also reported in Venezuela [34], Colombia [94] and Ecuador [40], and also extends down through Brazil [95, 96] and Argentina [97]. In the Andean countries, particularly the Bolivian Altiplano, *G. truncatula* plays a prominent role in *F. hepatica* transmission [13, 35, 98, 99]. This species may also be a key player in Chile [99] and Argentina [100]. *Galba viator* is also a very important intermediate host of *F. hepatica* in the southern region of Chile and Argentina [41, 101], although current reports of natural prevalence are lacking. According to Kleiman et al. [102], this species occurs as far south as beyond parallel 42°S in the Chubut province in the Patagonian region, where a 0.67% natural prevalence of *F. hepatica* was recorded [41]. There were in fact reports of natural infection in *G. viator* and *P. columella* from Argentina as assessed by mean of PCR amplification of the cytochrome c oxidase subunit I of *F. hepatica* [103]. Other South American Lymnaeidae are *Lymnaea diaphana* and *Lymnaea rupestris*. The former species is

described to serve as a host of *F. hepatica* in the southern part of the Chilean and Argentinean Patagonia [47]. The role of the second species *L. rupestris* in the transmission of *F. hepatica* is not known [104].

Transmission in Eurasia

Transmission in this region has been fairly frequently recorded in several studies except where climatic conditions are probably too harsh for the parasite life cycle, such as in Iceland [105] and probably Siberia. However, several lymnaeid species have been reported from these regions [14, 50, 106] that could eventually act as hosts.

European Lymnaeidae

In Britain and Ireland, there are at least eight lymnaeid species reported by Anderson [107]. However, transmission has been mainly linked to the widespread *G. truncatula* and to the local *Radix balthica* [108]. In continental Europe, several species such as *Radix peregra* have a broad distribution ranging from Nordic countries to southern regions and east to Ukraine. According to Schniebs et al. [60], *R. peregra* occurs also in Turkey and the Urals. Although there is no record of this species being naturally infected with *F. hepatica*, its role as well as that of *R. balthica* as incidental hosts in Belgium was demonstrated by Caron et al. [12] through series of experimental infections. More recently, the field prevalence of *F. hepatica* was confirmed in *R. balthica* (0.16%) and *G. truncatula* (1.31%) from Belgium and Luxembourg using a multiplex PCR [109]. Another species, *Stagnicola fuscus*, was experimentally tested with *F. hepatica* miracidia originating from France and proved to be partially refractory to infection although the snails have shed cercariae [63]. According to Novobilsky et al. [67], *S. fuscus* and *S. palustris* are also potential intermediate hosts of *F. hepatica* in Sweden. Overall, transmission in the field is commonly attributed to *G. truncatula* and *Omphiscola glabra* particularly in France [51, 110, 111]. Recorded prevalences for *G. truncatula* range between 5 and 33% in France and a mean of 11% in Spain [112], and 1.4–1.8% for French *O. glabra* [110]. *Galba truncatula* has been also found naturally infected in several districts of Moscow [113] and up to 85% prevalence was detected in Poland [114]. Although there are no much field data on prevalence on the snail populations, *G. truncatula* is presumed to be a key vector in dairy farms from south Germany and Austria [115] and natural prevalence of 7% is reported from Switzerland through real-time PCR [116]. Recently, some small-scale risk mapping of *F. hepatica* in farms from Belgium has been based on the spatial CAB Reviews distribution of *G. truncatula* [22]. From central Europe, several species have been described as potential hosts such as *Catascopia terebra*, *Stagnicola corvus* and *S. fuscus* in the Czech Republic [65]. Several introductions, probably through the aquarium plant trade, have occurred in the past few years and may increase the risk of transmission in some countries. Such introductions include *P. columella* in France [55] and *Austropelea viridis*, *G. schirazensis* and *G. cubensis* in Spain [92, 117, 118].

Asian Lymnaeidae

There are several species of lymnaeid snails described or reported in northern Asia from the Urals to eastern Russia [14, 50, 106, 119–121]. However, there are no significant reports on *F. hepatica* infection neither in natural nor under experimental conditions. In many other areas of Asia (particularly in the south), fasciolosis is caused by both *F. hepatica* and *F. gigantica* with some regions reporting the existence of hybrid forms of the parasite such as in South Korea and Vietnam [122, 123].

As in many other regions where it has been introduced, *G. truncatula* is held responsible for transmission of *F. hepatica* in some areas in Iran together with *L. stagnalis* [49]. Also, from southwest Asia, transmission of *F. gigantica* is generally linked to the presence of *Radix natalensis* (syn. *Lymnaea arabica*) and *S. palustris* in Saudi Arabia [62, 124], and *Radix gedrosiana* in Iran [59].

Southeast Asia is known to be heavily hit with both species of Fasciola. In Thailand, at least three species of lymnaeid snails have been recorded infected with *F. gigantica*: *Radix rubiginosa*, *Radix swinhoei* and *Galba viridis* [64]. Similarly, *G. viridis*, *R. auricularia* and *R. rubiginosa* are the main lymnaeid species recorded in Vietnam with the latter being reported infected in the field [125]. Unfortunately, not all field reports from fasciolosis outbreaks define the snail species responsible for the transmission. In southwest China, for example, after an outbreak of fasciolosis, the transmitting snails in the area were only identified as *Galba* spp. [126]. From Japan, several lymnaeids were experimentally infected using Australian strains of *F. hepatica* by Itagaki et al. [127]. Only the species *Austropelea ollula* and *R. auricularia* resulted infected while *G. truncatula* proved to be refractory.

Transmission in Africa

Fasciolosis in Africa may occur either by infection of *F. hepatica* or *F. gigantica*. One of the most affected regions is the Nile basin in Egypt [128]. In east Africa, both species are also responsible for infections in countries such as Kenya, Uganda, Ethiopia and Sudan [129].

The African Lymnaeidae

One of the lymnaeid species with broader distribution in the continent is *R. natalensis* described from South Africa [56], usually living in steady shallow waters, and considered as a very suitable host for *F. gigantica* [18]. Based on field and experimental studies, this species has been recognized as the main responsible for transmission of *F. gigantica* in Egypt [130]. However, *R. natalensis* is presumed to be also a potential host of *F. hepatica* after a successful experimental infection with French strains of this parasite [131]. It has also been found infected in other countries like Benin [132], Nigeria [133], Ghana [56] and is presumed to be the main transmitter in Ethiopia [134] and Uganda [135]. The distribution range reaches Tanzania and Cameroon but the transmission of either *Fasciola* spp. is not well assessed [136]. In western Africa, *R. natalensis* has been pointed as the main host for *F. gigantica* transmission in Senegal [137]. Outside African mainland, *R. natalensis* is also found in the island of Madagascar [138] where it is the main host of *F. gigantica* [139], and in Reunion Island [140]. The distribution of this species in other African countries includes Somalia and Gambia and is less common along the east and southwestern coasts [56]. According to Brown [56], the similar species *R. peregra* is also found in northwest Africa (Morocco and Algeria) with a single report from Ethiopia.

Moreover, *F. hepatica* transmission in Africa does not follow the same epidemiology than that of *F. gigantica*, with different hosts and distribution. In South Africa, *F. hepatica* is known to be transmitted by *G. truncatula* which inhabits preferably ecosystems of low-flowing water like borders of irrigation channels [141]. This species is also responsible for transmission in Lesotho [142] and Tunisia [143] where horses have been found infected with the parasite [144]. In northeastern Algeria, natural infected *G. truncatula* have been also recorded [145]. Susceptibility to Algerian strains of *F. hepatica* miracidia was experimentally tested showing that the number of obtained metacercariae did not vary regardless the origin of the parasite in that country [146]. Into the west, *G. truncatula* has been also found responsible for transmission of *F. hepatica* infecting sheep in the Middle-Atlas Mountains of Morocco [147]. Studies regarding the compatibility between Moroccan populations of *G. truncatula* and sympatric *F. hepatica* have been done by Belfaiza et al. [148] showing that snails may impose a bottleneck on the development of mother rediae which grows more and have a higher production of daughter rediae and cercariae. According to Rondelaud et al. [38], a prevalence of 3% has been recorded in field-collected Moroccan *G. truncatula*. In the east, *G. truncatula* is known to maintain *F. hepatica* life cycle in the highlands of Ethiopia [149]. Moreover, *G. truncatula* has been experimentally infected with Egyptian strains of *F. gigantica* with a frequency of 80% of cercariae-shedding snails proving that it may serve as a natural host for this parasite in Egypt [150]. *Galba truncatula* has also been reported from Zaire, Kenya and Tanzania [56].

