Impact of introduced gastropods on molluscan communities, northern North Island

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Summary

1. At least 29 gastropod species (the majority slugs) have been inadvertently introduced to New Zealand following the arrival of Europeans, and there is evidence that further species are arriving (the recent arrival of *Coneuplecta calculosa).*

2. Most of the introduced molluscs are herbivorous and many have become agricultural pests. Several, notably *Oxychilus cellarius* and *O. draparnaudi* are carnivorous and may be serious predators of the native land snail fauna.

3. Most records of introduced gastropods are from the vicinity of human settlements and disturbed natural areas. It is unclear whether this reflects real habitat preferences or spreading rates from release points, or perhaps uneven sampling effort.

4. The diversity of native mollusc fauna is highest in undisturbed native vegetation,and lowest in disturbed habitats. Introduced gastropod distribution is a mirror image of this, but too little information is available to determine if the relationship is causal.

5. A lack of standardisation in snail collecting techniques means information on past and present native landsnail diversity is too variable to draw conclusions as to whether some observed changes in diversity are due to predation by introduced gastropods or competition with them.

6. There are enough overseas examples of native mollusc faunas being wiped out by the introduction of very successful introduced gastropod species to take the threat in New Zealand seriously. Consequently it is recommended that:

   a) A number of representative sites are selected within which both the diversity and density of snail populations are regularly monitored using standardised techniques.

   b) The ecology of potentially the most dangerous introduced gastropods (*Oxychilus* and perhaps *Arion* species) be investigated via literature reviews from their country of origin together with the role they have taken up in the New Zealand environment. Study subjects include diet in New Zealand and potential to invade undisturbed natural areas in New Zealand.

   c) The seasonal abundance and ecology of the land snails most at risk of predation/competition with introduced gastropods be investigated.

1. Background

Coastal broadleaf and kauri/podocarp forest remnants in the Auckland Region support very species-rich communities of micro-molluscs. Over 60 species are known to live together in a small patch of coastal broadleaf forest (Waipipi Scenic Reserve (ScR), Awhitu Peninsula, SW Auckland), which is high compared with other regions of the world (Solem et al. 1981). A few other rich sites exist in the Hunua Range, SE Auckland and the Waitakere Ranges (Goulstone 1983, 1990). Interpatch faunal differences are relatively large with individual patches supporting different sets of species, depending on the structure of the forest habitat, topography and floral composition (Mahlfeld 1990). Over the last few years, however, concern has increased about introduced gastropods invading the habitat of native terrestrial molluscs.

Introduced gastropods are particularly common in the Auckland region around dwellings, in pasture, in crop fields and nurseries, but some species also occur in native forests modified by human activities. Repeated sampling in Waipipi ScR over the last two years has indicated lower numbers of species and individuals coupled with high numbers of introduced gastropods (on one occasion only 9 native species were collected from 15 litres of puriri litter and on another occasion over one-hundred introduced slugs were sighted, J. Goulstone, pers. comm.). It seemed that the diversity in this remarkable reserve had plunged considerably, and further assessment of the impact of introduced gastropods on the native fauna was initiated.

2. Introduction

Many of the 29 species of introduced gastropods were first recorded in the literature last century. Some were introduced so early that they were described as native species. Most of the introduced terrestrial molluscs are commonly found in gardens, nurseries, pastures, roadsides, cropfields and market gardens, but some of them also penetrate into native forest patches.

Appendix 1 provides a short profile for each known introduced species with regard to their distribution, diet, habitat and pest status in New Zealand and the possible time of introduction to the native fauna (the reader is referred to Barker (1999) for more detailed taxonomic and historic information on each species).

Cochlicopa lubrica, Oxychilus cellarius, Oxychilus draparnaudi, Arion hortensis, A. intermedius, and *Cantareus aspersus* are more frequently found in native forests than other introduced gastropods, but *Milax gigates, Deroceras panormitatum, D. reticulatum, Coneuplecta calculosa, Candidula intersecta, Lehmannia nyctelia., Limax maximus* and *Vallonia excentrica* have also been collected from forests. Although most introduced gastropods invade mainly disturbed forest remnants in coastal situations, *Arion interme-*

dius has also been found several kilometres into forests probably aided by logging (Barker, 1999, p.50).

