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[Management Brief]

Application of Household Disinfectants to Control New Zealand Mudsnails

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Abstract.—The New Zealand mudsnail *Potamopyrgus antipodarum* was recently discovered in Colorado, thereby expanding its invasion of the western United States. This exotic snail may invade streams through transport on angling gear and fishery equipment. Previous studies have demonstrated that some household cleaning products are lethal to New Zealand mudsnails and can be used to disinfect waders and boots. Two disinfectants, antibacterial Formula 409 All-Purpose Cleaner and Sparquat 256, were compared as potential control agents. Snails were submersed for 5 or 10 min in one of two Formula 409 solutions (50% or 100%) or one of three Sparquat 256 solutions (1.6, 3.1, or 4.7%). We used distilled water as the control treatment. Snail mortality at 48 h and 56 d after exposure was evaluated. Our findings suggest that the current recommendation (5-min application of 50% Formula 409) is not sufficient; half of the snails survived this treatment in our study. In contrast, a 10-min exposure to 100% Formula 409 or to a Sparquat 256 solution of at least 3.1% resulted in 100% snail mortality. In addition to its effectiveness in controlling New Zealand mudsnails, Sparquat 256 has also proven useful as a disinfectant for whirling disease spores and other fish pathogens.

The New Zealand mudsnail *Potamopyrgus antipodarum* is a highly fecund, nonnative species (Winterbourn 1970) that has rapidly invaded streams in the western USA. The first western U.S. discovery of the species occurred nearly two decades ago in Idaho's Snake River (Bowler 1991). Since then, New Zealand mudsnails have been found in 10 western states (Gustafson et al. 2003); recent discoveries include those in two transition zone streams of northeastern Colorado (Colorado Division of Wildlife 2005). New Zealand mudsnail invasions have the potential to negatively impact aquatic food web dynamics and ecosystem function (Hall et al. 2003). For example, New Zealand mudsnail densities in western streams can exceed 500,000 snails/m^2 (Richards et al. 2001; Richards 2002), which could overwhelm habitat and food resources required by native invertebrates (Kerans et al. 2005; Hall et al. 2006). New Zealand mudsnails may also adversely impact fish populations by reducing the native invertebrate prey base, although such indirect effects are not well documented. As a food source, New Zealand mudsnails have shown low nutritional value for salmonids because of their resistance to digestion (McCarter 1986; Vinson et al. 2007). Given the possibility for negative impacts to fisheries in western streams, methods of limiting New Zealand mudsnail invasions are greatly needed.

New Zealand mudsnails can invade a water body by several mechanisms, including attachment to angling gear (waders and boots) or fishery equipment (e.g., seines and nets); hitchhiking on aquatic vegetation associated with boats, trailers, and vehicles; importation into fish hatcheries; drift from invaded reaches upstream; and direct transfer on wildlife such as waterfowl or live passage through the guts of fish (Haynes et al. 1985; Richards 2002; Dwyer et al. 2003; Richards et al. 2004). Currently, there is no available method for in situ eradication of New Zealand mudsnails once they invade a stream. Therefore, efforts to limit their spread rely heavily on cooperation from anglers, agency fishery personnel, and recreationists in disinfecting their gear. Researchers have explored the efficacy of angler-friendly treatments, such as freezing, heating, desiccation, and application of household cleaning products, to eliminate New Zealand mudsnails from gear (Dwyer et al. 2003; Richards et al. 2004; Hosea and Finlayson 2005). A recent study indicated that soaking waders and boots in a bath of Formula 409 All-Purpose Cleaner (Clorox Company, Oakland, California) is a practical and effective method for controlling New Zealand mudsnails (Hosea and Finlayson 2005). Formula 409 contains 0.3% of the quaternary ammonium compound (QAC), alkyl (40% C_{12}, 50% C_{14}, and 10% C_{16}) dimethyl benzyl ammonium chloride; QACs are toxic to invertebrates and are a key ingredient in the molluscicides used to

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reduce biofouling in industrial cooling systems (Dobbs et al. 1995).

Industrial-strength disinfectants contain higher concentrations of QACs and may be more effective than household cleaning products for eliminating New Zealand mudsnails from angling gear. For instance, Sparquat 256 (Spartan Chemical Co., Maumee, Ohio) contains a mixture of QACs at 12.5% and is the chemical of choice for disinfecting fishery gear exposed to spores of *Myxobolus cerebralis*, the vector for whirling disease in trout (Colorado Division of Wildlife 2005). A chemical treatment that is lethal to New Zealand mudsnails in addition to whirling disease and fish pathogens would thus be highly desirable. Therefore, we conducted an experiment to compare Sparquat 256 (three concentrations) and antibacterial Formula 409 (two concentrations) in terms of their toxicity to New Zealand mudsnails. The snails were soaked in chemical baths for 5 or 10 min, and mortality at 48 h or 56 d postexposure was determined. One of the Sparquat concentrations was previously reported as lethal to *M. cerebralis*. Our objectives were to (1) test the efficacy of the Formula 409 treatments using a laboratory experiment similar to that of Hosea and Finlayson (2005) and (2) examine the potential use of Sparquat 256 as a control agent for New Zealand mudsnails.

