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Contents

Summary

The Chinese mystery snail (*Bellamya chinensis* (Gray, 1834)) is an alien species which originates from Asia. The snail was first recorded in the Netherlands in 2007. Since then the species has been recorded at 13 locations, 12 in the Netherlands and one in Belgium. The impacts of *B. chinesis* in its introduced range in North America appear to be limited, also, species densities are low and the potential for impacts relating to very high densities are unknown. *B. chinensis* scored moderate in a recent risk assessment for the European Union (EU). The present report presents an overview of potential management approaches for *B. chinensis* in the EU.

Pathways of introduction
B. chinesis is thought to have been introduced as a result of the trade in live animals and plants and its scattered distribution in the Netherlands and Belgium suggests repeated isolated introductions possibly associated with aquarium and pond disposal or escape from open rearing and stocking ponds at pond and garden centres. The species is attractive to hobbyists as its feeding behaviour maintains the clarity of the water without damaging water plants. Moreover, *B. chinensis* close its operculum in the presence of poor water quality and can survive air exposure for more than nine weeks. In the Netherlands, maintenance of water systems (e.g., dredging and weed control in ditches and canals) and the transfer of sediment, plant material or equipment containing snails between or within waterbodies is probably an important future pathway of secondary spread. Other potential pathways of secondary spread may include commercial shipping and recreational boaters who unintentionally transfer snail species between lakes via contaminated bait-buckets, live wells, fishing gear, and the boat itself. Probable natural dispersal vectors include waterfowl and aquatic mammals (otters, muskrats). Colonisation of rivers may result in rapid downstream dispersal with the water current and shipping. Unaided natural dispersal of 0.1 kilometres.year^{-1} was calculated during a 2016 field survey of Eijsder Beemden, a floodplain lake in the Netherlands.

Prevention of introduction and spread
Active attempts to prevent the introductions of invasive gastropods to the EU should focus on the aquarium, pet, and food trade. The erection of trade restrictions preventing the importation, breeding and sale, of high-risk species in areas where suitable habitat is available for establishment is recommended by some authors. A potential replacement applicable to the aquarium and pond trade is the common river snail *Viviparus viviparus* (Linnaeus, 1758), a species native to many countries in the EU. In the Netherlands, measures that encourage the cleaning of equipment used for maintenance of water systems before transferring it between or within waterbodies may reduce the risk of secondary dispersal. Secondary spread may be controlled by boater education. Awareness leaflets, press releases, calendars, lakeside notifications and an information website, warning of the environmental,

economic and social hazards posed by invasive species will contribute to public awareness. Recreational boaters in North America are encouraged to drain, dry and clean their watercraft in an effort to reduce the introduction of alien species to new water bodies. However, a survey in in Wisconsin demonstrated that large numbers of boats and trailers continued to carry attached macrophytes despite an intensive education campaign.

Early detection and rapid response
Because of the difficulty of eradicating *B. chinensis* once it is established, early detection (surveillance systems) and rapid response measures to prevent establishment and spread are of primary importance. Traditional approaches to mollusc sampling are not effective and *B. chinensis* juveniles may easily be missed due to their small size and the fact they hide in crevices between rocks and bury themselves in sediment. The best monitoring method is a visual approach possibly supplemented by touch. However, high turbidity of eutrophic water systems may limit its effectiveness in the Netherlands. Because traditional sampling approaches are ineffective, e-DNA techniques may be useful as supplementary method for the early identification of *B. chinensis*. It is recommended that the species is included in a list of potential IAS that should be subject to surveillance and monitoring.

Eradication, containment and population control techniques
B. chinensis is resistant to traditional invasive species management techniques (such as lake drawdown and chemical measures) making eradication following establishment difficult. For example, *B. chinensis* can withstand long periods of drought due to the presence of the operculum therefore drawdowns are probably ineffective. However, small juveniles are much more sensitive to air exposure than larger juveniles. Adult *B. chinensis* may be removed manually as they are easily recognised. However, juveniles maybe easily missed due to their small size. The addition of copper sulphate ($CuSO_4$) resulted in high levels of *B. chinensis* mortality in North America. However, application of $CuSO_4$ may lead to collateral damage such as fish kills and the application of biocides in water systems is not allowed in the Netherlands without exemption under current regulations and may not be supported by responsible authorities such as water boards. Reducing the availability of calcium carbonate ($CaCo_3$) may limit the growth and survival of juveniles. Accelerating water velocity may prevent the spread and establishment of *B. chinensis*. However, high water velocities will also negatively impact native species, particularly in lotic systems. The effectiveness of combinations of measures is unknown. Further research is required to assess the cost-effectiveness of combinations of measures such as extreme temperatures, predation and molluscicides.

1 Introduction

1.1 **Background and problem statement**

The Chinese mystery snail (*Bellamya chinensis* (Gray, 1834)) is an alien species which originates from Asia. The snail was first recorded in the Netherlands in 2007 (Instituut voor Natuureducatie en Duurzaamheid, 2016). Since then the species has been recorded at 13 locations, 12 in the Netherlands and one in Belgium (Soes et al., 2016; Collas et al., 2017). The species is thought to have been introduced as a result of the trade in live animals and plants and its scattered distribution in the Netherlands and Belgium suggests repeated isolated introductions possibly associated with aquarium and pond disposal or escape from the confinement of pond and garden centres (Collas et al., 2017; Matthews et al., 2017). The impacts of *B. chinesis* in its introduced range in North America appear to be limited, also, species densities are low and the potential for impacts relating to very high densities are unknown. *B. chinensis* scored moderate in a recent risk assessment for the European Union (EU) (Matthews et al., 2017). The present report presents an overview of potential management approaches for *B. chinensis* in the EU. The analysis is based on a detailed inventory and analysis of available data by a team of experts from the Radboud University (Nijmegen, the Netherlands).

