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RESEARCH ARTICLE

Germination of Invasive Plant Seeds after Digestion by Horses in California

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ABSTRACT: Using a unique sterile design intended to eliminate outside seed contamination of horse feces, we investigated whether weed seeds germinate after digestion by horses. Feces were collected from selected National Parks and other locations in central and northern California. All potted fecal samples were irrigated and grown in an enclosed sterile nursery environment. Thirty-two plant species emerged from these fecal samples, 24 of which were not native to California. None of these were identified on the California Department of Agriculture's Noxious Weed List, which is used as a basis to certify equine feed as weed free. However, seven of the non-native species are identified as moderately invasive on the California Invasive Plant Council's (Cal-IPC) list. These species are: *Hirschfeldia incana*, *Hordeum marinum, Lolium multiflorum, Mentha pulegium*, *Rumex acetosella*, *Trifolium hirtum*, and *Vulpia myuros.* In addition, the following four non-native plants are listed at the limited invasiveness level on the Cal-IPC list: *Hypochaeris glabra, Lythrum hyssopifolium, Medicago polymorpha,* and *Poa pratensis*. Because we did not survey invasive plant cover in locations from which we sampled, we cannot guarantee that species identified in our samples would have also germinated in the field. Our results add to a growing body of literature documenting germination of seeds after passing through the digestive system of horses and suggest that conscientious horse owners should select feed sources that are free of weeds. We also find that the current list of noxious weeds used to certify weed-free feed for equines should be comprehensive.

Index terms: California, horse feces, horse manure, invasive plant germination, non-native plants, weed seeds

INTRODUCTION

Invasive non-native plant populations are becoming increasingly widespread (Sharma et al. 2005). These aggressive species disperse widely, establish quickly, and spread rapidly throughout ecosystems, usurping resources upon which native plant populations rely (Sakai et al. 2001). This process can result in complete habitat conversion (Gaudet and Keddy 1988), which can severely diminish or eliminate populations of native fauna, and the ecological costs to wildlands due to invasive plants are grave. Land managers spend a great deal of time and money battling invasive populations after they have become established. Prevention programs should be in place to complement these control efforts (Leung et al. 2002). Specifically, if vectors of dispersal that are susceptible to management can be identified, prevention programs can be developed to slow or halt further spread into sensitive habitats.

Recreational use of equines in wildlands may introduce non-native forage species either in feed or in fecal matter left on trails and at camp sites. Seed germination after digestion by horses has been known for decades (Harmon and Keim 1934; Janzen 1981, 1984), but a growing number of researchers are attempting to determine equine contributions to introductions of new plant species in wildlands. Several researchers have collected fecal matter and demonstrated the ability of non-native seeds to germinate and grow in laboratory, greenhouse, nursery, or field conditions (Weaver and Adams 1996; van Dyk and Neser 2000; Campbell and Gibson 2001; Gower 2006; Wells 2006). However, with the exception of van Dyk and Neser (2000), none of these studies reported precautions to avoid contamination by outside seed sources.

The primary goal of our study was to establish the ability of seeds to germinate from horse feces using a unique method that removed any potential for the aforementioned contamination. In addition, we correlated the feed type of each horse with germination of invasive species seeds. The results of our study should give land managers greater confidence in making decisions that affect equestrians and the use of horses on public land.

MATERIALS AND METHODS

The fecal sampling protocol we developed prevented sample contamination by external sources, ensuring seeds that germinated had been ingested by horses in our study. Feces pass from a horse in individual ball shapes which form by intestinal activity as solid waste matter proceeds through its gut (Siegal 1996). Intact fecal piles were taken apart by removing the external fecal balls, leaving interior feces. Only feces that had been protected by external fecal material and that had not contacted ground were collected and placed individually in sealable 1-gallon plastic bags. In order to further eliminate chances of contamination, the individual wore new vinyl gloves to collect and handle each sample throughout the experimental period. For each sample, the following information was recorded: location, date, and time the sample was collected, whether the teeth of the horse had been filed or "floated" within the last year, and most recent or current feed (oat, alfalfa, wheat, pasture, pellets, grain, hay, grass, supplements, etc.). Floating is the process of filing the teeth of a horse to remove sharp points and maintain an even chewing surface (Siegal 1996), potentially impacting seed viability.