3. Objectives

The primary objective is to assess the impact of introduced gastropods on the native terrestrial molluscan fauna in the northern half of the North Island on the basis of existing knowledge in the literature and among collectors. For this purpose the following questions were considered:

- Is the diversity of the native land snail fauna in forest remnants in the northern half of the North Island (a) significantly reduced following the arrival of introduced gastropods or (b) significantly lower when introduced gastropods are present than in sites where they are not present?

- What information is available in the literature and amongst experts on the introduced species involved as to: (a) understanding the mechanics of predation/competition likely to have caused any observed changes, and (b) any appropriate methods of control?

- What steps can be taken to mitigate the impact of introduced gastropods?

4. Material studied

Species lists of 55 samples from the Hunua Range, 86 samples from South Auckland forest remnants (Goulstone 1990), 86 samples from the Waitakere Range (Goulstone 1983), 6 samples from forest remnants on Awhitu Peninsula, SW Auckland (including Waipipi Scenic Reserve), 5 samples from Maunganui Bluff, NW of Dargaville and 10 samples from around Waimarama, S of Hastings, Hawkes Bay (Maraetotara Scenic Reserve, Maraetotara Gorge ScR and Mohi Bush) were analysed in order to assess the reduction of diversity due to the presence of introduced gastropods. Species lists of all the 248 sampling sites and maps of the localities are provided in the appendices.

5. Evidence of loss of diversity

The lack of substantial litter samples before the large-scale destruction of the forest cover by humans, makes it impossible to determine exactly the number of species lost in a certain area. Prior to the mid-seventies, collecting of land

snails in New Zealand was mainly carried out by eye without taking litter samples. For this reason, many of the samples taken preceding the 70s will only reveal a fraction of the fauna found at a particular spot, and therefore mostly recent samples have been considered for this report.

5.1 DIVERSITY FOLLOWING THE ARRIVAL OF INTRODUCED GASTROPODS

Introduced species have been present in Waipipi Scenic Reserve for at least 20 years (Solem et al. 1981). A severe reduction in the number of species and snails in general was first noticed in October 1997, and snails were also scarcer in December 1997 and October 1998, when J.F. Goldstone revisited the reserve. In October 1998 only a small portion of the resident species was found, in stark contrast to the situation described in Solem et al. (1981), when snails were particularly plentiful.

Arion hortensis and *Cochlicopa lubrica* were the most common introduced species found in the reserve in March this year. *C. lubrica is* known from a wide variety of habitats, such as grasslands, woods, arable land and gardens in its native holarctic range. Little is known about the biology of this species in New Zealand: The snails reach maturity after approx. 2 years and live for at least another year. Reproduction seems to occur all year round and densities of up to 577 snails per square metre in grassland have been reported from grasslands in Europe and N America (Barker 1999). The snails feed on green and decomposed plant material.

Arion hortensis is an annual species and breeds from autumn to spring. It feeds on fungi and decaying leaf material (Barker 1999).

During the most recent survey (March 1999) high numbers of individuals of species tolerant to disturbance, such as *Laoma mariae*, *L. ariel*, *Discocharopa eta* and *Liarea hochstetteri carinella* and the introduced slug *Arion hortensis*, were collected. Whether changes in the faunal composition and structure of the landsnail community are taking place has to be seen. Despite the presence of introduced slugs and snails, the diversity is still high in Waipipi ScR, but the greatly varying numbers of species reported over the last two years could indicate a deterioration of the habitat due to a bloom of introduced gastropods.

B.F. Hazelwood collected *Laoma (Punctum) "brunneum"* n.sp. in 1977 but this species has not been collected again. *Laoma moellendorffi* was collected in 1981 and 1989 but has not been collected again. This species reaches its southern limit near Waikato and has a patchy distribution. The native carnivorous *Delos jeffreysiana,* which is only ever collected in small numbers, has not been re-collected in Waipipi Scenic Reserve since 1981, and is also scarce in Goldstone's Hunua survey (collected in 6 out of 55 samples).