1.2 **Research goal**

The aim of this research is to provide a description and discussion of the relative merits of different approaches for the management of *B. chinensis.* Attention is focussed on prevention of initial introduction, early detection of establishment and rapid response (eradication), and containment and population control measures. The management approaches discussed comply with guidelines set out in the EU regulation 1143/2014 for the prevention and management of invasive species.

1.3 **Outline**

The coherence between various research activities and outcomes of the study are visualised in Figure 1.1. The present chapter describes the problem statement, goals and research goals and methodology applied in order to describe and discuss the potential management of *B. chinensis* in the EU. Chapter 2 describes the results of the literature review, which includes sections describing preventative, eradication, and containment and population control measures. A section summarizing available literature on the practical effectiveness of these measures (case studies) is also included. Chapter 3 discusses the most promising management approaches, uncertainties and relevant knowledge gaps. Chapter 4 presents the main conclusions and describes opportunities for further research.

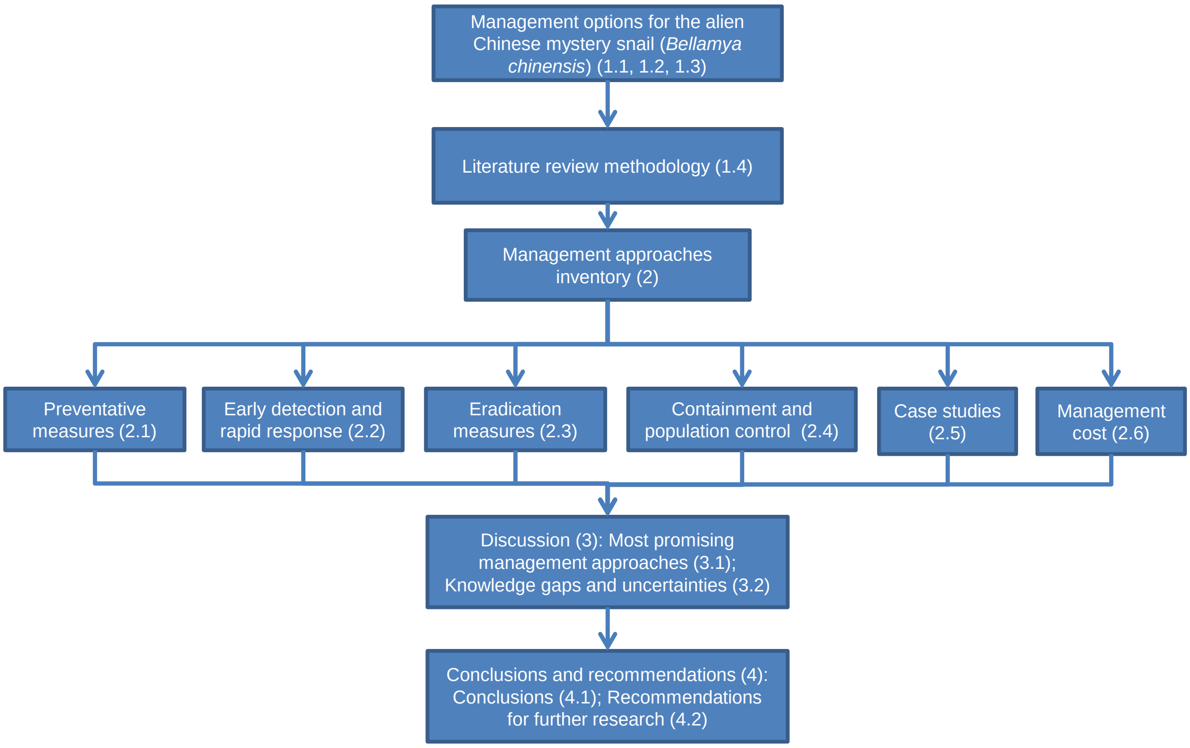

Figure 1.1: Flow chart visualising the coherence of various research activities (chapter numbers are indicated between brackets).

1.4 Literature review

An extensive literature review was carried out to compile a science based overview of the current knowledge on the different approaches for the management of *B. chinensis*. In this inventory, internationally published knowledge in scientific journals and reports was described. If relevant issues mentioned in the format for this inventory could not sufficiently be supported by knowledge published in international literature, 'grey literature' or 'best professional judgement' was used. In the latter case, this has been indicated in the report to clearly identify which arguments may be prone to discussion. Uncertainties and knowledge gaps are also addressed in the discussion.

Table 1.1. Search strategy to retrieve scientific literature on management approaches for the Chinese mystery snail (*Bellamya chinensis*).

Search engine	Search terms (hits)
Web of Science (All databases)	*Bellamya chinensis*, *Cipangopaludina chinensis*, Chinese mystery snail
Google scholar	*Bellamya chinensis*, *Cipangopaludina chinensis*, Chinese mystery snail, *Viviparus*, invasive species, snail, Apple snail, Ampullariidae, and eradication, containment, elimination, management
Google	Management Chinese mystery snail, Control Chinese mystery snail

The Web of Science and Google Scholar search engines were used to find general information on *B. chinensis* and more specific information on its distribution, tolerances, habitat characteristics and other aspects indicated by the search terms given in (Table 1.1). Google was used to find additional information on management or control of this species. Moreover, scientific names of some other large aquatic snails have been used to retrieve additional information on suitable management measures, using Google Scholar. All hits of the Web of Science searches and the first 150 hits of the Google Scholar and Google searches were screened for relevance.

