# Final Report

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## USDA Western Sustainable Agriculture Research and Education Program

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**Project Number**
Project Number SW03-037

**Project Title**
Confirmation of Riparian Friendly Grazing Project Results and Development of Achievable, Site Specific Reference Conditions for Grazed Riparian Areas

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**Summary**
Our objective was to identify grazing management to enhance riparian health on meadow streams. We collaborated with 35 ranchers and numerous agencies to survey grazing management and stream macroinvertebrates across grazed and non-grazed meadow streams in California. Results illustrate that active implementation of simple livestock distribution tools, such as herding and salting away from streams, is associated with increased riparian health. Negative riparian impacts attributable to livestock grazing can be overcome with technically simple techniques. Our results also show that stream characteristics such as substrate size must be considered when establishing aquatic habitat based riparian health targets in grazed systems.

**Introduction**
General concerns about livestock and riparian health include grazing impacts on riparian vegetation, stream channel stability, water quality, channel morphology, and habitat (Fleishner 1994, Belsky et al. 1999, Rinne 1999). On western U.S. rangelands, many assert that livestock grazing is non-sustainable and completely incompatible with healthy riparian areas (Fleischner 1994, Belsky et al, 1999). Others illustrate the lack of tested, real world solutions in the literature, and point out the critical need for new approaches to study and define sustainable riparian grazing (Allen-Diaz 1999, Larsen et al. 1998, Rinne 1999). In our opinion, defining sustainable riparian grazing is dependent upon: 1) working directly with grazing managers to

identify grazing practices which maintain riparian health yet are logistically and economically feasible; and 2) conducting research at the ranch and grazing allotment scale to insure the results are relevant at the management scale.

The project reported here was conducted as confirmation of the preliminary findings of a survey of grazing management and riparian health on 300 stream reaches across California. In a precursor project partially funded by SARE in 2001-02 our team was able to statistically correlate site-specific grazing management practices to riparian health (Ward et al. 2001, Ward 2002, Ward et al. 2002, SARE Project Number SW01-044 Final Report). These results provide strong statistical evidence that common grazing management practices such as herding and attracting (*e.g.*, supplemental feed stations, water tanks) livestock away from riparian areas are positively associated with improved riparian and stream health. The key result was that the amount of effort or implementation of a practice (*e.g.*, number of days each grazing season spent herding livestock away from the stream) was consistently positively associated with improved riparian health. Many of the relationships we identified between grazing management and riparian health would be impossible to document at the research plot scale. We quantified riparian health at each of the stream reaches enrolled in the study using three nationally accepted visual assessment protocols [U.S. EPA *Habitat Assessment Field Data Sheet (HAFDS)*, U.S. NRCS *Stream Visual Assessment Protocol (SVA)*, U.S. BLM *Proper Functioning Condition (PFC)* Protocol]. This simple and rapid evaluation of riparian health allowed us to enroll many sites into the study (large sample size), as well as verify that this survey-based research approach would yield meaningful results.

One major reason for the project reported here (SW03-037) was to confirm the results of project SW01-044 based upon a gold standard measurement of riparian health. We selected stream macroinvertebrates (aquatic insects) for this purpose. We focused our efforts upon stream types which we previously found to be most responsive to grazing management decisions. These were low gradient, mountain meadow associated stream reaches (Rosgen Category C and E, Rosgen 1996) in the entire Sierra Nevada Range, the Southern Cascades, and the arid plateaus of northeastern California. Relationships determined between specific grazing management practices and key indices of macroinvertebrate assemblages are presented in detail in following sections of this report.

The second purpose of this project was to commence the process of establishing realistic, site-specific expectations for rangeland riparian health. Stream macroinvertebrates were again used as a gold standard metric of riparian health. Designing sustainable riparian grazing management is impossible without a clear and attainable riparian health target. Our previous research clearly indicates that managers can modify grazing management to enhance important components of riparian health (*e.g.*, streambank vegetative cover**,** clean gravel fish spawning beds), but how do we determine when we have achieved a “healthy” riparian condition? It is reasonable to study long-term non-grazed sites for insight to the potential conditions a rangeland stream could obtain. Such sites are often called “reference conditions”. This approach is vulnerable to many valid criticisms. In particular, how does one account for inherent differences in elevation, streambed substrate, etc. between sites? In this report we compare macroinvertbrate assemblage data from grazed and non-grazed meadow associated streams, and specifically discuss the important role which inherent site differences play in setting riparian health targets.