Methods

Adult New Zealand mudsnails (mean length = 4.39 mm, SD = 0.55 mm) were collected from Boulder Creek, Boulder County, Colorado. Snails were removed from cobbles, and 25 individuals were randomly allocated to 473-mL plastic beakers filled with stream water. Our experimental design was a 6 × 2 factorial design (i.e., 6 chemical treatments × 2 exposure durations). Four replicate beakers with 25 snails each were randomly allocated to each treatment for a total of 100 snails/treatment. Treatments included antibacterial Formula 409 diluted to a 50% solution (1.5 mL of QACs/L of water) or undiluted (100% solution; 3.0-mL/L QACs) and Sparquat 256 at a concentration of 1.6, 3.1, or 4.7% (2-, 4-, and 6-mL/L QACs, respectively). Distilled water served as a control treatment and was also used for dilutions. Snails were exposed to the treatments for 5 or 10 min.

For exposures, snails from each beaker were transferred to 15-mL centrifuge tubes containing the assigned chemical treatment. Before exposure, the tubes were tempered to the stream water temperatures (15°C) in the containers. The tubes and contents were shaken for several seconds to expose the snails to the chemical bath; snails were then allowed to soak in the solution for 5 or 10 min. After exposure, the snails were rinsed with stream water and were returned to the beakers for observation. Beakers were held in a cooler to maintain ambient temperatures. After 48 h, snails were removed and examined under a 10× dissection microscope. Snails were first observed undisturbed and then were prodded with a dissecting probe. Snails that protruded from their shells with no movement or that were completely closed with no movement after 10 min were classified as dead. Lethargic snails that protruded from their shells and displayed very weak movement were classified as compromised. Snails were also assessed 56 d after exposure to determine the potential for recovery of compromised individuals. This assessment eliminated ambiguity regarding snail mortality; snails that recovered were clearly alive at 56 d, whereas those that perished had decomposed, leaving empty shells.

We calculated the mean percentages of snails from each chemical treatment and exposure time that were dead at 48 h and 56 d postexposure. A two-way analysis of variance (ANOVA) was conducted using the 56-d assessment data to determine whether snail mortality differed statistically among treatments and exposure times and whether treatment interacted with exposure time to influence snail responses. Tukey's multiple comparison procedure for differences between treatment means was conducted ($\alpha = 0.05$). Tests for the assumptions of normality and for independent and identically distributed errors were performed.

Results

At the 48-h assessment, no mortality was observed in control groups exposed to distilled water for 5 or 10 min (Table 1). The total number of dead snails after a 5-min exposure was similar between the 1.6% Sparquat 256 treatment and the 50% Formula 409 treatment; for both treatments, mortality was greater after the 10-min exposure than after the 5-min exposure (Table 1). The 100% Formula 409 treatment and the 3.1% and 4.7% Sparquat 256 treatments resulted in higher snail mortality than the weaker treatment concentrations after 5-min exposure and also produced fewer compromised snails; thus, the number of mortalities increased with increasing exposure time, whereas the number of compromised snails decreased. Compromised individuals were present after each treatment; hence, none of the treatments resulted in 100% mortality of New Zealand mudsnails at the 48-h assessment (Table 1).

At 56 d postexposure, only two snails were dead in the 5-min exposure control group and one snail was dead in the 10-min exposure control group (Table 1). All compromised snails that were present in the treatment groups at 48 h had either recovered or died

TABLE 1.—Description of chemical treatments applied to New Zealand mudsnails for 5 or 10 min (4 containers/treatment; 25 snails/container) and the resulting number of snails that were alive, compromised, or dead at 48 h and 56 d postexposure. Treatments were 100% distilled water (control), Formula 409 All-Purpose Cleaner (50% dilution in water or 100% [undiluted]), and Sparquat 256 (1.6% concentration = 15.6 mL of Sparquat/L of water; 3.1% concentration = 31.3 mL/L; or 4.7% concentration = 46.9 mL/L).