2 Management approaches

2.1 **Preventative measures**

2.1.1 Introduction to the European Union and the Netherlands

Intentional pathways of introduction

B. chinensis is likely introduced via the aquarium and ornamental trade pathway and this is reflected by the scattered isolated records of *B. chinensis* in the Netherlands and Belgium, expected to be the result of independent new introduction events (Kroiss, 2005; Strecker et al., 2011; Soes et al., 2016; Collas et al., 2017; Van den Neucker et al., 2017). Evidence for this pathway is further supported by the fact that *B. chinensis* is sold in pond and garden centres in the Netherlands and Belgium (Soes et al., 2016; Van den Neucker et al., 2017; F.P.L. Collas, personal observation). Both Soes et al. (2016) and Van den Neucker et al. (2017) describe open rearing and stocking ponds at garden and pond centres as a potential point of release of *B. chinensis* to the environment. Species may have been released during maintenance of the ponds (Van den Neucker et al., 2017).

Waltz (2008) states that deliberate release from aquariums is a potential vector for the introduction of *B. chinensis*. McAlpine et al. (2016) suggest that boat launches may be convenient locations for aquarium hobbyists to dump the contents of aquaria containing *B. chinensis*. However, this behaviour has not been observed for the EU. The species is attractive to hobbyists as it eats algae also by filter feeding but not water plants and therefore maintains the clarity of the water without damaging the plants (Soes et al., 2016). Moreover, *B. chinensis* closes its trapdoor, or operculum in the presence of poor water quality to survive, a characteristic that is appreciated by aquarium hobbyists as it warns of poor aquarium water quality (Waltz, 2008).

The origin of *B. chinensis* in the Netherlands is likely North America as few species are imported from the Far East, *B. chinensis*' native range, even though CO1 barcoding data indicates that *B. chinensis* collected in the Netherlands are identical with specimens collected in Japan (Soes et al., 2016). Simultaneous introduction of *B. chinensis*, with the virile crayfish (*Orconectes virilis* (Hagen, 1870)) and/or the white river crayfish (*Procambarus* cf. *acutus* (Girard, 1852)), both North American crayfish, suggests a route to the Netherlands from Japan via North America (Soes et al., 2016).

Original introductions to North America are thought to be related to the import of *B. chinensis* from its Asian native range as a live food source and the species was sold in food markets in San Francisco on the west coast (Wood, 1892; Haak, 2015). Indeed, the consumption of *B. chinensis* is actively encouraged through the presence of recipes available on websites (Invasivore.org, 2017; JCC, 2017).

However, no evidence of *B. chinensis* being sold as an ingredient for human consumption by retailers in the EU could be found in the available literature.

Non-intentional pathways of introduction

Introduction to North America may have occurred through bio-contamination where *B. chinensis* was introduced along with goldfish (*Carassius auratus* (Linnaeus, 1758)) that were added to a stream in an attempt to control mosquito larvae control (Jokinen 1982; Waltz, 2008). *B. chinensis* also likely spreads through the human-mediated movement of aquatic plants and the species may have been transported to the USA as a passive attachment on ornamental lotus plants (Smith, 1995 in Martin, 1999; Havel, 2011; Haak, 2015). However, no evidence indicating that these pathways have been observed for the EU was discovered during a search of available literature.

Measures to prevent introduction and spread

Haak (2015) states that active attempts to prevent the introductions of invasive freshwater gastropods to North America should focus on the aquarium, pet, and food trade. Considering the pathways of introduction discussed above, it is recommended that this approach is considered for the EU as well.

It is currently illegal to own *B. chinensis* in the USA (US-GS, 2017). Rixon et al. (2005) recommend the erection of trade restrictions preventing the importation, breeding and sale (e.g., at live fish markets), of high-risk species in areas where suitable habitat is available for establishment. In fact, the import and spread of certain aquatic snail species is already banned in the EU. Snails belonging to the genus *Pomacea* have been totally banned by the European Commission since 2012 (Commission Implementing Decision 2012/697/EU of 8 November 2012).

The banning of species may also be accomplished through the introduction of covenants or codes of conduct. In 2010, a code of conduct was introduced to reduce the spread of invasive aquatic macrophytes in the Netherlands (Verbrugge et al., 2013). This voluntary agreement between the government and horticulture sector (i.e. plant nurseries and retailers) aims to ban the sale of harmful invasive species and increase public awareness of potentially invasive plant species that are not banned. The Dutch code comprises two major elements: 1) a list of species that are banned from sale, similar to the EU list of invasive alien species of Union concern (European Commission, 2014); and 2) a list of species that maybe sold but only with a warning label that informs customers of the risks associated with invasiveness and instructions designed to reduce the risk of release of the species to the wider environment (Verbrugge et al., 2013).

While banning the sale of *B. chinensis* within the EU would help to block introductions via trade pathways, consequent economic losses may lead to resistance from the retail sector. Therefore, potential alternative species should be considered that may replace the trade of *B. chinensis*. A potential replacement applicable to the aquarium and pond trade is the common river snail (*Viviparus viviparus* (Linnaeus, 1758)), or other *Viviparus* species native for the EU. *V. viviparus* performs a similar function to *B. chinensis* and is already popular with aquarium hobbyists because of similar feeding, anatomical characteristics and colourful banded shell, but is smaller. However, retailers often mislabel the alien *Viviparus acerosus* (Bourguignat, 1862) as *V. viviparus* (D.M. Soes, pers. comm.).

2.1.2 Spread within the European Union and the Netherlands

Intentional pathways of secondary spread

No pathways of intentional secondary spread were found during a search of available literature.