## Project Objectives

**Objective 1:** Confirm the potential for site-specific grazing management practices to enhance important riparian health metrics, clearly documenting the potential for sustainable riparian grazing.

**Objective 2:** Develop a protocol to establish achievable, site-specific expectations for riparian health, which provides grazing managers with riparian health targets.

**Objective 3:** Extend the riparian grazing management recommendations developed from this work to private and public land grazing managers, as well as to regulatory and natural resources agencies.

## Materials and Methods

### Objective 1

The overall study design for objective 1 was a cross-sectional survey of grazing management practices and macroinvertebrate assemblages in grazed mountain meadow stream reaches in California. A subset of 58 grazed stream reaches were selected from those previously enrolled in project number SW01-044 and revisited during the summer of 2003 and 2004 for collection of macroinvertebrate samples, vegetative canopy cover, substrate size class, and other variables. Multivariate statistical analysis was then used to test for relationships between specific grazing practices (*e.g.*, stocking rate), stream characteristics (*e.g.*, substrate), and stream macroinvertebrate indices (*e.g.*, richness).

Table 1 reports physical characteristics of study stream reaches. Rosgen Category C and E streams associated with grazed mountain meadows (3,000 to 9,000 ft elevation) were targeted for this project, given that we have previously found these types of stream reaches to be most sensitive to grazing management. Stream reaches were selected from the Sierra Nevada Range of central California, the Southern Cascades of northern California, and the arid plateaus of northeastern California (Table 1). Stream reaches were selected to span the relative range of riparian health found across these systems (*e.g.*, unhealthy to healthy). All stream data and macroinvertebrate samples were collected within a 100 m stream reach located within each meadow associated stream system enrolled in the study. Aquatic habitat health score (EPA HAFDS) for the study reaches were: minimum=11.0, mean=16.3, median=16.9, and maximum=19.0. A score of 11 indicates sub-optimal health, while a score of 19 indicates excellent health. Following the BLM Proper Functioning Condition protocol, 53% of stream reaches were hydrologically functional, while 47% were at risk of becoming non-functional. Stream gradient on all study streams was < 3%. Stream vegetation was predominantly herbaceous species such as sedge (*Carex* spp.), rush (*Juncas* spp.), and grasses. Woody riparian plants were dominated by willow species (*Salix* spp.), but stream canopy cover was below 10% on all reaches. As Table 1 reports, mean mid-summer (Jun-Aug) solar radiation reaching the stream surface ranged averaged 71 to 77%. This value accounts for solar exposure due to time of year – latitude, stream aspect, vegetative canopy, streambank and topographic shade, and other factors effecting solar exposure.

Macroinvertebrate samples were collected with a D-ring kick net sampler fitted with a 500 micron mesh collection bag. In order to integrate variability across the channel, each sample represents a composite of 3 sub-samples collected across a transect perpendicular to streamflow. Transects were located at riffle areas of each stream reach. Each sub-sample was collected during a standardized 3 minute collection effort over a 0.33 $m^2$ collection area (total collection area of 1.0 $m^2$). Collections were immediately stabilized with 95% ethanol. Two samples were collected from each study stream reach. Samples were analyzed to family, genus, and in some cases species at the Utah State University Macroinvertebrate Laboratory, Logan, UT. Standard indicies describing macroinvertebrate assemblage characteristics were calculated from raw taxa data, and were utilized in the statistical analysis associated with Objective 1. Macroinvertebrate sample collection commenced in early June at low elevation sites (3000 to 5000 ft) and ended in late August at high elevation sites (7,500 to 9,000 ft). Substrate size class (cobble, gravel, fines), % available solar radiation reaching stream water surface, and embeddedness (%) of streambed substrates were measured along each macroinvertebrate sampling transect. Sediment deposition, streambank stability, and nutrient enrichment were quantified via EPA HAFDS and NRCS SVA applied to the entire 100 m stream reach.

Grazing pressure and livestock distribution control practices were quantified for each study site during project number SW01-044. These data were compiled via an on-site, one-on-one survey conducted with the site grazing manager and key metrics are reported in Table 2. Grazing metrics used in statistical analysis were: stocking rate for the entire allotment/pasture containing the study meadow (AUM/ac/yr), use of herding and/or off-stream attractants (*e.g.*, supplemental feed, drinking water tanks) to control timing and intensity of livestock use of study meadow (yes or no), and days each year spent herding and/or establishing/maintaining off-stream livestock attractants to control timing and intensity of livestock use of study meadow.