Another lymnaeid host of *F. hepatica* in Africa is the invasive species *P. columella*. This species has been reported as widely distributed in South Africa [56] but its contribution to fasciolosis transmission in this country is yet to be evaluated [141]. After the discovery of its introduction in South Africa in 1944, it has also been found in Mozambique, Zimbabwe, Zambia and Egypt [56]. However, populations of *P. columella* might be easily mistaken with *R. natalensis* and thus ancient distribution data should be re-evaluated. More recently, Grabner et al. [151] molecularly detected the natural infection of Egyptian populations of *P. columella* with several trematodes among which is *F. gigantica*.

Other lymnaeid species occurring in Africa are *L. stagnalis* and *S. palustris*, both recorded from Morocco and Algeria [56]. Transmission of *F. hepatica* by any of these lymnaeids is supposed but not assessed. Finally, it has been recently studied the introduction of *R. rubiginosa* into South Africa which could exacerbate the transmission of *F. gigantica* in this country and whose spread might go unnoticed due to similar shell morphology with the native *R. natalensis* [152].

Transmission in Australia and the Pacific islands

Transmission of *F. hepatica* in this region has been usually linked to the native lymnaeid *Austropeplea tomentosa*, particularly in Australia, Tasmania and New Zealand [23, 153]. The role of this species as the main host of *F. hepatica* in Australia was confirmed by Boray [154]. However, in this study, the author also confirms the introduction of three invasive lymnaeid species: *P. columella*, *G. viridis* and *R. auricularia*. Subsequent infection assays were carried out proving that both *P. columella* and *G. viridis* are highly susceptible, whereas *A.*

tomentosa remains the most suited host [154]. Later, Molloy and Anderson [23] concluded that although the introduced species may not yet have had an important impact in fasciolosis transmission, the adaptability of *P. columella* to tropical habitats could result in the expansion of *F. hepatica* in the north. Another species was described from Tasmania by Ponder and Waterhouse [153] named as *Kutikina hispida* but transmission capacity has yet to be assessed. Fasciolosis in mainland Australia not only affects bovines but also native marsupial hosts [155]. In the Indonesian archipelago, *R. rubiginosa* has been found infected with *F. gigantica* in irrigated rice fields of West Java [156]. From the Micronesia, particularly the Mariana Islands, the only lymnaeid species reported is *G. viridis* ranked as a native species but no transmission of *Fasciola* spp. has been described so far [44]. *Galba viridis* is also known to occur in Guam, Indonesia, Papua New Guinea and Thailand [157]. However, far northern in the Hawaiian archipelago the species *G. viridis* is a major intermediate host of the liver fluke *F. gigantica* [43]. This species has also been experimentally infected with *F. hepatica* and cercarial shedding was successfully verified [158]. Also, the invasive *P. columella* has been found in Hawaii [157]. In some other Pacific islands, *P. columella* has been reported from Tahiti, Rapa, Tubuai and Rurutu, but its role in the transmission of *F. hepatica* has not been established [159].

Concluding Remarks on Lymnaeidae–*Fasciola* spp. Transmission

As illustrated in this review, although many species may actually serve as intermediate hosts of *Fasciola* spp. in the field, there are a lesser number posing major threats at both regional or world scales. These threats can be due to several factors among which we may highlight: (a) the species is widely distributed and adapted to the circulating strains of liver fluke (shows higher compatibility in terms of surviving infection and redial burden, e.g.), (b) the species is capable of establishing itself in areas of cattle-related human activities (even very anthropized habitats) with ecological preferences that match those of the definitive hosts or (c) the species has a high invasive ability and the lack of genetic diversity of introduced individuals that may facilitate the transmission. Worldwide, the introductions of *G. truncatula* and *P. columella* may have played a key role in the spread of fasciolosis. Both species have a proved susceptibility to *F. hepatica* infection, but more important, a recognized invasive ability allowing both to succeed in new environments [35, 160]. As an attempt to highlight particular species by regions, major threats may be summarized for (a) the Americas: *G. truncatula*, *G. cubensis*, *G. viator* and *P. columella*; (b) Europe: *G. truncatula* and *R. balthica*; (c) Asia (particularly the southern regions): *R. rubiginosa* and *R. auricularia*; (d) Africa: *R. natalensis* and *G. truncatula*; and (e) Oceania: *A. tomentosa* and *G. viridis*. Although we have reviewed only the main actors in the *Fasciola*–Lymnaeidae interplay by region, we should note that the huge number of described lymnaeid snails in ancient and recent literature may lead to an annoying scenario of who transmit who in many regions. The absence of reliable morphological traits has led to confusion regarding specific identities of lymnaeid populations worldwide. Some species cannot be accurately distinguished because their shell morphology and anatomy are very similar. Even species relatively easy to identify such as *P. columella* or *G. cousini* could have been misidentified in the past due to, for instance, lack of experience in snail identification or the status of the individuals used for the identification (juveniles, worn or broken shells). Thus, studying lymnaeid species often requires an accurate molecular tool. The species identification of fasciolid larval stages found in nature also needs to be always verified, usually by experimental infections or by molecular markers. It is therefore necessary to review in the near future all reported names using the latest molecular tools and data available to reach a more plausible scenario in which, though probably complicated enough, we can picture the world transmission of liver flukes in a more reduced and comprehensible way.

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Figure 1 Life cycle of *Fasciola* spp. Adult parasites live in the bile ducts of mammals where sexual reproduction takes place (1). Approximately 40,000 eggs per individual are laid daily and carried out with the host faeces (2). If temperature and humidity conditions are favourable they hatch into miracidia. These larvae must find a susceptible lymnaeid snail in less than 24 h to which they are steered by means of chemotaxis and phototaxis (3). Once in the snail, the miracidium turns into a sporocyst (4) and then produces rediae (5) which, in time, can give place to other generations of daughter rediae. Inside each redia, several cercariae can be produced. These stages are part of the asexual reproduction of the parasite subjected to the compatibility with their host and can last between 30 and 80 days depending on the ecological conditions. When cercariae are mature, they leave the snail, usually producing fatal damages (6). In the water, they swim and encyst forming metacercariae in aquatic or semi-aquatic vegetation or any source of solid substratum (7). Susceptible mammals may close the parasite cycle by eating vegetation with encysted metacercariae. When the parasite reaches the intestine, the juveniles excyst and migrate to the liver where they achieve the adult form. Later, they establish themselves in the bile ducts where sexual maturation takes place.

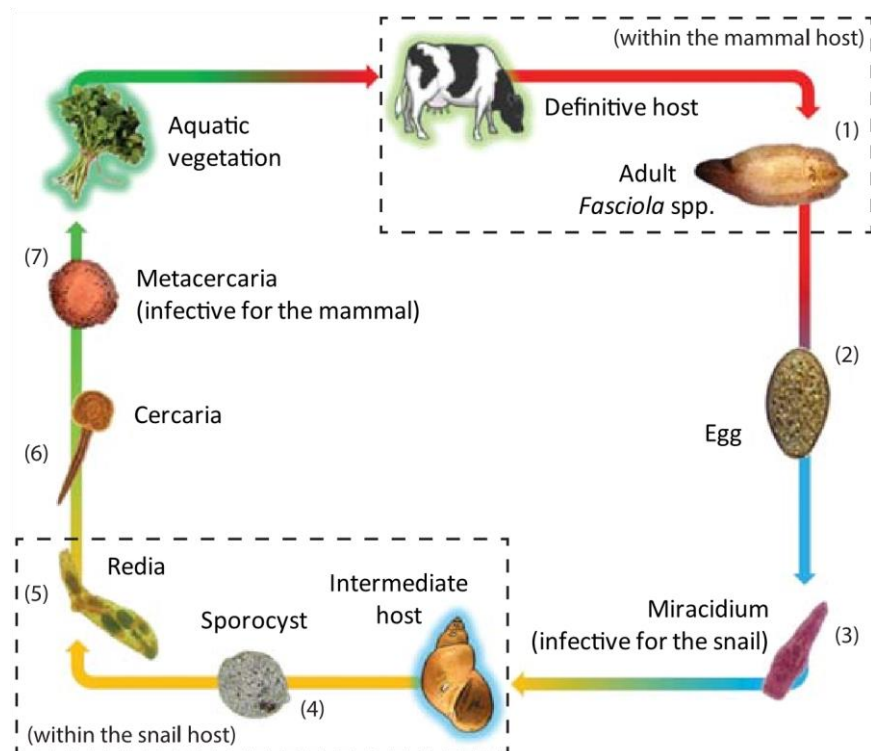


Figure 2 Worldwide transmission of fasciolosis. Map built using data gathered from different reports (Torgerson and Claxton,1999; WHO, 2013, 2014).

