# EUROPEAN BLACK SLUG RISK ASSESSMENT FOR THE COPPER RIVER DELTA AREA, ALASKA

**September 2010**

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**ON THE COVER**

European black slug, *Arion ater*, found along the Crater Lake trail, Cordova, Alaska
Photo credit: Tracey Gotthardt

# European Black Slug Risk Assessment for the Copper River Delta Area, Alaska

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## INTRODUCTION

To date, much of the state of Alaska has remained largely free from the negative ecological impacts due to invasive, non-native animal species, yet a number of introduced invaders have begun to threaten native ecosystem integrity in localized situations. Exotic species can have far-reaching effects on local ecosystems, sometimes causing extinctions of native species through predation or competition. Exotic species often thrive in new areas because of the lack of natural predators and/or competition. In the case of slugs, a new area may offer plant resources that have not developed natural defense mechanisms (Meyers 2006).

The European black slug (*Arion ater*) is native to the British Isles and much of northern Europe and thrives in wet, cool climates. Introduction of the European black slug into Alaska likely occurred within the past 20 to 25 years. Documented occurrences of this species are generally restricted to southeastern and southcentral Alaska coastal areas (Meyers and Harris 2005, Meyers 2006, C.Knight, Alaska Division of Agriculture, pers. comm.). New sightings of black slugs in recent years have increased the known range of the species in the state, particularly around the community of Cordova and surrounding Chugach National Forest. Surveys conducted in the Cordova area during 2005 and 2006 found that black slugs were especially prevalent near disturbed and heavily populated areas (Meyers and Harris 2005, Meyers 2006). The observed occurrence of slugs along roadways and in areas of heavy human use suggested the species range was expanding along roadways and trails. While some of the spread could be attributed to natural expansion, the occurrence of slugs in isolated pockets in areas of human use separated by large expanses of wilderness or to remote islands suggests that eggs or adult specimens are being transported in or on vehicles as well (Meyers and Harris 2005).

Invasion by exotic species has been identified as one of the major threats to global biodiversity. Loss of native species and addition of exotic species may have dramatic effects on ecosystem functioning by altering assemblages of species-specific traits, which can influence ecosystem processes (Carlsson et al. 2004). Introduced slugs have invaded many parts of the world where they are recognized as important pests of gardens and agriculture, but little is known about the effects of introduced slugs in natural areas. The effects of invasive slugs on wetlands plants and ecosystems are virtually unstudied. The ecological implications of the black slug invasion to the Chugach National Forest and Copper River Delta wetlands complex are not well researched or understood. Black slugs have been identified as a nuisance by local gardeners in the Cordova area, but it is unclear whether their introduction to the Copper River Delta area will be harmful to native species and/or ecosystem health.

**Project Need**

The USDA Forest Service recently made the identification and control of invasive species a priority issue within its public lands (Executive Order 13112 1999, Schrader and Hennon 2005). The Chugach National Forest surrounds the city of Cordova, and the European black slug has established populations within its borders, including small incursions onto the Copper River Delta (Meyers and Harris 2005, Meyers 2006). The Delta's mosaic of shallow ponds, lakes, marshes, and stream and river channels is the largest contiguous wetlands complex on the Pacific Coast of North America and is recognized for its importance as wildlife, waterfowl and fish habitat (NWF 2005). Consequently, management emphasis is on protection and enhancement of this unique and pristine habitat as well as for the native species that use the delta as a migration stopover area for breeding and rearing of young and for year-round residency. This area is commonly used by the general public and accidental introduction of slugs via vehicles or other modes of transport is highly probable. The ecological implications of the presence of the black slug in the Copper River Delta area are unclear and merit further investigation.

We developed this risk assessment to provide resource managers with the most up-to-date information regarding the current status of the European black slug in the Chugach National Forest and surrounding areas. The objectives were to summarize existing information about the distribution and invasiveness potential of the European black slug in the Copper River Delta area, and provide recommendations as to whether a control program is warranted and the likelihood of its success if implemented.

This report is divided into three sections: 1) an invasive species fact sheet that provides an overview of the biology, distribution and ecology of the species, 2) a risk assessment that rates the associated risk on a numerical scale and provides justification for the rating, and 3) a final evaluation. This risk assessment follows the format used by the Exotic Forest Pest Information System for North America, a joint project for the member organizations of the Insect and Disease Study Group of the North American Forest Commission. For a description of the evaluation process used, see Participant's Guidelines at http://www.spfnic.fs.fed.us/exfor/docs/guidelines.pdf.

# I. INVASIVE SPECIES FACT SHEET

## SPECIES DESCRIPTION

**Scientific name:** *Arion ater* (Linnaeus, 1758)

**Taxonomic Position:** Family Arionidae

**Synonyms:** *Arion rufus, Arion (arion) rufus*

**Common name(s):** black arion, European black slug, large black slug, chocolate slug, licorice slug

**Taxonomic comments**
*A. ater* was previously considered as two species *A. ater* and *A. rufus* (Quick 1947, 1949). Quick (1960) later recognized *A. ater* and *A. rufus* as subspecies of *A. ater* based on evidence of hybridization between the two forms.

The current taxonomic status of *A. ater* in Alaska is unclear. Certain experts suggest that what is currently considered the European black slug (*A. ater*) in Alaska is most likely a black color cohort of the exotic European red slug (*A. rufus*), which has been reported in the western United States for many years. Another possibility is it is a hybrid of the *A. rufus* and *vulgaris* species, an ARVC complex (C. Knight, Alaska Division of Agriculture, pers. comm. with R.G. Forsyth, University of British Columbia). The Alaska Division of Agriculture has been submitting specimens to a diagnostic laboratory on the east coast to sort out this identification, but results are currently pending.

Due to the taxonomic uncertainty and lack of clarification as to whether *A. ater* has actually ever been documented in North America, the remainder of this report will refer to the species of black slug present in Alaska as the *Arion* ARVC complex or simply the “black slug”. Whether the species proves to be *A. ater*, *A. rufus* or an Arion ARVC complex, each of these species is considered invasive to North America.

**Species identification**
The European black slug is classified as a gastropod, the class of molluscs that includes snails and slugs, and is defined by the presence of an unsegmented soft body, a large foot and a well-developed head. It is a member of the family Arionidae, with a vestigial internal shell and lacking a dorsal keel. A distinctive feature of this slug is the many grooves and ridges along the back (Featherstone 2006).

European black and red slugs are large and grow to about 180 mm long and range in color from black to brown, yellow-orange or brown-red. The sole of the foot ranges from white to black or a combination of both. Juvenile slugs display a broader range of color than adults. Adult slugs can be easily recognized by their color, large size and coarse granulation (Forsyth 2004) (Figure 1).

