ESTIMATING THE ECOSYSTEM SERVICE OF ALEUTIAN CACKLING GOOSE DROPPINGS ON PASTURES

By

Brian G. Fagundes

A Thesis Presented to

The Faculty of California State Polytechnic University, Humboldt

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Natural Resources: Wildlife

Committee Membership

Dr. Jeffrey M. Black, Committee Chair

Dr. Matthew D. Johnson, Committee Member

Dr. Susan E. Marshall, Committee Member

Dr. Erin C. Kelly, Program Graduate Coordinator

July 2022

ABSTRACT

ESTIMATING THE ECOSYSTEM SERVICE OF
ALEUTIAN CACKLING GOOSE DROPPINGS ON PASTURES

Brian G. Fagundes

The Aleutian cackling goose (*Branta hutchinsii leucopareia*) experienced a population low of 790 geese in 1974 and has recovered to the current estimate of 186,100 geese in 2021. Private livestock producers view geese as pasture competitors and use hazing and hunting to scare geese from private lands to adjacent public lands. I investigated if geese provide an ecosystem service via dropping fertilizing effects to improve pastures in northern California.

A greenhouse experiment was conducted from February-August 2019 at Cal Poly Humboldt, divided into two experiments: freshly sown ryegrass pasture and established plant and soil communities removed intact from pastures. Fresh goose droppings were added at different amounts every two weeks for two months and vegetation hand clipped to simulate grazing by geese in the spring. To imitate the departure of geese during summer, no droppings were added after 14 April, and vegetation was clipped twice to simulate two periods of summer haying by ranchers.

Pasture forage production significantly increased with the addition of goose droppings. Average forage weights were significantly higher than the control groups in both the ryegrass pasture system (108-334%) and the established pasture system (12-

45%). I measured several soil properties to connect dropping additions with vegetative growth and documented improved soil levels of phosphorus, potassium, and sodium in the ryegrass pasture system. I estimated an ecosystem service for enhanced hay production due to goose dropping additions of $79-$243/acre ($32-$98/ha) for newly sown ryegrass pasture, and $69-$251/acre ($28-$102/ha) on established pasture. Investigating the function of goose droppings on pastures is a first step towards estimating ecosystem services of Aleutian geese, which are benefits currently underappreciated by Del Norte and Humboldt County land managers.

ACKNOWLEDGEMENTS

I am incredibly thankful for my advisor Dr. Jeff Black for inspiring me as a starry-eyed high school senior looking for a college, to taking me and a group of fellow undergraduates to the Wildfowl & Wetlands Trust in Slimbridge, U.K. where I fell in love with waterfowl. His encouragement led me to graduate school several years later to pursue research on the resilient Aleutian cackling goose. I want to thank Dr. Matt Johnson for sharing his depth of knowledge and passion for wildlife research within agricultural systems, from California to Jamaica. Matt provided a career example of how to combine my Azorean Portuguese roots in farming and dairying with my flourishing interests in wildlife management. I would like to thank Dr. Susan Marshall for being my intellectual leader on soils; I could not have had a better teacher. Thank you to Brianne Lee for use of the experimental greenhouse and guiding me in the ways of greenhouse growing. I am truly thankful to Cliff Feldheim of CDWR, and Mike Casazza and Elliott Matchett of USGS WERC Dixon for hiring me and funding soil analyses through shutdowns and pasture floods. Thank you to the City of Arcata for permitting use of Jacoby Creek-Gannon Slough Wildlife Area and all the local ranchers for granting me access to collect goose poop in their pastures; hopefully in the future they will want the poop (and geese) to stay for fertilizer. I would like to thank all the wildlife grads/WiGSS and my lab mates Kachina Rowland, Matt Delgado, Jess Barger, Jessica Guenther, and Shaun Thornton for sharing in the graduate experience. Finally, I am deeply grateful for all the love and support from my family and friends, to pursue life with all my heart.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Wild goose populations have expanded dramatically in recent decades throughout Western Europe (Fox and Madsen 2017) and North America (USFWS 2021) due, in part, to increased production of agricultural crops (Owen and Black 1991) and the addition of wildlife refuges, which provided forage during the non-breeding season (Ankney 1996). Geese generally benefit from the energy and nutrient content of agricultural crops compared to forage found on natural grasslands or wetlands (Fox and Abraham 2017), although studies have observed variable protein and fat contents resulting in lower quality forage on agricultural lands compared to more natural areas (Prins and Ydenberg 1985, Prop and Black 1998). With the addition of lipid-rich foods in the form of agricultural crops and pastures, goose populations were no longer limited by smaller areas of natural habitat at the southern-most ends of their winter migration (Owen 1980, Ankney 1996, Fox and Abraham 2017). Over-abundant, local goose populations have been documented to provide a disservice to communities by contributing to urban pollution, eutrophication of freshwater sources, methane efflux, loss of plant cover, soil erosion, and loss of carbon storage (Buij et al. 2017). Shifting from natural habitats to agricultural land and grassland pastures led to conflicts with landowners calling for mitigation for losses due to goose grazing and trampling (Owen 1990, Moser and Kalden 1992). Focusing on the quantification of crop losses emphasizes negative human perceptions of wild geese, often leading to conflict escalation rather than resolution (*sensu* Owen 1990, Madsen et al. 1999, Green and Elmberg 2014, Black et al. 2014, Simonsen et al. 2017).

Wild geese may also provide positive ecosystem services to farmers and ranchers (*sensu* Kear 1963, Percival and Houston 1992). The ecosystem services concept is used to understand benefits humans can derive from nature, with the goal of more sustainable use of natural resources (MEA 2005). Assessing ecosystem services requires breaking down complex ecological processes into a more limited number of ecological functions (de Groot et al. 2002). Functions that provide services that humans value are considered benefits. Once quantified, benefits can be examined in relation to known disservices to develop a more complete understanding of perceived goose-agriculture relationships.

The relationship between wild geese and agricultural producers may be reframed as a dynamic relationship of negative and beneficial interactions within grassland ecosystems (*sensu* Black et al. 2014, Buij et al. 2017). The United Nations Millennium Ecosystem Assessment (MEA 2005) provides a framework to identify services from nature according to categories of provisioning, regulating, cultural, and supporting services. Provisioning services of geese have included the production of meat, down, feathers, and grease for human consumption and use (Kear 1990, Green and Elmberg 2014, Buij et al. 2017). Regulating services of geese involve modifying the quality of air, water, soil, and climate or by providing disease control (Green and Elmberg 2014, Buij et al. 2017). Cultural services consist of recreational hunting, birdwatching, ecotourism, conservation, and art (Green and Elmberg 2014, Buij et al. 2017). Geese can provide a supporting service via nutrient cycling, stimulating primary productivity, and increasing biodiversity (Green and Elmberg 2014, Buij et al. 2017). My study focused on supporting services of geese, which may provide currently unrecognized benefits to farmers.

Supporting services are “necessary for the production of all other ecosystem services” (MEA 2005:40).

The Aleutian cackling goose (*Branta hutchinsii leucopareia*), hereafter Aleutian goose, is a North American species whose population increase has led to conflicts with private landowners. In 1974 the total population reached a low of 790 geese after being listed as endangered in 1964 (USFWS 2001, Trost and Sanders 2008). During the following three decades of conservation and management initiatives, the population recovered to over 30,000 geese and the species was delisted in 2001 (Mini et al. 2011). By 2005, the population grew to approximately 100,000 geese, introducing impacts via their grazing on pastures in their spring staging grounds (Mini et al. 2011). Working groups called for coordinate hazing plans and late season hunting seasons to scare geese from private lands to adjacent public lands, resulting in shifts to new staging regions (Mini and Black 2009, Mini et al. 2011, Spragans et al. 2015). Conflict over grazing resources with agricultural operations increased at traditional and new spring staging areas in northern California (Black et al. 2004, Mini and Black 2009, Spragans et al. 2015), causing ranchers to alter stocking practices or provide supplemental feed (Mini et al. 2011). To quantify grazing resource conflicts, Tjarnstrom (2014) estimated Aleutian geese consumed an average of 572 lbs/acre of forage, valued at $42.90/acre, which could have supported one 900 lb steer for approximately 26 days.

Spring staging areas adjacent Humboldt Bay, California now support a majority of the Aleutian goose population on private and public lands from January to April (Spragens et al. 2015). The population reached an estimated high of 199,500 in 2019, decreased to 118,400 in 2020, and was last estimated at 186,100 in 2021 (USFWS 2021). Hunting is used to haze geese off private lands, and strategies to lure them to public areas have been investigated (Bachman 2008). Mini et al. (2011) recommended research to understand not just negative impacts, but also benefits of geese to communities. To date, no attempts have been made to quantify the functional, positive role of Aleutian geese which may provide beneficial services to human communities.

I investigated the response of vegetation and soil to simulated Aleutian goose grazing in Humboldt County using experimental greenhouse methods. I evaluated multiple levels of grazing and fecal matter deposition (hereafter referred to as goose droppings) to determine the level at which droppings would positively influence plant growth and soil quality. I tested if an increase in goose dropping deposition resulted in corresponding fertilizing effects on vegetation and soil. I converted vegetation production and soil improvements into financial values of hay to assess ecosystem services to livestock producers. Estimating potential financial benefits of geese provides livestock managers with an opportunity to consider geese as assets on their lands, steering the relationship between wildlife and agriculture away from conflict and towards beneficial co-existence.

METHODS

Study Area

Aleutian geese breed in the Aleutian Islands of Alaska and migrate south to fall and winter areas in Oregon and California (Woolington et al. 1979, Mini et al. 2011, Cocke et al. 2016). During fall migration, the Western Aleutian breeding population migrates to California where most of the population spends the winter in Central California at the San Joaquin River National Wildlife Refuge and San Joaquin-Sacramento River Delta (Mini et al. 2011). During spring migration, Aleutian geese in the 1970s to 1990s passed through the Humboldt Bay area to stage north in the Crescent City area of Del Norte County, California (Woolington et al. 1979, Springer and Lowe 1998). However, geese switched to visiting the Humboldt Bay area where they spring stage in numerous areas of northern California (Mini et al. 2011). From January-April, the Humboldt Bay spring staging region, including the Arcata bottomlands of North Humboldt Bay, supports a majority of the population prior to their return to Alaska for breeding (Spragens et al. 2015).

I collected vegetation and soil samples within Aleutian goose spring staging pastures adjacent to the North Humboldt Bay at the Jacoby Creek-Gannon Slough Wildlife Area, Humboldt, California. These pasturelands were formerly salt marsh habitat along the shore of Humboldt Bay, reclaimed in the late 1800s (Hoff 1979). Today, the study area consists of livestock-grazed pasturelands dominated by beef cattle

(*Bos taurus*) using time-controlled grazing (i.e. the 'Savory grazing method') in which livestock are rotated through subdivided pastures for specific periods of time (Savory and Parsons 1980).

The Humboldt Bay region has a moderate climate with annual precipitation normally occurring between October and April, permitting growth of pasture grasses throughout the year (Diamond 1990). Pastures used by the Aleutian geese within the region are comprised of velvet grass (*Holcus lanatus*), marsh grass (*Heleochloa schoenoides*), ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), white clover (*Trifolium repens*), meadow grass (*Poa spp.*), bentgrass (*Agrostis spp.*), and buttercup (*Ranunculus spp.*) (Bachman 2008, Mini and Black 2009).

The pastures are currently classified according to Cowardin et al. (1979) as palustrine, emergent, persistent, seasonally saturated wetlands. The dominant soil of the pastures are: Swainslough, 0 to 2 percent slopes classified as fine, mixed, superactive, nonacid, isomesic Fluvaquentic Endoaquepts. Swainslough soils are very poorly drained characterized by horizons of Oi (0 to 3 inches (0-7.6 cm), slightly decomposed plant material), A (3 to 12 inches (7.6-30.5 cm), silty clay loam), and Bg (12 to 65 inches (30.5-165.1 cm), silty clay loam) (NRCS 2018).

Field Methods

All methods were approved by the Cal Poly Humboldt Institutional Animal Care and Use Committee (IACUC) in Protocol Number 18/19.W.7-E, approved on 12 December 2018. Access to the Jacoby Creek-Gannon Slough Wildlife Area was granted with a Nature Area Entrance Permit, approved by the City of Arcata on 2 November 2018.

Soil and vegetation collection

I collected soil from 12 sites 25-27 January 2019. Sites were separated by approximately 100 m and restricted to locations with vegetation associated with Aleutian goose foraging habitat, surface contained no goose droppings or cattle manure, and surface was free from standing pools of water. The vegetation and O soil horizon were removed before soil from the A horizon was collected to a depth of 20 cm (NRCS 2012). The hole was filled in with surrounding soil and cow manure, then capped with vegetation and O soil horizon previously removed.

I collected five cores of intact vegetation and soil horizons from each of 10 sites 6-8 February 2019, yielding 50 pasture cores placed in pots. Sites were separated by approximately 100 m and restricted to locations with vegetation associated with: Aleutian goose foraging habitat, an area of homogenous vegetation large enough to remove five cores, surface contained no goose droppings or cattle manure, and surface was free from standing pools of water. I designed and constructed a metal device to collect cores to fit inside pots I made from PVC pipe glued to plastic saucers. First, the metal corer was hammered into the ground. I dug from one side of the pipe, ensuring not to disturb vegetation and soil on the other sides. I removed the pipe containing the core and trimmed soil attached at the bottom to create a core depth of 15 cm. A metal plate and drill were then used to press the core out directly into a pot. This process was repeated from locations directly adjacent to the prior removed cores to collect five cores from each site. The holes were filled in with unused soil collected in January in addition to cow manure and vegetation from nearby.

Dropping collection

To collect droppings, I visited pastures within the study area and private pastures in the Arcata Bottoms where I had access permission. I scanned the pastures from inside a vehicle with a spotting scope and/or binoculars to assess if Aleutian geese were present. If geese were present in the pasture, I watched them forage for 0.5-1 hour. Before walking into the pasture, I waited until the geese had either exited the pasture or moved to a distance greater than 100 m from the dropping collection sites. To reduce disturbance, I maintained a minimum distance of 100 m from any geese and observed their behavior for signs of heightened vigilance, fleeing on foot, or imminent flight. I walked transects across the pasture, weaving back and forth, collecting fresh droppings from locations I had observed geese foraging. After each collection event, a portion of the droppings were sent to A & L Western Laboratories in Modesto, California for analysis. Remaining droppings were stored in open plastic bags inside a refrigerator and used for experiments within 48 hours. Droppings collected over the entire study that were used for treatments consisted of the chemical components detailed in Table 1.

Table 1. Chemical components of wild Aleutian cackling goose (*Branta hutchinsii leucopareia*) droppings collected from pastures near Arcata, California for use in greenhouse experimental pasture treatments at Cal Poly Humboldt, California spring 2019. Values reported on a dry basis.

Dropping component	Average value	Pounds/dry ton
Moisture	85.99 %	n/a
Organic Matter	80.01 %	1,600
pH	7.2	n/a
Carbon:Nitrogen (C:N) Ratio	12:1	n/a
Nitrogen (N)	4.17 %	83.5
Ammonia Nitrogen (NH_3-N)	0.046 %	0.9
Nitrate Nitrogen (NO_3-N)	<0.005 %	<0.1
Phosphorus (P)	0.61 %	12.1
Phosphate (P_2O_5)	1.38 %	27.7
Potassium (K)	3.66 %	73.1
Potash (K_2O)	4.40 %	88.1
Sulfur (S)	0.44 %	8.7
Magnesium (Mg)	0.51 %	10.1
Calcium (Ca)	0.88 %	17.6
Sodium (Na)	0.10 %	2.0
Iron (Fe)	3,521 ppm	7.0
Aluminum (Al)	2,106 ppm	4.2
Manganese (Mn)	283 ppm	0.6
Copper (Cu)	16 ppm	<0.1
Zinc (Zn)	48 ppm	<0.1
Boron (B)	12 ppm	<0.1

<u>Geese observation</u>

I assessed Aleutian goose flock size and dropping rates by driving a transect through the Arcata Bottoms periodically from October 2018-April 2019 and September 2019-March 2020. I estimated the number of geese, if present, in each individual pasture. If geese were foraging and easily visible through a spotting scope, I would follow an individual and document each time a solid dropping was produced (Prop and Black 1998). Observations were stopped as soon as the abdomen was out of view. Dropping rate is the interval of time between the production of droppings, averaged across all observations (Owen 1971). These data were used to corroborate treatment group dropping amounts and produce field examples of results from greenhouse experiment.

Greenhouse Methods

I conducted two experiments inside the Department of Biological Sciences' Experimental Greenhouse at Cal Poly Humboldt from February-August 2019. I created a 'New Pasture Experiment' to simulate the effect of goose droppings on a pasture that was recently plowed and sown with grass seed. I also created a 'Established Pasture Experiment' to simulate the effect of goose droppings on a pasture that was vegetated and actively grazed by cattle and geese.

<u>New pasture experiment</u>

Soil I collected from 25-27 January 2019 was air dried in the greenhouse and passed through a 4 mm sieve to remove rocks, plant debris, and large roots. I then mixed the soil from all 12 sites into one batch. To measure soil characteristics at the start of the experiment, I sent samples from the composited batch to A & L Western Laboratories in Modesto, California for analysis. Soil samples were analyzed according to their standard laboratory protocols for 20 soil variables, including soil texture (particle size analysis), organic matter (% soil sample, by weight), soil pH, nitrate nitrogen (NO_3-N ppm), phosphorus (P ppm) using the Bray-P1 method, potassium (K ppm), sulfur (S ppm), sodium (Na ppm), magnesium (Mg ppm), calcium (Ca ppm), and cation exchange capacity (CEC meq/100g). These soil variables are common soil indicators in soil quality assessments as reviewed by Laishram et al. (2012) and Bünemann et al. (2018).