Chemical treatment	Exposure duration (min)	Assessment period	Number alive	Number compromised	Number dead
Control	5	48 h	100	0	0
	10	48 h	100	0	0
	5	56 d	98	0	2
	10	56 d	99	0	1
Formula 409, 50%	5	48 h	2	41	57
	10	48 h	0	20	80
	5	56 d	35	0	65
	10	56 d	1	0	99
Formula 409, 100%	5	48 h	1	23	76
	10	48 h	0	16	84
	5	56 d	20	0	80
	10	56 d	0	0	100
Sparquat, 1.6%	5	48 h	19	31	50
	10	48 h	1	26	73
	5	56 d	76	0	24
	10	56 d	9	0	91
Sparquat, 3.1%	5	48 h	2	14	84
	10	48 h	0	8	92
	5	56 d	0	0	100
	10	56 d	0	0	100
Sparquat: 4.7%	5	48 h	0	13	87
	10	48 h	0	7	93
	5	56 d	0	0	100
	10	56 d	0	0	100

by 56 d. Apparently, compromised individuals that eventually died were not able to reproduce successfully before death, because treatment beakers in which adult mortality was 100% by 56 d contained no live offspring, whereas treatment beakers with survivors contained high numbers of offspring (G.J.S., personal observation).

The 56-d assessment showed that a 10-min exposure to most treatments was more effective than the 48-h assessment suggested (Table 1): the majority of compromised snails observed at 48 h did not recover by 56 d. A 10-min exposure to undiluted Formula 409 or to 3.1% or 4.7% Sparquat 256 unequivocally killed all of the test organisms (Table 1). In contrast, many of the compromised snails in the groups exposed to Formula 409 (both treatments) or 1.6% Sparquat 256 for 5 min recovered by 56 d. Mortality in the 1.6% Sparquat 256 treatment group was actually lower at 56 d than at 48 h. Apparently, some snails in this treatment that were classified as dead at 48 h should have been classified as compromised. Misclassification of snail condition occurred only for this treatment; reasons for this are unknown.

Because of the high number of compromised individuals observed at 48 h, statistical analyses were conducted only with data from the 56-d assessment. A two-way ANOVA (overall model $F_{11,47} = 86.87$, $P < 0.0001$) revealed that chemical treatment, exposure duration, and the treatment × exposure duration interaction had significant effects on New Zealand mudsnail mortality (all $P < 0.0001$). All treatments (especially the Formula 409 treatments) were more effective when applied in a 10-min exposure than when applied in a 5-min exposure. The enhanced performance of Formula 409 at the longer duration was probably responsible for the significant chemical treatment × exposure duration interaction. Among 5-min exposures, 3.1% and 4.7% Sparquat 256 killed the highest mean percentage of snails, followed by 100% Formula 409 (Figure 1). For 10-min exposures, snail mortality increased and all treatments except 1.6% Sparquat 256 produced 99–100% mortality (Figure 1).

Discussion

We achieved the desired 100% mortality of New Zealand mudsnails when they were submersed for 10 min in undiluted antibacterial Formula 409 or in a solution of at least 3.1% Sparquat 256. Of the two disinfectant products, Sparquat 256 was generally more toxic to the snails than was Formula 409, especially for 5-min exposures. Previous studies have suggested that a 5-min submersion in 50% Formula 409 is adequate to eradicate New Zealand mudsnails from waders and boots (Hosea and Finlayson 2005). However, this treatment was not as effective in our study; snails that appeared to be dead at 48 h eventually recovered and

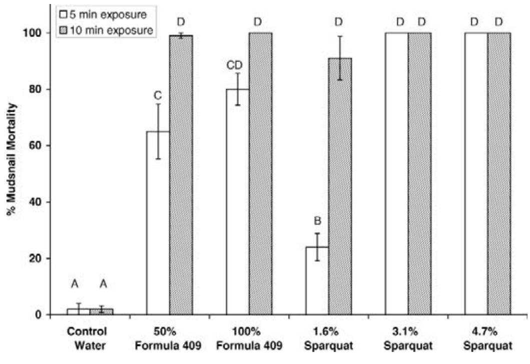

FIGURE 1.—Mean percent mortality (±SE) of New Zealand mudsnails exposed to a 5- or 10-min bath in distilled water (control), Formula 409 All-Purpose Cleaner (50% or 100% concentration), or Sparquat 256 (1.6, 3.1, or 4.7% concentration). Different letters indicate significant differences between treatment means (Tukey's multiple comparison procedure: $P < 0.05$). Absence of error bars indicates 100% mortality across all replicate exposure containers ($n = 4$ containers/treatment; 25 snails/container).

even reproduced by 56 d postexposure. This recovery is noteworthy because New Zealand mudsnails found in the USA are parthenogenic, and one individual surviving on fishing equipment could populate a stream. Our study results suggest that the 50% Formula 409 prescription, even when applied for 10 min, would not effectively control the spread of New Zealand mudsnails. Interestingly, the Sparquat 256 solution (1.6%) recommended for preventing the spread of *M. cerebralis* in Colorado (Colorado Division of Wildlife 2005) also is inadequate to ensure 100% mortality of New Zealand mudsnails.