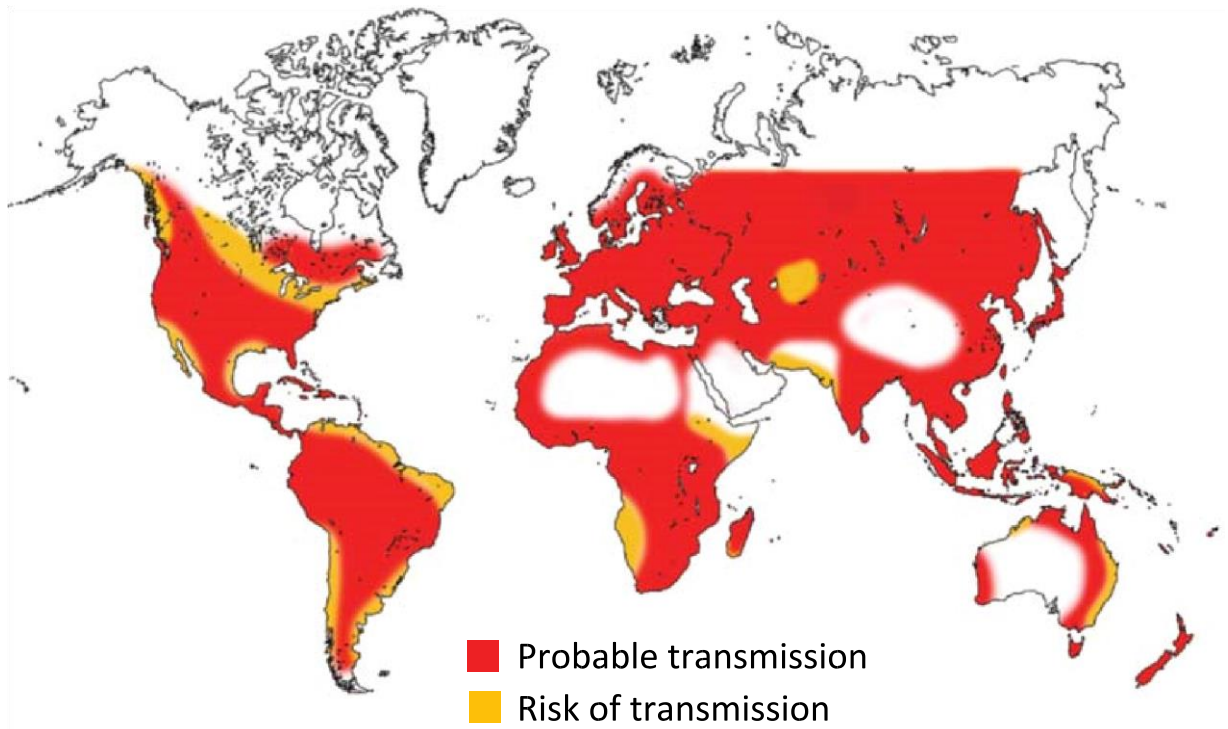


Figure 3 Most common ranges of the main lymnaeid species hosts of *Fasciola* spp.

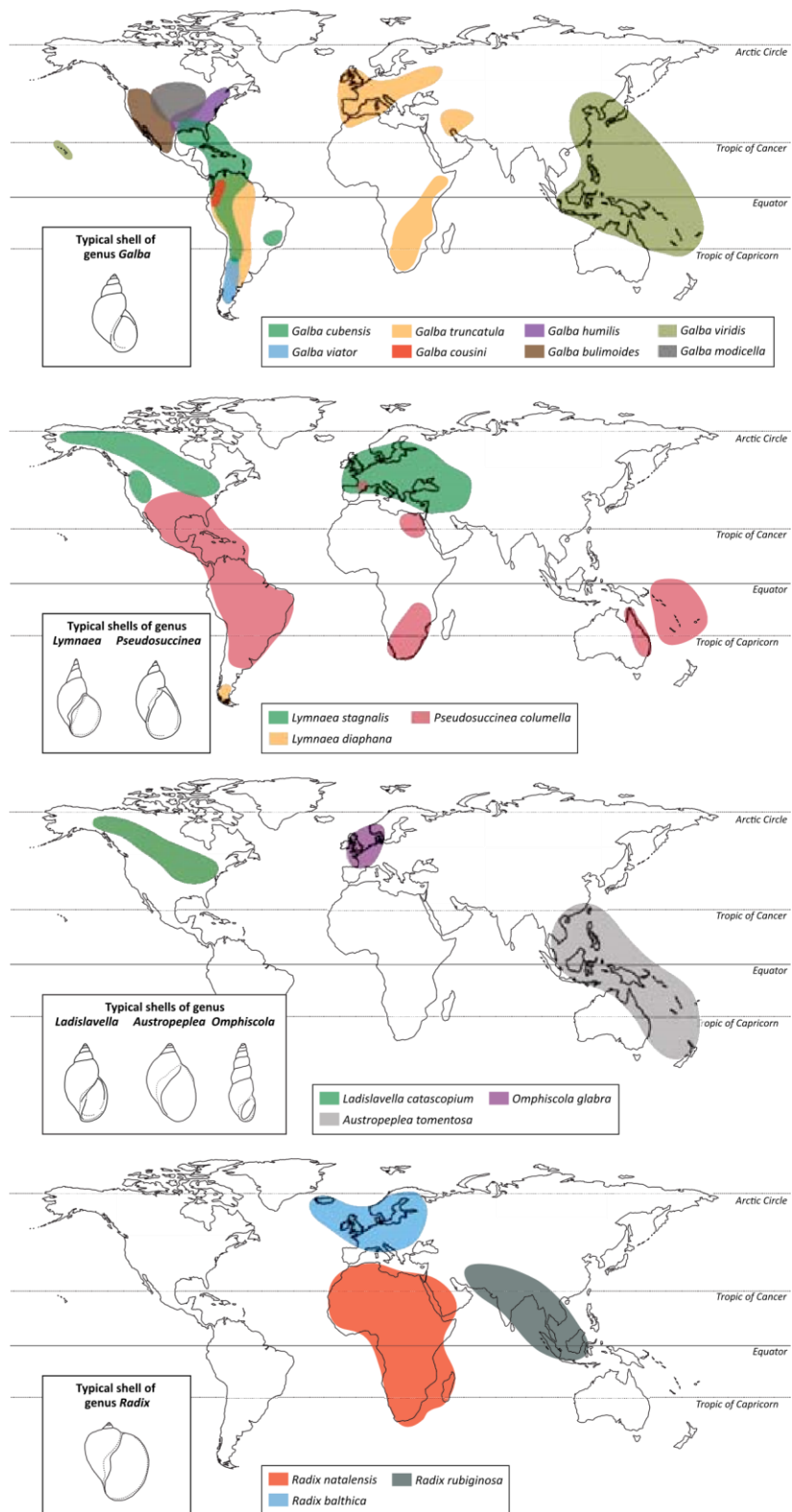


Table 1 Summary of the main lymnaeid species host of the liver flukes worldwide with their type localities, main geographic distribution and records of infection with either *Fasciola hepatica* or *Fasciola gigantica* (EI: means that the lymnaeid species has been only experimentally infected)