**Identification tests**
*A. ater* cannot be distinguished from the similar species, *A. rufus*, except by dissection of reproductive anatomy (Noble 1992). Color of the animal is not a reliable characteristic for determination of these two species. In *A. ater,* the atrium is generally more slender with its proximal portion smaller and shorter than the distal part. In *A. rufus*, the atrium is less slender,

with the proximal portion larger and much wider than the distal portion (Royal British Columbia Museum 2002).

Figure 1. Adult black slug photographed near the community of Cordova, Alaska.

**Symptoms**
Slug damage can be recognized by the distinctive holes left in the vegetation, stripped stems and the mucus trails left behind (Speiser et al. 2001). While damage is mostly cosmetic, extensive feeding can result in plant stress or death (Nielsen 1997, Hahn 2000). Other insects that do similar damage are cutworms, beetles, caterpillars, and sawflies. However, none of these leave a slime trail.

## GEOGRAPHIC DISTRIBUTION

**Global**
The European black slug (*A. ater*) is native to western and central Europe, from Scandinavia to Spain and from Ireland to Austria and the Czech Republic. It has been introduced to southeastern Australia and to North America, where it occurs in Newfoundland, southern British Columbia, the Pacific Northwest of the USA and some parts of Alaska (Featherstone 2006). As described above, identification of this species in North America is currently under debate.

The European red slug (*A. rufus*) is also native to western and central Europe; probably introduced to many places worldwide and often misidentified as *A. ater*. *A. rufus* is one of the more familiar slugs in southern British Columbia and is also introduced to the Queen Charlotte Islands (Forsyth 2004).

**Alaska**
Black slugs have been reported in and around the communities of Anchorage, Cordova, Yakutat, Gustavus, Juneau, Sitka, Tenakee Springs, Ketchikan and on Kodiak Island (Meyers and Harris 2005, Meyers 2006, Knight, unpubl. data) (Figure 2).

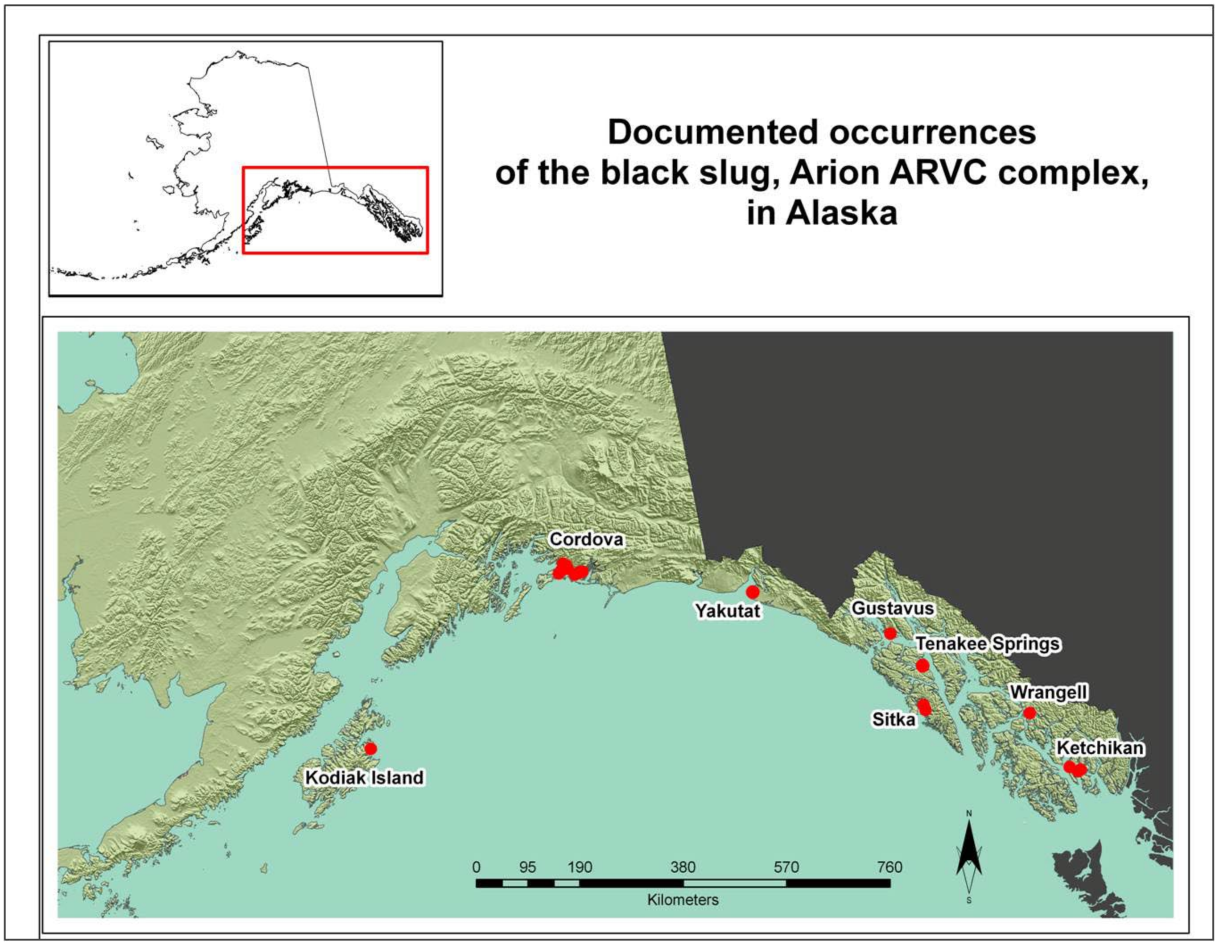


Figure 2. Documented occurrences of the black slug, *Arion* ARVC complex, in Alaska.

**History of introduction and geographical spread**

Although the exact mechanism for introduction of black slugs into the Cordova area is unknown, it is suspected they were transported as eggs or live specimens via nursery plants or potting soil that potentially originated in Washington state (Wittwer 2004, Meyers 2006), or may have arrived adhered to pallets, shipping containers or equipment that arrived at fish canneries (C. Knight, Alaska Division of Agriculture, pers. comm.). Interviews with local residents showed a large range of estimates for the time slugs have been resident in the Cordova area, dating back as far as 20 to 25 years ago (Meyers 2006). Meyers (2006) speculated that slugs have been present in the Cordova area at least that long and likely longer.

New sightings of black slugs in recent years have increased the known range of this species in the Cordova area (Meyers 2006). Slugs in Cordova were first reported in the 1980s near Cannery Point. Their distribution has gradually expanded throughout the Cordova road and trail system. Today, they are found as far east as Corona Way Creek, just west of Saddlebag Glacier Road. Surveys conducted by Meyers and Harris (2005), Meyers 2006, Knight (unpubl. data) and Gotthardt (unpubl. data) and incidental reports from Cordova residents indicate black slugs are most prevalent within a 10 km radius of town, but have also been sighted along the road system at the landfill, airport, Alaganik Slough Road and near the mouth of the slough, at Pipeline Lakes Trailhead, and at the McKinley Lake Trailhead and boat launch (Figure 3).