From the existing data for Waipipi ScR it is impossible to determine whether the decline in numbers of individuals is primarily due to previous dry sum-

mer weather or to predation and competition from introduced species or a combination of both factors.

The South Auckland sites outside the Hunua Ranges were divided by Goulstone (1990) into the following categories: "sites with secure reserve status which have retained bush from earlier days with a largely unmodified snail fauna"; "modified bush in secure reserves ... old farmlots where the trees can be quite magnificent but some have been damaged by other means and the snails greatly modified" (other means are for example browsing and trampling by stock); and "threatened sites". Of the South Auckland remnants, only patches of the first category contain reasonable numbers of species (Appendix 4): Combined samples from Raventhorpe ScR, N of Bombay Hills (sites 25-27, 44 species); Ngaheretuku Forest & Bird Reserve, Clevedon (sites 12, 13, 49 spp.); Wairoa Gorge ScR (sites 14-16, 52 spp.); Ponga Road Reserve (site 6, 45 spp.) and Point View Drive, Howick (sites 16-19 - private forest remnant, 40 spp.) produced 40 or more species.

Introduced gastropods are more often found in disturbed forests than undisturbed habitats. Goulstone's South Auckland samples show that the mean number of species per sample is smaller (up to 10-11 species) in more disturbed forests than less modified patches. Introduced gastropods were most common in the threatened sites (Appendix 6) and old farmlots (Appendix 7) outside the Hunua Ranges. Only 4 of the 34 samples (11.8 %) of the first category of sites contained introduced gastropods in comparison to 11 of 23 samples (47.8%) of the second category of sites and 13 of 29 (44.8%) of the threatened sites (Appendix l0).

"Sites 8, 9 & 10 in threatened sites (Kirkbrides Bush) was a piece of coastal bush not very wide - on the bank between the farm and a harbour beach. The bush was subject to a considerabe amount of spray from the harbour as it faced the prevailing wind & the harbour was wide at this point. From 1977-83 it contained about 15 native species some in large numbers. When the Auckland airport runway was built this beach was in an enclosed bay which quickly became choked with mangroves - right up to the beach. Although the bush remained the same, and in some ways flourished, within two or three years the native snail population disappeared, to be replaced by *Oxychilus cellarius* in big numbers. Today just an odd *Therasia decidua* can be found and *Dorilaoma marshalli* on some surviving coastal flax" (J.F. Goulstone in a letter from May, 1999).

There was little evidence of damage caused by introduced gastropods as fas as the native land snail fauna of the Hunua Range is concerned. Goulstone collected *Oxychilus cellcarius* near Cossey's Dam under tawa near the picnic area (site 4) and under *Blechnum* near the road (site 6, grid references in Appendix 9.). *Cochlicopa lubrica* was also recorded from site 4. More recent data on the spread of introduced gastropods into the Hunua Range are unfortunately not available, and it is not known whether introduced gastropods have actually spread further into the Hunuas from peripheral sites in the last ten years.

A total of 98 terrestrial molluscs were collected by Goulstone in the Hunua Ranges (Appendix 3). The most diverse localities were then sites 18-22 be-

low the Upper Mangatawhiri Dam (59 species) and sites 26-28 along the Moumoukai-Wharau Track (58 species, grid references in Appendix 9). The average number of species Goulstone collected in a bag of 1-4 litres of litter is 19 species, slightly less than the average number of species in a bag of litter from South Auckland " secure sites" outside the Hunua Ranges (see below) which holds 22-23 species.

It is very fortunate to have the material collected by A. Hamilton in the first decade of this century (J.F.Goulstone, pers. comm.) from a flood margin of a stream near Waimarama. The data indicate that c.40 species would have lived together in undisturbed conditions if not even more (Appendix 7, Figure 2). The total number of terrestrial species recorded from the area around Waimarama, Hawkes Bay is over sixty. There are now far less species surviving in Maraetotara Gorge Scenic Reserve, a small strip of riverine bush with limestone outcrops surrounded by farmland. Samples taken in 1976 and 1992 from this remnant produced 26 species, which is less than the number of species still present in nearby Maraetotara ScR (32 spp.) and Mohi Bush Scenic Reserve (41 spp.). Introduced open country *Candidula intersecta* was collected from Maraetotara Gorge ScR and Maraetotara ScR and *Cantareus aspersus* and an introduced slug were also collected from Maraetotara ScR. No introduced species were recorded for Mohi Bush ScR, the site with the highest number of native species, but this may be due to collectors ignoring introduced species because they did not pay much attention to introduced species until rather recently.