Lymnaeid species	Type locality	Main geographic range	Liver fluke	Reference
<i>Austropeplea tomentosa</i> (Pfeiffer, 1855)	Auckland (New Zealand)	Australia	<i>F. hepatica</i>	[23]
<i>Galba cousini</i> (Jousseau, 1887)	Chanchu-Yacu (Ecuador)	Ecuador, Colombia, Venezuela	<i>F. hepatica</i>	[24–26]
<i>Galba cubensis</i> (Pfeiffer, 1839)	Cuba	Cuba USA Lesser Antilles, Colombia Mexico, Uruguay, Venezuela	<i>F. hepatica</i>	[27, 28] [29] [30] [31]
<i>Galba humilis</i> (Say, 1822)	South Carolina (USA)	Mexico	<i>F. hepatica</i>	[32]
<i>Galba modicella</i> (Say, 1825)	Owego, New York (USA)	USA	<i>F. hepatica</i>	[33]
<i>Galba truncatula</i> (Müller, 1774)	Thangelstedt (Germany)	Argentina, Bolivia, Chile, Peru, Venezuela Africa Ireland, Europe	<i>F. hepatica</i> , <i>F. gigantica</i>	[34–36] [37] [38, 39]
<i>Galba viator</i> (d'Orbigny, 1835)	Río Negro (Argentina)	Argentina, Brazil, Peru, Uruguay	<i>F. hepatica</i>	[40–42]
<i>Galba viridis</i> (Quoy & Gaimard, 1832)	Guam	Hawaii Micronesia Australia	<i>F. hepatica</i> <i>F. gigantica</i>	[43] [44] [23]
<i>Hinkleyia caperata</i> (Say, 1829)	Indiana, USA	North America	<i>F. hepatica</i>	[45]
<i>Lymnaea bulimoides</i> (Lea, 1841)	Oregon (USA)	USA	<i>F. hepatica</i>	[46]
<i>Lymnaea diaphana</i> (King, 1830)	San Gregorio (Chile)	Argentina, Chile	<i>F. hepatica</i>	[47, 48]
<i>Lymnaea stagnalis</i> (Linnaeus, 1758)	Europe	Europe, Asia	<i>F. hepatica</i>	[49]
<i>Myxas glutinosa</i> (Müller, 1774)	Fridrichsdal (Denmark)	Urals, Siberia	<i>F. hepatica</i> (EI)	[50]
<i>Omphiscola glabra</i> (Müller, 1774)	Fridrichsdal (Denmark)	France	<i>F. hepatica</i>	[51]
<i>Pseudosuccinea columella</i> (Say, 1817)	near Philadelphia (USA)	Cuba, USA, Central and South America France Africa Australia, New Zealand	<i>F. hepatica</i>	[52–54] [55] [56] [23, 57]
<i>Radix auricularia</i> (Linnaeus, 1758)	Europe	Europe, Southeast Asia	<i>F. gigantica</i>	[58]
<i>Radix balthica</i> (Linnaeus, 1758)		Iceland, British Islands, Europe, western Siberia, Asia minor	<i>F. hepatica</i>	[12]
<i>Radix gedrosiana</i> (Annadale & Prasad, 1919)	Afghanistan	Afghanistan, Iran	<i>F. gigantica</i>	[59]
<i>Radix labiata</i> (Rossmaessler, 1835)		Europe, Turkey, Urals	<i>F. hepatica</i> (EI)	[12, 60]
<i>Radix lagotis</i> (Schränk, 1803)	Danube river (Germany)	Europe (Danube Basin)		[61]
<i>Radix luteola</i> (Lamarck, 1822)	Bengal (India)	Nepal	<i>F. gigantica</i>	[16]
<i>Radix natalensis</i> (Krauss, 1848)	Port Natal, Durban (South Africa)	Africa; Saudi Arabia	<i>F. gigantica</i>	[62]
<i>Radix ovata</i> (Draparnaud, 1805)	France	France	<i>F. hepatica</i>	[63]
<i>Radix peregra</i> (Müller, 1774)	Fridrichsdal (Denmark)	Central Europe	<i>F. hepatica</i> (EI)	[12]

<i>Radix rubiginosa</i> (Michelin, 1831)		Eastern Asia, Malaysia	<i>F. gigantea</i>	[64]
<i>Radix swinhoei</i> (Adams, 1866)		South eastern Asia, Philippines	<i>F. gigantea</i>	[64]
<i>Stagnicola corvus</i> (Gmelin, 1791)	Thuringia (Germany)	Europe	<i>F. hepatica</i>	[65]
<i>Stagnicola fuscus</i> (Pfeiffer, 1821)	Füred, Tihany (Hungary)	Europe	<i>F. hepatica</i>	[63, 65]
<i>Stagnicola palustris</i> (Müller, 1774)	Oregon, USA	USA	<i>F. hepatica</i>	[66]
		Europe		[67]

References

1. Robinson MW, Dalton JP. Zoonotic helminth infections with particular emphasis on fasciolosis and other trematodiasis. *Philosophical Transactions of the Royal Society B* 2009;364:2763–76.
2. Rapsch C, Dahinden T, Heinzmann D, Torgenson PR, Braun U, Deplazes P, et al. An interactive map to assess the potential spread of *Lymnaea truncatula* and the free-living stages of *Fasciola hepatica* in Switzerland. *Veterinary Parasitology* 2008;154:242–9.
3. Rojas L, Vázquez A, Domenech I, Robertson LJ. Fascioliasis: can Cuba conquer this emerging parasitosis? *Trends in Parasitology* 2010;26(1):26–34.
4. Mas-Coma S, Valero MA, Bargues MD. Fasciola, lymnaeids and human fascioliasis, with a global overview on disease transmission, epidemiology, evolutionary genetics, molecular epidemiology and control. *Advances in Parasitology* 2009;69:41–146.
5. Mas-Coma S, Bargues MD, Valero MA. Fascioliasis and other plant-borne trematode zoonoses. *International Journal for Parasitology* 2005;35:1255–78.
6. WHO. Report of the WHO expert consultation on foodborne trematode infections and taeniasis/cysticercosis. Vientiane: 2009 12–16 October 2009. Report No. WHO/HTM/NTD/PCT/2011.3.
7. WHO. The ‘neglected’ neglected worms. Geneva: 2007. December Issue 10.
8. Hurtrez-Boussès S, Meunier C, Durand C, Renaud F. Dynamics of host–parasite interactions: the example of population biology of the liver fluke (*Fasciola hepatica*). *Microbes and Infection* 2001;3:841–9.
9. Ménard A, L’Hostis M, Leray G, Marchandeu S, Pascal M, Roudot N, et al. Inventory of wild rodents and lagomorphs as natural hosts of *Fasciola hepatica* on a farm located in a humid area in Loire Atlantique (France). *Parasite* 2000;7(2):77–82.
10. Strong EE, Gargomini O, Ponder WP, Bouchet P. Global diversity of gastropods (Gastropoda; Mollusca) in freshwater. *Hydrobiologia* 2008;595:149–66.
11. Hubendick B. Recent Lymnaeidae, their variation, morphology, taxonomy, nomenclature, and distribution. *Kungliga Svenska Vetenskapsakademiens Handlingar* 1951;4(3):1–223.
12. Caron Y, Lasri S, Losson B. *Fasciola hepatica*: an assessment on the vectorial capacity of *Radix labiata* and *R. balthica* commonly found in Belgium. *Veterinary Parasitology* 2007;149:95–103.
13. Correa AC, Escobar JS, Noya O, Velázquez LE, González-Ramírez C, Hurtrez-Boussès S, et al. Morphological and molecular characterization of Neotropical Lymnaeidae (Gastropoda: Lymnaeoidea), vectors of fasciolosis. *Infection, Genetics and Evolution* 2011;11:1978–88.
14. Vinarski MV. A new species of stagnicoline snails (Mollusca: Gastropoda: Lymnaeidae) from the extreme North of Western Siberia. *Zootaxa* 2011;2817:55–8.
15. Bargues MD, Mas-Coma S. Reviewing lymnaeid vectors of fascioliasis by ribosomal DNA sequence analyses. *Journal of Helminthology* 2005;79:257–67.
16. Correa AC, Escobar JS, Durand P, David P, Jarne P, Pointier JP, et al. Bridging gaps in the molecular phylogeny of the Lymnaeidae (Gastropoda: Pulmonata), vectors of fascioliasis. *BMC Evolutionary Biology* 2010;10:381.
17. Vinarski MV. One, two, or several? How many lymnaeid genera are there? *Ruthenica* 2013;23(1):41–58.
18. Lotfy WM, Brant SV, DeJong RJ, Le TH, Demiaszkiewicz A, Rajapakse RPVJ, et al. Evolutionary origins, diversification, and biogeography of liver flukes (Digenea, Fasciolidae). *American Journal of Tropical Medicine and Hygiene* 2008;79(2):248–55.
19. Dreyfuss G, Correa AC, Djuikwo-Teukeng FF, Novobilsky A, Höglund J, Pankrác J, et al. Differences in the compatibility of infection between the liver flukes *Fascioloides magna* and *Fasciola hepatica* in a Colombian population of the snail *Galba* sp. *Journal of Helminthology* 2015;89:720–6.
20. Gutiérrez A, Pointier JP, Fraga J, Jobet E, Modat S, Pérez RT, et al. *Fasciola hepatica*: identification of molecular markers for resistant and susceptible *Pseudosuccinea columella* snail hosts. *Experimental Parasitology* 2003;105:211–8.
21. Vázquez AA, Sánchez J, Pointier JP, Théron A, Hurtrez-Boussès S. *Fasciola hepatica* in Cuba: compatibility of different isolates with two intermediate snail hosts, *Galba cubensis* and *Pseudosuccinea columella*. *Journal of Helminthology* 2014;88(4):434–40.
22. Charlier J, Soenen K, De Roeck E, Hantson W, Ducheyne E, Van Coillie F, et al. Longitudinal study on the temporal and micro-spatial distribution of *Galba truncatula* in four farms in Belgium as a base for small-scale risk mapping of *Fasciola hepatica*. *Parasites & Vectors* 2014;7(1):528.
23. Molloy JB, Anderson GR. The distribution of *Fasciola hepatica* in Queensland, Australia, and the potential impact of introduced snail intermediate hosts. *Veterinary Parasitology* 2006;137:62–6.
24. Pointier JP, Noya O, Amarista M, Théron A. *Lymnaea cousini* Jousseume, 1887 (Gastropoda: Lymnaeidae): First record for Venezuela. *Mémoires do Instituto Oswaldo Cruz*. 2004;99.
25. Brumpt E, Velázquez J, Ucros H, Brumpt L, Mission E. Brumpt et L.-Ch. Brumpt en Colombie et au Venezuela. 1.- Découverte de l’hôte intermédiaire, *Limnaea bogotensis* Pilsbry, de la grande douve, *Fasciola hepatica*, en Colombie. *Annales de Parasitologie Humaine et Comparée* 1939–1940;17:563–79.
26. Velázquez LE. Synonymy between *Lymnaea bogotensis* Pilsbry, 1935 and *Lymnaea cousini* Jousseume, 1887 (Gastropoda: Lymnaeidae). *Mémoires do Instituto Oswaldo Cruz* 2006;101(7):795–9.