The reported occurrence of black slugs along roadways and in areas of heavy human use suggests that this species is spreading along transportation corridors (Meyers 2006). While some of this spread may be attributed to natural expansion, isolated occurrences of black slugs in areas of human use separated by apparent large expanses of wilderness suggests that either eggs or live specimens are being transported (Meyers 2006). For example, slugs are abundant on Observation Island (E. Cooper, USDA Forest Service, pers. comm.), which is located approximately eight kilometers by water from Cordova. Incidental sightings have also been reported from Johnstone Point on Hinchinbrook Island and the eastern end of Hawkins Island, suggesting that modes of transport are likely human mediated (Figure 3).

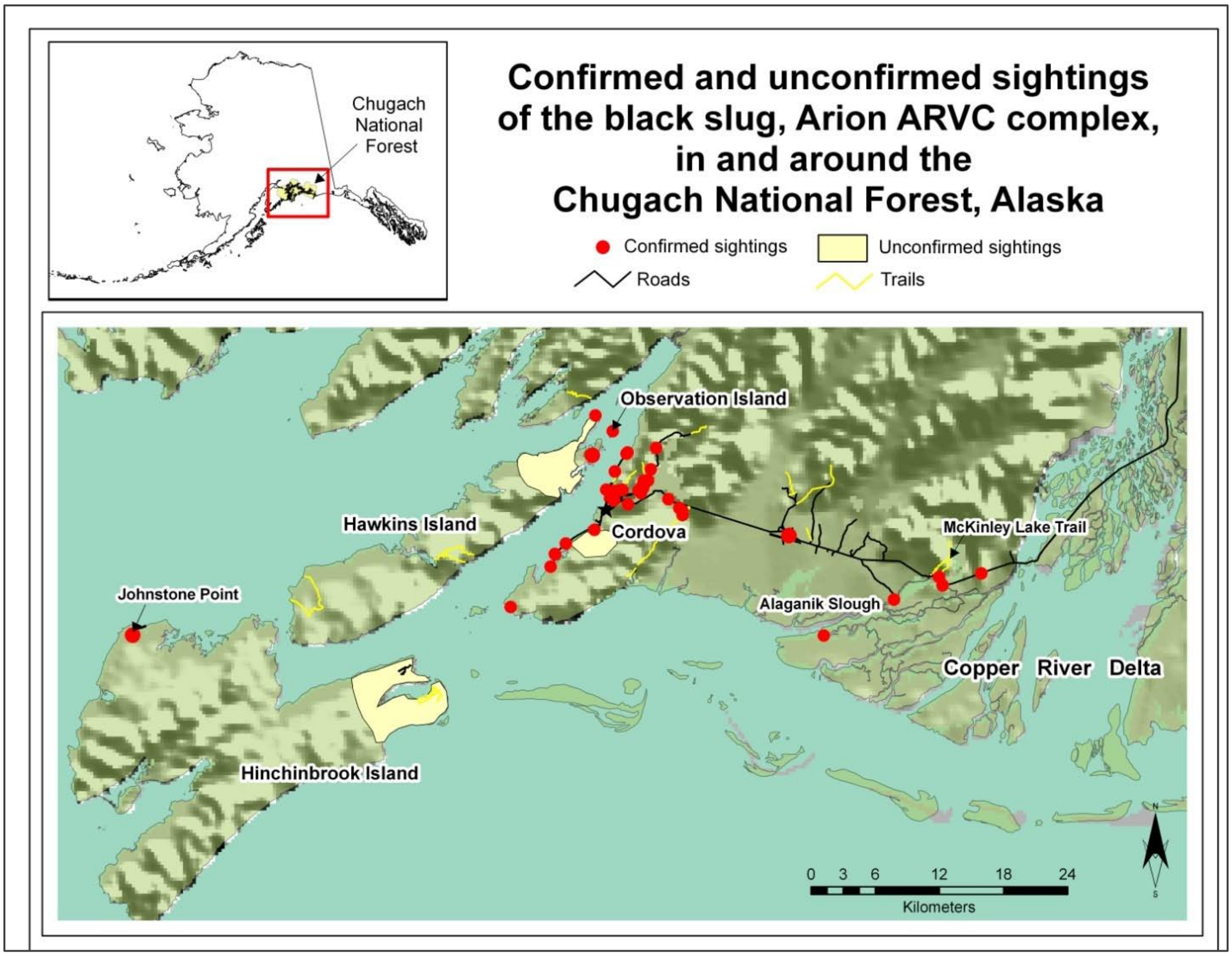


Figure 3. Documented occurrences of the black slug, *Arion* ARVC complex, in and around the Chugach National Forest, Alaska.

Black slugs have also been introduced into other communities in Southeast Alaska. On the Tongass National Forest, around the community of Sitka, black slugs were first recorded in 2004 around the Starrigavan Recreation Area. Since that time, black slugs have expanded their range along the road and trail system adjacent to the original point of observation. It is thought that black slugs arrived in this area via lumber or contracting equipment used in the reconstruction of the recreation area (S. Russell, USFS Sitka Ranger District, pers. comm.).

In the community of Tenakee Springs, black slugs were first noticed in the late 1970s in the vicinity of the old Superior Cannery property. Since that time, they have gradually spread at least three miles west of town along the road system and can be found at elevations as high as 500 m (M. Kemp, Tenakee Springs resident, pers. comm.). They have also been observed across Tenakee Inlet in the Kadashan watershed. Local residents speculate that the cannery was the original site of infestation and suggest that black slugs arrived along with shipping materials such as pallets or fish totes (M. Kemp, Tenakee Springs resident, pers. comm., J. McBeen, Tenakee Springs resident, pers. comm.).

Black slugs have also been identified in the community of Yakutat, at the northern edge of the Southeast Alaska panhandle. According to Miranda Terwilliger (Ecologist, Wrangell-St. Elias National Park, pers. comm.), black slugs are fairly abundant in the town of Yakutat and were likely introduced at the cannery via gardening soil. The exact timing of introduction is unknown.

**Pathways of introduction**

Possible vectors of introduction and expansion include nursery plants/pots and balled-burlap shrubs, potting soil, on the bottoms of canoes and boat trailers, trail construction materials (slugs often find refuge under drying timbers), pallets, fish totes and ice chests.

**Possible limits to distribution**

It is likely that temperature is a major factor limiting the distribution of black slugs in Alaska. Black slugs have been reported in the Anchorage area, but it is thought that severe winter conditions have prevented the species from becoming established (Wittwer 2004).

Many slug species have high phenotypic plasticity (Rollo & Shibata 1990) and are tolerant of moderately cold temperatures (Mellanby 1961). The eggs of the gray garden slug (*Deroceras reticulatum*) can successfully develop at temperatures as low as 4.4º C (Judge 1972). It is unknown at what temperature black slug development is impaired.