Forty-five samples for trial 1 were collected mainly from central California locations including Sacramento, Tahoe City, Tulare, Grass Valley, Orlands, Vacaville, San Francisco Bay Area, Danville, Pleasanton, Milpitas, Morgan Hill, Cupertino, Fremont, Livermore, Los Altos, Half Moon Bay, San Jose, and Monterey. These were collected between 9 and 16 June 2005, placed into a cooler, and delivered to Dominican University of California on 17 June 2005. Samples were refrigerated and subsequently processed and planted in pots. Forty-seven samples for trial 2 were collected from northern California locations including Lassen Volcanic National Park horse camp and trails, Whiskeytown Lake National Recreation Area horse camp and trails, Whiskeytown-Shasta Lake National Recreation Area, Whiskeytown-Trinity National Recreation Area, Juan Bautista de Anza National Historic Trailhead (San Juan Bautista), Stewart's Horse Camp (edge of Pt. Reyes National Seashore), Pt. Reyes National Seashore trailheads, and National Park Service Morgan Horse Farm located in Pt. Reyes National Seashore. These were collected between 19 and 23 October 2005 and delivered to Dominican University of California on the same day.

After 2-4 days of refrigeration, approximately 20 g of fecal matter were removed from each plastic bag, weighed, and split into two equal halves. One half of each sample was placed on a paper plate, covered with a paper towel, and left on a laboratory bench to dry for 3-4 days before being planted. The remaining "wet" half of each sample retained its initial moisture inside the sealed plastic bag and was kept refrigerated while the "dry" halves were allowed to desiccate. Following this treatment, all wet and dry samples were placed into 10-cm diameter, sterile, plastic pots with approximately 2.54 cm autoclaved commercial-grade potting soil. Samples from trial 1 were potted 22 June 2005 while trial 2 samples were potted 29 October 2005. Each trial ran for 60 days.

Pots were randomly arranged on an outdoor wooden nursery bench that was covered on all sides with netting (approximately 650 openings per 2.54 cm^2) and were exposed to ambient light radiation and temperature. An automatic water-misting system maintained a constant level of moisture in the pots. In both trials, 10 control pots were filled only with autoclaved potting soil and set among the 90 (45 wet and 45 dry) and 94 (47 wet and 47 dry) experimental pots in trial 1 and trial 2 respectively. The purpose of the controls was to assess whether any outside seed contamination occurred. Pots were monitored daily for growth, and photos of each seedling were taken. Once each plant achieved sufficient size for taxonomic work, it was removed from the pot, pressed, dried, and identified.

Statistical Analysis

At the time of feces collection, the type of feed administered to the horses was recorded. Feed types included oat, alfalfa, wheat, pasture, hay, grass, pellets, grain, supplement, and unknown. The California Invasive Plant Council's (Cal-IPC 2006) invasive plant list was used to determine the category of level of invasiveness of those non-native species that germinated.

Differences in the mean number of germinating species per pot for trial and wet/dry treatment (pooled over trials) were assessed using Mann-Whitney tests (we chose a non-parametric test because the data failed normality testing even after transformation attempts). Chi-square tests evaluated the presence and absence of germinants in each category according to trial. We used Instat 3.0b (GraphPad Software, San Diego, CA) to perform these analyses.

To determine the strength of the relationships among teeth floating, feed type, and invasiveness of germinated seeds, we performed a similarity analysis using Jaccard's dichotomy coefficient (J). This coefficient provides a measure of agreement between two binary datasets, and is commonly used to predict species presence/absence in relation to particular environmental variables (Real and Vargas 1996; Boyce and Ellison 2001). In our case, for example, the presence of moderately invasive species in a sample might have been associated with the presence of grass in the horse's diet. Values of J range from 0 (no association) to 1 (perfect association) (Boyce and Ellison 2001). Trials 1 and 2 were pooled in the similarity analysis. This statistical analysis was performed using Systat 10.0 (SPSS Inc, Chicago, IL).