27. Vázquez AA, Sánchez J, Alba A, Pointier JP, Hurtrez-Boussès S. Natural prevalence in Cuban populations of the lymnaeid snail *Galba cubensis* infected with the liver fluke *Fasciola hepatica*: small values do matter. *Parasitology Research* 2015;114:4205–10.
28. Alba A, Vázquez AA, Sánchez J, Fraga J, Hernández HM, Martínez E, et al. Assessment of the FasciMol-ELISA in the detection of the trematode *Fasciola hepatica* in field-collected *Galba cubensis*: a novel tool for the malacological survey of Q2 fasciolosis transmission. *Parasites & Vectors* 2016;9(22).
29. Cruz-Reyes A, Malek EA. Suitability of six lymnaeid snails for infection with *Fasciola hepatica*. *Veterinary Parasitology* 1987;24(3–4):203–10.
30. Malek EA. Snail hosts of schistosomiasis and other snail-transmitted diseases in Tropical America: a manual. PAHO Scientific Publication. 1985:478.
31. Lutz A. Estudios de zoología y parasitología venezolanas. Caracas: Reimpreso, UCV; 1928.
32. Cruz-Mendoza I, Ibarra F, Quintero MT, Naranjo E, Lecumberri J, Correa D. Seasonal transmission of *Fasciola hepatica* in cattle and *Lymnaea (fossaria) humilis* snails in central Mexico. *Parasitology Research* 2005;95:283–6.
33. Roglie MC, Dimke KL, Potts RS, Knapp SE. Seasonal transmission of *Fasciola hepatica* in Montana, USA, with detection of infected intermediate hosts using a DNA-based assay. *Veterinary Parasitology* 1996;65:297–305.
34. Pointier JP, Noya O, Alarcón de Noya B, Théron A. Distribution of Lymnaeidae (Mollusca: Pulmonata), intermediate snail hosts of *Fasciola hepatica* in Venezuela. *Mémoires do Instituto Oswaldo Cruz* 2009;104(5):790–6.
35. Meunier C, Tirard C, Hurtrez-Boussès S, Durand P, Bargues MD, Mas-Coma S, et al. Lack of molluscan host diversity and the transmission of an emerging parasitic disease in Bolivia. *Molecular Ecology* 2001;10:1333–40.
36. Durand P, Pointier JP, Escoubeyrou K, Arenas JA, Yong M, Amarista M, et al. Occurrence of a sibling species complex within neotropical lymnaeids, snail intermediate hosts of fascioliasis. *Acta Tropica* 2002;83:233–40.
37. Dar Y, Vignoles P, Rondelaud D, Dreyfuss G. *Fasciola gigantica*: the growth and larval productivity of redial generations in the snail *Lymnaea truncatula*. *Parasitology Research* 2002;88:364–7.
38. Rondelaud D, Vignoles P, Dreyfuss G. La Limnée tronquée, un mollusque d'intérêt médical et vétérinaire. Limoges: 2009.
39. Relf V, Good B, Hanrahan JP, McCarthy E, Forbes AB, deWaal T. Temporal studies on *Fasciola hepatica* in *Galba truncatula* in the west of Ireland. *Veterinary Parasitology* 2011;175:287–92.
40. Paraense WL. Planorbidae, Lymnaeidae and Physidae of Ecuador (Mollusca: basommatophora). *Mémoires do Instituto Oswaldo Cruz* 2004;99(4):357–62.
41. Kleiman F, Pietrokovsky S, Prepelitchi L, Carbajo A, Wisnivesky-Colli C. Dynamics of *Fasciola hepatica* transmission in the Andean Patagonian valleys, Argentina. *Veterinary Parasitology* 2007;145:274–86.
42. Carvalho OS, Cardoso PCM, Lira MP, Rumi A, Roche A, Berne E, et al. The use of the polymerase chain reaction and restriction fragment length polymorphism technique associated with the classical morphology for characterization of *Lymnaea columella*, *L. viatrix*, and *L. diaphana* (mollusca: Lymnaeidae). *Mémoires do Instituto Oswaldo Cruz* 2004;99(5):503–7.
43. Cowie RH. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the Hawaiian Islands. Bishop Museum Occasional Papers. 1997;50:66p.
44. Kerr A. Annotated checklist of the aquatic snails of the Marianas Islands, Micronesia. University of Guam Marine Laboratory Technical Report. 2013;147:26p.
45. Knapp SE, Dunkel AM, Han K, Zimmerman LA. Epizootiology of fascioliasis in Montana. *Veterinary Parasitology* 1992;42:241–6.
46. Foreyt WJ, Todd AC. Experimental infection of Lymnaeid snails in Wisconsin with miracidia of *Fascioloides magna* and *Fasciola hepatica*. *The Journal of Parasitology* 1978;64 (6):1132–4.
47. Bargues MD, Mera y Sierra RL, Artigas P, Mas-Coma S. DNA multigene sequencing of topotypic specimens of the fascioliasis vector *Lymnaea diaphana* and phylogenetic analysis of the genus *Pectinidens* (gastropoda). *Mémoires do Instituto Oswaldo Cruz* 2012;107(1):111–24.
48. Duffy T, Kleiman F, Pietrokovsky S, Issia L, Schijman AG, Wisnivesky-Colli C. Real-time PCR strategy for rapid discrimination among main lymnaeid species from Argentina. *Acta Tropica* 2009;109(1):1–4.
49. Yakhchali M, Baran AI, Malekzadeh-Viayeh R. Molecular detection of the infection with *Fasciola hepatica* in field-collected snails of *Galba truncatula* and *Lymnaea stagnalis* from West Azarbaijan, Iran. *Archives of Razi Institute* 2015;70(3):195–202.
50. Vinarski MV, Grebennikov ME, Shishkoedova OS. Past and present distribution of *Myxas glutinosa* (O.F. Müller, 1774) in the waterbodies of the Urals and Siberia. *Journal of Limnology* 2013;72(2):336–42.
51. Dreyfuss G, Vignoles P, Rondelaud D. Natural infections of *Omphiscola glabra* (Lymnaeidae) with *Fasciola hepatica* in central France. *Parasitology Research* 2003;91:458–91.
52. Gutiérrez A, Vázquez AA, Hevia Y, Sánchez J, Correa AC, Hurtrez-Boussès S, et al. First report of larval stages of *Fasciola hepatica* in a wild population of *Pseudosuccinea columella* from Cuba and the Caribbean. *Journal of Helminthology* 2011;85:109–11.
53. Malek EA, Cogswell FB. *Lymnaea (Pseudosuccinea) columella* in Colombia. *The Nautilus* 1980;94:112–4.