Oxychilus was only collected once from Maunganui Bluff, N of Dargaville by D.J.Roscoe in 1976 (Appendix 8). But *Deroceras panormitatum*, *D.* (*Agriolimax*) *reticulatum*, *Cantaeus aspersus* are reported from gardens and coastal cliffs in Barker (1999). Unfortunately, there are no more recent samples from the reserve at Maunganui Bluff to establish whether other introduced species are invading the reserve and what the causes are for the reduction in species numbers since 1976.

Many of the introduced slugs and snails were brought into the country in the last century, but collection data do not date back further than the 1970s (see Barker 1999), and definite information about the number of species before and after the introduction of introduced gastropods in a particular patch seldom exists. Reports from overseas (see chapter 6) suggest that predation by *Oxychilus* spp. reduces the number of native species.

5.2 DIVERSITY WHEN INTRODUCED GASTROPODS ARE PRESENT

Remnants with introduced gastropods are on average species-poorer than patches without introduced species. Most of the sites, however, were only collected once by J.F. Goulstone. In order to confirm this initial result Goulstone's survey needs to be repeated to confirm a trend.

The average number of species per litter bag is highest for reserves with some old bush left (22-23 spp.), while old farmlots harbour fewer species on aver-

age (13-14 species) despite remaining stands of old trees because other disturbances such as browsing and trampling had a detrimental impact on the litter fauna, which has not recovered to reach former diversity levels again. Threatened sites (mainly highly modified patches) produced an average number per litter sample of 11-12 spp.

6. Mechanics of predation/ competition by introduced gastropods

6.1 STUDIES IN NEW ZEALAND

The impact of introduced gastropods on the native terrestrial molluscan fauna has not been studied systematically yet. There is anecdotal information in surveys published by collectors, and the general impression among collectors is that, in sites where introduced slugs and *Oxychilus cellarius* are present, fewer native snails survive.

Oxychilus cellarius and *Oxvchilus draparnaudi* are omnivorous. They prey on snails and slugs and their eggs (Taylor 1906-14; Cotton 1954; von Proschwitz 1994). Barker (1999) has observed that *Oxychilus cellarius* feeds on native species such as *Charopa coma* (Gray), *Chaureopa roscoei* Climo, *Flammocharopa costulata* (Hutton), *Flammulina cornea* (Hutton), *Cavellia buccinella* (Reeve), *Allodiscus dimorphus* (Pfeiffer) and *Laoma mariae* (Gray). This suggests that *Oxychilus cellarius* preys on a range of native species of different sizes, and has not got any particular preference of prey. *Chaureopa roscoei* is a rare species only known from few localities in the Raukumara Peninsula-East Cape area (Haha Station, Tikitiki, Zl4/937707, D.J.Roscoe, 1978, Te Kaha, X14/266735, PMayhill, 1986, for example). *Flammulina cornea is* known from few localities in Northland, Coromandel, Little and Great Barrier Islands and the Hunua Ranges. If local populations of these species are being wiped out by *Oxychilus*, this could ultimately threaten the survival of these two species. Grafton Gully in Auckland has its own endemic species of *Delos,* which has been just recently discovered by D.J. Roscoe and B.F. Hazelwood (pers. comm.). It is feared, however, that the abundant introduced gastropods, including *0xychilus,* are going to wipe out the remaining scattered populations of native species. Recent surveys have shown that, in some places in Grafton Gully now, only introduced species survive.