I filled 60 six-inch (15.24 cm) wide, 4.5-inch (11.43 cm) deep greenhouse pots with 1,000 g of soil per pot. Resultant soil dimensions were approximately 15 cm wide and 10 cm deep. A saucer was placed under each pot to reduce soil and water loss. Based on the particle analysis the soil texture was loam, consisting of approximately 41% sand, 32.5% silt, and 26.5% clay. From 1-2 February 2019 I seeded each pot with one gram, approximately 200 seeds, of annual ryegrass (*Festuca perennis*) and 1.5 grams, approximately 450 seeds, of perennial ryegrass (*Lolium perenne).* Seed selection and proportions were based on local pasture seed mixes available from northern California agricultural suppliers used by ranchers (D. Hunt, pers. comm., 2019).

The 60 pots were assigned to control and treatment groups following a balanced completely randomized design: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D). I rotated and watered pots with tap water to maximum capacity without overflowing the saucer two to four times weekly. To manage aphids to keep the greenhouse free from pest outbreaks that could affect other projects, I applied a garden insect killer foliar spray consisting of plant oils on 7 April and 19 April.

The experiment was then divided into two periods: the spring grazing period and the summer haying period. The spring grazing period of 19 February to 14 April 2019 reflected the time of year when geese and cattle are present in the pastures. Any vegetation clipped from the pots simulated the removal of forage by grazing geese. Any droppings added to the pots replicated dropping deposition from grazing geese. The summer haying period of 14 April to 12 August 2019 reflected the time of year when no geese or cattle are present in the pastures. Any vegetation clipped from the pots simulated the removal of forage by a rancher to produce hay. No droppings were added during this period to simulate the absence of geese.

Spring grazing period.

Every two weeks, beginning 19 February and ending 14 April 2019, I directly measured the ten longest grass blades, from the soil surface to tip of blade, in each pot with a metal ruler in mm and estimated the average grass height (Stewart et al. 2001). For the clipping treatment groups, I trimmed the grass with hand shears to 3 cm and collected the clippings, which were oven dried at 60 C for 24-48 hours and weighed in grams. For the dropping treatment groups, I first mixed all the droppings together by hand. I then removed a portion of the dropping mixture equivalent to the amount required by each treatment group. I added the following amounts to each pot: 4 g (C1D), 12 g (C3D), 20 g (C5D), and 28 g (C7D). I mixed the dropping mixture for 3 seconds in 200 mL of water, added it to the middle of each pot, and watered the pots.

The amount of droppings applied was based on my field observations and methods, dropping densities, and goose numbers documented in prior studies on geese in general (Kear 1963) and Aleutian geese in particular (Bachman 2008, Spragens et al. 2015). I calculated treatment dropping amounts using a dropping wet weight of 4 g ($\bar{x}$ = 3.89, SE = 0.15, *n* = 15), assuming an average Aleutian goose body weight of 2,000 g, for a goose foraging 10 hours a day. I used an average dropping rate of 3.5 minutes ($\bar{x}$ = 3.45, SE = 0.11, *n* = 99) documented from observing 55 Aleutian geese using direct observation dropping interval methods (Owen 1971, Prop and Black 1998).

Experimental treatment groups used may be difficult to envision as actual goose use of pastures. A common strategy to standardize goose presence by area is estimating a variable called 'goose days'. A goose day is one goose being present at a location for one day, where day is set as the number of hours geese are likely to be present at a location, standardized by spatial area. A goose day can be flexible in its interpretation as one goose day can be thought of as either one goose present for ten hours at a location or five geese present for two hours at a location, for example. This flexibility allows examples to be generated that ease interpretation of experimental results through relatable field scenarios. A field example of the treatment groups after the six-week period of four clipping and dropping events were estimated as the following:

- clipping/no droppings (CND) group equivalent to zero droppings/m² and an unknown goose days/ha since grazing geese normally poop after ten hours in a pasture,

- clipping/1 dropping (C1D) group total of 4 droppings/pot equivalent to 220 droppings/m² and 12,800 goose days/ha,
- clipping/3 droppings (C3D) group total of 12 droppings/pot equivalent to 658 droppings/m² and 38,380 goose days/ha,
- clipping/5 droppings (C5D) group total of 20 droppings/pot equivalent to 1,097 droppings/m² and 63,967 goose days/ha; and
- clipping/7 droppings (C7D) group total of 28 droppings/pot equivalent to 1,535 droppings/m² and 89,553 goose days/ha.

Summer haying period.

Following the final clipping and dropping event on 14 April 2019 of the spring grazing period, I waited two months until 10 June 2019 to simulate a first haying event on the clipping treatment groups. I then waited another two months until 12 August 2019 to simulate a second haying event and ended the experiment. For the two haying events I estimated the average vegetation height, trimmed the clipping treatment group pots, and weighed the clippings following the same procedures described previously. To end the experiment, I trimmed the control group (NCND) and weighed the clippings. I then measured the vegetation density in each pot by counting every individual plant along two line transects and averaged them to assess potential dropping treatment method effects. I also collected approximately 500 mL of air-dried soil from each pot. I restricted the soil collected to greater than 2.5 cm from the soil surface to remove large roots and any O horizon that may have developed. I sent these samples to A & L Western Laboratories for analysis.

Established pasture experiment

The 50 cores I collected from 6-8 February 2019 were placed directly into PVC pipe pots I created. The pipe was glued to plastic saucers with drainage channels along the bottom of the pipe to allow water to transfer between saucer and pot. The pot dimensions were approximately 15 cm wide by 17 cm deep, leaving 2 cm from the top of the pot to the core soil surface. The 50 pots were assigned to control and treatment groups following a randomized complete block design: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D). The block design used the 10 groups of five pots containing cores collected from the same location. Blocking allowed for controlling in my analysis the expected variation in vegetation and soil characteristics between groups. Based on the particle analysis, the soil textures varied by block group and included loams, sandy loams, sandy clay loams, and clay loams. See Appendix A and B for full details on soil textures by block group.

I rotated and watered the pots with tap water to maximum capacity without overflowing the saucer two to four times weekly. To manage aphids to keep the greenhouse free from pest outbreaks that could affect other projects, I applied a garden insect killer foliar spray consisting of plant oils on 7 April and 19 April. To measure soil characteristics at the start of the experiment, I sent composited samples from each collection site to A & L Western Laboratories for analysis. The experiment was divided into the same two periods as the new pasture experiment: the spring grazing period and the summer haying period.

Spring grazing period.

During the spring grazing period from 19 February to 14 April 2019, I measured vegetation height, trimmed the clipping treatment group pots, added droppings to the dropping treatment group pots, and weighed the clippings following the same procedures described previously.

Summer haying period.

During the summer haying period following the final clipping and dropping event on 14 April of the spring grazing period, I waited two months until 12 June 2019 to simulate a first haying event on the clipping treatment groups. I then waited another two months until 13 August 2019 to simulate a second haying event and ended the experiment. For the two haying events I measured vegetation height, trimmed the clipping treatment group pots, and weighed the clippings following the same procedures described previously.

Prior to clipping vegetation for the second haying event, I assessed plant composition for each pot according to genus. I visually estimated the percentage of pot surface covered with vegetative growth from each plant genera using 5% increments. Earlier in the experiment the vegetation exhibited little to no reproductive structures as the periodic clipping prevented maturation. Waiting until the end allowed plants to grow and mature, easing plant identification. Plant genera documented were: *Agrostis*, *Aster*, *Holcus*, *Lolium*, *Lotus*, *Potentilla*, *Ranunculus*, *Rumex*, *Taraxacum*, and *Trifolium*. Plant composition varied by pot and block group. See Appendix C for full details.

After clipping the vegetation, I then measured vegetation density in each pot by counting every individual plant along two line transects and averaged them to assess potential dropping treatment method effects. To end the experiment, the remaining vegetation and O soil horizon were first removed to a depth of 7.5 cm. I then collected approximately 500 mL of air-dried soil of the A soil horizon from each pot. I sent these samples to A & L Western Laboratories for analysis.

Statistical Analysis

All analyses used a significance level of $P < 0.05$ and were conducted using Program R (R Version 3.6.2, www.r-project.org). Graphical evaluations of residual plots were used to check for normality.

Vegetation production

To test for confounding effects of plant density and genus composition (for the established pasture experiment) on vegetation production, parametric one-way analysis of variance (ANOVA) was used. A correlation matrix computing Pearson's correlation coefficient (r) was used to compare vegetation response variables. To test if goose dropping additions influenced vegetation production, parametric one-way ANOVA and repeated-measures ANOVA were used. Dependent variables were vegetation height and weight, the independent variable was treatment groups, the independent fixed factor was replicate blocks for the established pasture experiment, and the repeated factor was the sampling event. Post hoc Tukey's honestly significant difference (HSD) tests were used to assess differences between treatment groups and sampling events. To assess non-linear relationships between groups and events, polynomial regression ANOVA was used for linear, quadratic, cubic, and quartic relationships when appropriate. Two-way ANOVA to test for interactions between treatment groups and treatment events on vegetation height and weight was not used as the one-way ANOVA allowed comparisons of treatment groups at each treatment event. Post hoc Tukey's HSD tests then allowed multiple pairwise comparisons to determine which treatment groups and events were different.

Comparing data between the two study periods violated assumptions of normality and homogeneity of variance due to the different vegetation growth periods of two weeks for the spring grazing period and two months for the summer haying period. Analyses were completed individually for each treatment event and study period. I analyzed vegetation height and weight totals over the entire study period to avoid the issues of comparing between spring and summer events.

Soil quality

Soil quality can be simply defined as "the capacity (of soil) to function" (Karlen et al. 1997:6) and consists of physical, chemical, and biological factors. I collected information on physical and chemical factors. To assess the effect of goose droppings on soil quality, the soil quality index (SQI) assessment method was first used (Andrews et al. 2002, 2003, 2004; Karlen et al. 2003; de Paul Obade and Lal 2016*a, b*) due to the large number of soil response variables analyzed. The SQI method considers individual soil variables as indicators of soil quality, assigns these variables scores to determine positive or negative effects, and combines them into an index to summarize soil quality. While screening variables and running the principal component analysis (PCA) portion of the

SQI method, it was determined that there were too few statistically significant variables to successfully build and calculate the SQI. This resulted in all proceeding analyses using parametric one-way ANOVA with Tukey's HSD post hoc tests to assess differences between treatment groups for individual soil variables.

Ecosystem service

This study provided an economic value of the ecosystem service of geese on pastures. The Factor Income method and production function was used based on the review of Johnson and Hackett (2016). The Factor Income method values an ecosystem service by measuring the enhancement of income from the service. According to Johnson and Hackett (2016:37), "(t)his method is commonly applied in agricultural settings, by identifying the effect of birds on yields or costs. When birds enhance yield without altering costs, the increased yields directly translate into increased income" (Swinton et al. 2007). A production function is applied to value an ecosystem service "when an ecosystem service affects agricultural outputs and the need for various inputs" (Johnson and Hackett 2016:37). Increased production of pasture vegetation and soil quality improvements were the outputs, and goose dropping additions were the input.

It was assumed that the amount of vegetation that would be consumed by foraging geese was constant between treatment groups. Since vegetation was clipped to the same height in all treatment groups, by comparing vegetation produced from the four clipping treatment groups that received droppings with the clipping group that received no droppings, any increased vegetation production was considered additional forage available to farmer. The treatment group of clipping with no droppings is highly unlikely in a field scenario as geese poop while they graze. This treatment was considered a good control group for how vegetation responds if geese were grazing and not leaving droppings. This scenario is what Humboldt ranchers considered is happening, that geese directly consume forage and do not increase forage production.

The ecosystem service was when vegetation production increased in dropping treatment groups above the control group of clipping and no droppings, resulting in no cost to the farmer of lost cattle forage due to increased forage produced after the addition of droppings. Treatment groups with more droppings added simulated field scenarios with higher numbers of geese grazing on the pastures. It is acknowledged that more geese in a pasture inherently would consume more vegetation. For this experiment, I could not feasibly test the combined interaction of different grazing levels and different dropping amounts. This would have required more experimental groups and hundreds more greenhouse pots beyond facility and management capacity.

To calculate an economic value, pasture vegetation growth from the entire experimental period was monetized by first transforming the dry weight measured into the equivalent weight of grass hay with 15% moisture content. Next, the wet weight of hay per pot was converted to the equivalent pounds of hay produced per acre. The estimated hay weight produced per acre was finally used to calculate the value of hay in U.S. dollars (USD) as $/acre, using $150/ton as the average cost to purchase commercial hay. Hay values calculated and reported using USD, tons, and acres based on standard agricultural reporting for farmers from U.S. Department of Agriculture (USDA) Agriculture Marketing Service's California hay reports (USDA 2022). Individual soil variables that had statistically significant differences between treatment groups were not monetized but were considered benefits experienced by the farmer. I did not monetize goose dropping inputs based on the equivalent cost of human-provided inputs such as compost and fertilizer that would have been required to achieve similar forage production increases. I considered the addition of goose droppings as input replacements for production costs of adding commercial fertilizers.

RESULTS

New Pasture Experiment

Plant density varied with treatment group ($F_{5,54}$ = 22.73, $p \leq 0.001$) and was significantly lower in dropping groups three ($p \leq 0.005$), five ($p \leq 0.001$), and seven ($p \leq 0.001$) compared to the clipping/no droppings (CND) control group, causing issues of collinearity. Treatment groups were stronger predictors of vegetation weights ($F_{5,53}$ = 292.21, $p \leq 0.001$) than plant density ($F_{1,53}$ = 4.17, p = 0.046), supporting the removal of density from further analyses (density effects still warranted attention; see Discussion). For the entire experiment period from 19 February to 12 August 2019, total vegetation height and weight increased with the addition of goose droppings (height: $F_{5,54}$ = 515.7, $p \leq 0.001$, Figure 1, weight: $F_{5,54}$ = 276, $p \leq 0.001$, Figure 2). Vegetation height and weight were strongly correlated (r = 0.7). To reduce reporting similar results for both vegetation height and weight, only results from weight analyses will be provided below.

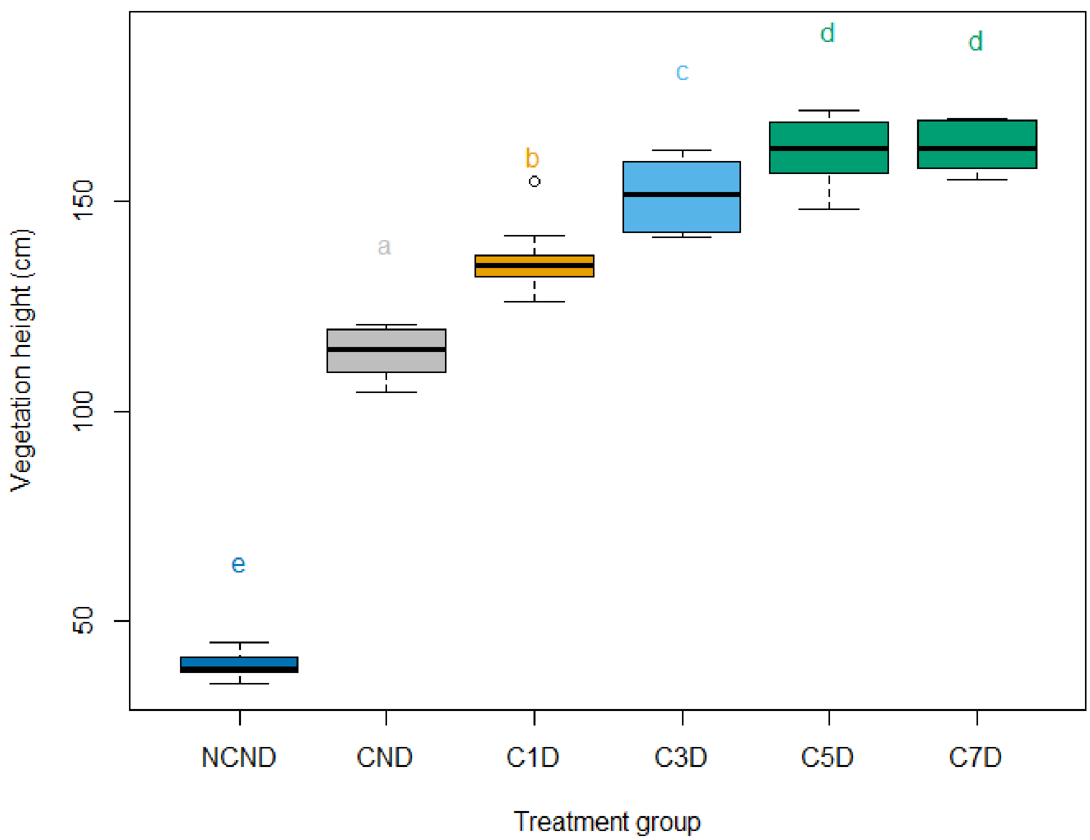


Figure 1. Box plots of total vegetation height (cm) of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown in 60 pots in greenhouse experiment 19 February to 12 August 2019 at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