Non-intentional pathways of secondary spread

Vander Zanden and Olden (2008) state that boaters may be responsible for the secondary spread of snail species between lakes through contaminated bait-buckets, live wells, fishing gear, and the boat itself (Waltz, 2008; Havel, 2011; Haak, 2015; McAlpine et al., 2016; USGS, 2017). Because juvenile *B. chinensis* often occur around the roots of emergent macrophytes, attachment to boats and trailers that also carry macrophytes may be particularly common (Havel, 2011). In the Netherlands, maintenance of water systems (e.g., dredging and weed control in ditches and canals) and the transfer of sediment, plant material or equipment containing snails between or within waterbodies is probably an important future pathway of secondary spread (D.M. Soes, pers. comm.).

Probable natural dispersal vectors include waterfowl and aquatic mammals (otters, muskrats) (Mackie, 2000b). Collas et al. (2017) states that if *B. chinensis* is able to colonise rivers, it can be expected that the downstream dispersal rate strongly increases due to water flow and shipping. *B. chinensis* may slowly spread unaided through natural dispersal. Unaided natural dispersal of 0.1 kilometres.year^{-1} was calculated during a 2016 field survey of Eijsder Beemden in the Netherlands (Collas et al., 2017).

Measures to prevent secondary spread

McAlpine et al. (2016) and Havel (2011) suggest that potential secondary spread via boat traffic emphasizes the need for better boater education combined with monitoring of vulnerable aquatic systems. Moreover, Haak (2015) suggests that educating the public on the possible risk to human health of the parasites carried by snails may reduce the number of introductions that take place. Awareness leaflets, press releases, calendars, lakeside notifications and an information website, warning of the environmental, economic and social hazards posed by invasive species will contribute to public awareness. Recreational boaters in North America are encouraged to drain, dry and clean their watercraft in an effort to reduce the introduction of alien species to new water bodies (Invasive Species of BC, 2017). However, the practical effect of education campaigns in Wisconsin, North America aimed at reducing the secondary spread of snails attached between lakes through boater education is questionable as Havel (2011) stated that large numbers of boats and trailers continued to carry attached macrophytes despite an intensive education campaign (of 50,039 boats inspected in 2009, 15% were infested with weeds and 25% had been at another water body in the last 5 days). *B. chinensis* may be transferred in weed attached to watercraft between waterbodies (Havel, 2011). In the Netherlands, measures that encourage the cleaning of equipment used for maintenance of water systems before transferring it between or within waterbodies may reduce the risk of secondary dispersal (D.M. Soes, pers. comm.).

2.2 **Early detection and rapid response**

After the introduction of an invasive alien species, early detection and rapid response measures are crucial to prevent their establishment and spread (European Commission, 2014). However, traditional approaches to mollusc sampling are not effective for the monitoring of *B. chinensis*. Netting techniques do not collect representative samples of snails and the best method is a visual approach possibly supplemented by touch (Soes et al., 2016). It should also be noted that snails may migrate to deeper water and bury themselves in sediment during the cold winter months making them more difficult to sample. In addition, visual monitoring is made difficult due to high turbidity levels in eutrophic water systems in the Netherlands, including the Eijsder Beemden (D.M. Soes, pers. comm.). The application of e-DNA techniques may contribute to (early) detection of presence of snails and estimations of their abundance in deep and/or turbid water bodies (see also below).

B. chinensis has colonized a number of Wisconsin lakes in the USA. Here a monitoring protocol has been designed to monitor the snail populations (Wisconsin Lake Partnership, 2014). Wisconsin Lake Partnership (2014) state that monitoring is best undertaken in late summer but can occur at any time of the year. Large snails may be sampled along the shoreline, in shallow water and to depths of up to approximately 4.5 metres. *B. chinensis* are often found in areas with mud and/or sand and are seldom found in rocky areas (Wisconsin Lake Partnership, 2014). In contrast with the information provided by Havel (2011), the Wisconsin Lake Partnership (2014) state that *B. chinensis* is seldom found in areas heavily colonised by plants.

It should be noted that *B. chinensis* in the Netherlands may be confused with *V. viviparus, Viviparus contectus* (Millet, 1813) and the alien *V. acerosus* during monitoring efforts. Species present in the EU but not in the Netherlands are *Viviparus ater* (Cristofori & Jan, 1832), *Viviparus janinensis* (Mousson, 1859), and

Viviparus mamillatus (Küster, 1852)*. B. chinensis* is often confused with the Japanese mystery snail (*Bellamya japonica*) in its native range and in North America, but *B. japonica* has not been observed in Western Europe (Soes et al., 2011). Both *B. chinensis* and *B. japonica* are native to Japan. *B. chinensis* juveniles may easily be missed due to their relatively small size and the fact they hide in crevices between rocks and bury themselves in sediment (Prezant et al., 2006; Breedveld, 2015). In its North American introduced range, *B. chinensis* tends to be locally distributed and is observed at low densities (Solomon et al., 2010; Kipp et al., 2014). These factors may hinder detection (McAlpine et al., 2016).

Because of the difficulty of eradicating *B. chinensis* once it is established, early detection (surveillance systems) and rapid response measures to prevent establishment and spread are of primary importance to the prevention of the ecological and socio-economic impacts of this species. Because traditional sampling approaches are ineffective, e-DNA techniques may be useful as supplementary method for the early detection of *B. chinensis*. It is recommended that the species is included in a list of potential IAS that should be subject to surveillance and monitoring.

2.3 **Eradication measures**

B. chinensis is resistant to traditional invasive species management techniques (such as lake drawdown and chemical measures) making eradication following establishment difficult (Haak et al., 2014). The effectiveness of combinations of measures is unknown (Unstad et al., 2013).