Little is known about the biology of most native species and little is known about the biology of the introduced species here in New Zealand, e.g. life cycle, behaviour and diet. Solem et al. (1981) and Solem & Climo (1985) and Mayhill (l 993) have published biological information based on field observations and terrarium studies, but these cover only a fraction of the fauna and only certain aspects, such as niches, incubation time of eggs, and growth rates of some species. Efford (1998) gives the latest information on the distribu-

tion, feeding behaviour and status of the carnivorous *Wainuia* and *Rhytida*. No quantitative studies exist on interactions between introduced and native gastropods.

6.2 OVERSEAS STUDIES

> "Habitat destruction and modification, over-collecting by shell collectors, and predation by accidentally introduced animals (notably rats but also ants and predatory flatworms) have certainly been important factors in the extinction of Pacific island land snails, but the deliberate introduction of carnivorous snails (most significantly *Euglandina rosea* but also *Gonaxis* spp.) on many Pacific islands (and elsewhere) has intensified the threat to these unique faunas to an extent that many species have gone extinct in the last few decades and many others are seriously endangered" (Cowie 1996, p.353).

The molluscan fauna of the Pacific islands has suffered severely from the impact of introduced gastropods. The carnivorous *Euglandina rosea* (Ferussac) was introduced to the Society Islands in 1977 to control the giant African snail *Achatina fulica* Bowdich, which had become an agricultural pest on the islands, but as a result the endemic *Partula* is now at the brink of extinction. *Euglandina* is also threatening species of *Samoana* Pilsbry and *Trochomorpha* Albers (Murray 1987; Murray et al. 1989; Wells 1988; Gerlach 1993). On Hawaii *Euglandina. is* responsible for the extinction of at least half of the 44 species of the endemic *Achatinella* Swainson (Hadfield 1986). Introduced ants probably caused the extinction of more than 100 species in the family Endodontidae (Wells 1988, Solem 1990).

The introduced *Oxychilus draparnaudi* has been found to have an impact on native species in the United States. Differences in the land snail faunas with and without *Oxychilus draparnaudi* in adjacent areas in Iowa suggest that this species is responsible in the decline of local populations of some native species (Frest & Sanders Rhodes 1982).

7. Appropriate methods of control

The spread of introduced gastropods is so closely linked with a variety of human activities, e.g. transporting of soils, seeds and plants, milling, farming, aerial topdressing and clumping of rubbish, that controlling their spread seems impossible. Buffer zones of scrub would probably slow clown the spread of introduced gastropods from the surrounding farmland and urban habitats into the forest and also help retain moisture levels within smaller remnants.

8. Conclusions

Remnants with introduced gastropods are on average species-poorer than patches without introduced species. Goulstone's South Auckland samples show that the mean number of species per sample is smaller (up to 10-11 spp.) in more disturbed forests than less modified patches, and introduced gastropods were also more often found in the more disturbed sites.

Rapid loss of habitat due to human activities is most likely the primary cause of the reduced diversity found in forest remnants. Introduced gastropods are becoming more widespread throughout Northland, Auckland, Waikato, Bay of Plenty and East Cape and have the potential to cause further decline of local populations of native molluscs as observations here and overseas suggest.

Introduced gastropods are likely to put additional stress on local faunas and species, particularly during dry weather, because large slugs or snails put further strain on the availability of moisture-retaining spaces, e.g. under rocks, pieces of wood or logs, depressions in the forest floor. *Oxychilus cellarius* and *0. draparnaudi* feed on native micro-molluscs and their eggs. Other introduced herbivorous species may compete with native species for the same food resources.

Many species are collected in low numbers, suggesting that communities are composed of mainly small species populations and few dominant species. Species with small populations will be more vulnerable to predation/competition than the more common ones.

9. Recommendations

1) Carry out additional surveys in Waipipi Scenic Reserve to establish which species *Oxychilus* preys on and which species have become extinct.

2) Assess properly the damage caused by the introduced *Prietocella barbara* to the Northland endemic *Succinea archeyi.*

3) Determine whether the native carnivorous *Delos jeffreysiana* is in decline, and whether it is due to competition with *Oxychilus.*

4) Update Molloy & Davis (1992) with respect to minute land snails.

5) Standardise sampling procedures.

It would be sensible to standardise sampling procedures among collectors and provide technical recommendations for collecting snails with issued permits, e.g. the need to record the sample size and type of litter to ensure that better comparisons between data are possible in future.