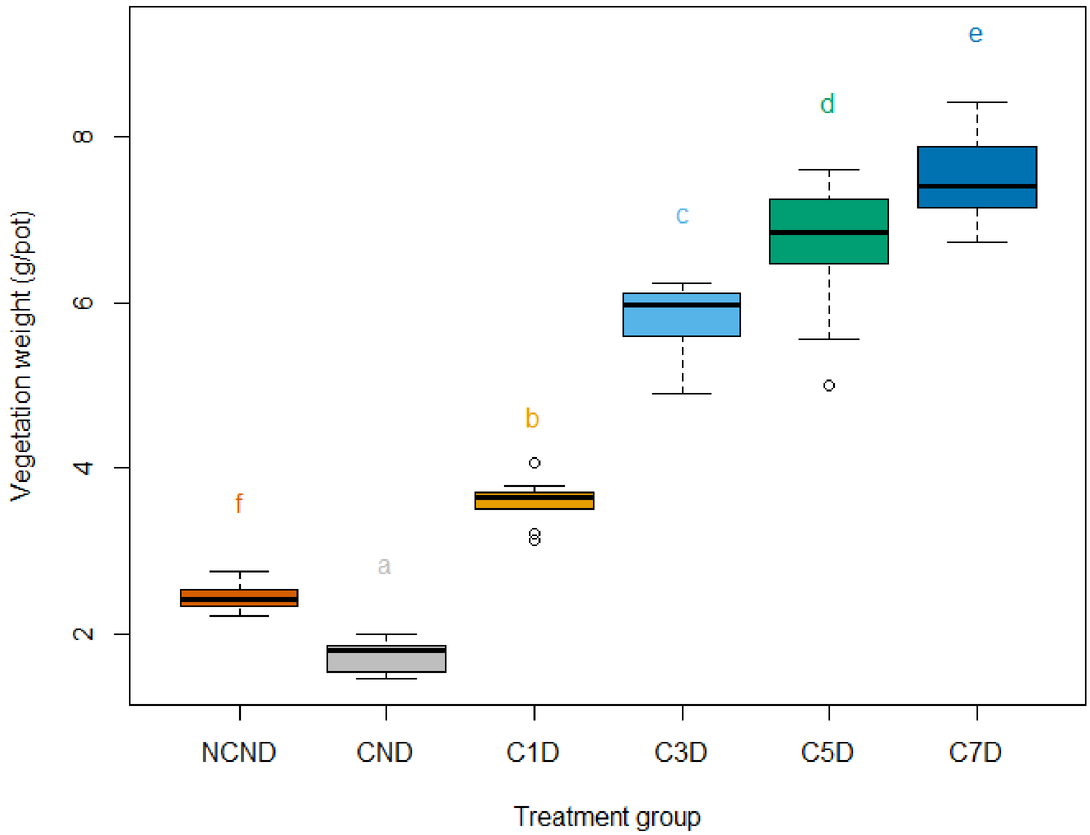


Figure 2. Box plots of total vegetation dry weight (g/pot) of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown in 60 pots in greenhouse experiment 19 February to 12 August 2019 at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

Spring grazing period vegetation production

During the spring grazing period, vegetation weight significantly varied between all four treatment events ($F_{3,192} = 80.38$, $p \leq 0.001$, Figure 3). Vegetation weight did not significantly vary between treatment groups after the first treatment event ($F_{4,45} = 0.53$, $p = 0.712$) or second treatment event ($F_{4,45} = 1.84$, $p = 0.138$). Vegetation weight significantly varied between treatment groups after the third treatment event ($F_{4,45} = 21.8$, $p \leq 0.001$). Mean weights of the third treatment event groups receiving one, three, five, and seven droppings were 132%, 283%, 220%, and 211% higher, respectively, than the control group of clipping with no droppings (Figure 4), exhibiting linear ($F_{1,45} = 48.03$, $p \leq 0.001$) and quadratic relationships ($F_{1,45} = 32.36$, $p \leq 0.001$). Vegetation weight significantly varied between treatment groups after the fourth treatment event ($F_{4,45} = 22.62$, $p \leq 0.001$). Mean weights of the fourth treatment event groups receiving one, three, five, and seven droppings were 178%, 322%, 153%, and 213% higher, respectively, than the control group (Figure 5), exhibiting linear ($F_{1,45} = 26.95$, $p \leq 0.001$), quadratic ($F_{1,45} = 35.79$, $p \leq 0.001$), and cubic relationships ($F_{1,45} = 11.59$, $p = 0.001$).

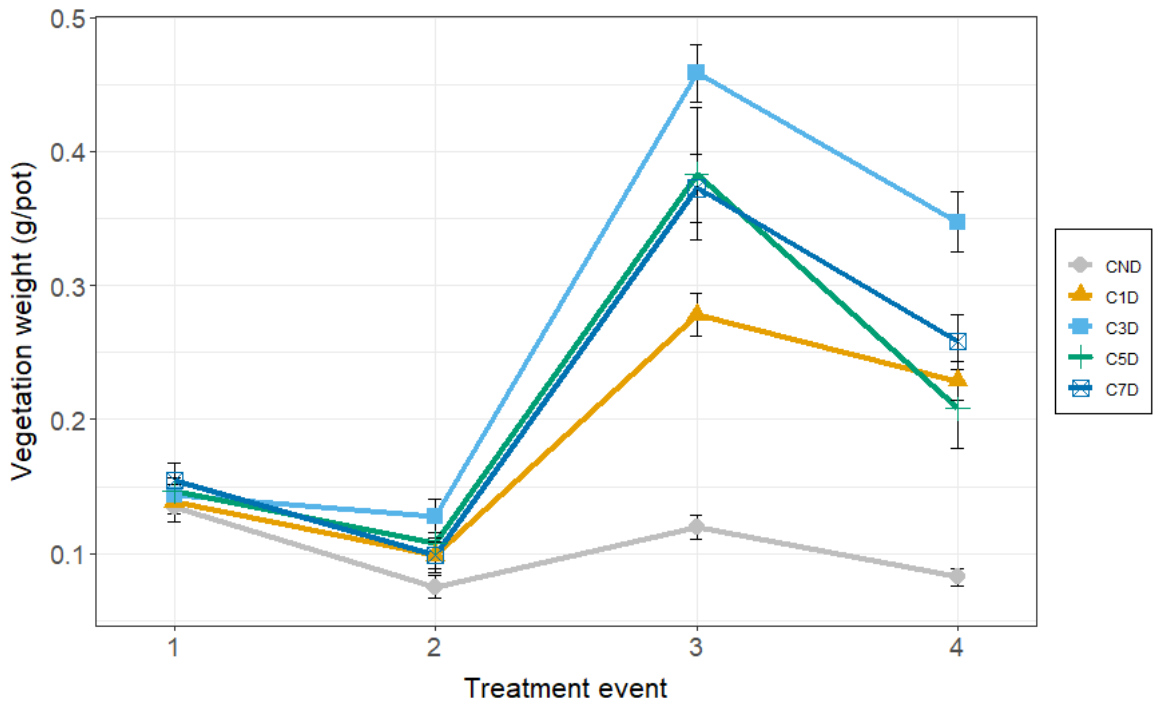


Figure 3. Mean dry weight (g/pot) of spring grazing period vegetation by treatment event and group of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 19 February to 14 April 2019 in 50 pots in a greenhouse experiment at Cal Poly Humboldt, California. Treatment event 1: 19 February-4 March, event 2: 4-17 March, event 3: 17-31 March, and event 4: 31 March-14 April. Plots color coded according to treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D). Error bars represent one standard error.

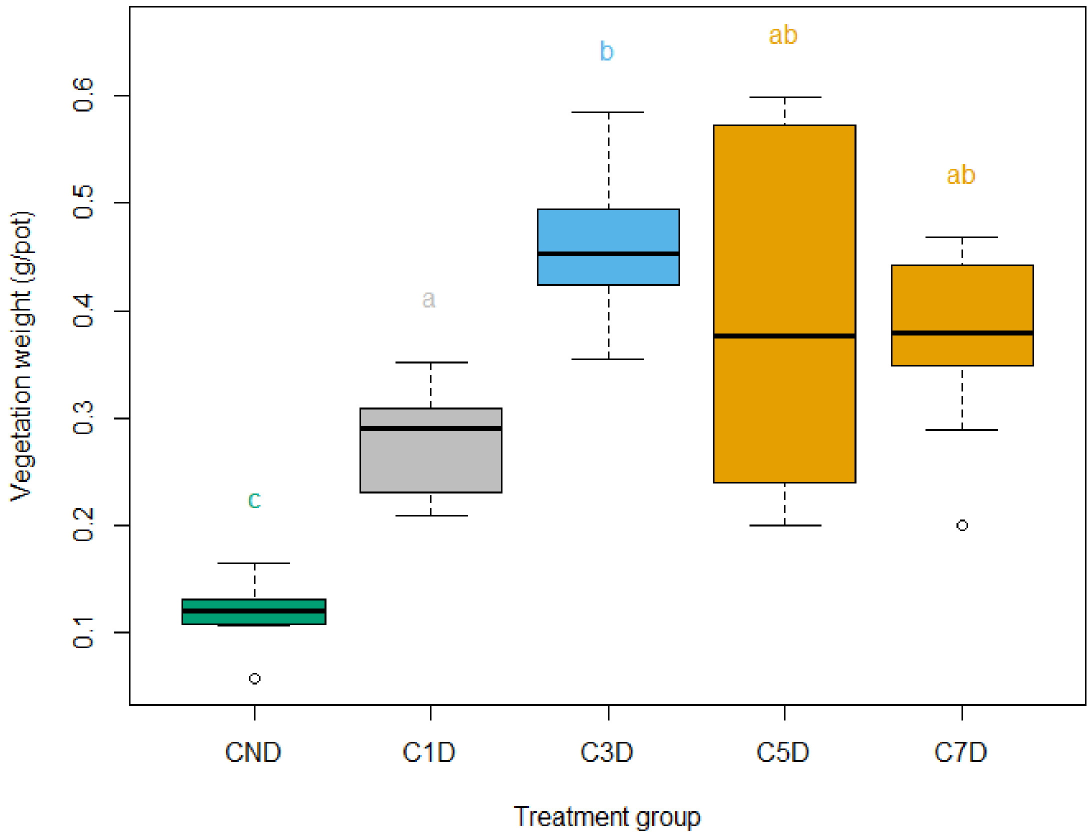


Figure 4. Box plots of third treatment event vegetation dry weight (g/pot) of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 17 March to 31 March 2019 in 50 pots in a greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

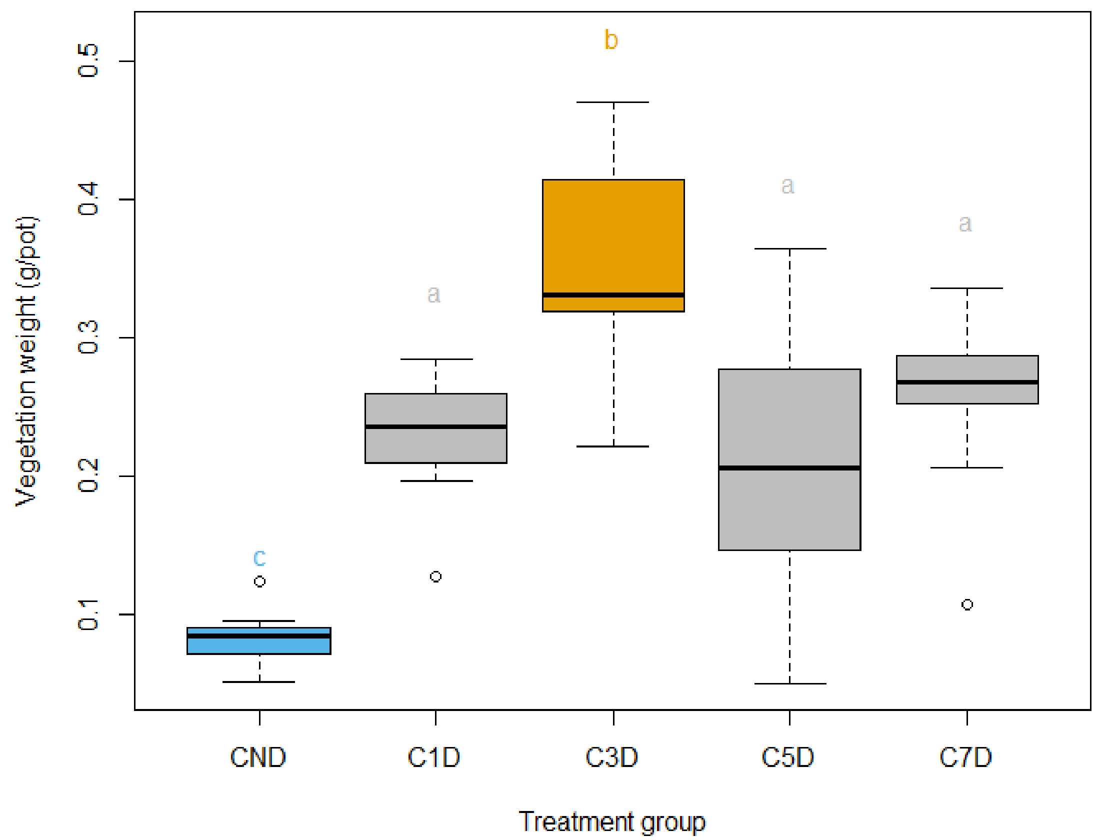


Figure 5. Box plots of fourth treatment event vegetation dry weight (g/pot) of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 31 March to 14 April 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

Summer haying period vegetation production

During the summer haying period, vegetation weight significantly varied between the two treatment events ($F_{1,94} = 166.98$, $p \leq 0.001$, Figure 6). Vegetation weight significantly varied between treatment groups for both the first haying event ($F_{4,45} = 24.99$, $p \leq 0.001$) and the second ($F_{4,45} = 77.42$, $p \leq 0.001$). Mean weights for the first haying event treatment groups receiving one, three, five, and seven droppings were 183%, 482%, 588%, and 647% higher, respectively, than the control group (Figure 7), exhibiting a linear ($F_{1,45} = 418.91$, $p \leq 0.001$) and quadratic relationship ($F_{1,45} = 18.45$, $p \leq 0.001$). Mean weights for the second haying event treatment groups receiving one, three, five, and seven droppings were 47%, 116%, 171%, and 233% higher, respectively, than the control group (Figure 8), exhibiting a linear relationship ($F_{1,45} = 308.89$, $p \leq 0.001$).

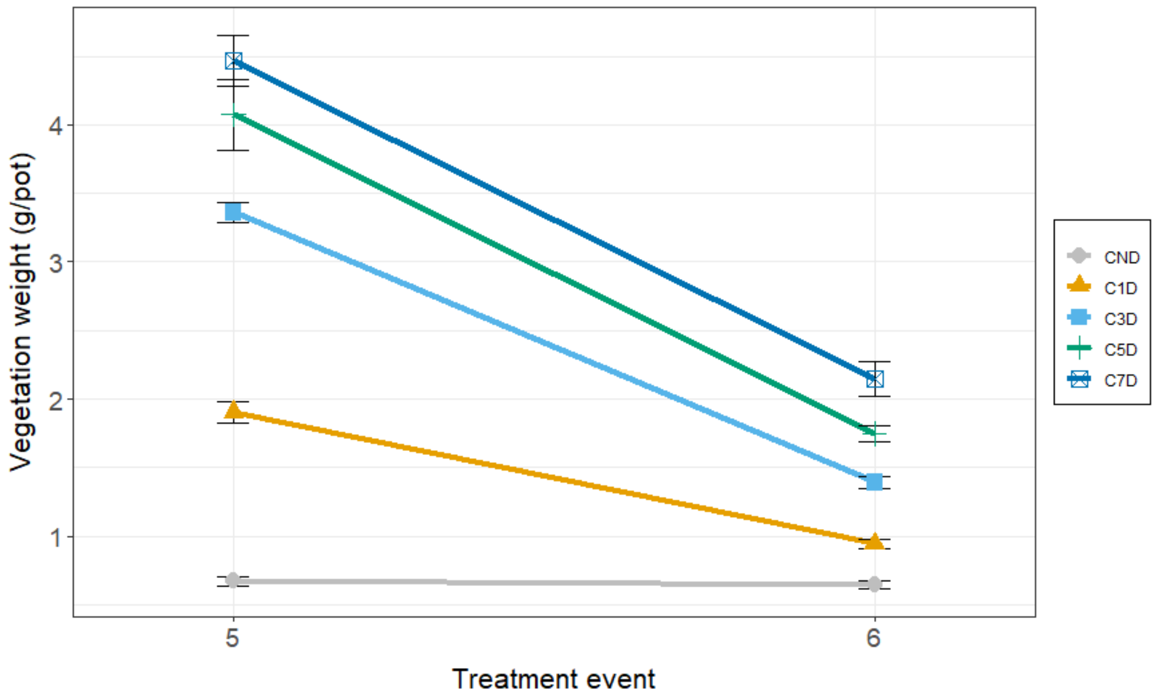


Figure 6. Mean dry weight (g/pot) of summer haying period vegetation by treatment event and group of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne*) grown 14 April to 12 August 2019 in 50 pots in a greenhouse experiment at Cal Poly Humboldt, California. Treatment event 5: 14 April-10 June, and event 6: 10 June-12 August. Plots color coded according to treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D). Error bars represent one standard error.

