Non-indigenous land and freshwater gastropods in Israel

Article *in* Biological Invasions · October 2009

DOI: 10.1007/s10530-008-9373-4

4 authors, including:

Tamar Dayan
Tel Aviv University
179 PUBLICATIONS **5,820** CITATIONS
SEE PROFILE

Daniel Simberloff
University of Tennessee
309 PUBLICATIONS **27,069** CITATIONS
SEE PROFILE

Henk K. Mienis
Tel Aviv University
5 PUBLICATIONS **283** CITATIONS
SEE PROFILE

Biol Invasions (2009) 11:1963–1972
DOI 10.1007/s10530-008-9373-4

ORIGINAL PAPER

Non-indigenous land and freshwater gastropods in Israel

Uri Roll · Tamar Dayan · Daniel Simberloff · Henk K. Mienis

Received: 25 April 2008 / Accepted: 24 September 2008 / Published online: 7 October 2008

Abstract Few comprehensive works have investigated non-indigenous snails and slugs as a group. We compiled a database of non-indigenous gastropods in Israel to explore how they arrived and spread, characteristics of their introduction, and their biological traits. Fifty-two species of introduced gastropods are known from Israel (of which nine species subsequently went extinct): 19 species of freshwater snails and 33 species of terrestrial gastropods. The majority of these species are found only in human-dominated habitats. Most of those found in natural habitats are aquatic species. Most snails are introduced unintentionally from various parts of the Holoarctic region, reaching Israel as stowaways with horticultural imports and the aquarium trade, but some are brought intentionally to be used as pets or for food. Because the study of this group in Israel is very limited, information regarding their distribution in the country and their effects on other species is incomplete. Though only nine species of non-indigenous snails have been found to date in natural habitats, some of these are very abundant. More information and research is required to enable effective management schemes.

Keywords Biogeographic origin · Gastropods · Impact · Israel · Slugs · Snails

U. Roll (✉) · T. Dayan · H. K. Mienis
Department of Zoology, Tel Aviv University,
Tel Aviv 69978, Israel
e-mail: uroll@post.tau.ac.il

D. Simberloff
Department of Ecology and Evolutionary Biology,
The University of Tennessee, Knoxville,
TN 37996-1610, USA

Introduction

Land- and freshwater snails and slugs have been introduced unintentionally and intentionally to many regions (Cowie and Robinson 2003; Smith 1989). Introductions of the golden apple snail (*Pomacea canaliculata*), giant African snail (*Achatina fulica*), and rosy wolf snail (*Euglandina rosea*) to various countries has greatly damaged native biodiversity (Lowe et al. 2000). Non-indigenous gastropods have also been inimical to both human health and agriculture (Halwart 1994; Morgan et al. 2001; Naylor 1996).

Introduced gastropods can prey upon or outcompete native species (Byers 2000; Hadfield et al. 1993; Kinzie 1992), transfer pathogens and parasites (Gerlach 2001), cause community and ecosystem level changes (Coote and Loeve 2003; Hall et al. 2003), and facilitate introduction of other species (Cowie 1998). Several works characterize attributes of snails introduced successfully (Appleton 2003; Robinson 1999).

Israel, situated at the edge of the Saharo-Arabian desert belt, boasts both arid and temperate climates. Winters are mild and wet and summers are dry and

hot (Jaffe 1988). The northern half of the country receives the majority of annual rainfall. For its size (27,000 km^2) Israel has many native gastropods (100 species). There is a north to south decline in number of snail species, with virtually no species in the extreme desert in the south, which comprises about one fourth of Israel (Heller 1993).

Non-indigenous gastropods have been noted in Israel for more than 30 years (Mienis 1973), and several authors list freshwater and terrestrial non-indigenous snails in this region (Ben-Ami 2006; Mienis 2004; Mienis and Ortal 1994). Here we compile an updated database of non-indigenous snails and slugs to explore how they arrived and spread, aspects of their introduction, their biological characteristics, and what impacts they might be having. We also compare characteristics of these gastropods to worldwide data.

Methods

We studied non-indigenous snails in the state of Israel and the Golan Heights. In general, zoological data were gathered from this entire area, but a sampling bias probably occurs with respect to the regions surveyed (discussed below). Few people study gastropods in the terrestrial or freshwater habitats of Israel, so data are limited. Many of our data were obtained from extensive observations and collections by H. K. Mienis. Data were also obtained from the National Collections of Natural History of the Tel-Aviv University and the Hebrew University of Jerusalem and published works (mostly for comparing local data to information from elsewhere). The snails and slugs were classified as either terrestrial or freshwater, because many attributes of these two groups differ greatly.

For each species we recorded systematic affinity, various life-history attributes, geographic range of native population and of source population for this introduction, new geographic range in this region, regional and global geographic trajectory of the invasion, local dispersal methods, means of introduction to this region, ecosystems affected, year of first discovery in this region, known economic or environmental impact (in this region), known records from elsewhere of this species as non-indigenous, and status of the species in this region.