## ECOLOGY

**Habitat description**

The black slug is strictly terrestrial and typically lives in moist, cool soil. It commonly occurs in road cutbanks, gardens, fields, campgrounds and other disturbed areas with patches of shade. On sunny days, slugs rest in moist places such as mulch, in the shade of plants, and under stones and logs. Slugs can also bury themselves under soil, with a preference for heavy, non-acidic soils. They can be invasive to grasslands and appear to have the most impact at wetter and highly fragmented sites, under tree and shrub canopies, and in the early spring when vegetation is still wet (Gary Oak Ecosystem Recovery Team 2003).

In the Chugach National Forest near Cordova, Alaska, black slugs were especially prevalent near disturbed soils and in heavily populated areas (Meyers and Harris 2005, Meyers 2006). Black slugs located along the Cordova trail system were generally found on moss and appeared to prefer areas with low forb and shrub cover, but high canopy cover (Meyers 2006).

Wintering habitat is largely unknown. In urban areas, the species may overwinter in compost piles (C. Knight, Alaska Division of Agriculture, pers. comm.).

**Diurnal activity**

Because of their dependence on staying moist, slugs are most active at night and on wet days. On dry sunny days slugs rest out of sight to conserve moisture. Similarly, they will stay deep in the soil on cold days, only becoming active when the temperature exceeds 5º C (Featherstone 2006).

**Reproduction and life cycle**

The black slug is hermaphroditic, with both male and female reproductive organs and is capable of reproducing without a mate by self-fertilization. Most black slugs can reproduce at three months of age. Mating occurs between June and October, depending on the weather. Eggs are laid a few weeks after mating, often in moist places such as under logs or boards and in plant litter. Eggs are white opaque and laid in a cluster of 150 or more, with each measuring approximately two mm in diameter. Eggs hatch in approximately four to six weeks, temperature depending. Juvenile black slugs are 10 mm long and yellowish grey in color, with a darker grey head. Black slugs overwinter as adults or nearly mature young, and will generally survive one to two years (Gary Oak Ecosystem Recovery Team 2003).

**Diet**

The black slug is omnivorous, and its diet includes fungi, carrion, lichens, earthworms, leaves, stems, live and decomposing vegetation and feces (Royal British Columbia Museum 2002). Their preferred food is seedlings (Fenner et al. 1999) and they are among the most important herbivores in low herbaceous vegetation in the cool-temperate zone (Buschmann et al. 2005). In the Cordova area, this species has been observed foraging on dandelion seeds and dog feces (E. Cooper, USDA Forest Service, pers. comm., C. Knight, Alaska Division of Agriculture, pers. comm.), but no concerted effort for assessing diet has been completed.

**Dispersal and spread**

Remarkably little is known about the spatial distribution and dispersal of slugs. Different slug species may also differ considerably in their dispersal capacity. Studies conducted on the grey garden slug found their home-range size averaged 45.4 $m^2$ when population densities were low; conversely, when densities were high, home-range size decreased to 12.4 $m^2$ (Grimm and Paill 2001). Banana slugs (*Ariolimax columbianus*) can travel 10 m/hour and the introduced grey garden slug can travel up to 12 m in a single night (Boersma et al. 2006).

The black slug is likely fairly sedentary and innate potential for long distance dispersal is low. Long distance dispersal is mainly by human mediated transport of soil, compost or plant material that contains adults, juvenile individuals or eggs. This species has probably been repeatedly introduced.

## ENVIRONMENTAL OR ECONOMIC IMPORTANCE

**Positive**

In general, slugs are crucial to ecosystem health. By processing decaying plant and fecal material, they help to recycle organic matter and nutrients back into a form that can be used by other organisms. This also aids in the maintenance of soil fertility. The mucus from slug activity is also known to accelerate nutrient cycling (e.g., C, N and P) (Theenhaus and Scheu 1996).

Slugs aid in the dispersal of plants. Seeds and spores are dispersed by slugs, as they get caught in the mucus or slime as a slug moves and are transported for varying distances before being deposited in new sites when the accumulated debris falls off the animal (Featherstone 2006).

Like most organisms, the black slug has its own suite of predators and parasites. Known predators include snakes, birds, amphibians and carabid beetles (Gary Oak Ecosystem Recovery Team 2003). In the Caledonian Forest, Scotland, known predators include badger (*Meles meles*), fox (*Vulpes vulpes*), hedgehog (*Erinaceus europaeus*), slow worm (*Anguis fragilis*) and various birds (Featherstone 2006). A parasitic nematode, French heartworm (*Angiostrongylus vasorum*), which affects dogs, has been reported as naturally occurring in the black slug in France, while a parasitic mite (*Riccardoella oudemansi*) also affects *A. ater* (Featherstone 2006).

**Negative**

Slugs are often a nuisance to horticulturists because of their choice of diet. Any sort of vegetation is at risk to slug damage. *A. ater* is considered to be among the most destructive of the slugs (Long 1999). Slugs reduce the vigor of some crops by killing seeds or seedlings, by destroying stems or growing points, or by reducing the leaf area. Such actions may slow crop development and/or reduce yield. In other crops, harvest is devalued by feeding damage, mucus trails, feces or presence of slugs. Slug feeding may also initiate mould growth or rotting (Speiser et al. 2001).

The following passage is excerpted from Rollo and Wellington (1975) and refers to *A. ater* in Washington state. "*A. ater* was probably introduced into Western North America in the Puget Sound area of Washington. By 1940 it was recognized as a garden pest in Seattle and by 1948 it was a major pest in gardens in the lower Puget Sound area. In 1955, *A. ater* prevented growth of all garden crops at Hope and Popcum, British Columbia. Slugs were observed traveling to gardens from rough pastures and their populations were estimated to be at least 0.8 per $m^2$. By 1962 this species was recognized as one of the worst molluscan pests of southern British Columbia."

Slugs are capable of altering community composition. In many forest communities slugs are dominant seedling predators (Nystrand & Granstrom 1997, South 1992). As a result, they can severely restrict seedling recruitment in favored species (Hanley et al. 1996). Black slugs have been known to graze and damage plants such as lilies and orchids. In British Columbia, they have impacted plant species at risk, including deltoid balsamroot (*Balsamorhiza deltoidea*) and yellow montane violet (*Viola praemorsa*). Black slugs may do the most damage in highly fragmented ecosystems and at sites with more abundant shrub or tree cover (Gary Oak Ecosystem Recovery Team 2003).

Because slugs prefer seedlings over mature plants, their impacts on a community level are likely out of proportion to the actual amount of vegetation consumed. Studies show molluscan herbivores capable of altering plant species abundance (Briner & Frank 1998), adult plant fecundity (Dirzo & Harper 1980, Rai & Tripathi 1985) and plant production of defensive compounds (Cates 1975, Raffaelli & Mordue 1990). The consumption of seedlings by molluscs in British grasslands was found to be the dominant factor regulating community composition (Wilby & Brown 2001).