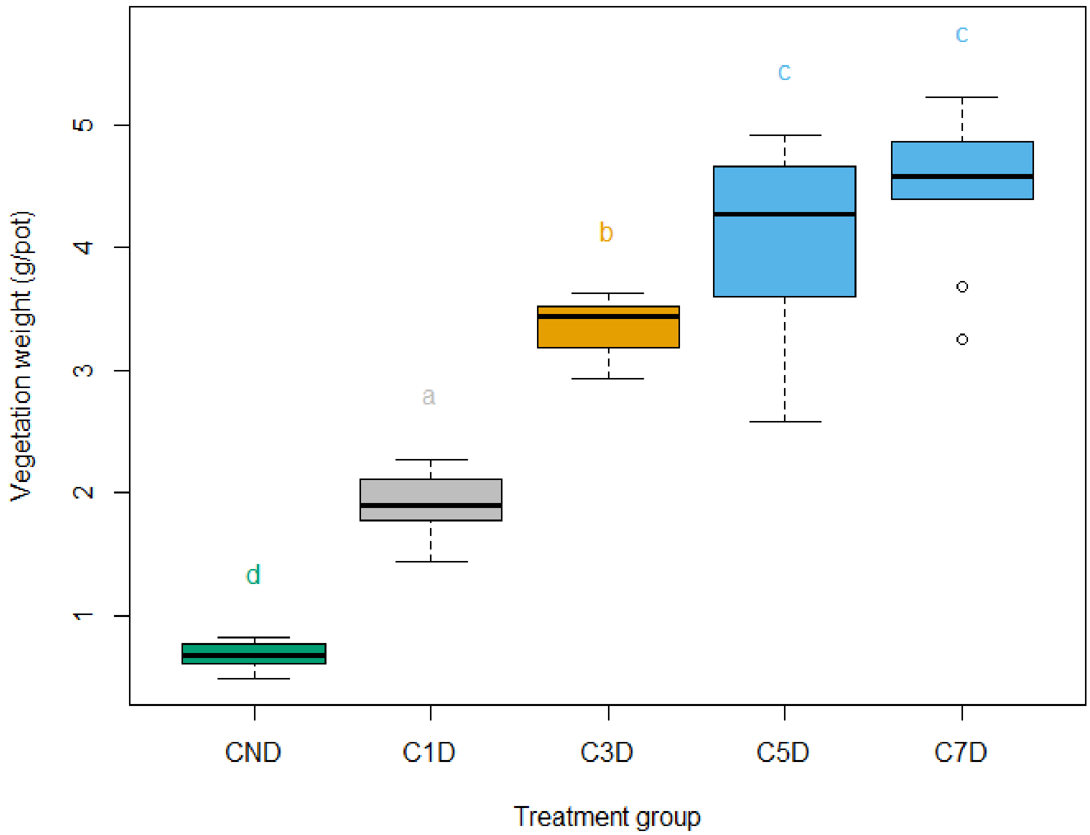


Figure 7. Box plots of first haying event vegetation dry weight (g/pot) of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 14 April to 10 June 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

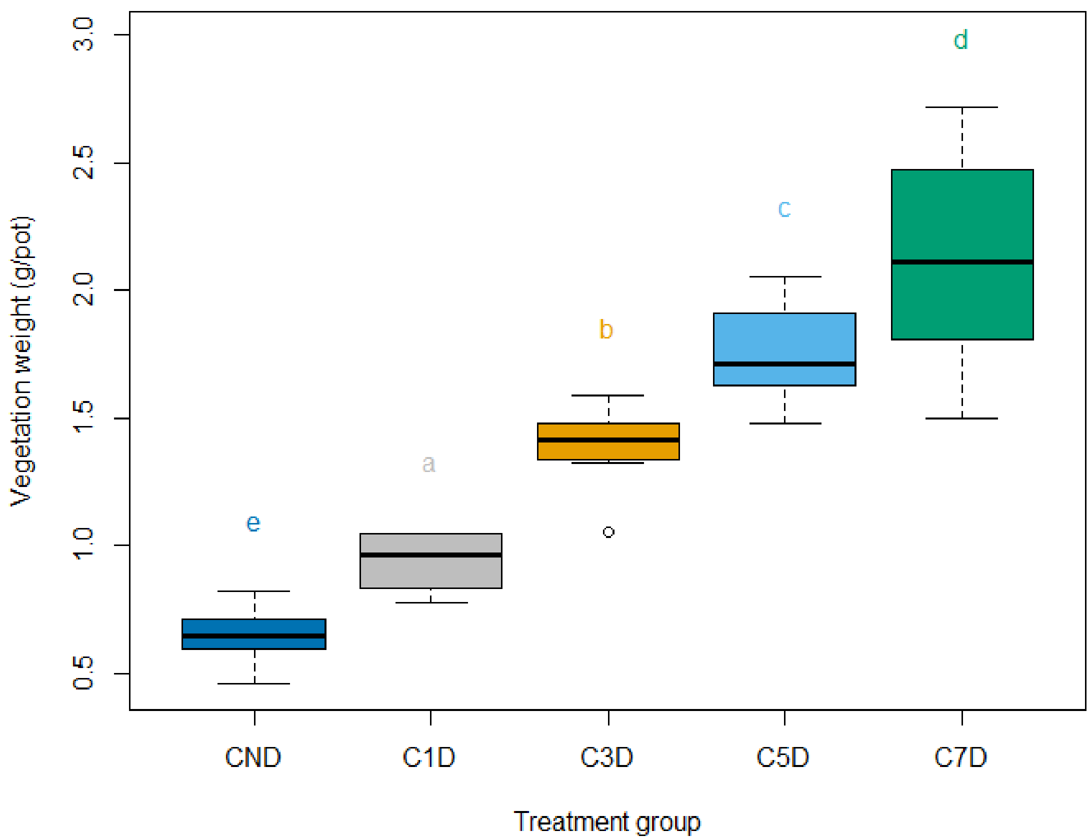


Figure 8. Box plots of second haying event vegetation dry weight (g/pot) of annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 10 June to 12 August 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

Soil quality

Organic matter percentage slightly decreased from start of experiment to end with no significant differences between treatment groups ($F_{5,54} = 0.82$, $p = 0.539$). Soil pH increased from 5.2 at start of experiment to 5.6 at the end with no significant differences between treatment groups ($F_{5,54} = 1.85$, $p = 0.119$). There were no differences of nitrate nitrogen (NO_3-N) levels between treatment groups ($F_{5,54} = 1.93$, $p = 0.105$). Phosphorus (P) levels slightly decreased from start of experiment to end with differences between treatment groups ($F_{5,54} = 3.50$, $p = 0.008$) corresponding to higher levels in seven dropping treatments compared to the clipping control ($p = 0.025$) and one dropping group ($p = 0.046$, Figure 9). Potassium levels increased from start of experiment to end with differences between treatment groups ($F_{5,54} = 97.56$, $p \leq 0.001$) corresponding to higher levels in three, five, and seven dropping treatments compared to the no clipping control, clipping control and one dropping groups ($p \leq 0.001$, Figure 10). Sulfate-sulfur (SO_4-S) levels decreased from start of experiment to end with differences between treatment groups ($F_{5,54} = 4.59$, $p = 0.002$) corresponding to lower levels in one, three, and seven dropping treatments compared to the no clipping control and clipping control groups ($p < 0.05$, Figure 11). Sodium (Na) levels decreased from start of experiment to end with differences between treatment groups ($F_{5,54} = 38.57$, $p \leq 0.001$) corresponding to less Na in treatments with clipping and as more droppings were added ($p < 0.05$, Figure 12). Magnesium levels slightly decreased from start of experiment to end with no differences between treatment groups ($F_{5,54} = 0.36$, $p = 0.874$). Calcium levels increased from start of experiment to end with no differences between treatment groups ($F_{5,54} = 1.02$, $p = 0.417$).

Cation exchange capacity (CEC) decreased from start of experiment to end with no significant differences between treatment groups ($F_{5,54} = 0.26$, $p = 0.933$).

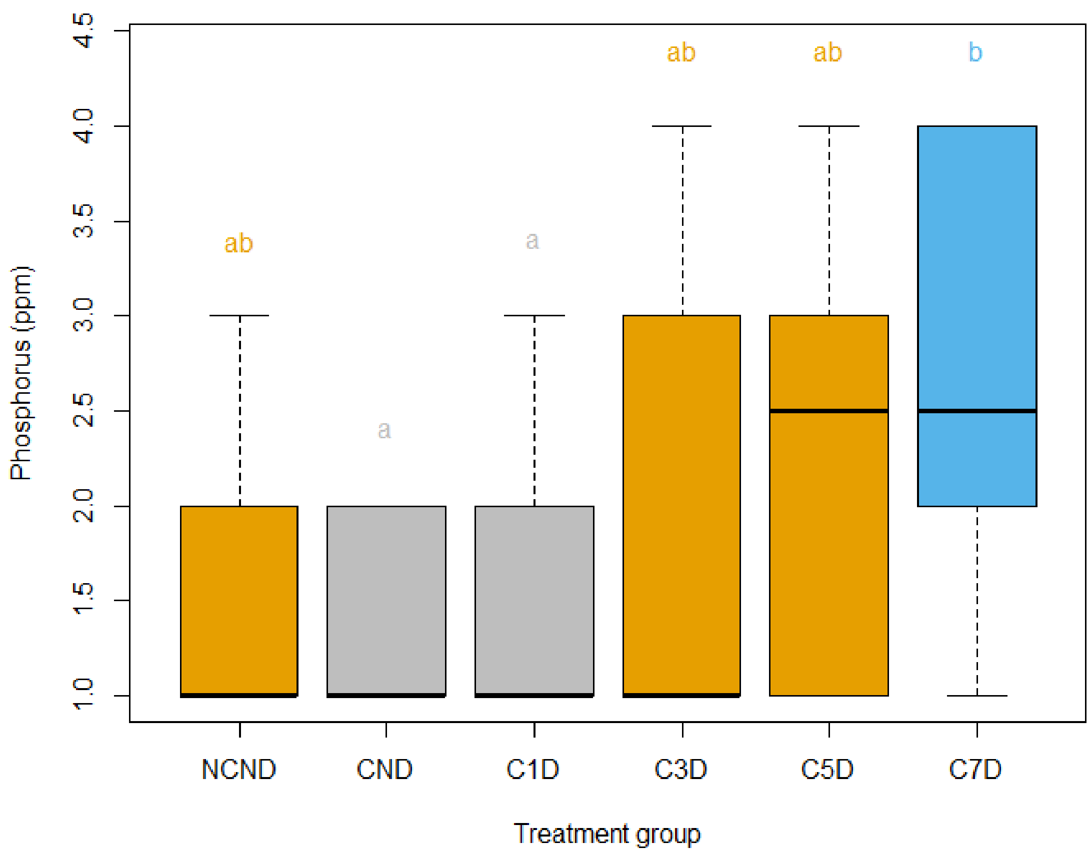


Figure 9. Box plots of soil phosphorus (P ppm) measured with Bray-P1 method in approximately 500 mL of air-dried soil collected 12 August >2.5 cm from soil surface in 60 pots containing annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 19 February to 12 August 2019 in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

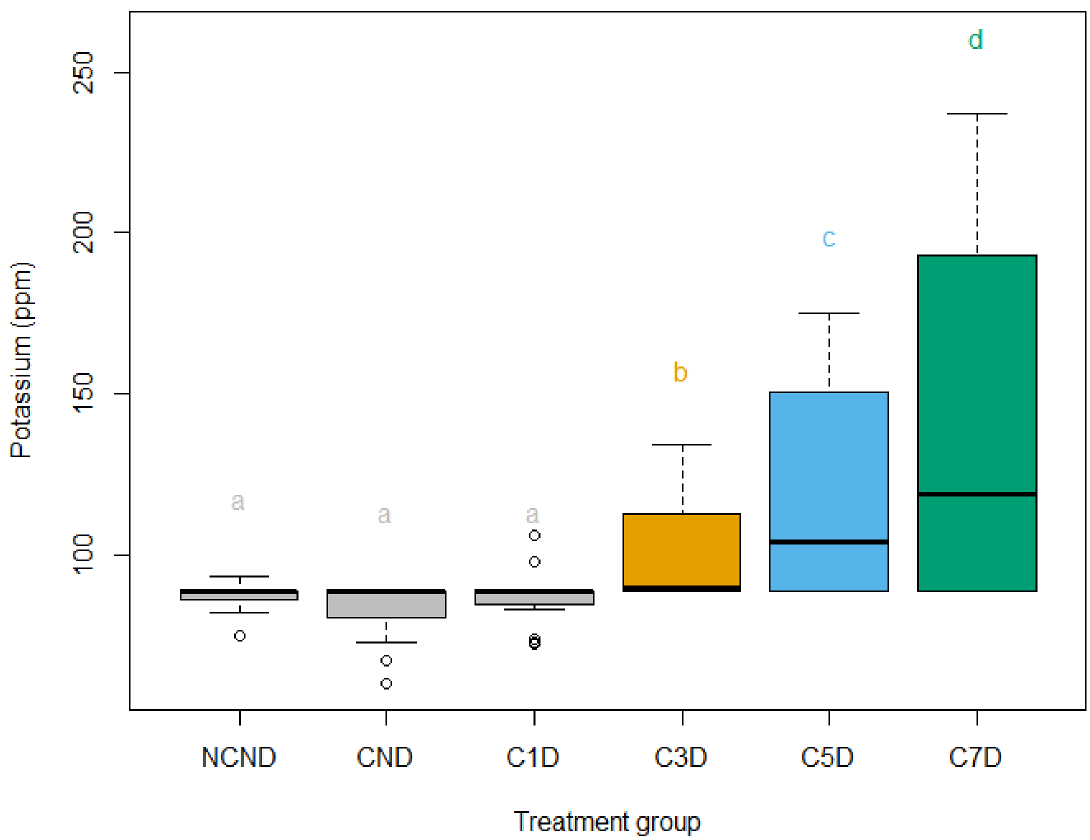


Figure 10. Box plots of soil potassium (K ppm) measured in approximately 500 mL of air-dried soil collected 12 August >2.5 cm from soil surface in 60 pots containing annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 19 February to 12 August 2019 in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

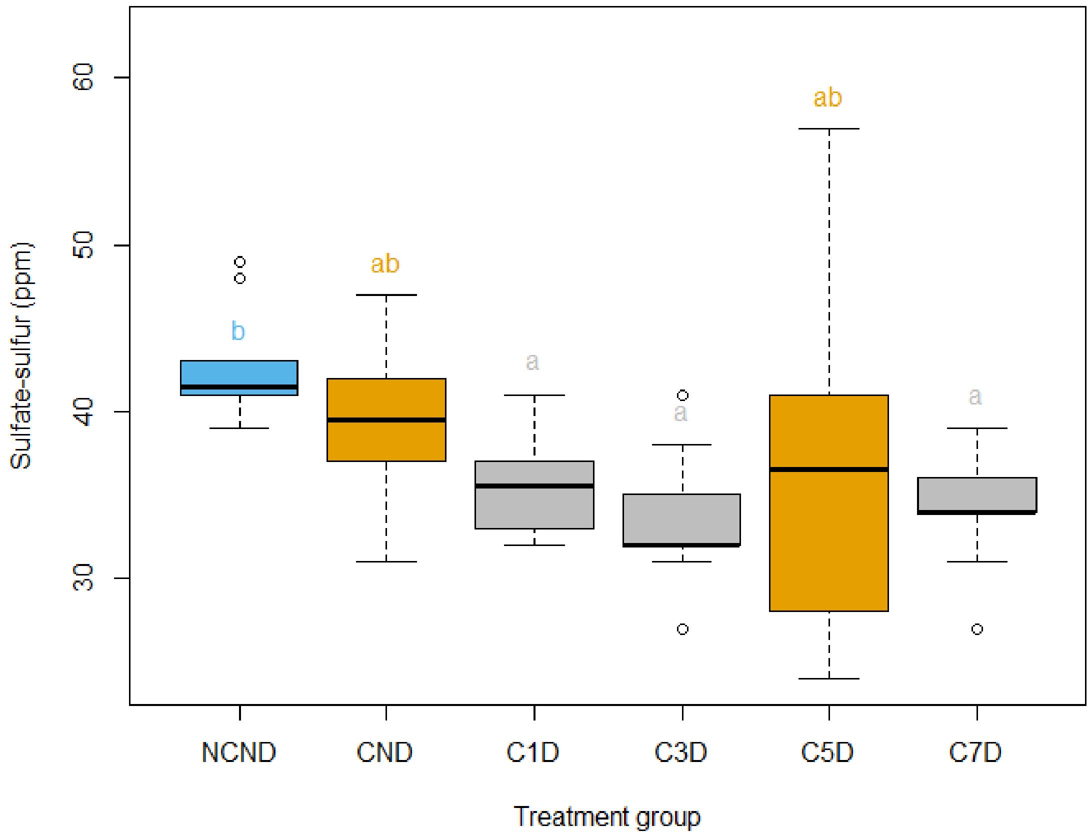


Figure 11. Box plots of soil sulfate-sulfur (SO_4-S ppm) measured in approximately 500 mL of air-dried soil collected 12 August >2.5 cm from soil surface in 60 pots containing annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 19 February to 12 August 2019 in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