Macroinvertebrate taxa and indice data are inherently count data (*e.g.*, number of Ephemeroptera organisms in the sample). We used a count-based analysis strategy, negative binomial regression (Intercooled Stata v.8.0), to test for relationships between 21 macroinvertebrate indices, 3 grazing metrics, and stream substrate size class. Substrate size class was treated as a continuous variable to conserve degrees of freedom (3=cobble, 4=gravel, 5=fines). Twenty-one individual regression analysis were conducted, one for each macroinvertebrate indice tested. Stream reach identity was used as a cluster variable in the analysis to account for spatial co-dependence between the 2 samples collected at each study reach. Analysis of taxa abundance based indices (*e.g.*, number of Ephemeroptera organisms in sample) were conducted with total number of organisms in sample as the exposure variable to account for uneven total organisms between samples, thus allowing reporting on a percentage basis. A backward stepping approach was used with all grazing metrics, streambed substrate size class, elevation (ft), and Julian Day of sample collection in the initial full model. Julian Day was introduced to account for possible variation due to timing of sample collection relative to seasonal dynamics of macroinvertebrate assemblage development. A P-Value<0.10 was set for inclusion into the final model.

**Objective 2**

In addition to the 58 grazed stream reaches used for Objective 1, we also enrolled 24 Rosgen Category C and E streams associated with non-grazed mountain meadows (3,000 to 9,000 ft elevation) for Objective 2. Eligible meadows had to be non-grazed for at least 10 years, and non-grazed stream reaches had to have optimal aquatic habitat health scores (EPA HAFDS score 16-20) and proper hydrologic function (BLM PFC). It was surprisingly difficult to find non-grazed meadows within the elevation range common to grazed mountain meadows in the region (3,000 to 9,000 ft). Non-grazed meadows are relatively common at elevations above 10,000 ft, but we did not consider such systems comparable with the 58 grazed sites enrolled in the study.

Table 1 reports physical characteristics of non-grazed study stream reaches. Non-grazed sites were selected from the pool available to us from livestock exclosures and vacant allotments on public lands (Sierra Nevada Range and Southern Cascades), as well as from Yosemite (Sierra Nevada Range) and Lassen Volcanic (Southern Cascades) National Parks. Stream vegetation was predominantly herbaceous species such as sedge (*Carex* spp.), rush (*Juncas* spp.), and grasses. Woody riparian plants were dominated by willow species (*Salix* spp.), but stream canopy cover was below 15% on all reaches. As Table 1 reports, mean mid-summer (Jun-Aug) solar radiation reaching the stream surface ranged averaged 67 to 75%. All macroinvertebrate and stream data were collected and analyzed in the same manner described for Objective 1.

Negative binomial regression (Intercooled Stata 8) was used to first test for differences between grazed and non-grazed sites for 21 common macroinvertabrate indices. To examine the inherent importance of elevation and substrate type on macroinvertebrate indices for grazed sites we used negative binomial regression to evaluate relationships between 3 key macroinvertebrate indices (no. total taxa, no. EPT taxa, no. intolerant taxa), elevation, and substrate. Substrate size class was treated as a continuous variable to conserve degrees of freedom (3=cobble, 4=gravel, 5=fines). Three individual regression analysis were conducted, one for each macroinvertebrate indice tested. Stream reach identity was used as a cluster variable in the analysis to account for spatial co-dependence between the 2 samples collected at each study reach. A backward stepping approach was used with streambed substrate size class, elevation (ft), and Julian Day of sample collection in the initial full model. Julian Day was introduced to account for possible variation due to timing of sample collection relative to seasonal dynamics of macroinvertebrate assemblages. A P-Value<0.10 was set for inclusion into the final model. Results of these analysis were combined with graphical display of raw data and products of analysis in Objective 1 to illustrate the importance of integrating site characteristics in the establishment of riparian health targets for grazed stream reaches.

**Results and Discussion**

Table 3 compares mean values for 25 common macroinvertebrate indices for grazed and non-grazed meadow associated stream reaches enrolled in this study. Table 3 also reports the results (P-Values) of negative binomial regression statistical tests for differences in the mean of each indice for grazed and non-grazed stream reaches. Figures 1 and 2 are boxplots which further illustrate differences in these 25 macroinvertebrate indices for grazed and non-grazed stream reaches.