Generalist herbivores such as slugs have the potential not only to reduce plant density and biomass, but also to alter species diversity within vegetation and consequently, affect the dynamics of plant succession. Their impact on species diversity may be either negative, if they concentrate feeding on less abundant plant species, or positive, if they feed on the most abundant plant species (Buschmann et al. 2005). Buschmann et al. (2005) found that slugs can have significant effects on species diversity in plant communities, and that the direction of that effect changes during the course of succession. In the earliest stages, when most species are present as seedlings or juveniles, slug grazing leads to reduced species diversity because favored species are eliminated. In closed vegetation, in which competitive interactions are important, slugs may reduce the dominance of the more competitive species and thus provide gaps in which plants can establish from seed. As a consequence, slugs tend to cause an increase in plant species diversity and may also reduce the rate of successional change by promoting the persistence of annual species. Buschmann et al. (2005) also observed that slug grazing helped maintain a more heterogeneous environment with a higher proportion of small gaps.

Slugs are commonly herbivorous but are capable of exploiting a number of nonplant foods (Runham & Hunter 1970). Slugs are not indiscriminate feeders, and have been described as acceptability-moderated generalists by Dirzo and Harper (1980). When slugs are abundant, favored food items can become rare or extirpated. Slug grazing at low elevations in Germany restricted the rare perennial *Arnica montana* to high-elevation slug-free habitat in the Harz mountains (Bruelheide & Scheidel 1999). In New Zealand, exotic slugs caused extensive defoliation in *Botrychium australe*, a native slow-growing fern, thereby opening space for alien weeds (Sessions & Kelly 2002). Thus, other species that are unattractive to slugs can benefit from a reduction in the abundance of a competing plant species.

## CONTROL METHODS AND POTENTIAL MANAGEMENT ALTERNATIVES

### Prevention methods

In natural surroundings it is very difficult to prevent exotic slugs from moving in if the species is in the vicinity. In small-scale gardening, slug fences can reduce immigration of slugs drastically, but are ineffective against the resident slug population. Barriers can be constructed to inhibit slugs from entering and area using sawdust, crushed eggshells, ground oyster shells, soap, cinders or diatomaceous earth. Slug fences with electric current are also available. Barriers are only effective in small areas and may be appropriate for protecting some populations of rare plants.

### Eradication and control

The eradication and control measures described below are effective on slugs in general. However, except for the manual removal technique, none of these techniques will distinguish between native and introduced black slugs. It is important to carefully identify all slugs before attempting any type of control.

#### ***Physical control***

Slug control sometimes requires manual labor, a physical barrier, traps or introducing other animals as predators. Fortunately, slugs do not move quickly and are easily persuaded by bait. Desiccators and rough surfaces can also be deterrents for slugs as they cause dehydration and scratch the slug's soft bodies.

*Hand collection*

Hand collecting and killing exotic slugs has proven one of the most effective eradication methods in home gardens, and is recommended by nearly every expert; however, this method has little relevance in natural or semi-natural settings as it is extremely labor intensive (Weidema 2006). Hand collection of slugs is best done at dusk or dawn when slugs are actively feeding. Collection of all life stages of the slugs should take place. Therefore, in addition to collecting adults and juveniles, it is also important to remove all the eggs (Speiser et al. 2001, Weidema 2006).

Collecting slugs early in the season contributes to reducing the number of eggs laid later in the season. Slugs must be euthanized after collection. Cutting slugs in half is not an effective killing technique. Covering slugs with salt and then burning them has proven an effective euthanization technique in the Cordova area (E. Cooper, USDA Forest Service, pers. comm.).

*Physical barriers*
Many products can be used as physical barriers between slugs and plant material. Plastic bottles or plastic edging can be effective as simple physical barriers against slugs over small areas, such as home gardens (Symondson 1996). Copper flashing has also been successful as a physical barrier. Copper supposedly reacts chemically with the slug, giving them an electric shock as they cross it, and copper itself is toxic to slugs (Firpo 1997).

Slugs avoid crossing rough surfaces and substances that may dry them out or burn their flesh (Weisenhorn 2001). Egg shells and diatomaceous earth are coarse substances that will burn the epidermis of the slug and act as effective slug deterrents. Caution should be exercised when using diatomaceous earth as it is toxic if inhaled. Wood chips not only scratch the slug's skin, but also contain high levels of tannins and are also a good deterrent. Wood chips should be small enough to eliminate the possibility of providing shelter for the slug (Symondson 1996).

Drawbacks to these types of physical barriers are they require replenishment as they lose effectiveness in wet weather, and they may alter the chemical properties of the soil (Weisenhorn 2001).

*Traps and bait*
Adult and juvenile slugs may be attracted to a variety of smelling attractants, which can be placed within slug traps. Both commercial and homemade box traps are efficient methods for trapping slugs in localized situations (Hagnell et al. 2006). Commercial slug traps are available for sale. Home-made slug traps can be made by filling containers with beer and sinking them into the ground. This technique is well known among home gardeners. The edges of the containers should stick out of the soil at least 1-2 cm to prevent trapping native beetles and spiders (Weisenhorn 2001).

***Biological control***
In horticulture, biological control has been used to control exotic slugs. However, much of the work done with biological control has been done in Europe and acquiring the biologicals in the United States is oftentimes impossible.

*Parasitic nematode*
The soil-dwelling nematode, *Phasmarhabditis hermaphrodita,* is a microscopic worm that is a parasite of slugs. The infectious nematode larvae actively seek out slugs and probably enter through a small pore near the respiratory canals and eventually cause slug death within a week or two (Weidema 2006). The parasitic characteristic of this nematode was discovered in the 1990s in Europe (Weisenhorn 2001). In the U.K., it has been used successfully in small-plot field experiments to protect Chinese cabbage seedlings and winter wheat (Wilson et al. 1995). Unfortunately, the nematode is not known to exist naturally in North America and the regulatory community is concerned about introducing a non-native species without thorough examination of the consequences (Speiser et al. 2001).

*Other predators*
There are several insects that prey on slugs and can assist in their biological control. The most important is Sciomyzids or marsh flies. Sciomyzid larvae kill slugs and utilize environments similar to slugs. Carabid beetles depredate slug eggs and have been used as biological control agents in certain areas. Large carabid beetles, such as *Abax parallelepipedus*, are predators of grey slugs and will also prey on caterpillars and aphids (Symondson 1996). However, controlling an exotic species by introducing another exotic species is not generally recommended.