Results

Our database include 72 non-indigenous snail species. Twenty of these were introduced but never established populations in Israel and were not analyzed further (see Appendix 1 for details). The remaining 52 species include 33 terrestrial gastropods and 19 freshwater snails. See Table 1 for the list of species and their habitat types. This list includes two subspecies of *Cornu aspersum* (*megalostomum* and *aspersum*) found in Israel that are distinguishable.

Species were divided into three status categories (Table 1): those that established populations in Israel but subsequently went extinct (9 species), those currently present in Israel only in human-dominated habitats and probably needing human activities to survive (34 species), and those also found in natural habitats (9 species).

We compared the proportions of snails found only in human-dominated habitats to those found in the wild between freshwater and terrestrial snails. Most snails found only in human-dominated habitats are terrestrial (25 of 34 species). Most species found also in wild habitats are freshwater snails (7 of 9 species). These proportions differ significantly ($P = 0.0078$; Fisher exact test).

We compared proportions of terrestrial and freshwater non-indigenous snails to proportions of "traveling snails" (a term used to describe established non-indigenous species, or invasive species) from these two habitats worldwide (45 terrestrial and 14 freshwater snails; Smith 1989); these did not differ ($P = 0.152$; Fisher exact test).

We tabulated year of first sighting for all species but the single one for which we could find no indication. In some cases only the decade of introduction was known, and in others the introduction was labeled only "long ago" (at least 150 years ago). Figure 1 is a cumulative depiction of decades of first sightings of non-indigenous gastropods, with terrestrial and aquatic species separated. Sixteen species (31%) were first seen during the 1970s.

Table 1 displays familial affiliations of all species and Table 2 shows number of species belonging to each family. This table is divided between freshwater and terrestrial habitats and the different status categories (see above). For each family with non-indigenous representatives, the number of species native to Israel is shown (after Mienis and Ortal 1994), as are the

Table 1 Introduced land- and freshwater snails in Israel

Taxon	Family	Origin	Aquatic/terrestrial	Effects	Status
Marisa cornuarietis (Linnaeus, 1758)	Ampullariidae	Neotr	Aquatic	–	ex
Pomacea bridgesi (Reeve, 1856)	Ampullariidae	Neotr	Aquatic	n,p,r,W	hdh
Pomacea canaliculata (Lamarck, 1819)	Ampullariidae	Neotr	Aquatic	n,p,r,W	hdh
Pomacea insularum (d'Orbigny, 1839)	Ampullariidae	Neotr	Aquatic	n,p,r,W	hdh
Pomacea paludosa (Say, 1829)	Ampullariidae	Nearc	Aquatic	?	hdh
Tarebia granifera (Lamarck, 1816)	Thiaridae	Trop	Aquatic	n,r,I	nh
Thiara scabra (Müller, 1774)	Thiaridae	Trop	Aquatic	s	nh
Pseudosuccinea columella (Say, 1817)	Lymnaeidae	Nearc	Aquatic	n,p,o,r,I,W	nh
Radix auricularia auricularia (Linnaeus, 1758)	Lymnaeidae	Pal	Aquatic	p,r,W	nh
Radix balthica (Linnaeus, 1758)	Lymnaeidae	Pal	Aquatic	p,r,W	hdh
Radix rubiginosa (Michelin, 1831)	Lymnaeidae	Orient	Aquatic	p,r,W	hdh
Radix viridis (Quoy & Gaimard, 1832)	Lymnaeidae	Orient	Aquatic	p,r,W	hdh
Gyraulus chinensis (Dunker, 1848)	Planorbidae	Orient	Aquatic	?	nh
Gyraulus parvus (Say, 1817)	Planorbidae	Nearc	Aquatic	?	hdh
Planorbella duryi (Wetherby, 1879)	Planorbidae	Nearc	Aquatic	n,o,I	nh
Haitia acuta (Draparnaud, 1805)	Physidae	Nearc	Aquatic	n,p,W	nh
Physella ancillaria (Say, 1825)	Physidae	Nearc	Aquatic	–	ex
Physella gyrina (Say, 1821)	Physidae	Nearc	Aquatic	–	ex
Stenophysa marmorata (Guilding, 1828)	Physidae	Neotr	Aquatic	?	hdh
Novisuccinea hortensis (Reinhardt, 1877)	Succineidae	Orient (?)	Terrestrial	p,q,o,I	hdh
Novisuccinea ovalis (Say, 1817)	Succineidae	Nearc	Terrestrial	p,q,o,I	hdh
Gastrocopta cf *pellucida* (Pfeiffer, 1841)	Chondrinidae	Nearc	Terrestrial	?	hdh
Gastrocopta procera (Gould, 1840)	Chondrinidae	Nearc	Terrestrial	?	hdh
Vallonia costata (Müller, 1774)	Valloniidae	Pal	Terrestrial	?	hdh
Vallonia excentrica Sterki, 1893	Valloniidae	Hol	Terrestrial	q,o,I	hdh
Vallonia pulchella (Müller, 1774)	Valloniidae	Pal	Terrestrial	q,o,I	hdh
Elia moesta moesta (Rossmässler, 1839)	Clausiliidae	Med-ME	Terrestrial	?	nh
Achatina fulica Bowdich, 1822	Achatinidae	Eth	Terrestrial	n,p,q,r,W	hdh
Lamellaxis clavulinus (Potiez & Michaud, 1838)	Subulinidae	Trop (?)	Terrestrial	q,o,I	hdh
Rumina decollata (Linnaeus, 1758)	Subulinidae	Med	Terrestrial	n,W	hdh
Rumina saharica (Pallary, 1901)	Subulinidae	Med	Terrestrial	n,W	hdh
Euglandina rosea (de Férussac, 1821)	Spiraxidae	Nearc	Terrestrial	–	ex
Lucilla scintilla (Lowe, 1852)	Helicodiscidae	Nearc	Terrestrial	q,o,I	hdh
Hawaiia minuscula (Binney, 1840)	Oxychilidae	Nearc	Terrestrial	q,o,I	nh
Oxychilus cyprius (Pfeiffer, 1847)	Oxychilidae	Med-ME	Terrestrial	–	ex
Oxychilus translucidus (Mortillet, 1854)	Oxychilidae	Pal	Terrestrial	q,o,I	hdh
Zonitoides arboreus (Say, 1816)	Gastrodontidae	Nearc	Terrestrial	n,p,q,o,I,W	hdh
Zonitoides nitidus (Müller, 1774)	Gastrodontidae	Pal	Terrestrial	n,q,W	hdh
Lehmannia valentiana (de Férussac, 1822)	Limacidae	Med	Terrestrial	n,p,o,I,W	hdh
Deroceras laeve (Müller, 1774)	Agriolimacidae	Pal	Terrestrial	n,p,q,o,I,W	hdh
Deroceras reticulatum (Müller, 1774)	Agriolimacidae	Pal	Terrestrial	n,p,q,o,I,W	hdh
Cornu aspersum aspersum (Müller, 1774)	Helicidae	Med	Terrestrial	n,p,c,o,I,W	hdh
Cornu aspersum megalostomum (Bourguignat, 1864)	Helicidae	Med	Terrestrial	n,p,c,o,I,W	hdh
Eobania vermiculata (Müller, 1774)	Helicidae	Med	Terrestrial	n,p,c,o,I,W	hdh
Helix cincta Müller, 1774	Helicidae	Med	Terrestrial	–	ex