RESULTS

Germination Rates

Eight species germinated in 10 of the 90 experimental pots in trial 1, while 27 species germinated in 62 of the 94 experimental plots in trial 2 (Table 1). No differences in the number of germinating plants were found between wet and dry samples (the respective means, standard errors, and sample size were: wet samples 1.6 S.E. ± 0.2, n = 37; dry samples: 1.9 S.E.± 0.2, n = 35; U = 556, p = 0.2983) in pooled data sets from both trials. Because no differences in wet and dry samples were found, manure samples from individual horses were consolidated for the purposes of further analyses. The total number of observations of germinating species was 46 (n = 9 from trial 1; n = 37 from trial 2). There was a significant difference in mean number of germinating species per pot between trials (trial 1 mean: 1.1 S.E.± 0.1, n = 9; trial 2 mean: 2.2 S.E.± 0.2 n = 37; U = 74.5, p = 0.0110). However, species germination within each category (i.e., natives and non-natives at different invasive-

Table 1: Scientific and common names for species germinating in both trials. The trial in which each species germinated is indicated by a '1' or a '2' in the last column. For species which were native or unknown, a lowercase "u" indicates unknown status, while lowercase "n" indicates the species is native to the United States. The 32 species are listed by category of invasiveness according to Cal-IPC (2006) and USDA, NRCS (2007). None of these species were categorized as noxious weeds by CDFA.

Species Name		Common Name	Trial
Cal-IPC Invasiveness Category: Moderate			
Hirschfeldia incana		summer mustard	1
Hordeum marinum		Mediterranean barley	2
Lolium multiflorum		Italian ryegrass	1 & 2
Mentha pulegium		pennyroyal	2
Rumex acetosella		sheep sorrel	2
Trifoliun hirtum		rose clover	2
Vulpia myuros		rat-tail fescue	2
Cal-IPC Invasiveness Category: Limited			
Hypochaeris glabra		smooth catsear	2
Lythrum hyssopifolium		hyssop loosestrife	2
Medicago polymorpha		bur-clover	1 & 2
Poa pratensis		Kentucky bluegrass	2
Introduced to the United States			
Aira cayophyllea		silver hairgrass	2
Arthemis cotula		stinking chamomile	2
Galium murale		hellow wall bedstraw	2
Linum bienne		pale flax	2
Linum usitatissimum		common flax	2
Malva nicaeensis		bull mallow	1
Poa annua		annual bluegrass	2
Polygonum aviculare		prostrate knotweed	1
Portulaca oleracea		common purslane	1
Pseudognaphalium luteoalbum		Jersey cudweed	1
Soliva sessilis		field burrweed	2
Stellaria media		common chickweed	2
Trifolium repens		white clover	2
U.S. Native or Unknown Status			
Amararthus spp	u	pigweed	2
Chamaesyce spp	u	sandmat	2
Matricaria occidentalis	n	valley mayweed	2
Gnaphalium palustre	n	Western marsh cudweed	2
Heteromeles arbutifolia	n	toyon	2
Juncus bufonius	n	toad rush	1 & 2
Trifolium bifidum	n	notchleaf clover	2
Veronica peregrina L. subspecies *xalapensis*	n	hairy purslane speedwell	2

The definitions of ratings are: "High – These species have severe ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal and establishment. Most are widely distributed ecologically; Moderate – These species have substantial and apparent—but generally not severe—ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal, though establishment is generally dependent upon ecological disturbance. Ecological amplitude and distribution may range from limited to widespread; Limited – These species are invasive but their ecological impacts are minor on a statewide level or there was not enough information to justify a higher score. Their reproductive biology and other attributes result in low to moderate rates of invasiveness. Ecological amplitude and distribution are generally limited, but these species may be locally persistent and problematic."

ness levels) did not differ between trials (2 x 4 contingency table, chi-squared test for independence, $\chi^2 = 1.210$, 3 degrees of freedom, P = 0.6437, see Table 1 for sample size). No germination occurred in the 10 control pots in either trial, confirming that our growing space was not contaminated by external seed sources.

Similarity Analyses

Trials were pooled in the similarity analysis (n = 46). In general, similarity coefficients were weak (J < 0.50, Table 2), but those that were greater than zero are presented to illustrate the relative strength of the relationships compared to those with zero-values. For example, germination of species of all categories was more likely to occur in manure of horses whose teeth had been floated within the previous year (0.26 < J < 0.42) compared to horses whose teeth were not floated (0.04 < J < 0.18). Floating did not disproportionately promote germination of invasive species, however, as J values for species of moderate invasiveness (J = 0.40) were comparable to native species (J = 0.42). Of all feed types, "pasture" had consistently stronger relationships with germinants of all categories (0.18 < J < 0.25) than other feed types. Oats and alfalfa were close behind, and grass supported both native and species of moderate invasiveness almost equally (Table 2).