Slugs have many natural predators, including ground beetles, pathogens, toads, turtles and birds (including blackbirds and thrushes, robins, starlings, crows, jays, ducks, gulls and owls), but most are rarely effective enough to provide satisfactory control. An exception to this is the domesticated duck. The domesticated runner duck (a special breed of the mallard duck, *Anas platyhynchos*) has been found efficient for slug control in the U.K. (IACR 2001). Runner ducks have been used by organic farmers with good results and have been able to substantially reduce slug populations in the long-run, but cannot be used for short-term slug control. These birds will also eat seedlings so they need to be managed.

***Chemical Control***
When using chemicals to control slugs it is important to choose a molluscicide, as slugs are not affected by insecticides or miticides (Weisenhorn 2001).

*Slug baits*
Slug pellets are baits which contain slug attractants, an edible matrix and a molluscicidal active ingredient. A number of iron compounds are molluscicidal. Iron (III) phosphate is a molluscicide that is sold in slug pellets and leads to feeding inhibition and ultimately to slug death (Weidema 2006). Iron (III) phosphate baits have the advantage of being safe for use around domestic animals and wildlife and humans (Speiser et al. 2001). The disadvantage is that iron phosphate degrades rapidly and must be reapplied regularly.

Other molluscicides, such as metaldehyde and carbamates are frequently used slug baits (Speiser et al. 2001). Metaldehyde is available commercially under product names such as Deadline, Bug-Geta, Slug-Geta, Slug-it, etc… Metaldehyde affects slugs by paralyzing them, causing them to excrete excessive amounts of mucus, with death resulting from dehydration and/or exposure to sunlight. Slugs absorb metaldehyde by contact or through the gut when eaten (Weisenhorn 2001). Metaldehyde baits are very effective at controlling slug populations, but are toxic to humans and other animals, including native slugs, and should only be used in extreme situations where they can be contained within tamper-proof bait stations.

Methiocarb, sold under the product names of Mesurol and Grandslam, is classified as a carbamate (Weisenhorn 2001). Methiocarb is a stomach and nerve poison that interferes with nerve impulse transmission (Weisenhorn 2001). Slugs can still move somewhat after poisoning, but eventually swell up with fluid and become immobile. Methiocarb is highly toxic to other organisms such as earthworms, pets, and natural predators such as carabid beetles, birds, and mammals, and its use is not encouraged (Symondson 1996).

*Sulfur-based products*
There are a number of sulfur-based products which have proven effective against slugs, including copper and iron sulfates. Copper sulfate is an effective means for controlling grey slugs, but has not been shown to be effective against other species. Copper sulfate is available in spray form and should be used when slugs are most active and may require repeated use

(Symondson 1996). Copper is a toxic chemical and should be handled with caution (Weisenhorn 2001).

Iron sulfate, sold under the product name of Escar-Go, is a more earth-friendly chemical means of controlling slugs (Weisenhorn 2001) and was found effective in trials in Switzerland (Speiser et al. 2000). Iron sulfate is available in granular form and is mixed with bait and spread around the base of plants. It is considered an environmentally-friendly chemical and could probably be used for slug control by certified organic growers (Center for Public Domain and UNC 1998).

## SUMMARY OF PREVIOUS WORK

**European Black Slug Population and Habitat Use on the Chugach National Forest, Cordova Ranger District 2005 and 2006** (Meyers and Harris 2005, Meyers 2006)

This project was conducted to identify the extent of the European black slug invasion on the Chugach National Forest, to determine some of the species habitat requirements, and to investigate the history of the distribution of slugs in the area. Surveys occurred over two seasons, 2005 and 2006, near the town of Cordova, Alaska. Distribution was assessed by conducting searches along road and trail systems, by putting out slug attractant, and by interviewing local residents. Road-based surveys included all roads within nine miles of town. Trail surveys consisted of walking routes on Crater Lake, Power Creek, McKinley, Eyak and Pipeline lakes trails and also in areas reported by the general public. Slug density was assessed by conducting off-trail surveys consisting of 100 x 2-m transects perpendicular to the trails at 500-m intervals. When a specimen was encountered, information was collected to measure slug density and distance from trail and also to determine if there were differences in microclimate at ground level. Four permanent plots were created to quantify slug diurnal activity patterns.

Interviews were conducted with long-time residents on the timing and the spread of the black slug in the Cordova area. Of the 14 respondents, none could precisely determine the appearance of slugs in Cordova. Two respondents stated they first noticed slugs 20 years ago, which was the longest time period stated. Most respondents felt that the population had increased over the past five to eight years.

Through either surveys or traps, slug presence was confirmed at numerous locations along the road and trail system and also on Hinchinbrook, Hawkins and Observation Islands. Slugs were especially prevalent near disturbed areas and in heavily populated areas. The occurrence of slugs along roadways, trails and on islands separated from the mainland suggested that human mediated transport was likely a factor in the expansion of this species range.

Slug densities were highest along roadsides and on and adjacent to hiking trails and lowest deeper in the forest as distance from trails increased. Highest densities were recorded along the Crater Lake trail. Slugs surveyed along trail systems preferred areas with low forb and shrub cover but high canopy cover. Slug density was apparently influenced by altitude, with the majority of detections below 150 m in elevation.

**Alaska Terrestrial Mollusk and Sudden Oak Death Survey 2007** (Alaska Department of Natural Resources and USDA Animal Plant Health Inspection Service Plant Protection and Quarantine 2008)

Data on exotic mollusks in Alaska were collected by the Alaska Division of Agriculture working in conjunction with USDA Animal Plant Health Inspection Service Plant Protection and Quarantine (APHIS PPQ) through the Cooperative Agricultural Pest Survey (CAPS). Surveys designed to detect new introductions of exotic molluscs and collect baseline information on exotic molluscs already established were conducted by the Alaska Department of Natural Resources (ADNR) at various locations throughout Southeast and Southcentral Alaska during 2007 and 2008. In 2007, surveys were conducted at six communities in Southeast Alaska including Haines, Juneau, Ketchikan, Sitka, Skagway and Wrangell. Surveys during 2008 focused on communities in southcentral Alaska and on Kodiak Island, Cordova and Valdez. Surveys were intended to detect new species and document where exotics occurred, particularly in high traffic areas such as ports of entry.

The following exotic species were detected during surveys: *Deroceras reticulatum*, *Arion circumscriptus*, *Arion subfuscus*, *Arion* ARVC complex, *Cochlicopa lubrica* and *Oxychilus* spp. Black slug determinations were designated as part of the *Arion* ARVC complex, due to lack of genetic support and speculation by R. Forsyth (University of British Columbia Museum) that the black slug present in Alaska is actually a black color morph of *A. rufus*. *Arion* ARVC slugs were located at 18 of 32 sites surveyed in and around the community of Cordova. In the Southeast surveys, black slugs were collected from numerous locations in Ketchikan and Sitka and from a single location near Wrangell.