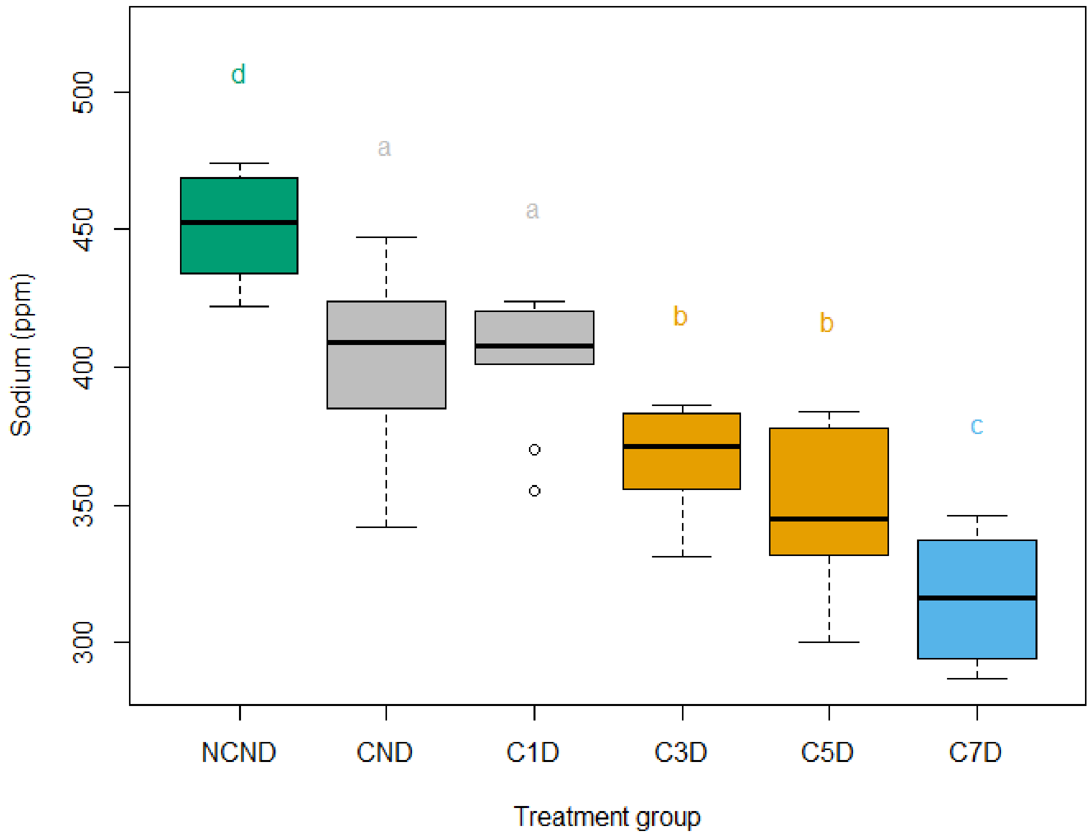


Figure 12. Box plots of soil sodium (Na ppm) measured in approximately 500 mL of air-dried soil collected 12 August >2.5 cm from soil surface in 60 pots containing annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown 19 February to 12 August 2019 in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

Ecosystem service

Estimated average value of grass hay produced from the new pasture experiment decreased between control groups, from 1,373 lbs/acre valued at $103/acre ($42/ha) in no clipping control group to 973 lbs/acre valued at $73/acre ($30/ha) in clipping control group. Addition of dropping treatments significantly increased hay production value, starting with the one dropping treatment of 2,027 lbs/acre valued at $152/acre ($61/ha). Forage production jumped up to 3,280 lbs/acre valued at $246/acre ($100/ha) with the 3 dropping treatment, 3,747 lbs/acre valued at $281/acre ($114/ha) with the 5 dropping treatment, and topped out at 4,213 lbs/acre valued at $316/acre ($128/ha) with the 7 dropping treatment (Figure 13).

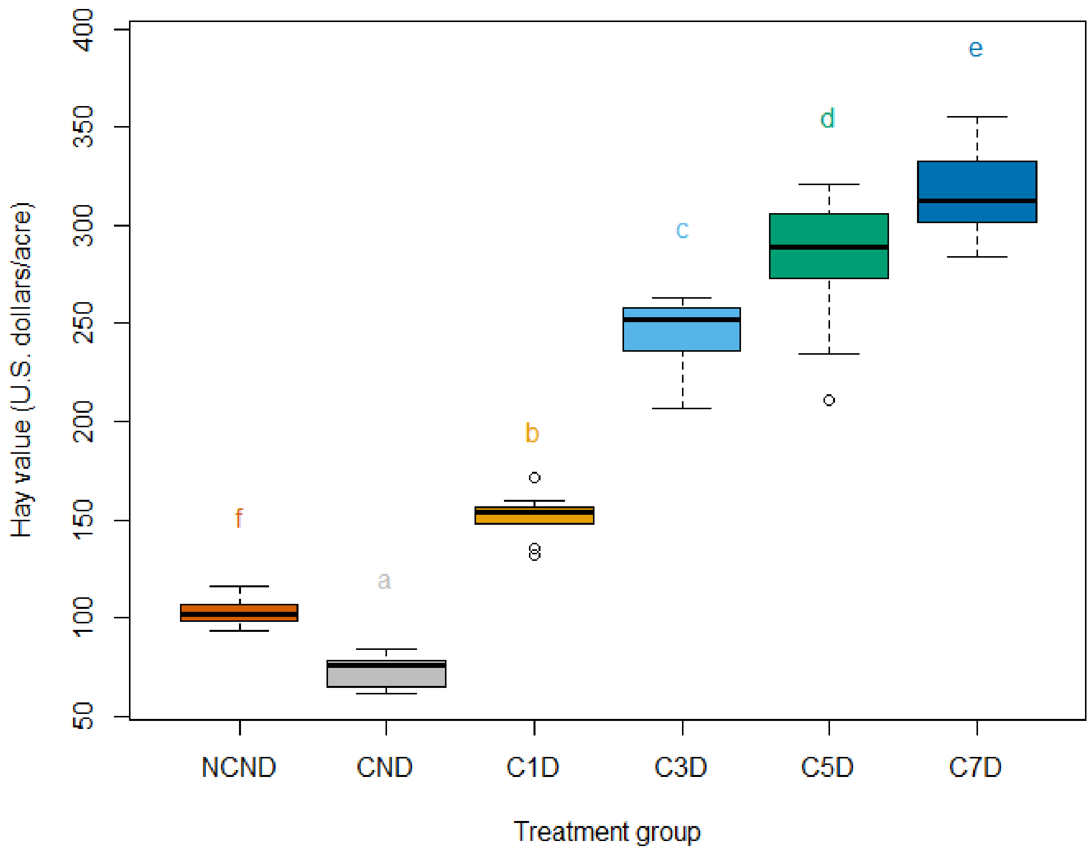


Figure 13. Box plots of total hay value in U.S. dollars ($) calculated using vegetation dry weight (g/pot), converting to pounds, adding 15% water weight, calculating dollar value using $150/ton, and converting to $/acre by estimating pots/acre. Hay values reported in $/acre based on standard agricultural reporting for farmers from U.S. Department of Agriculture. Dry weights from annual ryegrass (*Festuca perennis*) and perennial ryegrass (*Lolium perenne)* grown in 60 pots in greenhouse experiment 19 February to 12 August 2019 at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: no clipping/no droppings (NCND), clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

Established Pasture Experiment

Plant density varied with treatment group ($F_{4,36}$ = 18.08, $p \leq 0.001$) and was significantly lower when three, five and seven droppings were added ($p < 0.05$), raising collinearity issues. Dropping treatment groups were stronger predictors of vegetation weights ($F_{4,35}$ = 25.04, $p \leq 0.001$) than density ($F_{1,35}$ = 3.26, p = 0.079), supporting the removal of density from further analyses (density effects still warranted attention; see Discussion). Plant genus composition had no significant relationship with vegetation height ($F_{1,35}$ = 1.98, p = 0.168) and *Taraxacum* was the only genus to have a significant relationship with vegetation weight ($F_{1,35}$ = 7.69, p = 0.009). Percentages of *Taraxacum* did not vary by treatment group ($F_{4,36}$ = 1.63, p = 0.189) but varied by replicate block ($F_{9,36}$ = 4.08, p = 0.001), raising collinearity and unequal variance issues. Removing *Taraxacum* as a predictor resolved these issues from further analyses. Vegetation height and weight were weakly correlated (r = 0.2), thus results for both will be reported below.

From 19 February to 13 August 2019, vegetation height varied by treatment group ($F_{4,36}$ = 3.49, p = 0.016) but significantly increased only in the seven dropping treatment group compared to the control group (p = 0.02). Vegetation weights varied by treatment group ($F_{4,36}$ = 23.57, $p \leq 0.001$, Figure 14) and were greater in all treatments, except for the one dropping group, when compared to the control group ($p \leq 0.01$). Weights increased with a linear relationship to treatment groups ($F_{1,36}$ = 92.79, $p \leq 0.001$).

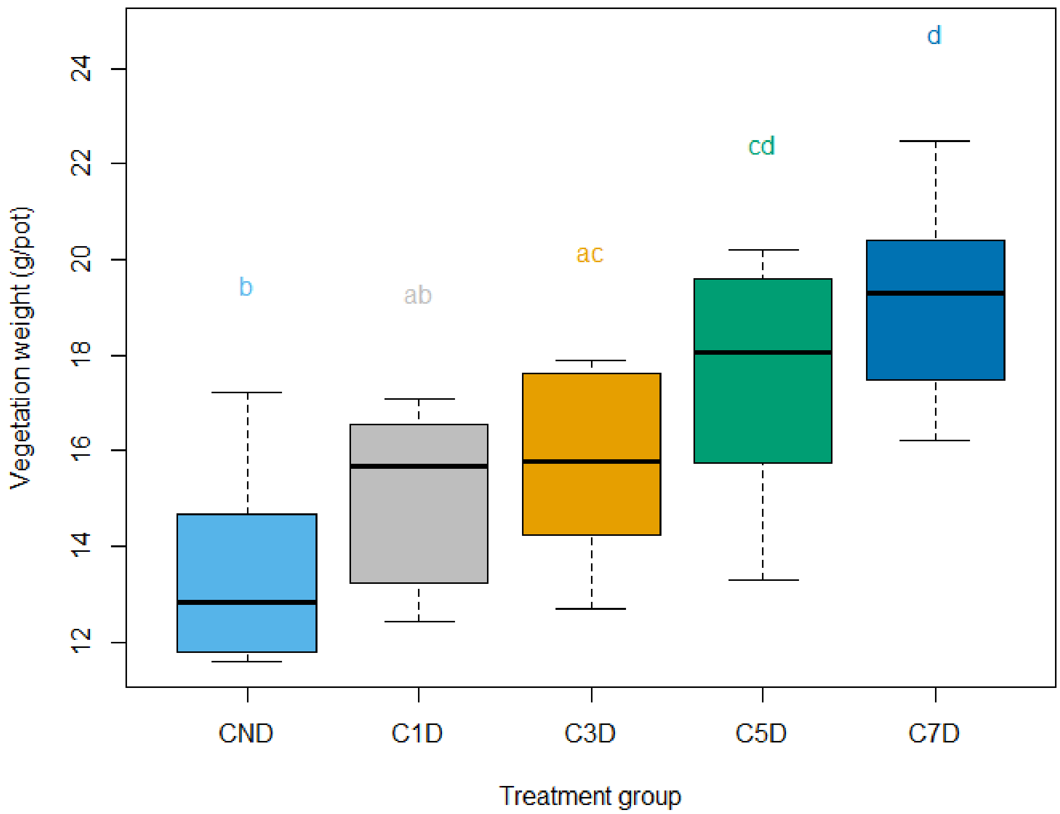


Figure 14. Box plots of total vegetation dry weight (g/pot) of pasture vegetation grown 19 February to 13 August 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

Spring grazing period vegetation production

During the spring grazing period, vegetation height after the first treatment event was higher only for the treatment group receiving three droppings when compared to the control group ($p = 0.027$). Vegetation height varied between treatment groups after the second treatment event ($F_{4,36} = 3.79$, $p = 0.011$). Mean heights of treatment groups receiving one, three, and seven droppings were taller than the control group ($p < 0.05$). Vegetation height did not vary between treatment groups after the third ($F_{4,36} = 2.26$, $p = 0.082$) and fourth treatment events ($F_{4,36} = 0.27$, $p = 0.897$). Vegetation weight significantly varied between treatment events ($F_{3,183} = 20.31$, $p \leq 0.001$, Figure 15). Vegetation weight did not significantly vary between treatment groups during the entire spring period ($F_{4,183} = 1.78$, $p = 0.134$). Weights also did not vary between treatment groups after the first ($F_{4,36} = 1.13$, $p = 0.356$), second ($F_{4,36} = 2.18$, $p = 0.091$), third ($F_{4,36} = 1.68$, $p = 0.176$) or fourth treatment events ($F_{4,36} = 1.28$, $p = 0.294$).

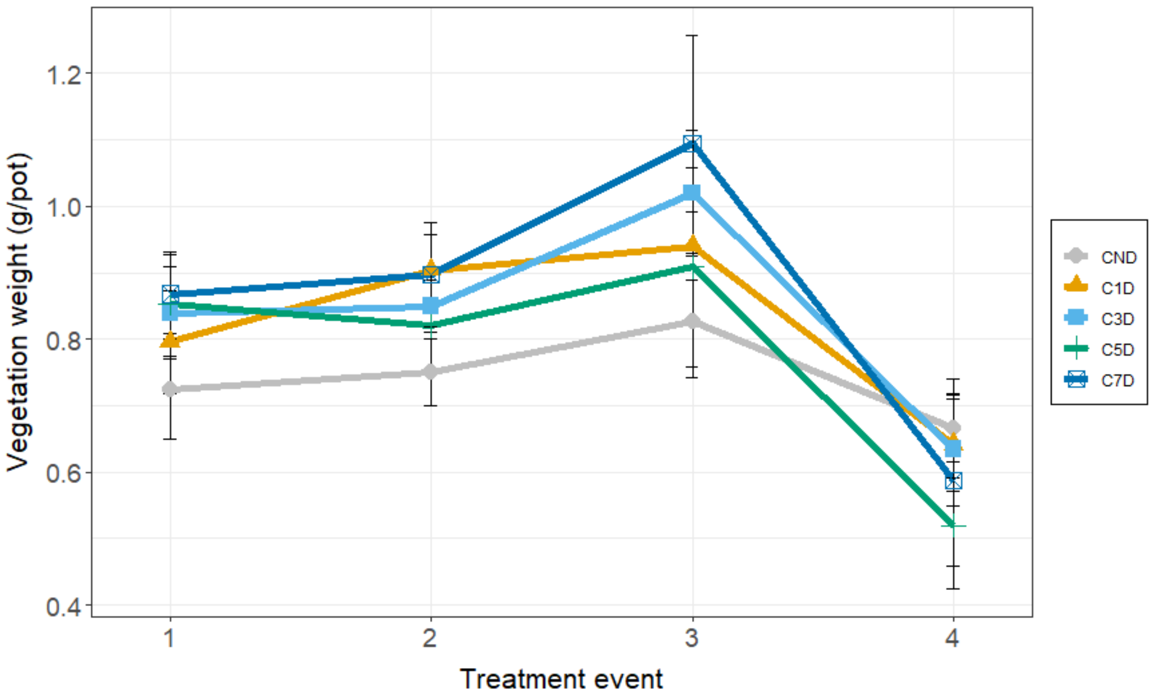


Figure 15. Mean dry weight (g/pot) of spring grazing period vegetation by treatment event and group of pasture vegetation grown 19 February to 14 April 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Treatment event 1: 19 February-5 March, event 2: 5-17 March, event 3: 17-31 March, and event 4: 31 March-14 April. Plots color coded according to treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D). Error bars represent one standard error.

Summer haying period vegetation production

During the summer haying period, vegetation height did not significantly vary between treatment groups after the first haying event ($F_{4,36} = 2.06$, $p = 0.107$). Mean height of treatment groups was no taller than the control after the second haying event ($p > 0.2$). Vegetation weight significantly varied between the two treatment events ($F_{1,85} = 44.37$, $p \leq 0.001$, Figure 16). Vegetation weight varied between treatment groups for both the first haying event ($F_{4,36} = 35.20$, $p \leq 0.001$, Figure 17) and the second ($F_{4,36} = 5.16$, $p = 0.002$, Figure 18). Mean weights for the first haying event of treatment groups receiving three, five, and seven droppings were 30%, 51%, and 74% higher, respectively, than the control group ($p < 0.002$), exhibiting a linear relationship ($F_{1,36} = 138.97$, $p \leq 0.001$). Mean weights for the second haying event of treatment groups receiving five and seven droppings were 26% and 30% higher, respectively, than the control group ($p < 0.015$), exhibiting a linear relationship ($F_{1,36} = 17.87$, $p \leq 0.001$).