Increased snail mortality observed at higher concentrations of Sparquat 256 and Formula 409 may be attributable to the toxicity of QACs in these disinfectants. The QACs interfere with gill membrane function of invertebrates and are a main component of the molluscicides used to reduce nuisance mollusk populations (e.g., Asiatic clam *Corbicula fluminea* and zebra mussel *Dreissena polymorpha*) on industrial cooling systems (Dobbs et al. 1995). Formula 409 also contains a degreaser, which may loosen a snail's opercular seal and allow for more-rapid and thorough exposure to the chemical bath. This enhanced exposure may explain why (1) 50% Formula 409 outperformed the lowest Sparquat concentration and (2) 100% Formula 409 produced mortality similar to that obtained by the highest tested Sparquat 256 concentration even though the former contained only half the QAC concentration of the latter. Other household disinfectant products, such as bleach and copper sulfate (a common algicide), are not as effective as QAC-based solutions for killing New Zealand mudsnails and eliminating them from fishing gear (Dwyer et al. 2003; Hosea and Finlayson 2005).

Nonchemical alternatives for eradicating New Zealand mudsnails from angling gear, such as mechanical removal and exposure to extreme temperatures, have also been suggested (Dwyer et al. 2003; Richards et al. 2004). Richards et al. (2004) found that New Zealand mudsnails did not survive several hours of freezing and that most individuals desiccated when exposed to high air temperature (30–40°C) and low humidity (<25%) for at least 2 h. Dwyer et al. (2003) found that water temperatures between 45°C and 50°C were 100% lethal to New Zealand mudsnails. These nonchemical disinfection alternatives are advantageous in that they do not involve a chemical water bath (which requires proper disposal) and they have no potential to affect nontarget organisms. However, the impacts of repeated freezing or heating on angling gear are unknown. Hosea and Finlayson (2005) found that the rubber, neoprene, and waterproof fabrics of waders and wading boots repeatedly soaked in 50% Formula 409 showed minimal damage. Fishery biologists in Colorado routinely disinfect waders, rubber boots, and other fishery equipment in a bath of 1–3% Sparquat 256, and reduced gear integrity has not been observed (Colorado Division of Wildlife 2005). However, the effects of more-concentrated Sparquat 256 and 100% Formula 409 treatments on angling gear and the effects of these chemicals (any concentration) on fishery equipment, such as nets and seines, have not been adequately tested.

We evaluated New Zealand mudsnail mortality in controlled laboratory exposures and did not directly test the efficacy of our chemical treatments for eliminating the snails from angling gear and fishery equipment. However, Hosea and Finlayson (2005) found that New Zealand mudsnail mortality in laboratory exposures accurately predicted mortality on angling gear that was soaked in equivalent chemical solutions in the field. Even though snails were hidden in crevices in the gear (e.g., boot laces and seams), Formula 409 chemical baths were effective for exposing and killing New Zealand mudsnails. On the basis of this correspondence between laboratory and field results, Hosea and Finlayson (2005; their Appendix 3) developed a prescription for disinfecting field gear. This prescription includes submersing the gear in a large tub filled with 50% Formula 409 for at least 5 min, scrubbing debris from the gear, and visually inspecting the gear for snails before rinsing. Rinse water must be from a New Zealand mudsnail-free source (to avoid reinfection), and the chemical bath must be properly disposed of away from the stream to avoid injury to nontarget aquatic organisms. Our results suggest that this prescription should be amended to require at least a 10-min exposure to 100% Formula 409 or to a Sparquat solution of at least 3.1%.

Currently, no management tool exists for eradicating New Zealand mudsnails once they have invaded a stream. Therefore, many western states must rely on cooperation from anglers and recreationists to help limit the spread of this exotic snail (Aquatic Nuisance Species Task Force 2006). For this approach to be successful, agencies must develop safe and simple solutions for reducing accidental transfer of the snails among water bodies. Our research confirms previous findings that household cleaning products containing QACs are useful as control agents for New Zealand mudsnails. However, further research is needed to test the effectiveness of these chemicals for disinfecting angling gear and fishery equipment in the field. Such studies will also help to determine the chemicals, concentrations, exposure durations, and additional steps necessary to limit New Zealand mudsnail invasions and thereby protect fisheries in western streams.

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