Table 2: Results of similarity analysis for both trials (n = 46), showing Jaccard's binary similarity coefficients (J). Values reflect the strength of the relationships between invasiveness categories of germinants and teeth status (A), and feed type (B). Most relationships were weak (J < 0.50) or nonexistent (J = 0).

	Moderate invasiveness	Limited invasiveness	Introduced to U.S.	Native to U.S.
A. Teeth				
Floated	0.40	0.30	0.26	0.42
Not floated	0.18	0.05	0.05	0.04
Unknown	0.07	0.20	0.20	0.08
B. Feed type				
Oat	0.16	0.19	0.19	0.17
Alfalfa	0.17	0.16	0.12	0.28
Pellets	0.13	0.00	0.11	0.04
Pasture	0.25	0.20	0.25	0.18
Grain	0.13	0.17	0.11	0.04
Hay	0.08	0.00	0.11	0.04
Grass	0.23	0.10	0.10	0.25
Supplement	0.08	0.21	0.10	0.08
Wheat	0.10	0.06	0.00	0.11

DISCUSSION

While other studies have demonstrated germination of wildland invasive plants from horse manure (Weaver and Adams 1996), those designs were such that manure could have been contaminated by seeds from external sources. Weaver and Adams (1996) collected manure along seven trails from three National Parks in Australia, but did not describe conditions of the trailside manure or any precautions taken against seeds that may have adhered to external surfaces (17 of 29 species that germinated from their samples were identified as weeds). Hay, hoof scrapings, and fecal samples were taken from five sites in Illinois, Wisconsin, Michigan, North Carolina, and Kentucky to determine weed seed germination in another study, but no mention was made of precautionary efforts against contamination (Gower 2006). Only weed seeds from hay samples germinated from the outdoor pot experiment in that report, and none germinated from hay, hoof scrapings, or fecal samples that were planted along trails (Gower 2006).

Campbell and Gibson (2001) collected 40 manure samples from trail transects placed in three forest areas in southern Illinois, but did not describe precautions against wayward seeds. Twenty-three non-native species germinated in greenhouse facilities in that study (Campbell and Gibson 2001). Wells (2006) reported greenhouse germination of 10 non-native species from horse manure collected along Colorado trails, using non-sterile trail sampling techniques. One published study used a design that eliminated likelihood of contamination by outside seed sources. In that study, manure was extracted by hand from the rectum of horses that were purposefully fed seeds of agricultural weeds to determine potential for germination and potential spread into wildlands (van Dyk and Neser 2000). This carefully conducted study showed many of these agricultural weed seeds were capable of germinating after digestion. Similar to their work, our sterile design guarantees that wildland invasive seeds were ingested by the horse, passed through the digestive tract intact, and successfully germinated.

We did not directly feed invasive weed seeds to the horses, but we did survey the owners regarding type of feed administered to the horse. While none of the feed types were strongly related to invasiveness of the germinating plants, horses that fed in pastures were relatively more likely to harbor germinable plant seeds of all categories documented in our study. To minimize this vector, pastures should be monitored and treated for invasive species. Aside from pasture feed, more species germinated in feces from alfalfa-, oat-, and grass-fed horses. If measures are taken to minimize the potential for horses to introduce weed seeds, these standard feed sources would have to be examined as well. A potential follow-up study would assess germination not only from manure but also from the feed of each horse used in the experiment. According to our results, the problem seems worse in northern California (trial 2) in comparison to central parts of the state (trial 1) and, therefore, increased management would be particularly important in that region. However, more studies would be needed to confirm these results.

We expected horses whose teeth had been floated in the previous year to render higher percentage of non-viable seeds compared to those whose teeth were not floated. However, the opposite pattern was seen. Seeds of all categories germinated in feces from horses whose teeth were floated, while only one category of germinating seeds grew in feces from "unfloated" horses. This suggests that routine floating will not necessarily minimize seed germination rates from horse feces. However, that conclusion can only be made after future studies specifically manipulate teeth quality and seed type in the diet.