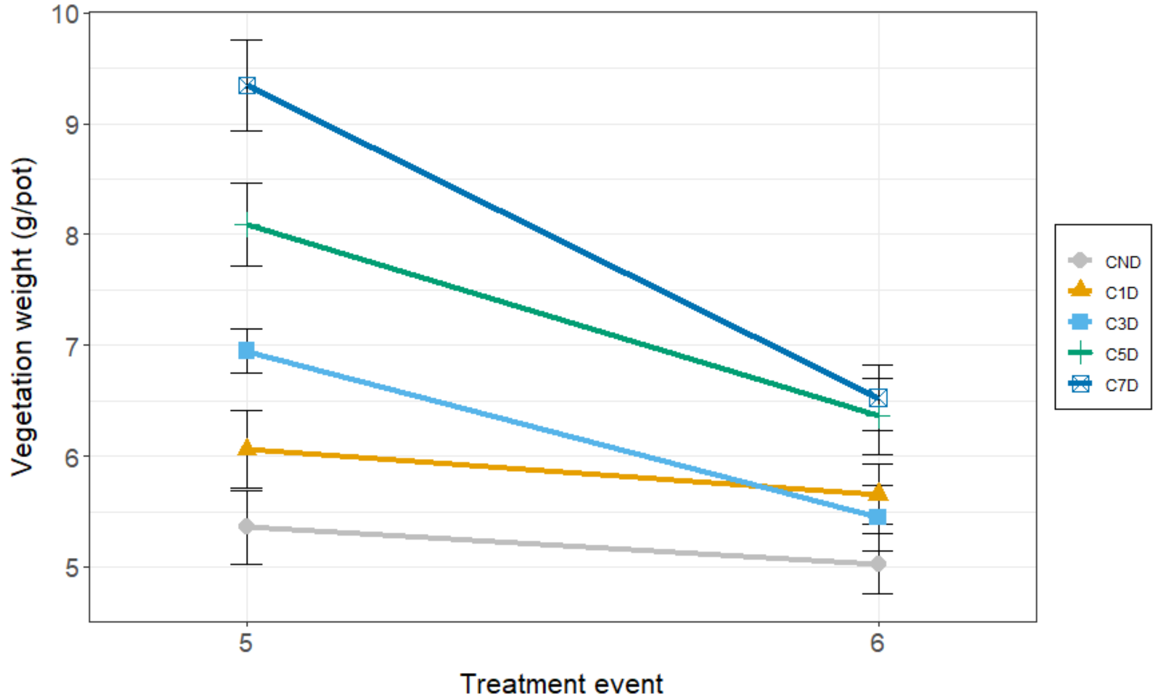


Figure 16. Mean dry weight (g/pot) of summer haying period vegetation by treatment event and group of pasture vegetation grown 14 April to 13 August 2019 in 50 pots in a greenhouse experiment at Cal Poly Humboldt, California. Treatment event 5: 14 April-12 June, and event 6: 12 June-13 August. Plots color coded according to treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D). Error bars represent one standard error.

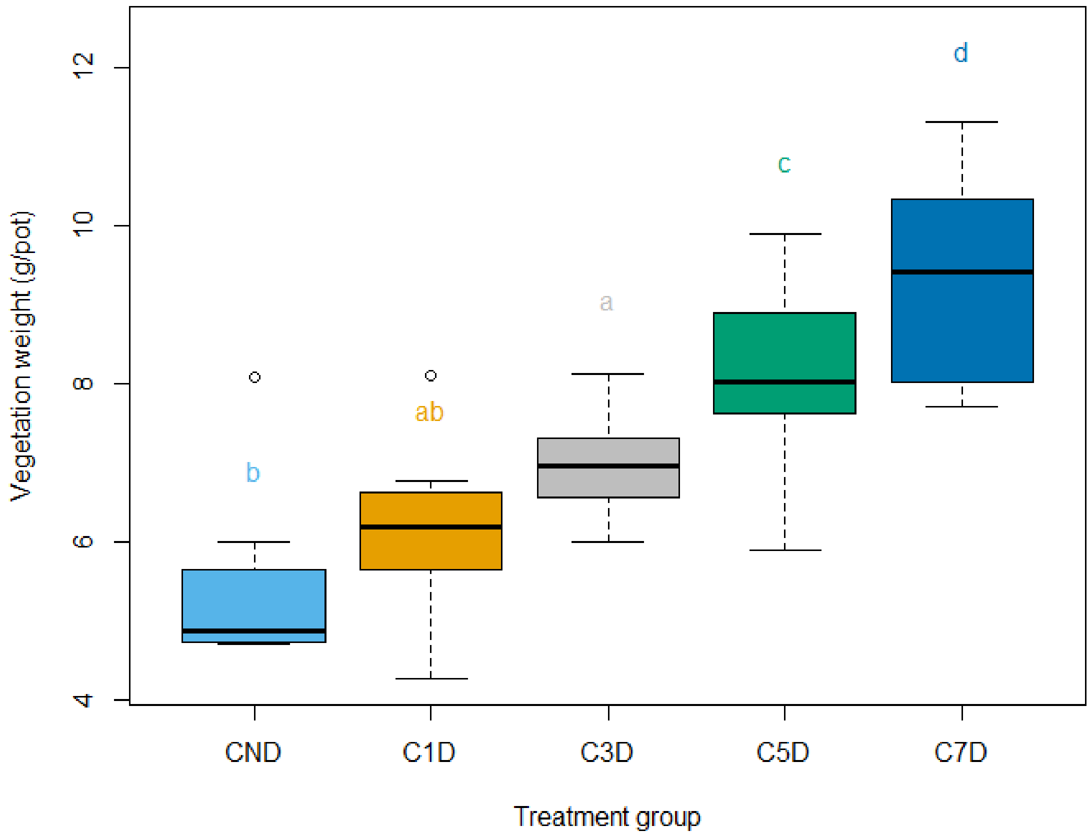


Figure 17. Box plots of first haying event vegetation dry weight (g/pot) of pasture vegetation grown 14 April to 12 June 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

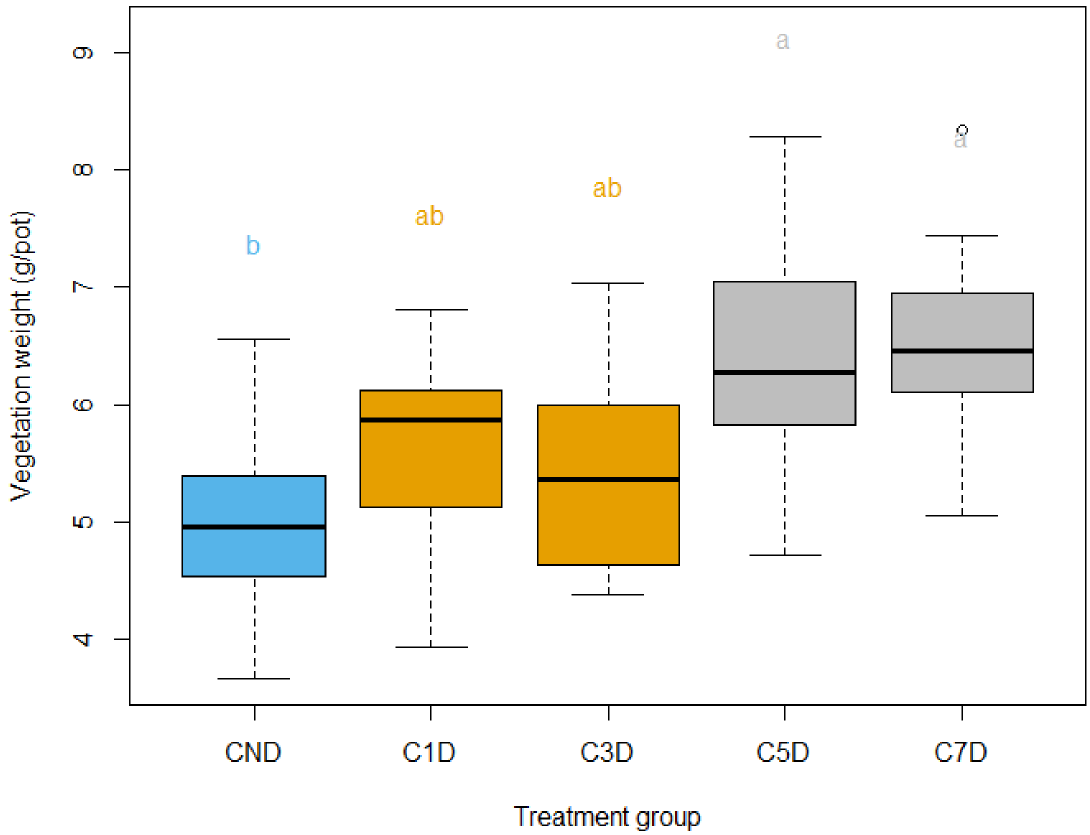


Figure 18. Box plots of second haying event vegetation dry weight (g/pot) of pasture vegetation grown 12 June to 13 August 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

<u>Soil quality</u>

Organic matter percentage did not significantly change from start of experiment to end with no differences between treatment groups ($F_{4,36} = 0.58$, $p = 0.676$). Soil pH did not change from the start of experiment to end with no differences between treatment groups ($F_{4,36} = 1.19$, $p = 0.333$). There were no differences of nitrate nitrogen (NO_3-N) levels between treatment groups ($F_{4,36} = 1.38$, $p = 0.262$). Levels slightly decreased from start of experiment to end with no differences between treatment groups for phosphorus ($F_{4,36} = 1.13$, $p = 0.357$), potassium ($F_{4,36} = 0.45$, $p = 0.772$), sulfur (SO_4-S) ($F_{4,36} = 1.13$, $p = 0.36$), sodium ($F_{4,36} = 2.27$, $p = 0.081$), and magnesium ($F_{4,36} = 2.35$, $p = 0.073$). Calcium levels slightly increased from start of experiment to end with no differences between treatment groups ($F_{4,36} = 1.72$, $p = 0.168$). Cation exchange capacity (CEC) slightly decreased from start of experiment to end with no differences between treatment groups ($F_{4,36} = 1.95$, $p = 0.124$).

<u>Ecosystem service</u>

Estimated average value of grass hay produced from the established pasture experiment did not significantly increase between the control (7,507 lbs/acre valued at $563/acre, $228/ha) and one dropping treatment (8,427 lbs/acre valued at $632/acre, $256/ha). Forage production value significantly increased to 8,853 lbs/acre valued at $664/acre ($269/ha) with the 3 dropping treatment, 9,867 lbs/acre valued at $740/acre ($300/ha) with the five dropping treatment, and topped out at 10,867 lbs/acre valued at $815/acre ($330/ha) with the seven dropping treatment (Figure 19).

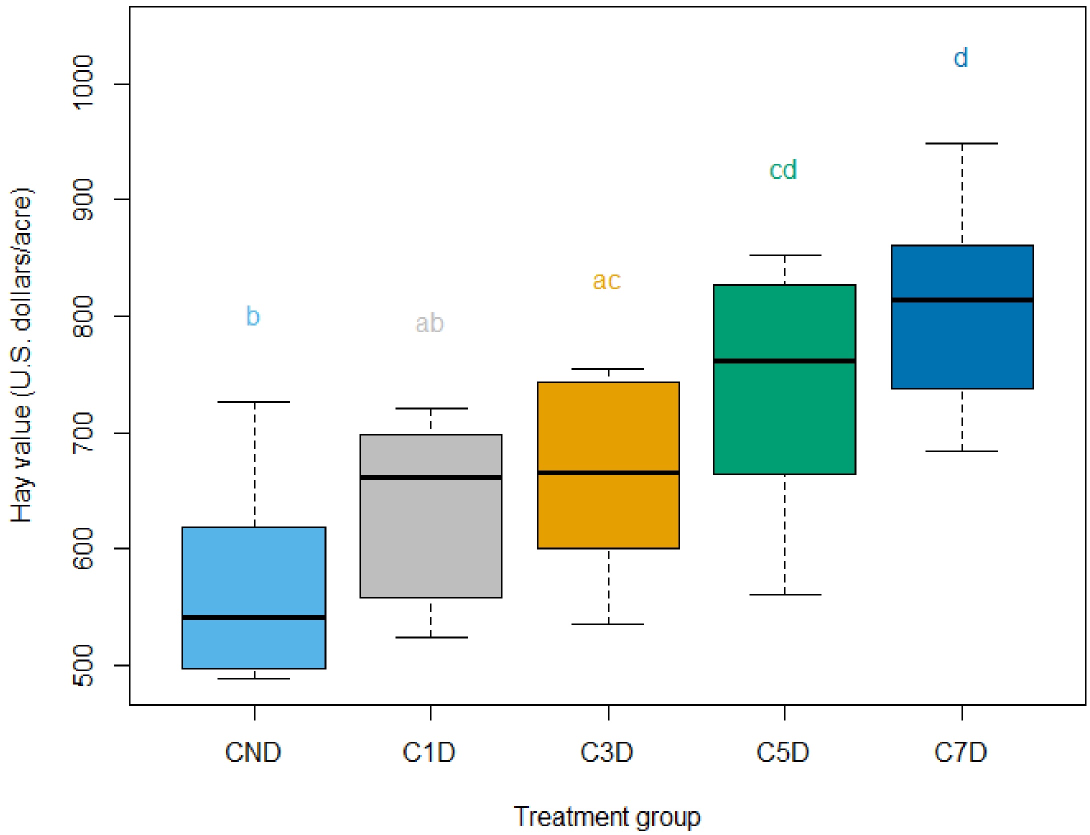


Figure 19. Box plots of total hay value in U.S. dollars ($) calculated using vegetation dry weight (g/pot), converting to pounds, adding 15% water weight, calculating dollar value using $150/ton, and converting to $/acre by estimating pots/acre. Hay values reported in $/acre based on standard agricultural reporting for farmers from U.S. Department of Agriculture. Dry weights from pasture vegetation grown 19 February to 13 August 2019 in 50 pots in greenhouse experiment at Cal Poly Humboldt, California. Plots color and letter coded according to statistical similarity from post hoc Tukey's honestly significant difference (HSD) tests. Treatment groups: clipping/no droppings (CND), clipping/1 dropping (C1D), clipping/3 droppings (C3D), clipping/5 droppings (C5D), and clipping/7 droppings (C7D).

DISCUSSION

Vegetation Production

Simulation of Aleutian goose grazing and dropping deposition on soil with newly sown ryegrasses (new pasture experiment) and established grass sward cores obtained from pastures (established pasture experiment) indicated positive effects on vegetation production as more goose droppings were added. New pasture experiment treatments with 4 to 28 total droppings added produced an average of 3.6 to 7.5 g/pot of vegetation during the study period compared with 1.7 g/pot in the clipped control treatment, representing a 108-334% improvement (Figure 2). Established pasture experiment treatments with 4 to 28 total droppings added produced an average of 14.9 to 19.3 g/pot of vegetation during the study period compared with 13.4 g/pot in the clipped control treatment, representing a 12-45% improvement (Figure 14). The increased vegetation production documented top-down and bottom-up effects (Gruner et al. 2008). Top-down effects (i.e., compensatory growth from grazing) and bottom-up effects (i.e., growth from addition of nutrients with fertilizing) regulate vegetation growth in a variety of systems (e.g. Burkepile and Hay 2006, Gruner et al. 2008, Shaughnessy et al. 2021).

The purpose of my study was to quantify bottom-up effects of geese on pasture vegetation which stimulates primary production through nutrient cycling via droppings. I controlled for top-down compensatory growth effects by keeping simulated grazing levels equal across all dropping treatment groups by trimming vegetation down to the same height in every group. Results indicated increased forage production during the spring from the fertilizing effects of goose droppings applied. Fertilizing effects were not limited to early spring when fresh goose droppings were applied, but also during the four summer months after the geese were gone and no droppings were added (Figures 7, 8, 17, 18). Fertilizing effects of droppings are documented in ecosystems that respond to inputs of nitrogen such as in sub-arctic salt marshes (Cargill and Jefferies 1984*a*, Bazely and Jefferies 1985) and temperate grasslands (Shimada and Mizota 2009). However, fertilizing effects of graylag geese (*Anser anser*) were limited to times of year when geese were physically present (van den Wyngaert et al. 2001). Generally, Fox et al. (2017) considered droppings added to clipping experiments had no demonstrable fertilizing effect and attributed this to small amounts of nutrients provided by droppings compared to agricultural fertilizer applications (e.g. Groot Bruinderink 1989).

Comparing wild goose droppings with commercial agricultural fertilizer applications may fail to capture the positive effects of wild geese on farms. Kear (1963) estimated the contribution of wild goose droppings to be of little benefit to the farmer when compared with the application of chemical fertilizers. Livestock pastures for beef production from my study area rarely use commercial fertilizers and pastures for dairy production primarily spread manure collected from their operations (D. Hunt, pers. comm., 2019), making comparisons between the use of goose droppings versus chemical fertilizers to increase forage production inappropriate. Hik and Jefferies (1990) documented the dependence of increased primary production on grazed versus ungrazed swards with the presence of goose droppings on La Pérouse Bay, Manitoba salt marsh, due in part to the rapid recycling of nutrients via droppings. Marriott (1973) applied fresh Cape Barren goose (*Cereopsis novaehollandiae*) droppings to ryegrass and clover plots grown in boxes outdoors to simulate managed Australian pastures and found increased grass production at higher levels of dropping application. My study builds on these previous studies, which indicate that wild goose droppings increased primary production of grasses, in this case on agricultural lands in northern California.

Important feedbacks occur between aboveground herbivores and producers, and belowground soil communities (van der Putten et al. 2013). Bardgett and Wardle (2003) describe nutrient-rich grasslands as common examples of how foliar herbivory benefits dominant plant species through positive feedbacks between herbivores, plants, and soil biota. McNaughton (1979) proposed the herbivore grazing optimization model as an example of how aboveground grazing enhances primary production. This model predicts enhanced net primary production at intermediate levels of grazing and decreased primary production at higher grazing intensities, including below that of ungrazed systems. Ruess and McNaughton (1984, 1987, 1988) documented grazing by large ungulates resulted in increased vegetation production based on the recycling of nutrients from feces and urine through soil, microbial, and root pathways.