Table 1 continued

Taxon	Family	Origin	Aquatic/terrestrial	Effects	Status
Helix ligata Müller, 1774	Helicidae	Med	Terrestrial	–	ex
Helix xeraethia Rolle & Kobelt, 1895	Helicidae	Med-ME	Terrestrial	–	ex
Prietocella barbara (Linnaeus, 1758)	Cochlicellidae	Med	Terrestrial	p,q,o,I	hdh
Cernuella virgata (Da Costa, 1778)	Hygromiidae	Med-Atl	Terrestrial	–	ex
Monacha species	Hygromiidae	Med-ME	Terrestrial	?	hdh
Xeroclausa meda (Porro, 1840)	Hygromiidae	Med	Terrestrial	?	hdh
Xerotricha conspurcata (Draparnaud, 1801)	Hygromiidae	Med	Terrestrial	q,o,I	hdh

The table displays species names (with authority) and family affiliation. Origin is tabulated based on the major biogeographic regions abbreviated as follows: Palearctic divided into general Palearctic (Pal), the Mediterranean area (Med) or more particularly to the latter's subregion the Middle East (Med-ME) or Mediterranean Atlantic (Med-Atl), Holarctic (Hol), Nearctic (Nearc), Neotropical (Neotr), Tropical Africa or Ethiopian (Eth) and Tropical (Trop) for species with a natural distribution in Africa, SE Asia and islands in the Indian and Pacific Ocean. The table shows if the species is found in terrestrial or aquatic habitats. Also displayed are claimed effects: (*n* on the natural environment, *p* pest of agriculture or other practices, *q* quarantine species, i.e. species not allowed to be on fresh agricultural products for export, *s* suspected, *c* commercial species, *o* observed, *r* researched, *I* data from Israel, *W* data from elsewhere). Status indicates in which general habitats a snail is found (*nh* natural habitats, *hdh* human dominated habitats, *ex* currently extinct)