Additional work is needed to determine

implications of these results in the field. For example, while we have clearly demonstrated ability for invasive species to germinate from manure in controlled nursery conditions, we did not seek to document subsequent establishment and, more importantly, spread of these species from manure piles in the field. Several studies have compared extent of invasive plant cover in different land use areas, but their results were contradictory. For example, Campbell and Gibson (2001) documented greater cover of exotic species on equestrian trails than trails that did not allow horses. Invasive plant cover in campgrounds was shown to be greater when horses were allowed in one study (Cole and Hall 1992), but no difference was found between hiker and stock campgrounds in another (Marcus et al. 1998). The latter study focused on a single invasive species, *Centaurea maculosa* L., and did not report coverage values of other invasive plants (Marcus et al. 1998). Only native species germinated from hay, hoof scrapings, and manure samples placed along trails in another study in the eastern United States, and no difference in non-native species composition was found when comparisons were made between equestrian and hiker-only trails (Gower 2006).

Recommendations made to public land managers and the equestrian community would be of greater value if correlations between seed germination from horse manure and subsequent spread of weeds were to be demonstrated more clearly. Such information would be of use to public land agencies, such as the National Park Service, that are mandated by Congress to maintain natural ecological processes on land they manage. It is noteworthy that federal and state agencies in some states, such as Colorado and Wyoming, legally require use of weed-free feed for equines traveling on public land. These agencies are apparently basing their requirements on the precautionary principle, which is certainly the best management practice if we are to preserve our natural ecosystems.

Categories of Invasiveness

The State of California's Department of Food and Agriculture (CDFA 2006) define a noxious weed as any plant that "is, or is liable to be, troublesome, aggressive, intrusive, detrimental, or destructive to agriculture, silviculture, or important native species, and difficult to control or eradicate." Inclusion of a species on the CDFA list mandates control or eradication depending on its listing level. A- and Q-rated species are the only groups for which eradication is enforced by all state entities. Control actions of lower ratings are either enforced at the discretion of individual County Agricultural Commissioners (B rated) or not enforced (C or D rated) (CDFA 2006). California County Agricultural Commissioners refer to the CDFA list in determining whether to certify crops as weed-free feed, and are mandated to deny this certification if species at the A- or Q-level are found. Using these standards, results of our study included no problematic species at any level. However, certain species whose distribution has become widespread or whose control is as difficult or costly as to be prohibitive are not listed by CDFA. For example, one of the most infamous species known to California land managers, yellow starthistle (*Centaurea solstitialis* L.), (Roche et al. 1994; DiTomaso 2000) is listed at the C-level by CDFA (CDFA 2006). This rating category carries no mandate for control except to retard spread at the discretion of individual Agricultural Commissioners (CDFA 2006). The same is true for other extremely invasive species such as cheatgrass (*Bromus tectorum* L.), Pampas grass (*Cortaderia jubata* Lem.), Scotch broom (*Cytisus scoparius* L.), medusahead (*Taeniatherum caput-medusae* L.) and others (CDFA 2006). While we do not suggest that the germinants in our study are necessarily as invasive as yellow starthistle or cheatgrass, we note that a discrepancy exists between species that have been documented as ecologically relevant invaders and those that are used to define the content of "weed-free" horse feed.

To better assess the potential ecological impact of the germinants in our study (Table 1), we referred to a list compiled by the California Invasive Plant Council (Cal-IPC 2006). This inventory is compiled within a rating system that evaluates evidence of the ecological impact of 238 species, but carries no regulatory mandates. Using the Cal-IPC system, seven species were listed at the moderate level (Cal-IPC 2006), including summer mustard (*Hirschfeldia incana*), Mediterranean barley (*Hordeum marinum*), Italian ryegrass (*Lolium multiflorum*), pennyroyal (*Mentha pulegium*), sheep sorrel (*Rumex acetosella*), rose clover (*Trifolium hirtum*), and rat-tail fescue (*Vulpia myuros*). Four were listed at the limited level (Cal-IPC 2006), namely smooth cat's ear (*Hypochaeris glabra*), hyssop loosestrife (*Lythrum hyssopifolium*), bur-clover (*Medicago polymorpha*), and Kentucky bluegrass (*Poa pratensis*). Rye grasses, blue grasses, clovers, and barley are common pasture forages planted for grazing animals. These species may have potentially substantial and persistent ecological impacts if they germinate from horse feces along wildland trails, but they are currently unlisted by the CDFA that governs feed certification (CDFA 2006).

A third database was consulted for species that were not listed by CDFA or Cal-IPC. The Natural Resources Conservation Service of the U.S. Department of Agriculture maintains a website that provides standardized information, including nativity, for plants that occur within the United States and its territories (USDA, NRCS 2007). Using this database, we determined that 13 species had been introduced and eight species were either listed as being native to the United States or were unknown (Table 1) (USDA, NRCS 2007).