Thirteen of the 25 indices (52%) reported in Table 3 were statistically different at P<0.10, and 9 (36%) were statistically different at P<0.05. Grazed stream reaches had lower numbers of several taxa commonly considered intolerant to pollution and habitat degradation. The largest differences between grazed and non-grazed stream reaches were for the indices of % EPT (Ephemeroptera + Plecoptera + Tricoptera), number of and % Ephemeroptera taxa, number of Plecoptera, number of and % intolerant taxa (to pollution and habitat degradation), and % of sample composed of dominant taxa (% dominant taxa). On average, grazed stream reaches had values 15 to 50% lower for indices considered sensitive to pollution and habitat degradation (*e.g.*, total taxa, EPT, intolerant taxa). Grazed stream reaches had values 20 to 35% higher for indices considered tolerant of pollution and habitat degradation (*e.g.*, % dominant taxa, % Chironomidae taxa).

Figure 3 plots overall mean (grazed and non-grazed reaches combined) values for 15 key indices for the 3 substrate size classes encountered in this study (cobble, gravel, fines). There were evident relationships between substrate size and macroinvertebrate indices. In general, sensitive (intolerant) taxa indices decreased as substrate size decreased from cobble to gravel to sand. The inverse was evident for tolerant (insensitive) taxa indices. Table 1 reports that the percent of sites with fine substrate (sands and silts) was 13% higher for grazed reaches, and that cobble substrate was 12% lower for grazed sites compared to non-grazed sites. Streambed substrate is an inherent characteristic of a stream reach, and is relatively impervious to short term management (*e.g.*, 10 year grazing history). Cobble substrate provides a large quantity of diverse macroinvertebrate habitat, compared to gravel and fine substrate stream reaches. We have previously found that substrate size will bias riparian health assessments which are based upon relative complexity and availability of aquatic habitat (Ward et al. 2003), and the data in Figure 3 further confirm this finding.

On average, grazed stream reaches had relatively higher insensitive and lower sensitive taxa. This is not surprising given that the literature and case study history is clear that at some level livestock grazing will reduce riparian health, logically leading to a shift in macroinvertebrate community composition. What is important to note (Figures 1 and 2) is that there is overlap between the grazed and non-grazed data, many grazed streams are well within the confidence intervals of mean values for non-grazed streams. The interesting question, and crux of this project, is how does the management of livestock on grazed streams with relatively intolerant assemblages differ from those with relatively tolerant assemblages.

A major result, and success, of this project is reported in Table 4 and Figures 4-6. These results are confirmation of the results of project SW01-044, and document the specific achievement of Objective 1 of this project. We were able to statistically correlate ($P<0.10$) livestock distribution effort (days each year spent herding and/or establishing/maintaining off-stream livestock attractants to control timing and intensity of livestock use of study meadow) with 11 macroinvertebrate indices, indices which were significantly different between grazed and non-grazed stream reaches (Table 3). Table 4 reports the negative binomial regression models defining these correlations. Substrate was a significant factor in 9 of these models, and confirms data presented in Figure 3. Livestock distribution effort on grazed study meadows and associated stream reaches ranged from 0 to 41 days per year, with a mean of 8.9 and a median of 5.0 (Table 2). Positive correlations were found between livestock distribution effort and all sensitive (intolerant) macroinvertebrate indices, while negative correlations were found for all insensitive (tolerant) indices. For instance, increasing livestock distribution effort from 0 to 40 days resulted in a mean increase of number of EPT taxa from 6.6 to 14.7 for fine substrate streams, and from 8.8 to 19.6 for cobble substrate streams (Figure 4). Alternatively, percent of dominant taxa decreased from 43.3 to 25.7% over this same range of livestock distribution effort (Figure 5). Elevation and Julian Day were not significant predictors in any models ($P>0.10$).

When considered collectively with results from project SW01-044, these results clearly illustrate that active, consistent implementation of common livestock distribution tools (*e.g.*, herding, salting, water tanks) are associated with increased riparian health. The meadows and stream reaches enrolled in this study are contained within large pastures and allotments, typical of mountain grazing lands in California. Mean pasture/allotment size was 18,000 ac, with a median of 3,000 ac (Table 2). In these large, topographically diverse systems achieving desired grazing utilization levels across the system is a major livestock distribution management challenge. It is well known that livestock will concentrate in areas of forage and water (*e.g.*, meadows with associated stream reaches) and that modifying this tendency is a major management challenge. The simple act of implementing a distribution practice (yes v. no) was not significantly correlated to macroinvertebrate indices, or to HAFDS in project SW01-044. Rather, it is the amount of consistent, annual effort exerted by the manager on-the-ground to achieve the objective of the distribution practice. These results are extremely intuitive and credible with livestock managers and the general public.