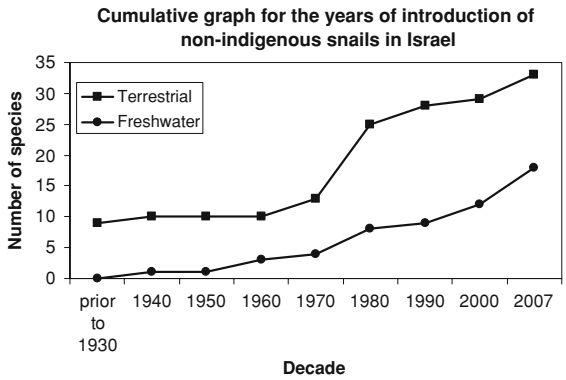

Fig. 1 Cumulative graph for the years of introduction of non-indigenous snails to Israel; terrestrial and aquatic snails are shown separately. The last data-points are for snails introduced from 2000 to 2007

number of "traveling species" intercepted in the USA between the years 1993–1998 (after Robinson 1999) and the number of "traveling snails" from temperate, tropical and subtropical regions (after Smith 1989).

We assigned biogeographic regions to the non-indigenous snails (Table 1); the Palearctic was divided into Mediterranean and Middle East and general Palearctic. Most terrestrial introduced gastropods come from the Palearctic (22 of 33 species—66.7%), whereas most freshwater species are from the New World (12 of 19 species 63.2%). Most Palearctic species come from the Mediterranean or Middle East regions (16 of 24 species—66.7%). Species of gastropods also found in native habitats in Israel come from the Palearctic (two species), Nearctic (four species), Oriental (one species), or general tropical (two species) regions.

We also compared regions of origin of non-indigenous snails of Israel to those of snails introduced to Hawaii (compiled by Cowie and Robinson 2003). Assigning all non-indigenous snails of Israel to the five regions of origin used by Cowie and Robinson (Pacific, Asia/Australasia, New World, Europe, Africa), we found significant differences in proportions of regions of origin between species introduced to Hawaii and Israel ($\chi^2 = 19.82$, $P = 5.43\text{E-}4$; goodness of fit chi-square test). Israel has proportionally more non-indigenous snails of European origin than Hawaii.

We assigned the non-indigenous snails to habitat types (several species were found in more than one habitat). Of the 27 terrestrial species currently in Israel, 20 are found in gardens, 14 in orchards, plantations, or tree nurseries, and 7 in greenhouses. The two species found in natural habitats in Israel are in locations that receive water year-round. The introduced freshwater snail species in Israel are found in aquaria, pools, and fishponds. The six species also found in the wild inhabit various habitats such as streams, springs and ponds.

Aquatic snails arrive in Israel as hitchhikers with aquatic plants imported for horticulture (5 species).

Table 2 The number of non-indigenous gastropod species from each family

Family	Extinct	hdh	nh	Native	USA	World
Freshwater						
Ampullariidae	1	4	–	–	1	1
Thiaridae	–	–	2	1	3	1
Lymnaeidae	–	3	2	5	3	3
Physidae	2	1	1	–	1	1
Planorbidae	–	1	2	9	3	5
Terrestrial						
Achatinidae	–	1	–	–	3	1
Agriolimacidae	–	2	–	2	4	–
Chondrinidae	–	1	1	3	–	–
Clausiliidae	–	–	1	8	–	–
Cochlicellidae	–	1	–	1	2	–
Gastrodontidae	–	2	–	–	1	3
Helicidae	3	3	–	13	10	12
Helicodiscidae	–	1	–	–	–	–
Hygromiidae	1	3	–	32	11	–
Limacidae	–	1	–	3	5	6
Oxychilidae	1	2	–	3	3	3
Pristilomatidae	–	1	–	1	–	1
Spiraxidae	1	–	–	–	–	–
Subulinidae	–	3	–	–	7	3
Succineidae	–	2	–	1	1	–
Valloniidae	–	3	–	2	3	1
	9	35	9	81	61	41

The table is divided between different habitat types and status categories: extinct, *hdh* human dominated habitats, *nh* natural habitats (see text). Also shown are the number of species from these families that are native to Israel (after Mienis and Ortal 1994) in the "Native" column. The "USA" column shows the number of "traveling species" intercepted in the USA 1993–1998 (after Robinson 1999). The "World" column shows the number of "traveling snails" from temperate, tropical and subtropical regions of the world (after Smith 1989); freshwater snail data are just from the temperate regions. The three last columns show only the number of species from families that are represented as non-indigenous in Israel

Other species arrive either intentionally or unintentionally with the aquarium trade (8 species). These are either snails smuggled in to be used as pets or those that arrive with aquarium materials (two more species probably reached Israel both with plants and the aquarium trade). Most terrestrial gastropods (23 species) reached Israel with horticultural plants, either potted ones or fresh flowers. Seven more species were brought intentionally for food and other purposes, and for four species the introduction pathway is unknown. Elsewhere, non-indigenous snails are also known to be transported with tiles (see Cowie and Robinson 2003; Robinson 1999). However, in Israel this mode of transport is not documented, though this could reflect insufficient study.