# II. RISK ASSESSMENT

**RISK RATING SUMMARY**

Numerical Score: **3**

Relative Risk Rating: **Moderate**

Uncertainty: **High**

Uncertainty in this assessment results from: Knowledge of the species range within the Chugach National Forest is incomplete. The exact mechanism and timing of introduction is unknown. Means of transport and spread are somewhat understood and human mediated transport is likely. Ecological or other limits to the species further distribution are largely unknown. Ecological implications of this introduction remain uncertain.

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**RISK RATING DETAILS**

**CRITERION 1 - Establishment Potential Is *High Risk***

This factor considers the likelihood that the plant pest will successfully colonize a new area once it has entered North America. It does not include consideration of the pest's likelihood of entry nor the rate at which populations will expand to fill its expected range. Assume that the pest has been found somewhere in North America and estimate its likelihood to become established. Establishment potential is estimated as a proportion of the pest's host range in North America.

The relevant criteria chosen for this organism are:

- Organism has successfully become established in locations(s) outside its native distribution.
- Suitable climatic conditions and suitable host material coincide with ports of entry or major destinations in North America.
- Organism has high inoculum potential or high likelihood of reproducing after entry.

Justification: The European black slug is native to western and central Europe, from Scandinavia to Spain and from Ireland to Austria and the Czech Republic. It has been introduced to southeastern Australia and to North America, where it occurs in Newfoundland, southern British Columbia, the Pacific Northwest of the U.S. and some parts of Alaska (Featherstone 2006).

Introduction of black slugs into Alaska has likely been within the past 20 to 25 years, and these introductions have occurred in a few relatively isolated situations, mostly in southeastern and southcoastal Alaska. According to Cordova area residents, once the black slug was introduced there it became established and has progressively spread along the road and trail systems. A systematic inventory of the distribution of the black slug in the Cordova area has not been conducted. The current distribution of this species is largely based on three surveys (Meyers and Harris, 2005, Meyers 2006, and Knight, unpubl. data) and is likely incomplete, as these surveys do not include areas far from trails or roads.

The climatic tolerances of the black slug in Alaska are largely unknown. The species has been able to survive in the Cordova area for at least the past 20 years, thus we assume that climatic conditions are suitable for the species reproduction and survival in that area. Winter temperatures further inland or further north are generally colder, which could potentially limit the establishment of black slugs. If winter temperatures are colder on the delta than in the town of Cordova, this could potentially limit the species ability to establish. For example, black slugs have been reported from areas further north in Alaska, such as Anchorage, where it is thought that more severe winter conditions have prevented the species from becoming established there (Wittwer 2004). Comparative temperature data and an understanding of the climatic tolerances of the black slug are needed to better address this consideration.

It is also possible that one or two cold winters could greatly reduce population numbers. In Manchester, England, adverse weather conditions have had marked effects on the native slug numbers, but populations recovered once conditions returned to normal (South 1992). Prolonged periods of intense cold during the winter and drought during the spring and early summer can have adverse effects on slug numbers while mild wet seasons generally lead to increases in slug numbers (Miles et al. 1931). In Leningrad, Russia, eggs of the native slug species, *D. reticulatum*, were able to resist temperatures as low as -11C and that it was uncommon for eggs to be killed during winter, provided that there was adequate snow cover to insulate the soil against lower temperatures (Dmitrieva 1969)

**CRITERION 2 - Spread Potential Is *Moderate Risk***

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| This criterion considers the likelihood of the plant pest spreading beyond the initial colonized area following its introduction. The rating for spread potential is a reflection of the pest's estimated potential to reach new habitats in North America following its establishment in one or more locales. |

The relevant criteria chosen for this organism are:

- Organism has demonstrated ability for redistribution through human assisted-transport.
- Organism has high reproductive potential.
- Eradication techniques are unknown, infeasible, or expected to be ineffective.

Justification: Since first reported in the Cordova area at least 20 years ago, the distribution of the black slug has spread from the point of introduction predominantly along road and trail systems, but isolated incidents have also been reported. The occurrence of black slugs along roadways and in areas of heavy human use suggests the species is spreading along transportation corridors. Some of this spread is likely attributed to natural expansion. However, the incidence of isolated occurrences of black slugs in areas of human use separated by large expanses of wilderness have been noted (e.g., Whitshed Point; Meyers 2006, E. Cooper, USDA Forest Service, pers. comm.). Additionally, black slugs have been reported from islands located several kilometers east of the mainland, suggesting redistribution through human assisted transport via boat.

Slugs, in general, have high reproductive potential. The black slug is hermaphroditic, with both male and female reproductive organs and is capable of reproducing without a mate by self-fertilization. Most black slugs can reproduce at three months of age and lifespan is one to two years. Eggs are laid in a cluster of 150 or more, and hatch in approximately four to six weeks.

While numerous eradication techniques are available for exotic slugs, few are effective over large areas, such as natural or semi-natural sites. Furthermore, except for manual removal techniques, none of the other available eradication techniques distinguish between native and introduced black slugs.

**CRITERION 3 - Economic Potential Is *Low Risk***

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| This element considers the potential economic impact of the pest if it were to become established in North America. Assume that it occupies the full extent of its host(s)' range. Consider the economic importance of the host(s) and the direct and indirect economic effects of infestation. Do not consider environmental effects because they are considered in criterion 4. Use all available sources of information, including historical records of the pest's effects in its native range or in other locations, to reach the best possible estimate of the potential economic effects of introduction. |

The relevant criteria chosen for this organism are:

- No effective control measures exist.

Justification: Black slugs are a known horticultural nuisance in the Pacific Northwest, including the states and provinces of Oregon, Washington, and British Columbia (Washington State University Cooperative Extension 1994, Boersma et al. 2006, Casper 2008), and are generally considered a garden pest in the Cordova area. Whether or not black slugs play a role in altering wetland vegetation or wetland community structure in the Copper River Delta is unknown, thus, direct and indirect economic effects of the current level of infestation are unclear.

To our knowledge, there are no large scale eradication campaigns for black slugs in natural settings throughout their introduced range. In the Alaska communities of Sitka, Tenakee Springs, Yakutat and Cordova, hand collection and killing of black slugs has proven the most effective method to control populations at very local levels (M. Terwilliger, Ecologist, Wrangell-St. Elias National Park, pers. comm., S. Russell, USFS Sitka Ranger District, pers. comm., E. Cooper, USDA Forest Service, pers. comm., J. McBeen and M. Kemp, Tenakee Springs residents, pers. comm.). This method is labor intensive, and only serves to reduce the potential population in localized situations. Due to the species extensive range in the Cordova area, localized control methods would be of little use in reducing the overall population. Available control options for widespread infestations do not discriminate between native and introduced slugs and could potentially have adverse effects on naturally occurring slug populations.

**CRITERION 4- Environmental Potential is *Low Risk***

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| This element considers the potential environmental impact if the pest were to become established in North America. In selecting the most appropriate ranking for this element, assume that the pest occupies the full extent of its host(s)' range. Consider the environmental significance of the host(s) and the direct and indirect environmental effects of infestation. Use all available sources of information, including historical records of the pest's effects in its native range or in other locations, to reach the best possible estimate of the potential environmental effects of introduction. |

The relevant criteria chosen for this organism are:

- None of the ranking criteria apply.