CONCLUSIONS

Results from this study and others clearly indicate that seeds are capable of germination in greenhouse conditions after digestion by horses. More work is required to determine the importance of horses as potential weed dispersal vectors in field conditions, but the fact that weed germination has been documented should caution owners to carefully select feed sources free of weeds before bringing horses onto trails. Our comprehensive literature review on the role of horses and weed dispersal suggests that in situ germination of invasive species from equine feces on trails and into adjacent plant communities is uncommon. However, several studies show that in some locations weeds become established. When suitable conditions are lacking for germination of weed seeds transported by horse manure, the seeds may remain viable in soil banks for years. Such weeds have potential to sprout and grow in subsequent years under favorable conditions.

It is true that none of the species that germinated in this study are currently considered A- or Q-rated noxious weeds by CDFA, which oversees horse feed production in California, but we cannot rule out the possibility of presence of such noxious weed seeds in a viable state based on our small sample size. We also point out that the official lists used to label feed sources as "weed free" are not comprehensive, as they fail to include weeds of ecological significance, and we propose that such lists be modified accordingly.

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Lauren Quinn currently resides in Australia, where she works in a research role for the Commonwealth Scientific and Industrial Research Organization (CSIRO). She conducted her doctoral research on the riparian invader Arundo donax in southern California, and has studied Centaurea maculosa and Tamarix ramosissima in other parts of the Western U.S. She is interested in questions of habitat susceptibility to plant invaders and impacts of plant invaders on native ecosystems, and is currently applying these questions to freshwater systems in Australia.

Mietek Kolipinski began his early scientific work with microbiological cancer research and later received a PhD in marine science in Miami, Florida. Kolipinski then conducted research in marine and freshwater hydrobiology in South Florida. Since 1971 and currently he is a natural resources and research administrator with the Pacific West Region of the National Park Service. Kolipinski is an Honorary Teaching Fellow at Dominican University of California and conducts research with faculty and students in U.S. national parks.

Vania R. Coelho is an Assistant Professor of Environmental Sciences, Department of Natural Sciences and Mathematics, Dominican University of California, San Rafael, California. Dr. Coelho's research focuses on ecology and evolutionary biology of marine invertebrates. Her research interests include benthic community ecology, population biology, behavior, systematics of crustaceans, and coral reef ecology.

Bonnie Davis, an avid trail rider and horsecamper for over 40 years, has presented workshops, clinics, lectures and presentations on horsecamping, trail riding, preserving trails, and developing and keeping trails accessible to equestrians and trail riders. Her columns, articles and stories have appeared in local, national, and worldwide publications. Her recognized, informational, educational website focuses on locating Certified Weed Free Feeds nationwide. She maintains a nationwide presentation schedule, Consulting Editor to 'The Trail Rider Magazine,' and is the owner of Two Horse Enterprises, a website/catalog business dedicated to trail riding and horsecamping.

John-Mary Vianney graduated in the spring of 2006 from Dominican University of California as an environmental studies scholar student and with academic honors. She was an active member of our invasive plants research program. Currently, she is a graduate student at Western Michigan University where she is performing research on neuroscience.

Orgiltuya Batjargal graduated in the spring of 2008 from Dominican University of California, where she assisted in studies of germinating invasive plant seeds after their digestion by horses. Batjargal was an exemplary student and enjoyed field and laboratory research. She learned to be patient and knew she was making a difference. She has been admitted to St. George's University, Granada, where she will pursue an MD and fulfill her dreams to practice medicine.

Monika Alas graduated in the spring of 2008 from Dominican University of California with high academic honors. Monika was active on campus as a teaching assistant and was a "student ambassador" representing the university to prospective students. She carried out undergraduate research including studies on impacts of non-native plants in natural areas. She plans a career practicing medicine and has been accepted to begin her studies in the medical school at the University of Southern California.

Sibdas Ghosh is Chair and Professor of Biology, Department of Natural Sciences and Mathematics, Dominican University of California, San Rafael, CA. Dr. Ghosh received scientific training in Calcutta, India, and the U.K. and earned a PhD in Plant Molecular Physiology and Biochemistry from the University of Waterloo, Canada. Ghosh has over 30 publications and 100 conference presentations to his credit, many with student co-authors.

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