2.3.1 Mechanical

Adult *B. chinensis* may be removed manually as they are easily recognised. However, juveniles maybe easily missed due to their small size and use of refuges in crevices and sediment (Prezant et al., 2006; Breedveld, 2015).

2.3.2 Chemical and physical

In general, the use of chemicals such as rotenone has a limited effect on *B. chinensis* due to the impenetrability of the shell, large shell size and operculum (Haak et al., 2014). However, the addition of copper sulphate ($CuSO_4$), a common molluscicide, to lakes colonised by *B. chinensis* resulted in high levels of *B. chinensis* mortality in North America (Freeman, 2010). Freeman (2010) reported that within one month of treatment, more than 27,000 dead snails were removed from two ponds. However, copper is also highly to very highly toxic to fish and other aquatic life (Boone et al., 2012). Trout and juvenile fish of several species are known to be particularly sensitive to copper. Fish kills have been reported after copper sulphate applications for algae control in ponds and lakes (Boone et al., 2012). Oxygen depletion due to decay and increased debris has been reported as the cause of most fish deaths (Boone et al., 2012). Adding a chemical that reduces the availability of calcium carbonate ($CaCo_3$) may limit the growth and survival of juveniles, and may slowly reduce population sizes over a period of 4 to 5 years (Haak, 2015). Altering the water's pH (ranging from 4 to 10) is not effective (Haak unpublished observations in Haak, 2015).

2.3.3 Biological

No information regarding the eradication of *B. chinensis* through the application of biological measures could be found during a review of available literature.

2.4 Containment and population control

Local containment of newly established populations in hydrologically connected water bodies may be difficult due to the small size of juveniles and their ability to hide in rock crevices and sediment (Prezant et al., 2006; Breedveld, 2015). The measures outlined in § 2.1.2, measures to prevent secondary spread, may also be applied in an effort to contain and control populations.

2.4.1 Ecosystem-based measures

Rivera (2008) observed that *B. chinensis* does not tolerate water currents of 4.7 m/s or more and suggest that culverts, or other ways of accelerating water flow may prevent the spread and establishment of the species. However, high current velocities will also have impacts on native species.

In the past, drawdowns have been used as a method for the control of snails that are intermediate hosts of parasites or agricultural pests (Cridland, 1967; Cowie, 2002; Havel, 2011). However, *B. chinensis* can withstand long periods of drought due to the presence of the operculum making drawdowns probably ineffective (Unstad et al., 2013; Havel, 2011; Havel et al., 2014). However, small juveniles are much more sensitive to air exposure than larger juveniles (Havel, 2011). A potentially effective approach is to combine drawdown and manual removal techniques. Whilst drawdown may kill sensitive juveniles, the low water level facilitates the simultaneous manual removal of adults. However, adults quickly release juveniles when exposed to stress (Breedveld, 2015). Therefore, if not all adults are removed recolonization may occur in this way.

2.5 Case studies

There are no ongoing management programs for the eradication of *B. chinensis* in the EU. The species has generally not been seen as a problematic in North America where densities are relatively low (Solomon et al., 2010; Mackie, 2000a; McAlpine et al., 2016). This may explain the lack of available information on the management of *B. chinensis* in the USA where it is widely present. In one example, copper sulphate was applied following the discovery of thousands of *B. chinensis* in White City ponds in Oregon, the USA. Approximately 27,000 dead snails were removed from the water surface in the weeks following treatment. Signs were posted at the site for 48 hours following the application by which time American Environmental Protection Agency (EPA) guidelines suggest the chemical will have dissipated (Freeman, 2010; GISD, 2011). Once this 48 hour period expired, the public were encouraged to remove snails by encouraging competition between snail collectors. 100% eradication was not achieved, possibly because of the small size of newly released juveniles. However, this method may be successful for controlling populations (Freeman, 2010).

2.6 **Management cost**

The economic costs associated with management of *B. chinensis* in the EU in the past and future are unknown. Estimations of the total cost of management efforts for the EU and North America are not available.

3 Discussion

3.1 Most promising management approaches

The prevention of introduction of invasive species is seen as the most cost-efficient way of preventing impacts relating to invasive species (Wittenberg & Cock, 2001). *B. chinensis* has already been recorded at 12 locations in the Netherlands and one location in Belgium. However, the widely scattered pattern of these records and its observed slow natural dispersal ability suggests that the current distribution in the EU is the result of isolated and perhaps independent species introductions. Therefore, preventative measures may be effective at controlling further introductions and limit the distribution of this species in the EU. Indeed, the limited available information on the effectiveness of eradication and control measures suggesting that *B. chinensis* is tolerant of available eradication methods emphasises the importance and potential greater effectiveness of preventative measures compared to eradication measures. Despite limited evidence demonstrating the success of eradication methods, the limited current distribution of the species suggests that eradication of the species may still be achievable through, for example, the application of copper sulphate and manual removal, if *B. chinensis* abundances are low. However, the application of copper sulphate in water systems is not allowed in the Netherlands without exemption under current regulations and may not be supported by responsible authorities such as water boards (CTGB, 2017; De Hoop et al., 2015; EU Monitor, 2017). Assessments of abundance and manual removal are difficult because the species is easily missed due to burying behaviour in winter and the small size of young. Therefore, manual removal is best performed during spring and summer when the species is more clearly visible in and on the sediment. A hand-removal program appeared also to be successful for eradication of the alien apple snail, *Pomacea analiculata* (Lamarck, 1819), in a pond in the USA (Bernatis & Warren, 2014). Compared with chemical methods, manual control of this species was achieved with lower monetary cost and less ecological risk. It is likely that continued monitoring will be required in subsequent years following eradication efforts to ensure that the species has been completely removed. The application of e-DNA techniques may be useful as supplementary method for detection of *B. chinensis* in deep or turbid water bodies. Repeated attempts at eradication may be required if attempts at removal are not entirely successful.