Additional surveys following wetter weather will reveal whether some of the populations have crashed beyond recovery in Waipipi Scenic Reserve. This and other reserves are very suitable for monitoring the impact of introduced gastropods because they are situated in farmland in an area that is diverse in land snails and records of previous surveys exist. In Appendices 9 & 11 data are included from the Waitakere Range. According to J.F. Goldstone (pers. comm.) records or specimens of introduced gastropods were not kept although introduced gastropods were seen at times. Since the Waitakere Range data provide useful information on the species diversity in this particular area of Auckland,they have been included for future reference.

Succinnea archeyi (Powell), found living on foredunes in Northland, is threatened by *Prietocella barbara* (Linneaus) (R. Parrish, DOC, Whangarei). The extent of the damage caused by *Prietocella barbara.* needs to be assessed and measures of control need to be devised and implemented. *Succinea archeyi* should be listed in the next revised edition of Molloy & Davis (1992).

The carnivorous native species *Delos jeffreysiana* is found in Northland, Auckland, Coromandel, Volcanic Plateau, Taranaki and Waikato. These are areas where introduced gastropods are most common. *Delos jeffreysiana* has not been re-collected since 1976 from Maunganui Bluff, N of Dargaville and was last collected in 1981 in Waipipi Scenic Reserve. Its conservation status needs to be assessed properly. This in fact is lacking for most species of the small land snails. Currently more than 200 species of micro-molluscs are known only from few areas and few specimens. Many of these have not been re-collected for the last 10-20 years. The welfare of these taxa is unknown. The available data on *Delos jeffreysiana* are not sufficient to determine beyond doubt whether *D. jeffreysiana* has suffered from the impact of introduced gastropods. There is a possibility of predator pressure from the introduced carnivorous *Oxychilus cellarius* but this needs to be ascertained. Further fieldwork is necessary to establish whether this species has disappeared from Waipipi ScR and Maunganui Bluff and, if so, whether it is due to the impact of introduced gastropods.

Logging and mining operations further the spread of introduced gastropods into large tracks of native forests. This should be monitored more closely to evaluate the impact.

Species in coastal habitats, dunes, cliffs, grassland, flax and scrub are likely to decline due to the impact of introduced gastropods. The groups concerned are species of the genus *Therasia* Hutton, *Tbalassohelix zelandiae* (Gray) - complex, *Thalassohelix igniflua* (Reeve), and *Phacussa prousei* (Powell). *Therasia thaisa* (Hutton) and 10 related undescribed species live in open country habitats; e.g. limestone outcrops, coastal cliffs and forest margins in the eastern part of the South Island. These are also sites where introduced species thrive. Most of the *Therasia* species are local endemics and are only known from few specimens. A threat from introduced species cannot be entirely excluded without closer examination.

The commonest stage of forest fragmentation is now small to moderate patches in a matrix of agricultural land, infrastructure and settlements. Small fragments have small populations with higher probabilities of extinction (Merriam

& Wegner 1992). Yet we do not know any local extinction probabilities of species. There is no knowledge of interpatch connectivity values, which affect local extinction rates, and the effects of isolation within particular landscapes. Unless investigation targets whole landscape mosaics, these questions cannot be answered, yet they are crucial for conservation management. While patchiness may enhance survival chances for organisms with good means of dispersal, for slow dispersers, such as terrestrial micro-molluscs, habitat fragmentation is detrimental to their long-term survival. Collecting in secondary regrowth, for example, usually produces few native species indicating that the re-establishment of native species takes a long time to occur after habitat destruction.