Twenty-seven species of Israeli non-indigenous gastropods are noted as non-indigenous elsewhere. Of these, 10 are now cosmopolitan and 6 others nearly cosmopolitan.

Data are scarce on impact of non-indigenous snail species in Israel. However, one species currently found in the wild (*Pseudosuccinea columella*) may outcompete native species (H. K. Mienis, personal observations). Another (*Tarebia granifera*) has been found to be detrimental to a native species (*Melanoides tuberculatus*) from the same family—Thiaridae (Ben-Ami 2006). Three other species of the genus *Pomacea* (Table 1) may threaten native fauna if they find their way to the wild (H. K. Mienis, personal observations); one of these, *P. canaliculata*, is a

major agriculture and conservation pest in other regions to which it has been introduced (Lowe et al. 2000). Two species (*P. columella* and *Gastrocopta procera*) are locally very abundant and one (*Haitia acuta*) is the most common snail in freshwater habitats in Israel. Ten species are currently considered agricultural pests. Furthermore, a few of the non-indigenous snails of Israel are problematic in other countries, both to native species and as agricultural pests. See Table 1 for data on effects of non-indigenous snails of Israel both in Israel and the world.

Discussion

The study of freshwater molluscs in Israel is very limited. Almost all data on non-indigenous mollusc species in Israel were obtained from surveys of this group carried out by one of us (H. K. Mienis). Therefore, several biases prevail. First, the years of introduction—the high number of species discovered during the 1970s (31% of all species, see Fig. 1)—correspond with the time H. K. Mienis started to collect land- and freshwater molluscs in Israel. The three sites with highest density of non-indigenous snails—Tel Aviv University, Hebrew University of Jerusalem, and Kibbutz Netzer Sireni—simply constitute his residence and places of work. Nevertheless, these biases in the data can indicate that when we look for non-indigenous species we usually find them (see also Roll et al. 2007a)

Most non-indigenous snails found in natural habitats in Israel are freshwater species, even though there are fewer established non-indigenous freshwater snails than terrestrial snails. This result could reflect Israel's long, dry summers, which may limit many snails of temperate or tropical origin that require year-round moisture. Most terrestrial snails are found in human-dominated habitats, where they receive additional irrigation. Nevertheless, these species could establish themselves in natural habitats with more available water (as two species already have) or even develop adaptations that enable their spread to wild habitats (Bohn et al. 2004; Garcia-Ramos and Rodriguez 2002).

The non-indigenous snails of Israel come both from families already represented in Israel (in some cases in large numbers) and from those not previously represented (Table 2). At least until 1989, several snail families were not represented among "traveling snails" in various regions of the world (Smith 1989) but are among the Israeli non-indigenous snail fauna (Table 2). In some cases Israel also has more species in those families than are represented elsewhere. This result may be explained by different categories used to designate a species as "traveling" (Smith 1989) as opposed to the non-indigenous snail definition used in this work.

Most non-indigenous terrestrial snails come from the Palearctic region, predominantly from other Mediterranean or Middle-Eastern countries. By contrast, most freshwater snails come from either the Neotropical or the Nearctic regions. This latter pattern resembles that displayed by introduced inland fishes of Israel (Roll et al. 2007b). These differences between terrestrial and freshwater snails could arise from different means of introduction (discussed below). Regions of origin of the non-indigenous snails of Israel differ from those of non-indigenous insects and birds, which have more Paleotropical species (Roll et al. 2007a, 2008). There are also more introduced snails of European origin in Israel than in Hawaii. This is perhaps due to "climatic matching" (Duncan et al. 2003), but it is also possible that intensive trade and short travel distances between Israel and Europe facilitate snail introduction.

Terrestrial snails and slugs

Terrestrial non-indigenous snails and slugs usually arrive with plants, which are imported for use in greenhouses, horticulture and agriculture. Most plants arrive by air at Ben-Gurion airport, where they are inspected by Ministry of Agriculture officials (Moran 2004). However, inspectors are guided by a puzzling policy. Any shipment containing snails thought (by the inspector) to be already present in Israel (either as native or as foreign) are passed along without quarantine measures. If the snail is unfamiliar to the inspector, a local expert is consulted. If the expert affirms that the species is known from greenhouses or even if it has already spread into plantations, the shipment passes through without quarantine. This policy takes no account of much recent research showing that several extremely harmful invasions were spurred by subsequent introductions of new genotypes of species that had been long established

and harmless (e.g., Lavergne and Molofsky 2007; Roman 2006; Saltonstall 2002).