The effectiveness of preventative measures for introduction is dependent on a number of factors. Voluntary agreements such as covenants and codes of conduct that ban certain species depend on the continued cooperation of many actors in the trade of live animals and plants. Previous experience of a voluntary covenant to prevent the introduction of invasive water plant species in the Netherlands demonstrated that, despite recognition of its importance by actors within the plant trade, voluntary efforts to enforce it reduced in the three years following its introduction. This was associated with limited increases in public awareness surrounding the potential risks associated with invasive species. Moreover, while retailers were quite well informed about the general topic of invasive species, their specific knowledge about the covenant, species lists and warning labels was limited (Verbrugge et al., 2013).

Even mandatory banning may not guarantee a total removal of species from the market in live animals and plants. For example, the online trade in aquarium species is thriving and freshwater species are particularly dominant in this trade (Mazza et al., 2015). Online trade in potentially invasive animals and plants poses a huge regulatory problem for authorities due to its ability to reach beyond political borders. Retailers based outside the EU will be particularly difficult to legislate against. For example, the effectiveness of the recent EU ban of snails belonging to the genus *Pomacea* was brought into question by Mazza et al. (2015), who states that the apple snail (*P. canaliculata*) was still sold online in 2015, two to three years since the legislation's initial introduction in November, 2012. Moreover, incorrect identification raises management problems as misidentified species could be released bypassing the few existing laws (Mazza et al., 2015). For example, the misidentification of *B. chinensis* sold in the USA as *B. japonica* may have contributed to its spread in North America (Haak, 2015).

3.2 **Knowledge gaps and uncertainties**

There are no ongoing management programs for the eradication of *B. chinensis* in the EU and impacts relating to the species in North America are thought to be limited. Little practical information relating to the management of this species in its alien ranges is available. Therefore, the (limited) effectiveness of individual management measures has been described, mostly conceptually, in the previous paragraphs. Moreover, the cost-effectiveness of combinations of these measures is unknown. Further research is required to assess the effectiveness of combinations of measures such as extreme temperatures, predation and molluscicides (Unstad et al., 2013).

The application of copper sulphate to lakes infested with *B. chinensis* in North America resulted in high levels of snail mortality. However, it is not known to what degree the entire population in these lakes was reduced by this intervention. Moreover, the impact of the application of this chemical on the native biodiversity in the lakes was not reported. What is likely is that repeated applications of copper sulphate will be required to limit snail abundance as surviving individuals will continue to reproduce.

4 Conclusions and recommendations

4.1 **Conclusions**

EU recorded distribution and risk assessment

- The Chinese mystery snail (*Bellamya chinensis*) is an alien species which originates from Asia. The snail was first recorded in the Netherlands in 2007. Since then the species has now been recorded at 13 locations, 12 in the Netherlands and one in Belgium.
- *B. chinensis* scored moderate in a recent risk assessment of for the EU.

Pathways of introduction to the EU

- The species is thought to have been introduced to the EU as a result of the trade in live animals and plants. The species is attractive to hobbyists as its feeding behaviour maintains the clarity of the water without damaging water plants. Moreover, *B. chinensis* close its operculum in the presence of poor water quality and can survive air exposure for more than nine weeks.
- *B. chinensis*' scattered distribution in the Netherlands and Belgium suggests repeated isolated introductions possibly associated with aquarium and pond disposal or escape from the confinement of pond and garden centres.
- Open rearing and stocking ponds at garden and pond centres are an additional potential pathway of *B. chinensis* to the environment.

Pathways of secondary spread within the EU

- In the Netherlands, maintenance of water systems (e.g., dredging and weed control in ditches and canals) and the transfer of sediment, plant material or equipment containing snails between or within waterbodies is probably an important future pathway of secondary spread. In general, commercial shipping and recreational boaters may be responsible for the secondary spread of snail species between lakes through contaminated bait-buckets, live wells, fishing gear, and the boat itself.
- Probable natural dispersal vectors include waterfowl and aquatic mammals (otters, muskrats).
- If *B. chinensis* is able to colonise rivers, it can be expected that the downstream dispersal rate strongly increases due to water flow and shipping.
- Unaided natural dispersal of 0.1 $km.year^{-1}$ was calculated during a 2016 field survey of Eijsder Beemden in the Netherlands.

Pathway management

- Active attempts to prevent the introductions of invasive gastropods to the EU should focus on the aquarium, pet, and food trade.

- The erection of trade restrictions preventing the importation, breeding and sale, of high-risk species in areas where suitable habitat is available for establishment is recommended by some authors.
- A potential replacement applicable to the aquarium and pond trade is the common river snail (*V. viviparus*), or other *Viviparus* species native for the EU.
- In the Netherlands, measures that encourage the cleaning of equipment used for maintenance of water systems before transferring it between or within waterbodies may reduce the risk of secondary dispersal. Secondary spread may also be controlled by boater education. Awareness leaflets, press releases, calendars, lakeside notifications and an information website, warning of the environmental, economic and social hazards posed by invasive species will contribute to public awareness. Moreover, a clean, drain and dry policy for overland transport of recreational boats may be considered.

Early detection and rapid response

- Because of the difficulty of eradicating *B. chinensis* once it is established, early detection (surveillance systems) and rapid response measures to prevent establishment and spread are of primary importance to the prevention of the ecological and socio-economic impacts of this species.
- Traditional approaches to mollusc sampling are not effective and the best monitoring method is a visual approach possibly supplemented by touch.
- *B. chinensis* juveniles may easily be missed due to their small size and the fact they hide in crevices between rocks and bury themselves in sediment.
- Because traditional sampling approaches are ineffective, e-DNA techniques may be useful as supplementary method for the early identification of *B. chinensis*.
- It is recommended that the species is included in a list of potential IAS that should be subject to surveillance and monitoring.