Experimental, manipulative studies provide evidence supporting the herbivore grazing optimization model by McNaughton (1979) for barnacle geese (*Branta leucopsis*) (Prins and Ydenberg 1985, van der Graaf et al. 2005, 2007), brent geese (*Branta bernicla*) (Prins et al. 1980), Eurasian wigeon (*Mareca Penelope*) (Mayhew and Houston 1999), Greenland white-fronted geese (*Anser albifrons flavirostris*) (Fox et al. 1998), and lesser snow geese (*Anser caerulescens caerulescens)* (Hik and Jefferies 1990). Percival and Houston (1992) found a significant positive effect of barnacle geese grazing on silage yield in one year but documented a negative effect during a year with a considerably colder spring that delayed grass growth. It is noted that another study on barnacle geese grazing ryegrass-dominated pastures did not result in predicted compensatory growth (Cope et al. 2003). Hik and Jefferies (1990) documented a quadratic relationship between lesser snow goose gosling foraging and vegetation response curves by tracking regrowth for up to 60 days. Hik and Jefferies (1990) indicated in one experiment that increased growth was only observed in clipped plots with droppings when compared to both clipped plots without droppings and ungrazed plots. In comparison to Hik and Jefferies (1990), my study also documented increased growth within clipped pots that received droppings when compared to clipped pots without droppings and unclipped pots.

An attribute that influences vegetation growth I was unable to control for may have been plant density. I documented plant density decreased as more droppings were added to pots. This could have been a confounding effect due to the reduction in competition for resources between individual plants within each pot (Trinder et al. 2013). Yet, agronomic evidence establishes that crop density and yield is primarily a positive relationship with intraspecific competition occurring at high densities (Donald 1963, Weiner et al. 2010, Kolb et al. 2012). Thus, observed density effects, if any, were opposite of expected and unlikely to be confounding.

Soil Quality

Kear (1963:74) suggested additional benefits of goose droppings to farmers, including “the rapid turnover of organic matter in improving and conserving the soil.” I measured soil properties related to soil quality from measurements taken at the start and end of the experiment and by comparing soil from experimental treatment plots with controls. Soil metrics measured provide a coarse perspective on soil quality influence on forage production (Andrews et al. 2004, Karlen et al. 2003, de Paul Obade and Lal 2016*a*, *b*). I focus on five key soil nutrients expected to influence vegetation production, starting with nitrogen and phosphorus.

Primary producers are thought to be limited by nitrogen (N) and phosphorus (P) in most major habitats around the globe (Elser et al. 2007). In my study’s soils, nitrate nitrogen (NO_3-N) did not increase over the course of the new or established pasture experiment, nor did NO_3-N vary among experimental treatment groups compared to controls. This lack of soil NO_3-N levels varying at the end of the experiment, despite increased vegetation production in pots with more droppings, may have been due to plant uptake and use of the available nitrogen. Nitrogen added to my experiment was equivalent to approximately 84.4 lbs/dry ton of droppings, containing 4.17% N, small amounts of ammonia N (NH_3-N), and extremely low amounts of NO_3-N (See Table 1 for dropping component summary). As more nitrogen was added to pots from goose droppings, that mobile nitrogen could have been quickly utilized by plants. For lesser snow geese, two-thirds of nitrogen in droppings were soluble (Cargill 1981). Rapid leaching of nitrogen compounds into the soil was proposed as evidence for substantial increases in above-ground primary production documented by Cargill and Jefferies (1984*b*) and Bazely and Jefferies (1985, 1989). Those researchers traced nitrogen cycled from lesser snow goose droppings to soil and vegetation to understand nitrogen cycling in nutrient-limited, nitrogen-deficient salt marshes. Shimada and Mizota (2009) concluded goose droppings contributed to significantly higher rye-grass N content and inorganic soil N within *Lolium hybridum* grasslands that were grazed versus ungrazed. The function of Aleutian goose droppings on pastures in northern California is likely similar to geese in these other studies.

The macronutrient phosphorus (P) is important for energy storage and transfer in plants (Havlin et al. 2016). At the end of my experiment, only soil from plots with the most droppings added in the new pasture experiment had significantly more soil P compared to the clipping control and one dropping groups. Droppings added to my experiment contained 0.61% P and 1.38% phosphate (P_2O_5), equivalent to approximately 39.8 lbs/dry ton. The addition of phosphorus from goose droppings could provide an explanation of increased soil P. The mineralization process associated with microbial communities decomposing droppings could increase soil P amounts, although the low amount of soil P measured, leaching, short study time, and form of phosphorus in soil may have rendered it unavailable to plants (Havlin et al. 2016). Cargill and Jefferies (1984a) documented higher primary production when nitrogen and phosphorus fertilizers were added compared to plots when only nitrogen fertilizer was added. Goose droppings contain both nitrogen and phosphorus, supporting why primary production increased in my study and in those of Cargill and Jefferies (1984*b*) and Bazely and Jefferies (1985).

Three additional soil nutrients (potassium, sulfur and sodium) changed during the experiment or varied among treatment groups that may have effected vegetation production. By the end of the new pasture experiment, soil potassium (K) levels were significantly higher in plots receiving high amounts of droppings. Droppings added to my experiment contained 3.66% K and 4.40% potash (K2O), equivalent to approximately 161.2 lbs/dry ton. Bell et al. (2021) emphasized how different functional sources of soil K effects plant K acquisition and soil K dynamics. Increased potassium, which is essential for photosynthesis, may have been a product of microbial communities decomposing droppings into solution for plant uptake (Havlin et al. 2016). More potassium made available to plants may have led to increased forage production in my experiment. However, by the end of the established pasture experiment, soil K levels had significantly decreased. Declines in soil K was documented in another grass/clover pot trial experiment, which the authors explained was likely due to how “plants grown in pot trials exploit the soil more thoroughly than plants grown in the field, owing to the reduced volume available for root exploration” (Fortune et al. 2004:408).

Sulfur (S) is an essential nutrient for plant growth and is important in agriculture, as it is often considered the fourth major plant nutrient after nitrogen, phosphorus, and potassium (Jamal et al. 2010). Sulfate-sulfur (SO_4-S) levels significantly decreased from start to end of both new and established pasture experiments, with lower SO_4-S levels in pots with more droppings compared to the control groups in the new pasture experiment.

Droppings added to my experiment contained 0.44% S, equivalent to approximately 8.7 lbs/dry ton. Sulfate-sulfur in soil is a form readily available to plants (Havlin et al. 2016), which could explain the increased plant production documented in my experiment. After months of plant uptake, growing ryegrass utilized SO_4-S in the soil, causing lower soil S levels to be measured at the end of experiment. Microbiological biomass is important for S turnover in soil, with organic matter applications generally increasing microbial S (Jamal et al. 2010). Goose droppings may have functioned as important organic matter additions, leading to increased soil S, although the nutrient pathway from droppings to soil is subjected to losses via volatilization and leaching, especially under wet conditions (Havlin et al. 2016).

Generally, less sodium in soils is important as high levels of sodium are toxic to many plants as it increases salinity, causing decreased plant growth (Maathuis 2014). Sodium levels significantly decreased from start to end of both new and established pasture experiments. Pots in the new pasture experiment that were clipped and those with more droppings added had less soil sodium. Crops are tolerant to various amounts of sodium and respond with increased yields as exchangeable sodium percentages decreases (Gupta and Sharma 1990). Pasture forage yields documented in my study may have benefited from the lower soil sodium levels. It is noted that droppings added to my experiment did contain sodium, but at very low amounts (0.10%) equivalent to approximately 8.7 lbs/dry ton.

Ecosystem Service

I estimated the ecosystem service value for increased hay forage production as \$79-\$243/acre (\$32-\$98/ha), 108%-334% above the control, for newly sown ryegrass pasture (Figure 13) and \$69-\$251/acre (\$28-\$102/ha), 12%-45% above the control, on established pasture (Figure 19). It is noted that these valuations are conservative estimates as I used a hay value of \$150/ton to ease comparisons with results from Tjarnstrom (2014), yet current hay values have risen far higher. The method used to calculate ecosystem services was based on the Factor Income method and production function from Johnson and Hackett (2016). The Factor Income method values an ecosystem service by measuring the enhancement of income from the service when birds enhance yields without altering costs. The amount of vegetation I removed via clipping did vary between treatment groups as every pot was trimmed down to the same height. I assumed this loss of forage to simulated goose grazing did not cost the farmer for lost cattle forage due to the enhanced forage produced after the addition of droppings.

The function of pasture fertilization by goose droppings to stimulate primary productivity is considered a supporting ecosystem service, providing benefits to farmers (Green and Elmberg 2014). My study focused on the supporting services of geese as they are “necessary for the production of all other ecosystem services” (MEA 2005:40). It is important to consider the ecological function of wild geese within agricultural systems has been documented to have both positive and negative impacts (Buij et al. 2017). Tjarnstrom (2014) quantified Aleutian geese consumed an average of 572 lbs/acre of forage, valued at $42.90/acre based on $150/ton hay value. Results of my research documented forage increases from spring into the summer months of 1,053-3,240 lbs/acre valued at $79-$243/acre ($32-$98/ha) for newly sown ryegrass pasture, and 920-3,347 lbs/acre valued at $69-$251/acre ($28-$102/ha) on established pasture. Comparing my results with Tjarnstrom (2014), I estimated forage production from dropping additions were greater than the estimates of goose consumption. Further research within these pasture systems, which consider aspects of grazing and dropping fertilization in field settings during goose presence and afterwards, can improve estimates of net goose impacts.

Benefits extend beyond the supporting service documented in my study to cultural and provisioning services, which can be assessed to broaden the scope of understanding of contributions by wild geese. Cultural services, which can be applied to wild geese, include recreational hunting, birdwatching, ecotourism, conservation, and art (Green and Elmberg 2014, Buij et al. 2017). Provisioning services of geese include the production of meat, down, feathers, and grease for human consumption and use (Kear 1990, Green and Elmberg 2014, Buij et al. 2017).

CONCLUSIONS

In response to the rapid growth of the Aleutian goose population in Del Norte and Humboldt County in northern California over the past 30 years, livestock producers have partnered with wildlife managers, government officials, and university researchers to address the relationship between geese and livestock. A working group of landowners and agency personnel formed in 1990, the Lake Earl Working Group, to find solutions to reduce goose grazing on private land (USFWS 2001). The Aleutian Goose Working Group formed in 2003 with the goal to "work cooperatively to develop and implement management strategies acceptable on public and private lands on the spring staging area so that the Aleutian Goose is an asset to the community" (Aleutian Goose Working Group 2005). Management focused on implementing hazing and hunting programs to push geese from private lands and lure them to public properties where geese were encouraged to forage (Bachman 2008, Mini et al. 2011, Spragens et al. 2015). My research contributed to a goal expressed by the Aleutian Goose Working Group, to view the Aleutian goose as an asset to the community rather than a liability. This project presented evidence that Aleutian geese provide a beneficial fertilizing effect on pastures by increasing pasture forage production. This is an ecosystem service provided by geese for livestock ranchers managing their pastures.

The Jacoby Creek-Gannon Slough Wildlife Area (JCGSWA) was my project's study area where grazing lands provide important floodplains and wetland habitats for wildlife and fish. Through partnerships with government agencies and community organizations, over 1,300 acres (> 526 ha) of bayland habitats were protected in the Baylands Restoration and Enhancement Project, including the 600-acre (243 ha) JCGSWA, which the City of Arcata manages to benefit the once endangered Aleutian geese (City of Arcata 2022). Cattle create pasture conditions which provide suitable grazing habitats for the geese. The JCGSWA pastures also provide a no hunting zone where geese may escape hunting pressure during the 85-day regular waterfowl season from November to January and the 20-day late season in February and March (CDFW 2021). Ecosystem services provided by geese on these lands were previously unknown, leading some ranchers to view geese as pasture competitors. Results of this study provide the City of Arcata with a positive economic valuation for welcoming geese on JCGSWA pastures.

This study was a first step in assessing potential benefits of Aleutian geese in northern California pastures. Other benefits include recreational hunting, birdwatching, ecotourism, conservation, and artistic inspiration (Kear 1990, Green and Elmberg 2014, Buij et al. 2017). Future students may wish to evaluate such benefits of wild geese to help celebrate the conservation success story of Aleutian geese. To better manage lands for both people and nature, it is important to understand the role of Aleutian geese more fully in the complex social-ecological systems that are Del Norte and Humboldt County farms and ranches.

LITERATURE CITED

Aleutian Goose Working Group. 2005. Living with Aleutian geese on the Pacific north coast. Digital copy obtained from J. M. Black, Cal Poly Humboldt, Arcata, California, USA.

Andrews, S. S., C. Flora, J. Mitchell, and D. Karlen. 2003. Growers' perceptions and acceptance of soil quality indices. Geoderma 114:187-213.

Andrews, S. S., D. L. Karlen, and C. A. Cambardella. 2004. The soil management assessment framework: a quantitative soil quality evaluation method. Soil Science Society of America Journal 68:1945-1962.

Andrews, S. S., J. P. Mitchell, R. Mancinelli, D. L. Karlen, T. K. Hartz, W. R. Horwath, G. S. Pettygrove, K. M. Scow, and D. S. Munk. 2002. On-farm assessment of soil quality in California's central valley. Agronomy Journal 94:12-23.

Ankney, C. D. 1996. An embarrassment of riches: too many geese. The Journal of Wildlife Management 60:217-223.

Bachman, D. 2008. Managing grassland pastures at Humboldt Bay National Wildlife Refuge for Aleutian geese. Thesis, Cal Poly Humboldt, Arcata, California, USA.

Bardgett, R. D., and D. A. Wardle. 2003. Herbivore-mediated linkages between aboveground and belowground communities. Ecology 84:2258-2268.

Bazely, D., and R. Jefferies. 1985. Goose faeces: a source of nitrogen for plant growth in a grazed salt marsh. Journal of Applied Ecology 22:693-703.

Bazely, D., and R. Jefferies. 1989. Lesser snow geese and the nitrogen economy of a grazed salt marsh. Journal of Ecology 77:24-34.

Bell, M., M. Ransom, M. Thompson, P. Hinsinger, A. Florence, P. Moody, and C. Guppy. 2021. Considering soil potassium pools with dissimilar plant availability. Pages 163-190 *in* Murrell, T. S., R. L. Mikkelsen, G. Sulewski, R. Norton, M. L. Thompson, editors. Improving potassium recommendations for agricultural crops. Springer International Publishing, Cham, Switzerland.

Black, J. M., J. Prop, and K. Larsson. 2014. The barnacle goose. T & AD Poyser/Bloomsbury Publishing, London, United Kingdom.

Black, J. M., P. F. Springer, E. T. Nelson, K. M. Griggs, T. D. Taylor, Z. D. Thompson, A. Maguire, and J. Jacobs. 2004. Site selection and foraging behavior of Aleutian

Canada geese in a newly colonized spring staging area. Pages 106-113 *in* Proceedings of the International Canada Goose Symposium, 19-21 March 2003, Madison, Wisconsin, USA.

Buij, R., T. C. Melman, M. J. Loonen, and A. D. Fox. 2017. Balancing ecosystem function, services and disservices resulting from expanding goose populations. Ambio 46:301-318.

Bünemann, E. K., G. Bongiorno, Z. Bai, R. E. Creamer, G. De Deyn, R. de Goede, L. Fleskens, V. Geissen, T. W. Kuyper, P. Mäder, M. Pulleman, W. Sukkel, J. W. van Groenigen, and L. Brussaard. 2018. Soil quality-a critical review. Soil Biology and Biochemistry 120:105-125.

Burkepile, D. E., and M. E. Hay. 2006. Herbivore vs. nutrient control of marine primary producers: context-dependent effects. Ecology 87:3128-3139.

Cargill, S. M. 1981. The effects of grazing by lesser snow geese on the vegetation of an Arctic salt marsh. Thesis, University of Toronto, Toronto, Canada.

Cargill, S., and R. Jefferies. 1984*a*. Nutrient limitation of primary production in a sub-arctic salt marsh. Journal of Applied Ecology 21:657-668.

Cargill, S., and R. Jefferies. 1984*b*. The effects of grazing by lesser snow geese on the vegetation of a sub-arctic salt marsh. Journal of Applied Ecology 21:669-686.

City of Arcata. 2022. Arcata baylands restoration/enhancement project. <https://www.cityofarcata.org/219/Arcata-Baylands-Restoration-Enhancement->. Accessed 12 April 2022.

California Department of Fish and Wildlife [CDFW]. 2021. Approved 2021-2022 waterfowl hunting regulatory language. California Fish and Game Commission Section 502 Title 14 California Code of Regulations, Sacramento, USA.

Cocke, J., S. K. Alton, and J. M. Black. 2016. Observations of Aleutian cackling geese *Branta hutchinsii leucopareia* breeding on Buldir Island, Alaska: forty-seven years after discovery of a remnant population. Wildfowl 66:112-125.

Cope, D., J. Rowcliffe, and R. Pettifor. 2003. Sward height, structure and leaf extension rate of *Lolium perenne* pastures when grazed by overwintering barnacle geese. Grass and Forage Science 58:70-76.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. Laroe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.

Diamond, R. A. 1990. The influence of wastewater irrigation on the quantity and quality of dairy forage in mid-coastal Humboldt County. Thesis, Cal Poly Humboldt, Arcata, California, USA.

de Groot, R. S., M. A. Wilson, and R. M. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41:393-408.

de Paul Obade, V., and R. Lal. 2016*a*. Towards a standard technique for soil quality assessment. Geoderma 265:96-102.

de Paul Obade, V., and R. Lal. 2016*b*. A standardized soil quality index for diverse field conditions. Science of The Total Environment 541:424-434.

Donald, C. M. 1963. Competition among crop and pasture plants. Pages 1-118 *in* A. G. Norman, editor. Advances in Agronomy Volume 15. Academic Press, New York, New York, USA.

Elser, J. J., M. E. Bracken, E. E. Cleland, D. S. Gruner, W. S. Harpole, H. Hillebrand, J. T. Ngai, E. W. Seabloom, J. B. Shurin, and J. E. Smith. 2007. Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. Ecology Letters 10:1135-1142.