Imported fresh flowers usually pose less of a problem than potted plants. Fresh cut flowers arriving at the flower market in Aalsmeer, the Netherlands must be accompanied by a health certificate provided by the exporting country. If, after marketing, they are exported to a third country such as Israel, they are again thoroughly screened for the presence of pathogens and pests prior to reshipment. Several countries (e.g., Japan and the USA) maintain for that purpose their own quarantine staff in the flower bourse of Aalsmeer (H. K. Mienis, personal experience).

For potted plants that arrive with their root system and soil, only their aboveground parts are inspected. The soil is not inspected; however it is probably the place where most snails are located either as eggs or as adults. Potted plants go to greenhouses, where the snails enjoy constant irrigation and few natural enemies. If there is an infected shipment, a large population can quickly establish under these conditions. Most snails that reach private homes may eventually die but those that find their way into orchards or gardens can sustain a viable population.

Several European species of Helicidae have been imported for food, probably since ancient times. Various species of *Helix* snails from Cyprus have been found in the excavation of Tel-Maresha and Uvdat with markings indicating use as food (H. K. Mienis, personal observations). Introductions of edible snails continue to the present. Snail farms are built and in some cases encouraged by the Ministry of Agriculture as alternative agricultural practices, to produce edible snails exported to a growing market in Western Europe. The dominant species grown in such snail farms is *Cornu aspersum megalostomum*, which can now be collected in gardens and parks in the major cities throughout Israel. In addition *Cornu aspersum aspersum* and other species have been imported from Italy recently for this purpose (M. Algouati, personal information). Universities and other scientific institutes are also regularly importing large numbers of living snails, especially *Helix pomatia*, for experiments and demonstrations (Sh. Moran, personal information to H. K. Mienis). Surviving snails are not always destroyed.

Accidental introduction of land snails into Israel also dates to ancient times. For example, the snail *Rumina saharica* has been found in the Roman towns of Cesarea and Apollonia. In the latter, it lived until the mid-twentieth century (Mienis 2003). In this species self-fertilization is possible, so in theory a single individual can establish an entire population. Recently a small population of this species of unknown origin was discovered in a neighborhood of Tel-Aviv (Mienis 2003).

Once species are already present in Israel, their monitoring is so limited that we cannot discuss within-country ranges in depth. Few non-indigenous terrestrial snails have spread into natural habitats. Some species remain localized. For example, *Rumina decollata* is apparently found only in the back yard of the Terra Sancta monastery in Jerusalem (Bar-Ze'ev and Mienis 2002). By contrast, *Cornu aspersum megalostomum* is spreading from Haifa (in northern Israel) to neighboring towns and to other parts of the country (in gardens that are watered year-round). The snail *G. procera*, brought with date seedlings from California, established a large population in date plantations in the En Gedi oasis. From there it spread to other plantations along the Rift Valley. This species could spread to the nearby nature reserve (H. K. Mienis, personal observations).

Freshwater snails

Many freshwater snails enter as stowaways with aquatic vegetation. Aquatic plants that enter Israel are also subject to Ministry of Agriculture inspection. However, many snail eggs are inconspicuous, transparent saliva-like pellets easily missed by inspectors. Undetected snails arrive at aquarium shops and garden centers that carry aquatic plants. The ability of most freshwater snails to self-reproduce aids quick population increase. From these locations snails spread throughout the country. From homes or gardens, snails can enter natural water systems by releases of aquarium contents to nearby water systems, runoff from open pools, and transfer with various animals to new locations. Once in natural habitats, snails spread to new habitats by various means and are limited only by unfavorable conditions.

Some freshwater snails are imported intentionally as pets or for scientific research. Several species from the genus *Pomacea* are sold as pets and have been found in outdoor pools in several locations. Although non-indigenous apple snails do not yet pose a major

threat to agriculture in Israel as they do in the Far East (Halwart 1994; Naylor 1996; Teo 2003), they may harm native biota by consuming aquatic plants.

Several freshwater snail species have established populations in natural freshwater bodies of Israel. Some are spreading and are even found in remote locations; for instance the snail *H. acuta* was found in isolated freshwater springs in the Sinai desert (Tchernov 1971 as *Physa acuta*). This non-indigenous American species has become the most abundant freshwater snail in Israel and could have reached remote locations in feathers of waterfowl (Vagvolgyi 1975). One factor limiting spread of non-indigenous snails to natural habitats is pollution. Most freshwater streams that flow into the Mediterranean Sea are polluted to some degree (Fishelson 1983), which may prevent establishment of such species as the gill-breathing prosobranchs that are more vulnerable to low dissolved oxygen levels.

Concluding remarks

Israel has many non-indigenous species of snails and slugs, but most are not yet found in wild habitats. Nevertheless, several species found in natural habitats are dominant and could greatly affect the native biota. Further research on effects of non-indigenous snails in Israel is imperative, as are stricter guidelines and enforcement to prevent other species from establishing or new genotypes from being introduced. Eradication or containment schemes should be considered for species already established.