Eradication measures

- Adult *B. chinensis* may be removed manually as they are easily recognised. However, juveniles maybe easily missed due to their small size.
- The addition of copper sulphate ($CuSO_4$) resulted in high levels of *B. chinensis* mortality in North America. However, application of $CuSO_4$ may lead to collateral damage such as fish kills. The application of biocides in water systems is not allowed in the Netherlands without exemption under current regulations and may not be supported by responsible authorities such as water boards.
- Reducing the availability of calcium carbonate ($CaCo_3$) may limit the growth and survival of juveniles.
- Accelerating water velocity may prevent the spread and establishment of *B. chinensis*. However, high water velocities will negatively impact native species..
- *B. chinensis* can withstand long periods of drought due to the presence of the operculum therefore drawdowns are probably ineffective. However, small juveniles are much more sensitive to air exposure than larger juveniles.

4.2 **Recommendations for further research**

Further research is required to assess the cost-effectiveness of combinations of eradication measures such as extreme temperatures, predation and molluscicides. Moreover, the development of e-DNA technique for early detection and monitoring of spread of *B. chinensis* is recommended.

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References

Bernatis JL., Warren GL. 2014. Effectiveness of a hand removal program for management of nonindigenous apple snails in an urban pond. Southeastern Naturalist 13(3):607-618.

Breedveld SKD. 2015. Risk analysis of the non-native Chinese mystery snail (*Bellamya chinensis*) in the Netherlands. Department of Environmental Science. Radboud University, Nijmegen. 51 pp.

Boone C, Bond C, Buhl K, Stone D. 2012. Copper Sulfate. Oregon, USA: National Pesticide Information Center, Oregon State University. http://npic.orst.edu/factsheets/cuso4gen.html. Accessed 21-03-2017.

Collas FPL, Breedveld SKD, Matthews J, Van der Velde G, Leuven RSEW. 2017. Invasion biology and risk assessment of the recently introduced Chinese mystery snail, *Bellamya* (*Cipangopaludina*) *chinensis* (Gray, 1834) in the Rhine-Meuse river delta in Western Europe. Aquatic Invasions (in press).

Cowie RH. 2002. Apple snails (Ampullariidae) as agricultural pests: their biology, impacts and management. In: Barker GM, editor. Molluscs as Crop Pests. CABI, Wallingford, UK. p 145-192.

Cridland CC. 1967. Resistance of *Bulinus* (*Physopsis*) *globosus Bulinus* (Ph.) *africanus*, *Biomphalaria pfefferi* and *Lymnaea natalensis* to experimental desiccation. Bulletin of the World Health Organization 36:507-513.

CTGB 2017. Download toegelaten en vervallen middelen. http://www.ctgb.nl/toelatingen/download-toegelaten-en-vervallen-middelen. Accessed 06-01-2017

De Hoop L, Hollander H, De Hullu E, Van Kessel N, Van Kleef HH, Lam TEPA, Odé B, Schiphouwer M, Spikmans F, Leuven RSEW 2015. Een effectieve aanpak van invasieve exoten in Nederland: Inventarisatie van verbetervoorstellen voor juridische instrumenten op nationaal niveau. Nederlands Expertise Centrum Exoten (NEC-E), Radboud Universiteit Nijmegen (Instituut voor Water en Wetland Research en Vaksectie Bestuursrecht), Stichting Bargerveen, Bureau van de Zoogdiervereniging, Natuurbalans – Limes Divergens, FLORON en RAVON. Verslagen Milieukunde 499. Radboud University, Nijmegen, 64 pp.

European Commission. 2014. Regulation (EU) No 1143/2014 of the European Parliament and of the council 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. Official Journal of the European Union L 317/35.

EU Monitor 2017. Niet-opneming van rotenone, extract van equisetum en kinine hydrochloride in bijlage I bij Richtlijn 91/414/EEG en de intrekking van de toelating voor gewasbeschermingsmiddelen die deze stoffen bevatten. https://www.eumonitor.nl/9353000/1/j4nvk6yhcbpeywk_j9vvik7m1c3gyxp/vi8rm2zuuozz/. Accessed 30-01-2017.

Freeman M. 2010. Invasive snails pose threat if not eradicated. http://www.mailtribune.com/apps/pbcs.dll/article?AID=/20101030/NEWS/10300304. Accessed 21-03-2017.

GISD (Global Invasive Species Database). 2017. *Bellamya chinensis* (mollusc). http://www.issg.org/database/species/ecology.asp?si=1812&fr=1&sts=sss&lang=EN. Accessed 28-02-2017.

Haak DM. 2015. Bioenergetics and habitat suitability models for the Chinese mystery snail (*Bellamya chinensis*). University of Nebraska-Lincoln, Nebraska, USA. 234 pp.

Haak DM, Stephen BJ, Kill RA, Smeenk NA, Allen CR, Pope KL. 2014. Toxicity of copper sulfate and rotenone to Chinese mystery snail (*Bellamya chinensis*). Management of Biological Invasions 5:371-375.

Havel JE. 2011. Survival of the exotic Chinese mystery snail (*Cipangopaludina chinensis malleata*) during air exposure and implications for overland dispersal by boats. Hydrobiologia 668:195-202.

Instituut voor Natuureducatie en Duurzaamheid. 2016. De Wissel IVN afdeling Eijsden. 28 pp.