54. Prepelitchi L, Kleiman F, Pietrokovsky SM, Moriena RA, Racioppi O, Alvarez J, et al. First report of *Lymnaea columella* Say, 1817 (Pulmonata: Lymnaeidae) naturally infected with *Fasciola hepatica* (Linnaeus, 1758) (Trematoda: Digenea) in Argentina. *Mémoires do Instituto Oswaldo Cruz*. 2003.
55. Pointier J, Coustau C, Rondelaud D, Théron A. *Pseudosuccinea columella* (Say 1817) (Gastropoda, Lymnaeidae), snail host of *Fasciola hepatica*: first record for France in the wild. *Parasitology Research* 2007;101:1389–92.
56. Brown DS. *Freshwater Snails of Africa and Their Medical Importance*. Second ed. London, UK: Taylor and Francis; 1994.
57. Pullan NB, Whitten LK. Liver fluke *Fasciola hepatica* in New Zealand, Part 1. A spreading parasite in sheep and cattle. *New Zealand Veterinary Journal* 1972;20:69–72.
58. Al-jibouri M, Al-Mayah S, Hassan H. The factors affecting metacercarial production of *Fasciola gigantica* from *Lymnaea auricularia* snails. *Journal of Basrah Researches* 2011;37(4E):9–16.
59. Ashrafi K, Massoud J, Holakouei K, Mahmoodi M, Joafshani MA, Valero MA, et al. Evidence suggesting that *Fasciola gigantica* might be the most prevalent causal agent of fascioliasis in northern Iran. *Iranian Journal of Public Health* 2004;33(4):31–7.
60. Schniebs K, Glöer P, Vinarski MV, Hundsdoerfer AK. Intraspecific morphological and genetic variability in the European freshwater snail *Radix labiata* (Rossmässler, 1835) (Gastropoda: Basommatophora: Lymnaeidae). *Contributions to Zoology* 2013;82(1):55–68.
61. Bank R. Fauna Europaea project. Systematical and distributional checklist of species-group taxa of continental Mollusca of Europe. version 24. Available from: URL: <https://www.faunaeur.org>2011.
62. Lotfy WM, Alsaqabi SM. Climate change and epidemiology of human parasitoses in Saudi Arabia: A review. *Journal of Coastal Life Medicine* 2016;4(7):580–8.
63. Dreyfuss G, Abrous M, Rondelaud D. The susceptibility of *Lymnaea fuscus* to experimental infection with *Fasciola hepatica*. *The Journal of Parasitology* 2000;86(1):158–60.
64. Kaset C, Eursitthichai V, Vichasri-Grams S, Viyanant V, Grams R. Rapid identification of lymnaeid snails and their infection with *Fasciola gigantica* in Thailand. *Experimental Parasitology* 2010;126:482–8.
65. Beran L. A contribution to distribution of genus *Stagnicola* and *Catascopia* (gastropoda: Lymnaeidae) in the Czech Republic. *Malacologica Bohemoslovaca* 2008;7:70–3.
66. Lang BZ. Snail and mammalian hosts for *Fasciola hepatica* in Eastern Washington. *Journal of Parasitology* 1977;63:938–9.
67. Novobilsky A, Kašný M, Beran L, Rondelaud D, Höglund J. *Lymnaea palustris* and *Lymnaea fuscus* are potential but uncommon intermediate hosts of *Fasciola hepatica* in Sweden. *Parasites & Vectors* 2013;6(1):251.
68. Cichy A, Faltýnková A, Zbikowska E. Cercariae (Trematoda, Digenea) in European freshwater snails – a checklist of records from over one hundred years. *Folia Malacologica* 2011;19(3):165–89.
69. Horák P, Mikeš L, Lichtenbergová L, Skála V, Soldánová M, Brantc SV. Avian schistosomes and outbreaks of cercarial dermatitis. *Clinical Microbiology Reviews* 2015;28(1):165–90.
70. Kaplan RM, Dame JB, Reddy GR, Courtney CM. The prevalence of *Fasciola hepatica* in its snail intermediate host determined by DNA probe assay. *International Journal for Parasitology* 1997;27(12):1585–93.
71. Jokinen EH. *The Freshwater Snails (Mollusca: Gastropoda) of New York State*. The University of the State of New York, New York; 1992.
72. Wu SK. *Colorado Freshwater Molluscs*. University of Colorado Museum, Colorado; 1989.
73. Leonard AB. *A Yarmouthian Molluscan Fauna in the Midcontinent Region of the United States*. University of Kansas Paleontological Contributions; 1950. p. 1–48.
74. Bouvry M, Rau MB. Seasonal variations in egg passage of *Fasciola hepatica* in dairy cows in Quebec. *Veterinary Parasitology* 1986;22:263–73.
75. Cruz-Mendoza I, Figueroa AJ, Correa D, Ramos-Martínez E, Lecumberri-López J, Quiroz-Romero H. Dynamics of *Fasciola hepatica* infection in two species of snails in a rural locality of Mexico. *Veterinary Parasitology* 2004;121:87–93.
76. Sterki V. Ohio Mollusca: additions and corrections. *Ohio Journal of Science* 1914;14(5):270–2.
77. Johnson PD, Bogan AE, Brown KM, Burkhead NM, Cordeiro JR, Garner JT, et al. Conservation status of freshwater gastropods of Canada and the United States. *Fisheries* 2013;38(6):246–82.
78. Kutz S, Ducrocq J, Verocai G, Hoar B, Colwell D, Beckmen K, et al. Parasites in ungulates of Arctic North America and Greenland: a view of contemporary diversity, ecology, and impact in a world under change. *Advances in Parasitology* 2012;79:99–252.
79. Vinarski MV, Bolotov I, Schniebs K, Nekhaev IO, Hundsdoerfer AK. Endemics or strangers? The integrative re-appraisal of taxonomy and phylogeny of the Greenland Lymnaeidae (Mollusca: Gastropoda). *Comptes Rendus Biologies*. 2017.

80. Vázquez AA, Sánchez J, Hevia Y. Distribución y preferencia de hábitats de moluscos hospederos intermediarios de *Fasciola hepatica* en Cuba. *Revista Cubana de Medicina Tropical* 2009;61(3):248–53.
81. Gutiérrez A, Pointier JP, Yong M, Sánchez J, Théron A. Evidence of phenotypic differences between resistant and susceptible isolates of *Pseudosuccinea columella* (Gastropoda: Lymnaeidae) to *Fasciola hepatica* (Trematoda: Digenea) in Cuba. *Parasitology Research* 2003;90:129–34.
82. Pointier JP. Invading freshwater snails and biological control in Martinique Island, French West Indies. *Mémoires do Instituto Oswaldo Cruz* 2001;96 Suppl. :67–74.
83. Pointier JP, David P. Biological control of *Biomphalaria glabrata*, the intermediate host of schistosomes, by *Marisa cornuarietis* in ponds of Guadeloupe: long-term impact on the local snail fauna and aquatic flora. *Biological Control* 2004;29:81–9.
84. Gómez J, Vargas M, Malek EA. Moluscos de agua dulce de República Dominicana. Santo Domingo, Rep. Dom.: Instituto de Investigaciones en Biliarzia; 1986.
85. Bendezu P, Frame AD, Frame EL, Bonilla C. Watercress cultivation sites and their relationships to fascioliasis in Puerto Rico. *Journal of Agriculture of the University of Puerto Rico* 1988;72:405–11.
86. Bundy DAP, Arambulo III PV, Grey CL. La Fasciolosis en Jamaica: aspectos epidemiológicos y económicos de una zoonosis parasitaria transmitida por caracoles. *Boletín de la Organización Panamericana de la Salud* 1984;96(1):1–20.
87. Barges MD, Artigas P, Khoubbane M, Flores R, Glöer P, Rojas-García R, et al. *Lymnaea schirazensis*, an overlooked snail distorting fascioliasis data: genotype, phenotype, ecology, worldwide spread, susceptibility, applicability. *PLoS ONE* 2011;6(9):e24567.
88. Sodeman WA Jr, Rodrick GE, Paraense WL, Vargas M. *Biomphalaria straminea* and other planorbids in the Dominican Republic. *Mémoires do Instituto Oswaldo Cruz* 1985;80(4):453–6.
89. Alda P, Lounnas M, Vázquez AA, Ayaqui R, Calvopiña M, Celi-Erazo M, et al. A new multiplex PCR assay to distinguish among three cryptic *Galba* species, intermediate hosts of *Fasciola hepatica*. *Veterinary Parasitology* 2018;251:101–5.
90. Uribe N, Becerra WM, Velázquez LE. *Lymnaea cousini*, huésped de *Fasciola hepatica* en el trópico alto andino de Colombia, y sus nuevos haplotipos, confirmados con el marcador mitocondrial del gen de la citocromo oxidasa I. *Biomédica* 2014;34(4):598–604.
91. Villavicencio A, Carvalho de Vasconcellos M. First report of *Lymnaea cousini* Jousseaume, 1887 naturally infected with *Fasciola hepatica* (Linnaeus, 1758) (Trematoda: Digenea) in Machachi, Ecuador. *Mémoires do Instituto Oswaldo Cruz* 2005;100(7):735–7.
92. Lounnas M, Correa AC, Alda P, David P, Dubois MP, Calvopiña M, et al. Population structure and genetic diversity in the invasive freshwater snail *Galba schirazensis* (Lymnaeidae). *Canadian Journal of Zoology* 2018;96:425–35.
93. Caron Y, Celi-Erazo M, Hurtrez-Boussès S, Lounnas M, Pointier JP, Saegerman C, et al. Is *Galba schirazensis* (Mollusca, Gastropoda) an intermediate host of *Fasciola hepatica* (Trematoda, Digenea) in Ecuador? *Parasite* 2017;24(24):1–9.
94. Salazar L, Estrada VE, Velázquez LE. Effect of the exposure to *Fasciola hepatica* (Trematoda: Digenea) on life history traits of *Lymnaea cousini* and *Lymnaea columella* (Gastropoda: Lymnaeidae). *Experimental Parasitology* 2006;114:77–83.
95. Coelho LHL, Lima WS, Guimarães MP. Sympatric and allopatric combinations of *Lymnaea columella* and *Fasciola hepatica* from southern and southeastern Brazil. *Journal of Helminthology* 2009;83:285–8.
96. Paraense WL. *Lymnaea columella* in northern Brazil. *Mémoires do Instituto Oswaldo Cruz* 1983;78:477–82.
97. Moriena RA, Alvarez JD, Pietrovsky S, Rubel D, Prepelitchi L, Racioppi O, et al. Presencia de *Pseudosuccinea columella* naturalmente infestada con *Fasciola hepatica* en Santo Tomé (Corrientes, Argentina). *Revista Veterinaria* 2008;19(2):147–9.
98. Alarcón EP, Velázquez LE. Descripción morfológica de *Cotylophoron cotylophorum* (Digenea: Paramphistomidae) hallado en bovinos de Rionegro, Antioquia, Colombia. *Revista Colombiana de Ciencias Pecuarias* 2009;22:168–77.
99. Barges MD, Artigas P, Khoubbane M, Ortiz P, Naquira C, Mas-Coma S. Molecular characterisation of *Galba truncatula*, *Lymnaea neotropica* and *L. schirazensis* from Cajamarca, Peru and their potential role in transmission of human and animal fascioliasis. *Parasites & Vectors* 2012;5:174.
100. Barges MD, Mera y Sierra RL, Gómez HG, Artigas P, Mas-Coma S. Ribosomal DNA ITS-1 sequencing of *Galba truncatula* (Gastropoda, Lymnaeidae) and its potential impact on fascioliasis transmission in Mendoza, Argentina. *Animal Biodiversity and Conservation* 2006;29(2):191–4.
101. Pointier JP, Cazzaniga N, González-Salas C, Gutiérrez A, Arenas J, Barges MD, et al. Anatomical studies of sibling species within Neotropical lymnaeids, snail intermediate hosts of fascioliasis. *Mémoires do Instituto Oswaldo Cruz* 2006;101(4):431–5.
102. Kleiman F, Pietrovsky S, Paraense WL, Wisnivesky-Colli C. Southernmost finding of *Lymnaea viatrix* Orbigny, 1835 (Pulmonata: Lymnaeidae), intermediate host of *Fasciola hepatica* (Linnaeus, 1758) (Trematoda: Digenea), in urban and rural areas of Patagonia, Argentina. *Mémoires do Instituto Oswaldo Cruz* 2004;99(1):23–4.
103. Cucher MA, Carnevale S, Prepelitchi L, Labbé JH, Wisnivesky-Colli C. PCR diagnosis of *Fasciola hepatica* in field-collected *Lymnaea columella* and *Lymnaea viatrix* snails. *Veterinary Parasitology* 2006;137:74–82.
104. Paraense WL. *Lymnaea rupestris* sp. n. from southern Brazil (Pulmonata: Lymnaeidae). *Mémoires do Instituto Oswaldo Cruz* 1982;77(4):437–43.