Acknowledgments We thank M. Algouati and Sh. Moran for valuable data and the internal university fund (Tel-Aviv University) for supporting this research.

Appendix 1

Interceptions by inspectors of the Plant Protection and Inspection Service of the Ministry of Agriculture of land and freshwater gastropods for which no specimens have been found so far in Israel

Taxon	Family	Terrestrial/ freshwater	Origin	Year	Remarks
Filopaludina martensi martensi (von Frauenfeld, 1865)	Viviparidae	Freshwater	Thailand	2005/2006	For food
Filopaludina martensi cambodjensis (Mabille & Le Mesle, 1869)	Viviparidae	Freshwater	Thailand	2006	For food
Pila ampullacea (Linnaeus, 1758)	Ampullariidae	Freshwater	Thailand	2006/2007	For food
Digoniostoma truncata (Eydoux & Souleyet, 1852)	Bithyniidae	Freshwater	Singapore/ Hong Kong	Pre-1979	On aquarium plants
Ameriana carinata (H. Adams, 1861)	Planorbidae	Freshwater	Singapore/ Hong Kong	Pre-1979	On aquarium plants
Gyraulus convexiusculus (Hutton, 1842)	Planorbidae	Freshwater	Singapore/ Hong Kong	Pre-1979	On aquarium plants
Planorbarius corneus (Linnaeus, 1758)	Planorbidae	Freshwater	Germany	2002	On waterlilies
Planorbis planorbis planorbis (Linnaeus, 1758)	Planorbidae	Freshwater	Germany	2002	On waterlilies
Succinea putris (Linnaeus, 1758)	Succineidae	Terrestrial	Germany	2002	On waterlilies
Succinea striata (Krauss, 1848)	Succineidae	Terrestrial	South Africa	2001	Among grapes
Gittenbergia sororcula (Benoit, 1859)	Valloniidae	Terrestrial	"Netherlands" (France)	2002	On Sempervivum
Achatina achatina (Linnaeus, 1758)	Achatinidae	Terrestrial	Ghana	2001	As "pets"
			Nigeria	2002	As "pets"
			"Netherlands" (Togo)	2007	On Codiaeum (Croton) cuttings
Discus rotundatus (Müller, 1774)	Discidae	Terrestrial	Netherlands	2002	On Orchid

Appendix continued

Taxon	Family	Terrestrial/ freshwater	Origin	Year	Remarks
Oxychilus draparnaudi (Beck, 1837)	Oxychilidae	Terrestrial	Belgium	1986	In potplants
Limax maximus Linnaeus, 1758	Limacidae	Terrestrial	Netherlands	2007	In Bromeliacea
Arion species	Arionidae	Terrestrial	Netherlands	2001	On Sedum (specimen rotten)
Arianta arbustorum (Linnaeus, 1758)	Helicidae	Terrestrial	Estonia	2007	In peat
Cernuella cisalpina (Rossmaessler, 1837)	Hygromiidae	Terrestrial	"Cyprus"	2000	Among tomatoes
Cernuella neglecta (Draparnaud, 1805)	Hygromiidae	Terrestrial	Spain	1987	In peat
Monacha parumcincta (Menke, 1828)	Hygromiidae	Terrestrial	"Cyprus"	2000	Among tomatoes

Pre-1979 identifications by the late Dr. L. Forcart (Basel), all other identifications by H. K. Mienis

References

Appleton CC (2003) Alien and invasive fresh water Gastropoda in South Africa. Afr J Aquat Sci 28:69–81

Bar-Ze'ev UJ, Mienis HK (2002) The pilgrim snails of Terra Sancta. Holy Land spring 2002:11–12

Ben-Ami F (2006) First report of the invasive freshwater snail *Tarebia granifera* (Lamarck, 1816) (Gastropoda: Thiaridae) from Israel. Nautilus 120:156–161

Bohn T, Sandlund OT, Amundsen PA, Primicerio R (2004) Rapidly changing life history during invasion. Oikos 106:138–150. doi:10.1111/j.0030-1299.2004.13022.x

Byers JE (2000) Competition between two estuarine snails: implications for invasions of exotic species. Ecology 81: 1225–1239

Coote T, Loeve E (2003) From 61 species to five: endemic tree snails of the society islands fall prey to an ill-judged biological control programme. Oryx 37:91–96. doi:10.1017/S0030605303000176

Cowie RH (1998) Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian Islands. Biodivers Conserv 7:349–368. doi:10.1023/A:1008881712635

Cowie RH, Robinson DG (2003) Pathways of introduction of nonindigenous land and freshwater snails and slugs. In: Ruiz GM, Carlton JT (eds) Invasive species: vectors and management strategies. Island Press, Washington, DC, pp 93–122

Duncan RP, Blackburn TM, Sol D (2003) The ecology of bird introductions. Annu Rev Ecol Evol Syst 34:71–98. doi:10.1146/annurev.ecolsys.34.011802.132353