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Appendix 1: Introduced gastropods of New Zealand

	Distribution	Habitat	Diet	Pest status	First records in New Zealand
AGRIOLIMACIDAE (slugs)					
Deroceras laeve (Müller)	AK, WO (Map 1)	nurseries, greenhouses, gardens, wet pastures,stream banks	omnivorous, cannibalistic; living plant material, litter with faeces, carrion, earthworms, aphids, mealybugs, insect caught in spider webs	pest in cultivations plants (floriculture)	1950? (Barker, 1999)
Deroceras panormitanum (Lessona & Pollonera)	Kermadec Is, ND, AK, CL, WO, BP, TO, GB, TK, HB, WI, WN, WA, NN, BR, KA, MC, WD, SC, DN, Chatham Is (Map 2)	pastures, nurseries, greenhouses, gardens, commercial food crops, forest edges, disturbed forests, *Phormium*, roadsides, scrubland	living and decaying plant material; cannibalistic	pest in pastures, nurseries, greenhouses, gardens, commercial food crops	1890? Musson (1891)
Deroceras (*Agriolimax*) *reticulatum* (Müller)	ND, AK, CL, WO, BP, GB, TO, TK, HB, WI, WN, NN, BR, KA, MC, WD, SC, DN, CO, Stewart, Chatham, Auckland, Campbell islands (Map 3)	gardens, parks, roadsides, pastures, arable fields, nurseries, disturbed forest		pest in pastures and food crops (asparagus)	Hutton (1881)
ARIONIDAE (slugs)					
Arion distinctus Mabille	AK, WO, BP, WI, NN, DN (Map 4)	under stones, pieces of wood in gardens, parks, disturbed habitats		pest in vegetable crops	late last century (Barker, 1999)
Arion hortensis d'Audebard de Férussac	ND, AK, CL, WO, BP, GB, TO, TK, WI, WN, SD, NN, MB, MC, BR, DN (Map 5)	under stones and pieces of wood, tussock-forming grasses in gardens, coastal forest remnants, forest fringes and clearings, arable land, roadsides, commercial food crops, coastal grassy areas	fungi, decaying leaf materials	pest in vegetable crops	Musson (1891)
Arion intermedius Normand	ND, AK, CL, WO, BP, TO, GB, TK, RI, WI, WA, WN, NN, BR, KA, WD, MC, OL, CO, DN, SL, Stewart, Chatham, Auckland Is (Map 6)	hedgerows, scrubland, plantation forest, native forest, pasture, coastal grassy areas			late last century (Barker, 1999)

Appendix 1: Introduced gastropods of New Zealand

	Distribution	Habitat	Diet	Pest status	First records in New Zealand
LIMACIDAE (slugs)					
Lehmannia nyctelia (Bourguignat)	ND, AK, WO, BP, WI, WN, NN (Map 7)	under rocks, logs, pots in gardens, nurseries	living plant material		Barker (1979); introduced in 1970s
Lehmannia valentiana (d'Audebard de Férussac)	AK, WO, TK (Map 8)	greenhouses, nurseries, gardens	living plant material?		1979 (Barker, 1999)
Limacus flavus (Linnaeus)	AK, WO, BP,TK, WN, BR, MC, DN, SL (Map 9)	around domestic dwellings, gardens, roadsides, parks, pasture	decaying vegetable matter, fungi, lichens		Hutton (1879)
Limax maximus Linnaeus	ND, AK, CL, WO, BP, GB, TO, TK, WN, NN, BR, DN (Map 10)	forest margins, disturbed forest and secondary forest, shelter belts, plantation forest, gardens, drift timber, roadsides	decaying plant material, fungi, compost, carrion		Hutton (1879)
MILACIDAE (slugs)					
Milax gagates (Draparnaud)	ND, AK, CL, WO, BP, GB, TK, HB, WI, NN, SC, DN, Chatham Is (Map 11)	gardens, nurseries, field crops, pastures, disturbed coastal forest	living plant material?	pest in potato and carrot crops	1840 (Gould, 1852; Barker, 1999)
Tandonia budapestensis (Hazay)	ND, AK, WO (Map 12)	gardens, nurseries, greenhouses, pasture	living plant material?	pest in root crops (potatoes)	Barker (1979)
Tandonia sowerbyi (d'Audebard de Férussac)	AK, WO, GB, TK, HB, WI, MC, SC (Map 13)	pasture	living plant material?	pest in root crops (potatoes)	Barker (1979)
TESTACELLIDAE (slugs)					
Testacella haliotidea Draparnaud	AK, GB, HB (Map 14)	gardens, pasture	earthworms, slugs, snails, soil animals		Hutton (1881)
COCHLICOPIDAE					
Cochlicopa lubrica (Müller)	Kermadec Is, ND, AK, CL, WO, BP, GB, TK, HB, WI, WN, NN (Map15)	gardens, disturbed forests	living and decaying plant material		Crosse (1893)
EUCONULIDAE					
Coneuplecta calculosa (Gould, 1852)	CL (Map 16)	broadleaf forest	?		1995 (Barker, 1999)