Justification: Potential environmental impacts of the black slug to wetland plants and community structure in the Chugach National Forest are relatively unstudied. Elsewhere, slugs have been responsible for altering community composition and plant diversity by restricting seedling recruitment in early stage communities and by reducing dominant plants in later successional stage forests (Buschmann et al. 2005). Black slugs have been known to graze and damage plants such as lilies and orchids. In British Columbia, black slugs have been known to impact plant species at risk and may do the most damage in highly fragmented ecosystems and at sites with more abundant shrub or tree cover (Gary Oak Ecosystem Recovery Team 2003). Meyers (2006) did not report any observable ecological damage caused by black slugs during surveys conducted around the community of Cordova in 2005 and 2006.

In many forest communities slugs are dominant seedling predators (Nystrand & Granstrom 1997, South 1992). Slugs can restrict seedling recruitment in favored species (Hanley et al. 1996). When slugs are abundant, favored food items can become rare or extirpated in an area. Black slugs have been observed consuming vegetative matter around the town of Cordova, but heavy herbivory on any one species has not been reported (Harris 2006) and there is a general lack of information about the species year round diet or preferred food items.

The impact of black slugs on native slug species in Alaska is unknown. Exotic slugs that have ecological flexibility to establish in new environments and spread and prosper in new habitats are generally considered of concern. While the black slug has proven capable of establishing in new areas and expanding its range, it remains uncertain what the ecological implications of this introduction are in the Copper River Delta. Introduced slugs are known to out-compete native slug species. In Vancouver, British Columbia, the native banana slug (*Ariolimax* spp.) was displaced by non-native slugs over a 14 year time period (Boersma et al. 2006, Busch 2007). Slug species native to the Copper River likely include banana slugs and taildropper slugs (*Prophysaon* spp.), but a comprehensive inventory is lacking. Whether or not black slugs out-compete these native species for food resources is unknown and merits further investigation. If native slugs are an important food base for passerines, reductions in their populations could have cascading effects throughout the trophic structure (Meyers 2006).

## III. FINAL EVALUATION

The exotic black slug has successfully established in the Chugach National Forest, most notably around the town of Cordova. Based on reports from Cordova area residents, the species was first noticed in the area between 20 to 25 years ago. Since that time, its distribution has been observed to spread from localized infestations in the town of Cordova throughout the road and trail system as far as Corona Way Creek, 4 km west of the Copper River. The current distribution of the black slug in the Chugach National Forest is based on limited survey data (Meyers and Harris 2005, Meyers 2006, C. Knight unpubl. data, Gotthardt, unpubl. data) and reports from local residents, and is likely incomplete. Current information suggests that black slugs are most prevalent near disturbed sites or heavily populated areas (Meyers and Harris 2005, Meyers 2006). However, most surveys were conducted near road or trail accessible areas, which could have produced misleading results. True occurrence of black slugs away from areas of human activity in the Copper River Delta area is generally unknown. Available evidence, however, suggests a strong association of black slugs to human presence (Meyers 2006).

Movement and the dispersal capabilities of the species are relatively unstudied. These slugs are probably fairly sedentary and lack any mechanism for innate long distance dispersal. The exact mechanism for the observed expansion in range in the Cordova area is not well understood. The occurrence of black slugs in isolated pockets of human use separated by the presence of potentially suitable but unoccupied habitat, or on islands separated from the mainland, suggests that human assisted transport is at least one contributing factor to the expansion of the species range.

Why this exotic slug has not yet become established on the Copper River Delta remains uncertain. Black slugs appear to be thriving in Cordova proper, but have only been found on the delta where they have likely been transported via vehicles, based on their proximity to parking areas. The habitat on the delta is highly fragmented by sloughs which may serve as natural barriers to slug expansion and impede further dispersal of slugs beyond the vicinity of parking areas. Additionally, most of the delta is roadless, limiting “hitchhiking” opportunities.

Minor introductions onto the delta may also have failed because the vegetation is unpalatable or canopy cover is insufficient. Abiotic factors such as temperature and lack of heavy ground cover may also limit slug dispersal in this area. Meyers (2006) reported that black slugs along the Cordova trail system were generally found on moss, where they were probably feeding, and showed a preference for low forb and shrub cover and high canopy cover. Forested habitats likely provide greater cover from aerial predators than the more open wetlands complex of the delta. Elsewhere in Southeast Alaska, black slugs have been documented near communities (e.g., Sitka, Gustavus, Tenakee Springs, Ketchikan) that are characterized by coastal rainforest, suggesting arboreal preferences by this species. The literature also suggests a strong association by this species to coniferous and deciduous woodlands (South 1992 and references therein).

Winter temperatures may be colder on the Copper River Delta, especially sections of the delta that are further inland, which could potentially limit the establishment of black slugs in that area. It is also possible that one or two cold winters could reduce population numbers. For example, black slugs have been reported from areas further north in Alaska, such as Anchorage, where it is thought that more severe winter conditions have prevented the species from becoming established there (Wittwer 2004). Comparative temperature data and an understanding of the climatic tolerances of the black slug are needed to better address this consideration.

It is also possible that the slugs are not able to establish in the myriad uplifted marshes, outwash plains and mudflats that cover the delta because of substrate aversion or due to the fact that many of these areas are inundated at different times throughout the year. Slugs, in general, tend to avoid alkaline conditions (pH of 7.0 or higher) and species richness for woodland slugs is highest on soils with pH between 4.0 and 5.0 (South 1992 and sources therein). Threshold pH values for *A. ater* in southwest Sweden were 4.5 (Walden 1981). In the Copper River Delta area, spruce forests (*Picea glauca*) with huckleberry (*Vaccinium ovalifolium*) understory had pH values between 4.5 to 5.1, while peatlands had pH values ranging from 3.8 to 6.4 (Boggs 2000). Both of these habitat types appear to fall within the published physiological tolerances of the black slug and similar taxa, therefore pH is likely not a key limiting factor in the species dispersal and establishment on the delta, but merits further investigation.

The relative risk assessment rating for the black slug on the Copper River Delta was moderate, with a high degree of uncertainty associated with lack of knowledge about the species range, the mechanism and timing of introduction, and limits to distribution and ecological implications. A comprehensive literature review revealed no documented ecological impacts from invasive slugs in wetland habitats, although the species has been associated with wetlands within its native range in Europe (South 1992). The species is more commonly associated with coniferous and deciduous forest habitats, where it is a known seedling predator and may hinder early forest regeneration by foraging on first-season seedlings (Elliott 1985). At this time, we do not recommend biological control measures, as most are harmful to native slug populations and generally not effective in natural settings.

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