105. Blair D. Observations and experiments on some larval trematodes of freshwater snails and fish from southern Iceland. *Journal of Helminthology* 1973;47(4):409–14.
106. Vinarski MV. Three lymnaeid species (Gastropoda:Lymnaeidae) new for the Irtysh River basin (Western Siberia). *The Bulletin of the Russian Far East Malacological Society* 2008;12:71–8.
107. Anderson R. An annotated list of the non-marine Mollusca of Britain and Ireland. *Journal of Conchology* 2005;38(6):607.
108. Jones R, Williams H, Dalesman S, Brophy P. Confirmation of *Galba truncatula* as an intermediate host snail for *Calicophoron daubneyi* in Great Britain, with evidence of alternative snail species hosting *Fasciola hepatica*. *Parasites & Vectors* 2015;8:656.
109. Caron Y, Martens K, Lempereur L, Saegerman C, Losson B. New insight in lymnaeid snails (Mollusca, Gastropoda) as intermediate hosts of *Fasciola hepatica* (Trematoda, Digenea) in Belgium and Luxembourg. *Parasites & Vectors* 2014;7:66.
110. Dreyfuss G, Vignoles P, Rondelaud D. *Fasciola hepatica*: epidemiological surveillance of natural watercress beds in central France. *Parasitology Research* 2005;95:278–82.
111. Rondelaud D, Hourdin P, Vignoles P, Dreyfuss G. The contamination of wild watercress with *Fasciola hepatica* in central France depends on the ability of several lymnaeid snails to migrate upstream towards the beds. *Parasitology Research* 2005;95:305–9.
112. Rondelaud D, Belfaiza M, Vignoles P, Moncef M, Dreyfuss G. Redial generations of *Fasciola hepatica*: a review. *Journal of Helminthology* 2009;83:245–54.
113. Villavicencio A, Gorochoy V, Carvalho de Vasconcellos M. *Lymnaea truncatula* Müller, 1774 (Pulmonata: Lymnaeidae) infected with *Fasciola hepatica* (Linnaeus, 1758) (Trematoda: Digenea), in Moscow districts, Russian Federation. *Revista de Patología Tropical* 2006;35(1):59–64.
114. Kozac M, Wędrychowicz H. The performance of a PCR assay for field studies on the prevalence of *Fasciola hepatica* infection in *Galba truncatula* intermediate host snails. *Veterinary Parasitology* 2009;168(1–2):25–30.
115. Knubben-Schweizer G, Torgerson PR. Bovine fasciolosis: control strategies based on the location of *Galba truncatula* habitats on farms. *Veterinary Parasitology* 2015(208):77–83.
116. Schweizer G, Meli ML, Torgerson PR, Lutz H, Deplazes P, Braun U. Prevalence of *Fasciola hepatica* in the intermediate host *Lymnaea truncatula* detected by real time TaqMan PCR in populations from 70 Swiss farms with cattle husbandry. *Veterinary Parasitology* 2007;150:164–9.
117. Schniebs K, Glöer P, Quiñonero-Salgado S, Lopez-Soriano J, Hundsdoerfer AK. The first record of *Galba cubensis* (L. Pfeiffer, 1839) (Mollusca: Gastropoda: Lymnaeidae) from open fields of Europe. *Folia Malacologica* 2018;26(1):3–15.
118. Schniebs K, Glöer P, Vinarski MV, Quiñonero-Salgado S, Lopez-Soriano J, Hundsdoerfer AK. A new alien species in Europe: first record of *Austropeplea viridis* (Quoy & Gaimard, 1833) (Mollusca, Gastropoda, Lymnaeidae) in Spain. *Journal of Conchology* 2017;42(5):357–70.
119. Vinarski MV, Aksenova OV, Bespalaya YV, Bolotov I, Gofarov MY, Kondakov AV. *Ladislavella tumrokensis*: The first molecular evidence of a Nearctic clade of lymnaeid snails inhabiting Eurasia. *Systematics and Biodiversity* 2016. Q3
120. Vinarski MV, Glöer P. Taxonomic notes on Euro-Siberian freshwater molluscs. 3. *Galba occulta* Jackiewicz, 1959 is a junior synonym of *Lymnaea palustris* var. *terebra* westerlund, 1885*. *Mollusca* 2008;26(2):175–85.
121. Vinarski MV, Glöer P. Taxonomic notes on Euro-Siberian snails, 4. Re-examination of *Limnaea psilia* Bourguignat 1862, with the description of *Radix parapsilia* n. sp. *Archives für Molluskenkunde* 2009;138(2):123–36.
122. Agatsuma T, Arakawa Y, Iwagami M, Honzako Y, Cahyaningsih U, Kang S-Y, et al. Molecular evidence of natural hybridization between *Fasciola hepatica* and *F. gigantica*. *Parasitology International* 2000;49:231–8.
123. Le TH, van De N, Agatsuma T, Nguyen TGT, Nguyen QD, McManus DP, et al. Human fascioliasis and the presence of hybrid/introgressed forms of *Fasciola hepatica* and *Fasciola gigantica* in Vietnam. *International Journal for Parasitology* 2008;38(6):725–30.
124. Dajem SMB. Molecular typing of the fresh water snail *Lymnaea arabica*, the possible intermediate host of *Fasciola hepatica*, collected from Saudi Arabia, by RAPD-PCR. *Egyptian Academy Journal of Biological Sciences* 2012;4(1):173–81.
125. Dung BT, Doanh PN, The DT, Loan HT, Losson B, Caron Y. Morphological and molecular characterization of lymnaeid snails and their potential role in transmission of *Fasciola* spp. in Vietnam. *Korean Journal of Parasitology* 2013;51(6):657–62.
126. Chen JX, Chen MX, Ai L, Xu XN, Jiao JM, Zhu T, et al. An outbreak of human Fascioliasis *gigantica* in southwest China. *PLoS ONE* 2013;8(8):e71520.
127. Itagaki T, Fujiwara S, Mashima K, Itagaki H. Experimental infection of *Lymnaea* snails with Australian *Fasciola hepatica*. *Japanese Journal of Veterinary Science* 1988;50(5):1085–91.
128. Esteban JG, González C, Curtale F, Muñoz-Antoli C, Valero MA, Bargues MD, et al. Hyperendemic fascioliasis associated with schistosomiasis villages in the Nile Delta of Egypt. *American Journal of Tropical Medicine and Hygiene* 2003;69(4):429–37.
129. Malone JB, Gomme R, Hansen J, Yilma JM, Slingenberg J, Snijders F, et al. A geographic information system on the potential distribution and abundance of *Fasciola hepatica* and *F. gigantica* in east Africa based on Food and Agriculture Organization databases. *Veterinary Parasitology* 1998;78:87–101.
130. Dar Y, Rondelaud D, Dreyfuss G. Update of fasciolosis transmitting snails in Egypt (review and comment). *Journal of the Egyptian Society of Parasitology* 2005;35(1):477–90.