Fortune, S., J. Hollies, and E. Stockdale. 2004. Effects of different potassium fertilizers suitable for use in organic farming systems on grass/clover yields and nutrient offtakes and interactions with nitrogen supply. Soil Use and Management 20:403-409.

Fox, A. D., J. Elmberg, I. M. Tombre, and R. Hessel. 2017. Agriculture and herbivorous waterfowl: a review of the scientific basis for improved management. Biological Reviews 92:854-877.

Fox, A. D., and J. Madsen. 2017. Threatened species to super-abundance: the unexpected international implications of successful goose conservation. Ambio 46:179-187.

Fox, A. D., J. N. Kristiansen, D. A. Stroud, and H. Boyd. 1998. The effects of simulated spring goose grazing on the growth rate and protein content of *Phleum pratense* leaves. Oecologia 116:154-159.

Fox, A. D., and K. F. Abraham. 2017. Why geese benefit from the transition from natural vegetation to agriculture. Ambio 46:188-197.

Green, A. J., and J. Elmberg. 2014. Ecosystem services provided by waterbirds. Biological Reviews 89:105-122.

Groot Bruinderink, G. W. T. A. 1989. The impact of wild geese visiting improved grasslands in the Netherlands. Journal of Applied Ecology 26:131-146.

Gruner, D. S., J. E. Smith, E. W. Seabloom, S. A. Sandin, J. T. Ngai, H. Hillebrand, W. S. Harpole, J. J. Elser, E. E. Cleland, M. E. Bracken, E. T. Borer, and B. M. Bolker. 2008. A cross-system synthesis of consumer and nutrient resource control on producer biomass. Ecology Letters 11:740-755.

Gupta, S., and S. Sharma. 1990. Response of crops to high exchangeable sodium percentage. Irrigation Science 11:173-179.

Havlin, J. L., S. L. Tisdale, W. L. Nelson, and J. D. Beaton. 2016. Soil fertility and fertilizers: an introduction to nutrient management. Pearson Education, New York, New York, USA.

Hik, D., and R. Jefferies. 1990. Increases in the net above-ground primary production of a salt-marsh forage grass: a test of the predictions of the herbivore-optimization model. Journal of Ecology 78:180-195.

Hoff, C. J. 1979. Bird use of agricultural lands around North Humboldt Bay, California. Thesis, Cal Poly Humboldt, Arcata, California, USA.

Jamal, A., Y-S. Moon, and M. Zainul Abdin. 2010. Sulphur-a general overview and interaction with nitrogen. Australian Journal of Crop Science 4:523-529.

Johnson, M. D., and S. C. Hackett. 2016. Why birds matter economically: values, markets, and policies. Pages 27-48 *in* C. H. Sekercioglu, D. G. Wenny, and C. J. Whelan, editors. Why birds matter: avian ecological functions and ecosystem services. The University of Chicago Press, Chicago, Illinois, USA.

Karlen, D. L., C. A. Ditzler, and S. S. Andrews. 2003. Soil quality: why and how? Geoderma 114:145-156.

Karlen, D. L., M. Mausbach, J. Doran, R. Cline, R. Harris, and G. Schuman. 1997. Soil quality: a concept, definition, and framework for evaluation (a guest editorial). Soil Science Society of America Journal 61:4-10.

Kear, J. 1963. The agricultural importance of wild goose droppings. Wildfowl 14:72-77.

Kear, J. 1990. Man and wildfowl. T & A.D, Poyser, London, United Kingdom.

Kolb, L. N., E. R. Gallandt, and E. B. Mallory. 2012. Impact of spring wheat planting density, row spacing, and mechanical weed control on yield, grain protein, and economic return in Maine. Weed Science 60:244-253.

Laishram, J., K. G. Saxena, R. Maikhuri, and K. S. Rao. 2012. Soil quality and soil health: a review. International Journal of Ecology and Environmental Sciences 38:19-37.

Maathuis, F. J. 2014. Sodium in plants: perception, signalling, and regulation of sodium fluxes. Journal of Experimental Botany 65:849-858.

Madsen, J., G. Cracknell, and A. D. Fox. 1999. Goose populations of the Western Palearctic: a review of status and distribution. Wetlands International 48:328-341.

Marriott, R. W. 1973. The manurial effect of Cape Barren goose droppings. Wildfowl 24:131-134.

Mayhew, P., and D. Houston. 1999. Effects of winter and early spring grazing by wigeon *Anas penelope* on their food supply. Ibis 141:80-84.

McNaughton, S. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. The American Naturalist 113:691-703.

Millennium Ecosystem Assessment [MEA]. 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, D.C., USA.

Mini, A. E., and Black, J. M. 2009. Expensive traditions: energy expenditure of Aleutian geese in traditional and recently colonized habitats. Journal of Wildlife Management 73:385-391.

Mini, A. E., D. C. Bachman, J. Cocke, K. M. Griggs, K. A. Spragens, and J. M. Black. 2011. Recovery of the Aleutian cackling goose *Branta hutchinsii leucopareia*: 10-year review and future prospects. Wildfowl 61:3-29.

Moser, M., and C. Kalden. 1992. Farmers and waterfowl: conflicts or co-existence- an introductory overview. Pages 13-19 *in* M. van Roomen and J. Madsen, editors. Waterfowl and agriculture: review and future perspective of the crop damage conflict in Europe. International Waterfowl and Wetlands Research Bureau Special Publication 21, Slimbridge, United Kingdom.

Natural Resources Conservation Service [NRCS]. 2018. Web soil survey. <https://websoilsurvey.sc.egov.usda.gov/>. Accessed 12 Nov 2018.

Natural Resources Conservation Service [NRCS]. 2012. Field book for describing and sampling soils. National Soil Survey Center, NRCS, U.S. Department of Agriculture, Washington, D.C., USA.

Owen, M. 1971. The selection of feeding site by white-fronted geese in winter. Journal of Applied Ecology 8:905-917.

Owen, M. 1980. Wild geese of the world: their life history and ecology. B. T. Batsford, London, United Kingdom.

Owen, M. 1990. The damage-conservation interface illustrated by geese. Ibis 132:238-252.

Owen, M., and J. M. Black. 1991. Geese and their future fortune. Ibis 133:28-35.

Percival, S., and D. Houston. 1992. The effect of winter grazing by barnacle geese on grassland yields on Islay. Journal of Applied Ecology 29:35-40.

Prins, H. T., and R. Ydenberg. 1985. Vegetation growth and a seasonal habitat shift of the barnacle goose (*Branta leucopsis*). Oecologia 66:122-125.

Prins, H. T., R. Ydenberg, and R. Drent. 1980. The interaction of brent geese *Branta bernicla* and sea plantain *Plantago maritima* during spring staging: field observations and experiments. Acta Botanica Neerlandica 29:585-596.

Prop, J., and J. M. Black. 1998. Food intake, body reserves and reproductive success of barnacle geese *Branta leucopsis* staging in different habitats. Norsk Polarinstitutt Skrifter 200:175-193.

Ruess, R., and S. McNaughton. 1984. Urea as a promotive coupler of plant-herbivore interactions. Oecologia 63:331-337.

Ruess, R., and S. McNaughton. 1987. Grazing and the dynamics of nutrient and energy regulated microbial processes in the Serengeti grasslands. Oikos 49:101-110.

Ruess, R., and S. McNaughton. 1988. Ammonia volatilization and the effects of large grazing mammals on nutrient loss from East African grasslands. Oecologia 77:382-386.

Savory, A., and Parsons, S. D. 1980. The Savory grazing method. Rangelands 2:234-237.

Shaughnessy, F. J., S. L. Ferson, A. J. Frimodig, D. C. Barton, M. Hurst, and J. M. Black. 2021. Growth and flowering responses of eelgrass to simulated grazing and fecal addition by Brant Geese. Ecosphere 12:e03690.

Shimada, T., and C. Mizota. 2009. The effects of grazing by geese on the dry mass and soil inorganic nitrogen of *Lolium hybridum* grasslands. Japanese Journal of Ornithology 58:201-205.

Simonsen, C. E., I. M. Tombre, and J. Madsen. 2017. Scaring as a tool to alleviate crop damage by geese: revealing differences between farmers’ perceptions and the scale of the problem. Ambio 46:319-327.

Spragens, K. M., J. M. Black, and M. D. Johnson. 2015. Aleutian cackling goose *Branta hutchinsii leucopareia* use of pastures in relation to livestock management. Wildfowl 65:31-50.

Springer, P. F., and R. W Lowe. 1998. Population, distribution, and ecology of migrating and wintering Aleutian Canada geese. Pages 425–434 *in* Biology and management of Canada geese. Proceedings of the International Canada Goose Symposium, Milwaukee, Wisconsin, USA.

Stewart, K., N. Bourn, and J. Thomas. 2001. An evaluation of three quick methods commonly used to assess sward height in ecology. Journal of Applied Ecology 38:1148-1154.

Swinton S., Lupia F., Robertson G.P., and Hamilton, S.K. 2007. Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecological Economics 64:245-252.

Tjarnstrom, F. R. 2014. Determining the impacts of forage consumption by Aleutian cackling geese on livestock production from north coastal pasture lands in Humboldt County, California. Thesis, Cal Poly Humboldt, Arcata, California, USA.

Trinder, C. J., R. W. Brooker, and D. Robinson. 2013. Plant ecology’s guilty little secret: understanding the dynamics of plant competition. Functional Ecology 27:918-929.

Trost, R., and T. Sanders. 2008. Pacific flyway data book- waterfowl harvest and status, hunter participation and success in the Pacific flyway and United States. U.S. Fish and Wildlife Service, Portland, Oregon, USA.

U.S. Department of Agriculture [USDA]. 2022. Agriculture Marketing Service California direct hay report. < https://mymarketnews.ams.usda.gov/viewReport/2904>. Accessed 12 April 2022.

U.S. Fish and Wildlife Service [USFWS]. 2001. Endangered and threatened wildlife and plants; final rule to remove the Aleutian Canada goose from the federal list of endangered and threatened wildlife. Federal Register 66:15643-15656.

U.S. Fish and Wildlife Service [USFWS]. 2021. Waterfowl population status, 2021. U.S. Department of the Interior, Washington, D.C. USA.

van den Wyngaert, I. J. J., A. K. Hilgers, J. C. Berk, and J. T. A.Verhoeven. 2001. Effects of grazing greylag geese on nutritional fluxes: decomposition of litter and faecal material. *In* Grazing of extensive reed beds by moulting greylag geese: effects on nutrient dynamics and growth of the *Phragmites australis* vegetation and consequences for the lake ecosystem. Dissertation, University of Utrecht, Utrecht, The Netherlands.

van der Graaf, A. J., J. Stahl, and J. P. Bakker. 2005. Compensatory growth of *Festuca rubra* after grazing: can migratory herbivores increase their own harvest during staging? Functional Ecology 19:961-969.

van der Graaf, A., J. Stahl, G. Veen, R. Havinga, and R. Drent. 2007. Patch choice of avian herbivores along a migration trajectory- from temperate to arctic. Basic and Applied Ecology 8:354-363.

van der Putten, W. H., R. D. Bardgett, J. D. Bever, T. M. Bezemer, B. B. Casper, T. Fukami, P. Kardol, J. N. Klironomos, A. Kulmatiski, J. A. Schweitzer, K. N. Suding, T. F. J. Van de Voorde, and D. A. Wardle. 2013. Plant-soil feedbacks: the past, the present and future challenges. Journal of Ecology 101:265-276.

Weiner, J., S. B. Andersen, W. K.-M. Wille, H. W. Griepentrog, and J. M. Olsen. 2010. Evolutionary agroecology: the potential for cooperative, high density, weed-suppressing cereals. Evolutionary Applications 3:473-479.

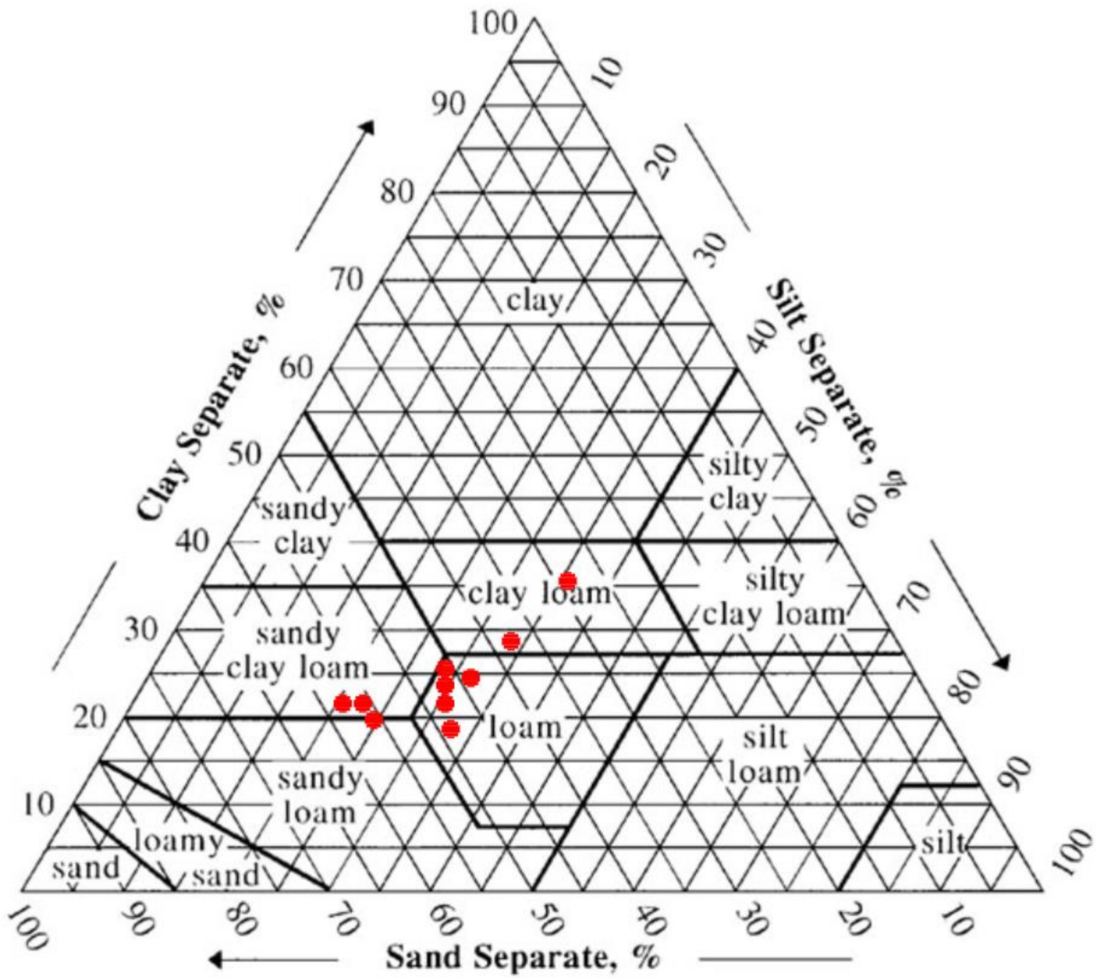
Woolington, D. W., P. Springer, and D. Yparraguirre. 1979. Migration and wintering distribution of Aleutian Canada geese. Pages 299-309 *in* Management and biology of Pacific flyway geese. Oregon State University Press, Corvallis, USA.

APPENDICES

Appendix A: Average soil textures calculated from particle size analysis by block group. Soil collected 13 August 2019 >7.5 cm from soil surface in 50 pots containing pasture vegetation grown 19 February to 13 August 2019 in greenhouse experiment at Cal Poly Humboldt, California.

Block group	Soil texture	Sand (%)	Silt (%)	Clay (%)
1	Loam	49	30	21
2	Sandy loam	57	24	19
3	Sandy clay loam	57	22	21
4	Clay loam	30	35	35
5	Loam	45	31	24
6	Sandy clay loam	59	20	21
7	Clay loam	39	33	28
8	Loam	50	32	18
9	Loam	47	28	25
10	Loam	48	29	23

Appendix B: Average soil textures calculated from particle size analysis and mapped on soil texture triangle by block group with red dots. Soil collected 13 August 2019 >7.5 cm from soil surface in 50 pots containing pasture vegetation grown 19 February to 13 August 2019 in greenhouse experiment at Cal Poly Humboldt, California.



Appendix C: Average plant genera composition percent (%) per pot by block group as measured at end of experiment. Composition percentage estimated visually using 5% increments; totals may exceed 100%. Each block group consisted of five pots with 50 pots total containing pasture vegetation grown 19 February to 13 August 2019 in greenhouse experiment at Cal Poly Humboldt, California.

Block group	*Agrostis*	*Aster*	*Holcus*	*Lolium*	*Lotus*	*Potentilla*	*Ranunculus*	*Rumex*	*Taraxacum*	*Trifolium*	Unknown grass
1	5	0	0	50	5	0	0	5	0	5	40
2	5	0	0	30	10	0	0	0	0	5	50
3	65	0	0	0	5	10	5	5	0	10	10
4	15	0	10	5	5	5	0	0	15	5	40
5	5	0	5	30	5	0	0	5	20	5	25
6	0	0	10	25	5	5	5	0	0	10	45
7	15	0	45	10	0	10	0	5	0	0	20
8	10	0	25	25	0	5	0	0	0	10	30
9	5	0	10	25	5	5	0	0	5	40	15
10	0	15	15	25	5	0	5	5	5	20	20