Appendix 1: Introduced gastropods of New Zealand

	Distribution	Habitat	Diet	Pest status	First records in New Zealand
FERUSSACIIDAE					
Cecilioides acicula (Müller)	AK, BP (Map 17)	gardens, cementries, dry pastures, grassy areas	fungi?, fine roots?		Suter (1913)
HELICIDAE					
Cantareus aspersus (Müller)	ND, AK, CL, WO, BP, TO, GB, RI, TK, HB, WI, WA, WN, SD, NN, KA, BR, NC, MC, DN, Chatham Is (Map 18)	gardens, coastal dunes and cliffs, disturbed coastal forests	living and dead plant material		1860 (Barker, 1999)
HELICODISCIDAE					
Helicodiscus (*Hebetodiscus*) *singleyanus* (Pilsbry)	CL, BP, WO, TO, TK, NN, MC (Map 19)	subterraneous water sources, pasture, limestone shingle, alluvial deposits	?		1970 (Climo)
HYGROMIIDAE					
Candidula intersecta (Poiret)	ND, CL, WO, BP, GB, RI, HB, WI, WN, KA, MC, SC, Stewart Id (Map 20)	coastal dunes, limestone outcrops, open scrub, pasture	?		Suter (1891)
Prietocella barbara (Linnaeus)	ND, AK (Map 21)	coastal dunes and cliffs, lucerne, dry pastures	living and decaying plant material		1979? (Barker, 1999)
PUPILLIDAE					
Lauria cylindracea (da Costa)	ND, AK, CL, WO, BP, NN (Map 22)	coastal dunes and cliffs, gardens, grassland, rockwalls	?		1940s? (Barker, 1999)
VALLONIIDAE					
Vallonia excentrica Sterki	Kermadec Is, ND, AK, CL, WO, BP, GB, TO, TK, HB, WN, NN (Map 23)	coastal dunes and grasslands, pastures, roadsides, disturbed coastal forest	?		Crosse (1893)
VERTIGINIDAE					
Vertigo ovata (Say)	ND, AK, CL, WO, BP, WI, GB (Map 24)	limestone outcrops, pasture, grassy areas adjacent to forests,	?	?	1950s? (Barker, 1999)

Appendix 1: Introduced gastropods of New Zealand

	Distribution	Habitat	Diet	Pest status	First records in New Zealand
ZONITIDAE					
Oxychilus allarius (Müller)	ND, AK, CL, WO, BP, GB, TK, WI, WN, NN, MC (Map 25)	greenhouses, gardens, roadsides, hedgerows, parks, plantations, pastures, disturbed coastal forest	living plant material		Musson (1891)
Oxychilus cellarius (Müller)	ND, AK, CL, WO, BP, GB, TK, HB, RI, WI, WN, NN, BR, MC, WD, SC, DN (Map 26)	pasture, gardens, parks, scrubland, roadsides, native forest	slugs, snails, eggs of slugs and snails		Pfeiffer (1862)
Oxychilus draparnaudi (Beck)	ND, AK, WO, CL, BP, TK, WI, NN (Map 27)	gardens, exotic plantations, grassy wasteland, disturbed native forest	omnivorous; molluscs and their eggs		1880s (Suter, 1904; Barker, 1999)
Vitrea crystallina (Müller)	ND, AK, CL, WO, HB, NN, BR, DN (Map 28)	limestone outcrops in pasture, scrubland, roadsides	decaying plant material, snails		Crosse (1893)
Zonitoides arboreus (Say)	ND, AK, CL, WO, BP, HB, TK, WA, WN, MC (Map 29)	gardens, greenhouses	living plant material	pest in greenhouse cultivars (orchids, ferns)	1950? (Barker, 1999)

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