131. Dar Y, Djuikwo FF, Vignoles P, Dreyfuss G, Rondelaud D. *Radix natalensis* (Gastropoda: Lymnaeidae), a potential intermediate host of *Fasciola hepatica* in Egypt. *Parasite* 2010;17:251–6.
132. Assogba MN, Dougnon JT, Alkoiret IT, Akpo Y, Boukari M, Youssao AKI. Epidémiologie de la fasciolose bovine au Bénin et essai de lutte biologique. *Livestock Research for Rural Development* 2011;23(12):248.
133. Adediran OA, Uwalaka EC. Laboratory breeding of *Lymnaea natalensis* (Krauss, 1848), intermediate host of *Fasciola gigantica* (Cobbold, 1856). *New York Science Journal* 2013;6(8):55–7.
134. Fromsa A, Meharent B, Mekibib B. Major trematode infections of cattle slaughtered at Jimma municipality abattoir and the occurrence of the intermediate hosts in selected water bodies of the zone. *Journal of Animal and Veterinary Advances* 2011;10(12):1592–7.
135. Howell A, Mugisha L, Davies J, LaCourse EJ, Claridge J, Williams DJL, et al. Bovine fasciolosis at increasing altitudes: parasitological and malacological sampling on the slopes of Mount Elgon, Uganda. *Parasites & Vectors* 2012;5(1):196.
136. Stothard JR, Kristensen TK. Medical and veterinary malacology in Africa. *Parasitology Today* 2000;16(3):85–6.
137. Vassiliades G. Capacité de résistance à la sécheresse de l'limnée (*Limnaea natalensis*), mollusque hôte intermédiaire de *Fasciola gigantica*, au Sénégal. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux* 1978;31(1):57–62.
138. Stothard JR, Brémond P, Andriamaro L, Loxton NJ, Sellin B, Sellin E, et al. Molecular characterization of the freshwater snail *Lymnaea natalensis* (Gastropoda: Lymnaeidae) on Madagascar with an observation of an unusual polymorphism in ribosomal small subunit genes. *Journal of Zoology* 2000;252:303–15.
139. Daynes P. La distomatose à Madagascar. Rapport sur destravaux réalisés de *Fasciola gigantica*. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux* 1967;20(4):557–62.
140. Barré N, Isautier H, Frandsen F, Mandahl-Barth G. Inventaire des mollusques d'eau douce de la Réunion. *Revue d'Élevage et de Médecine Vétérinaires des Pays Tropicaux* 1982;35:35–41.
141. Kock KN, Wolmarans CT, Bornman M. Distribution and habitats of the snail *Lymnaea truncatula*, intermediate host of the liver fluke *Fasciola hepatica*, in South Africa. *Journal of the South African Veterinary Association* 2003;74(4):117–22.
142. Prinsloo JF, Van Eeden JA. Population dynamics of freshwater snails in Lesotho with particular reference to *Lymnaea truncatula*, the intermediate host of *Fasciola hepatica*. *Wetenskaplike Bydraes van die PU vir CHO, Reeks B: Natuurwetenskappe* 1973;72:1–60.
143. Ghouaidia J, Hammami H. Interaction between the intermediate host of fascioliasis in Tunisia, *Galba truncatula* and a possible competitor, *Melanoides tuberculata* (Muller, 1774): a field study. *African Journal of Ecology* 2014;52(3):328–33.
144. Amor N, Farjallah S, Said K, Slimane BB. First report of *Fasciola hepatica* in *Equus caballus* host species from Tunisia based on the ribosomal internal transcribed spacer regions. *Turkish Journal of Veterinary Animal Science* 2011;35(5):319–24.
145. Mekroud A, Benakhla A, Vignoles P, Rondelaud D, Dreyfuss G. Preliminary studies on the prevalences of natural fasciolosis in cattle, sheep, and the host snail (*Galba truncatula*) in north-eastern Algeria. *Parasitology Research* 2004;92:502–5.
146. Mekroud A, Titi A, Benakhla A, Vignoles P, Rondelaud D. *Fasciola hepatica* : sensibilité des *Galba truncatula* du nord-est algérien à l'infestation expérimentale avec des miracidiums sympatriques. *Revue de Médecine Vétérinaire* 2006;157(10):494–501.
147. Khallayoune K, Stromberg BE, Dakkak A, Malone JB. Seasonal dynamics of *Fasciola hepatica* burdens in grazing Timahdit sheep in Morocco. *International Journal for Parasitology* 1991;21(3):307–14.
148. Belfaiza M, Moncef M, Rondelaud D. *Fasciola hepatica*: an unusual case of adaptation to a Moroccan population of *Galba truncatula*. *Parasitology Research* 2005;95:374–8.
149. Goll P, Scott J. The interrelationship of *Lymnaea truncatula* and ovine fascioliasis in the Ethiopian central highlands. *British Veterinary Journal* 1978;134(6):551–5.
150. Dar Y, Rondelaud D, Dreyfuss G. Cercarial shedding from *Galba truncatula* infected with *Fasciola gigantica* of distinct geographic origins. *Parasitology Research* 2003;89:185–7.
151. Grabner D, Mohamed FAAM, Nachev M, Méabed EMH, Sabry AHA, Sures B. Invasion biology meets parasitology: a case study of parasite spill-back with Egyptian *Fasciola gigantica* in the invasive snail *Pseudosuccinea columella*. *PLoS ONE* 2014;9(2):e88537.
152. Nadasan DS. The invasive potential of the freshwater snail *Radix rubiginosa* recently introduced into South Africa [PhD thesis] University KwaZulu-Natal; 2011.
153. Ponder W, Waterhouse J. A new genus and species of Lymnaeidae from the lower Franklin River, South Western Tasmania, Australia. *Journal of Molluscan Studies* 1997;63:441–68.
154. Boray JC. The potential impact of exotic *Lymnaea* spp. on fascioliasis in Australia. *Veterinary Parasitology* 1978;4:127–41.
155. Spratt DM, Presidente PJA. Prevalence of *Fasciola hepatica* infection in native mammals in southeastern Australia. *Australian Journal of Experimental Biology and Medical Sciences* 1981;59(6):713–21.
156. Estuningsih SE, Copeman DB. Trematode larvae in *Lymnaea rubiginosa* and their definitive hosts in irrigated rice fields in West Java. *Jurnal Ilmu Ternak dan Veteriner* 1996;1(3):200–5.

157. Cowie RH. Invertebrate invasions on Pacific Islands and thereplacement of unique native faunas: a synthesis of the land and freshwater snails. *Biological Invasions* 2001;3:119–36.
158. Lee CG, Cho SH, Lee CY. Metacercarial production of *Lymnaea viridis* experimentally infected with *Fasciola hepatica*. *Veterinary Parasitology* 1995;58(4):313–8.
159. Pointier JP, Marquet G. Taxonomy and distribution offreshwater molluscs of French Polynesia. *The Japanese Journal of Malacology* 1990;48:147–60.
160. Lounnas M, Correa AC, Vázquez AA, Dia A, Escobar JS, Nicot A, et al. Self-fertilization, long-distance flash invasion and biogeography shape the population structure of *Pseudosuccinea columella* at the worldwide scale. *Molecular Ecology* 2017;26:887–903.