Invasive Species Council of BC. 2017. Clean Dry Drain. http://bcinvasives.ca/resources/programs/clean-drain-dry. Accessed 06-04-2017.

Invasivore.org. 2017. Species profile: Chinese mystery snail. http://invasivore.org/2011/01/welcome-

to-snail-week/. Accessed 21-02-2017.
JCC. 2017. Snails. http://youhavetocookitright.blogspot.nl/2012/05/snails.html. Accessed 28-02-2017.
Jokinen EH. 1982. *Cipangopaludina chinensis* (Gastropoda: Viviparidae) in North America, review and update. The Nautilus 96:89-95.
Kipp RM, Benson AJ, Larson J, Fusaro A. 2014. *Cipangopaludina chinensis malleata*. USGS Nonindigenous Aquatic Species Database, Gainesville, Florida. http://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1046. Accessed 28-02-2017.
Kroiss S. 2005. The mystery of the Chinese mystery snail: ecological impacts of an invader. Undergraduate ecology research reports. Institute of Ecosystem Studies, Millbrook, New York, USA. 12 pp.
Mackie GL. 2000a. Mollusc introductions through the aquarium trade. In: Claudi R, Leach JH, Editors. Nonindigenous Freshwater Organisms Vectors, Biology and Impacts. Lewis Publishers, Boca Raton, USA. p 135-149.
Mackie GL. 2000b. Introduction of molluscs through the import of live food. In: Claudi R, Leach JH, Editors. Nonindigenous freshwater organisms vectors, biology and impacts. Lewis Publishers, Boca Raton, USA. p 305-313.
Martin SM. 1999. Freshwater Snails (Mollusca: Gastropoda) of Maine. Northeastern Naturalist 6:39-88.
Matthews J, Collas FPL, Van der Velde G, Leuven RSEW. 2017. Risk assessment of the alien Chinese mystery snail (*Bellamya chinensis*). Reports Environmental Science 557. Radboud University, Nijmegen, the Netherlands. 73 pp.
Mazza G, Aquiloni L, Inghilesi AF, Giuliani C, Lazzaro L, Ferretti G, Lastrucci L, Foggi B, Tricarico E. 2015. Aliens just a click away: the online aquarium trade in Italy. Management of Biological Invasions 6:253-261.
McAlpine DF, Lepitzki DAW, Schueler FW, McAlpine FJT, Hebda A, Forsyth RG, Nicolai A, Maunder JE, Noseworthy RG. 2016. Occurrence of the Chinese mystery snail, *Cipangopaludina chinensis* (Gray, 1834) (Mollusca: Viviparidae) in the Saint John River system, New Brunswick, with review of status in Atlantic Canada. BioInvasions Records 5:149-154.
Ornamental Aquatic Trade Organisation. 2017. Aquatic trade body offers its response to EU legislation. http://www.ornamentalfish.org/uncatogorized/response-to-eu-legislation. Accessed 22-02-2017.
Rixon CAM, Duggan IC, Bergeron NMN, Ricciardi A, MacIsaac HJ. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiversity & Conservation 14:1365-1381.
Soes DM, Majoor GD, Keulen SMA. 2011. *Bellamya chinensis* (Gray, 1834) (Gastropoda: Viviparidae), a new alien snail species for the European fauna. Aquatic Invasions 6:97-102.
Soes DM, Neckheim CM, Majoor GD, Keulen SMA. 2016. Het huidige voorkomen van de Chinese moerasslak *Bellamya chinensis* (Gray, 1834) in Nederland. Spirula Correspondentieblad van de Nederlandse Malacologische Vereniging 406:11-18.
Solomon CT, Olden JD, Johnson PTJ, Dillon RT, Vander Zanden MJ. 2010. Distribution and community-level effects of the Chinese mystery snail (*Bellamya chinensis*) in northern Wisconsin lakes. Biological Invasions 12:1591-1605.
Strecker AL, Campbell PM, Olden JD. 2011. The aquarium trade as an invasion pathway in the Pacific Northwest. Fisheries 36:74-85.
USGS (United States Geological Survey). 2017. *Cipangopaludina chinensis malleata*. https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1045. Accessed 06-02-2017.
Unstad KM, Uden DR, Allen CR, Chaine NM, Haak DM, Kill RA, Pope KL, Stephen BJ, Wong A. 2013. Survival and behavior of Chinese mystery snails (*Bellamya chinensis*) in response to simulated water body drawdowns and extended air exposure. Management of Biological Invasions 4:123-127.
Van den Neucker T, Schildermans T, Scheers K. 2017. The invasive Chinese mystery snail *Bellamya chinensis* (Gastropoda: Viviparidae) expands its European range to Belgium. Knowledge and Management of Aquatic Ecosystems 418:1-3.
Vander Zanden MJ, Olden JD. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences 65:1512-1522.

Verbrugge LNH, Van den Born RJG, Leuven RSEW. 2013. Evaluatie Convenant Waterplanten 2010-2013. Verslagen Milieukunde nr. 440. Radboud Universiteit Nijmegen. 98 pp.

Waltz J. 2008. Chinese mystery snail (*Bellamya chinensis*) review. University of Washington, Washington, USA. 51 pp.

Wisconsin Lakes Partnership. 2014. Mystery snails monitoring protocol. Aquatic invasive species monitoring manual. Citizen Lake Monitoring Network, Wisconsin, USA. 168 pp.

Wittenberg R, Cock MJ. 2001. Invasive alien species: a toolkit of best prevention and management practices. CABI International, Wallingford, United Kingdom. p 228.

Wood WM. 1892. *Paludina japonica* (V. Martens) for sale in the San Francisco Chinese markets. Nautilus 5:114-115.