Fishelson L (1983) Plants and animals of the land of Israel—life in water. Ministry of Defense, Tel-Aviv (in Hebrew)

Garcia-Ramos G, Rodriguez D (2002) Evolutionary speed of species invasions. Evol Int J Org Evol 56:661–668

Gerlach J (2001) Predator, prey and pathogen interactions in introduced snail populations. Anim Conserv 4:203–209. doi:10.1017/S136794300100124X

Hadfield MG, Miller SE, Carwile AH (1993) The decimation of endemic Hawaiian tree snails by alien predators. Am Zool 33:610–622

Hall RO Jr, Tank JL, Dybdahl MF (2003) Exotic snail dominate nitrogen and carbon cycling in a highly productive stream. Front Ecol Environ 1:407–411. doi:10.1890/1540-9295(2003)001[0407:ESDNAC]2.0.CO;2

Halwart M (1994) The golden apple snail *Pomacea canaliculata* in Asian rice farming systems: present impact and future threat. Int J Pest Manag 40:199–206

Heller J (1993) Land snails of the land of Israel. Natural history and a field guide. Ministry of Defence, Israel (in Hebrew)

Jaffe S (1988) Climate of Israel. In: Yom-Tov Y, Tchernov E (eds) The zoogeography of Israel the distribution and abundance at a zoogeographical crossroad. Dr. W. Junk Publishers, Dordrecht, pp 79–94

Kinzie RA (1992) Predation by the introduced carnivorous snail *Euglandina rosea* (Ferussac) on endemic aquatic lymnaeid snails in Hawaii. Biol Conserv 60:149–155. doi:10.1016/0006-3207(92)91248-Q

Lavergne S, Molofsky J (2007) Increased genetic variation and evolutionary potential drive the success of an invasive grass. Proc Natl Acad Sci USA 104:3883–3888. doi:10.1073/pnas.0607324104

Lowe S, Browne M, Boudjelas S, De Poorter M (2000) A selection from the Global Invasive Species Database. 100 of the World's Worst Invasive Alien Species. Published by The Invasive Species Specialist Group (ISSG), a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12 pp. First published as special lift-out in Aliens 12, December 2000. Updated and reprinted version: November 2004

Mienis HK (1973) *Eobania vermiculata* (Muller) in Israel (Gastropoda, Helicidae). Argamon Isr J Malacol 4:9–10

Mienis HK (2003) A new colony of *Rumina saharica* discovered in Israel. Tentacle 11:11–12

Mienis HK (2004) List of freshwater molluscs known to have been introduced in Israel. Tentacle 12:16–18

Mienis HK, Ortal R (1994) The names of fresh-water and terrestrial mollusks in Israel (with indication of endangered species). The Nature Reserve Authority, Jerusalem (in Hebrew)

Moran S (2004) The prevention of snail introductions. Yevul See 7:36 (in Hebrew)

Morgan JAT, Dejong RJ, Snyder SD, Mkoji GM, Loker ES (2001) *Schistosoma mansoni* and Biomphalaria: past history and future trends. Parasitology 123(Supp):S211–S228. doi:10.1017/S0031182001007703

Naylor R (1996) Invasions in agriculture: assessing the cost of the golden apple snail in Asia. Ambio 25(7):443–448

Robinson DG (1999) Alien invasions: the effects of the global economy on nonmarine gastropod introductions into the United States. Malacologia 41:413–438

Roll U, Dayan T, Simberloff D (2007a) Non-indigenous insect species in Israel and adjacent areas. Biol Invasions 9:629–643. doi:10.1007/s10530-006-9064-y

Roll U, Dayan T, Simberloff D, Goren M (2007b) Characteristics of the introduced fish fauna in Israel. Biol Invasions 9:813–824

Roll U, Dayan T, Simberloff D (2008) Non-indigenous terrestrial vertebrates in Israel and adjacent areas. Biol Invasions 10:659–972. doi:10.1007/s10530-007-9160-7

Roman J (2006) Diluting the founder effect: cryptic invasions expand a marine invader's range. Proc R Soc Lond B Biol Sci 273:2453–2459. doi:10.1098/rspb.2006.3597

Saltonstall K (2002) Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. Proc Natl Acad Sci USA 99:2445–2449. doi:10.1073/pnas.032477999

Smith BJ (1989) Traveling snails. J Med Appl Malacol 1:195–204

Tchernov E (1971) Freshwater molluscs of Sinai-Peninsula. Isr J Zool 20:209–221

Teo SS (2003) Damage potential of the golden apple snail *Pomacea canaliculata* (Lamarck) in irrigated rice and its control by cultural approaches. Int J Pest Manag 49:49–55. doi:10.1080/713867835

Vagvolgyi J (1975) Body size, aerial dispersal, and origin of pacific land snail fauna. Syst Zool 24:465–488. doi:10.2307/2412906