Table 5 and Figures 7 and 8 report results which achieve objective 2 of this project. Table 5 reports the results of negative binomial regression analysis correlating streambed substrate size class to 3 key macroinvertebrate indices (total taxa, number of EPT taxa, and number of intolerant taxa) for non-grazed stream reaches. All three indices were significantly lower on grazed compared to non-grazed stream reaches (sensitive) and were positively responsive to increased livestock distribution effort (Tables 3 and 4, Figure 4). All three indices significantly declined as substrate size decreased from cobble to fines ($P<0.001$). Figure 7 plots mean and predicted values for these indices for cobble, gravel, and fine substrate non-grazed stream reaches. Mean values for total taxa for cobble, gravel, and fine substrates under no grazing was 27.2, 20.1, and 15.4, respectively. Mean values for EPT taxa for cobble, gravel, and fine substrates under no grazing was 17.4, 10.5, and 6.3, respectively. Mean values for intolerant taxa for cobble, gravel, and fine substrates under no grazing was 11.0, 5.8, 3.1, respectively. Elevation and Julian Day were not significant predictors in any models ($P>0.10$). It appears that substrate type is a major determinant of the potential macroinvertebrate assemblage that a given stream reach can support in the absence of livestock grazing, and should be considered in setting riparian health targets based upon macroinvertbrate indices or aquatic habitat health assessments (Ward et al. 2003). Figure 8 illustrates this point for total taxa, EPT taxa, and intolerant taxa, indicating the expected level of livestock distribution required on average to achieve mean non-grazed values for these indices on grazed streams dependent upon substrate type. The important point of this figure is that the expected value for each indice is variable by substrate, and is in all cases achievable with appropriate grazing management effort.

**Impact of Results/Outcomes**

These results are unique in that they are derived from a simultaneous examination of on-the-ground grazing management and a gold standard measure of riparian health conducted at the management scale. These results clearly demonstrate that common grazing management tools can be implemented to improve and maintain riparian health. The scientific literature is full of studies which illustrate the potential negative impacts of livestock grazing in riparian areas, these results provide a unique verification that these negative impacts can be overcome with technically simple, low infrastructure dependent techniques. The key is for the manager to exert consistent, adequate effort to control the timing and intensity of livestock use on meadow associated stream reaches. The project is also unique in that it illustrates the power of cooperation between managers and applied scientists to conduct research at the management scale. The success of this project, and what we have learned from it, has allowed us to develop similar projects examining relationships between livestock grazing and the endangered Yosemite Toad, as well as with aspen stand restoration in the Sierra Nevada.

**Economic Analysis**

These results can be easily translated into direct and indirect cost by an individual rancher. The primary costs associated with recommended livestock distribution efforts are labor related. Annual operating costs associated with activities such herding (*e.g.*, hiring a rider) and establishing and maintaining off-stream livestock attractants (*e.g.*, previously developed water sources, salt) include salary, liability insurance, saddle/pack stock feed and veterinary care, salt/mineral, vehicle/transportation costs, and miscellaneous supplies and replacement parts (*e.g.*, water control floats, salt). If off-stream water sources are a feasible option (*e.g.*, available ground water), there can be significant initial infrastructure development costs. These costs can often be cost-shared with federal and state funding sources (*e.g.*, NRCS EQIP, Clean Water Act Sec. 319).

**Publications and Outreach**

The information developed from this project has been, and will continue to be aggressively extended to ranchers, state and federal land management agencies, state and federal technical assistance agencies, state and federal regulatory agencies, and the interested public. These results have been presented at California Cattlemen's Association and California Farm Bureau Federation annual conferences, to formal continuing education conferences of the U.S. Forest Service, the U.S. Natural Resources Conservation Service, the Society for Range Management, and other such organizations. Results have been incorporated into the UCCE-NRCS Ranch Water Quality Planning Short Course (George et al. 2002a and b). This course has lead to the development of over 400 ranch water quality plans, covering over 1.2 million acres of private rangelands in California.

The results of this project will be submitted to a leading natural resources journal for publication. This is a very data rich project, with extensive and defensible statistical analysis. We also plan to combine the results of this project with those of project SW01-044 and develop a synthesis articles written for agency and natural resources professionals in applied outlets such as *Rangelands* or *California Agriculture.*

**Farmer Adoption**

Producer involvement in, and support for, this project has been stellar. Given the conflict that exists over riparian grazing, the fact that so many producers have been willing provide us access to property and management information as well as to share resulting data illustrates the livestock industry's contribution and investment in these results. As a result of the direct involvement of producers in the development of these results, the results have significant credibility with industry. The raw simplicity and intuitive nature of the recommendations of this project also greatly facilitate adoption of results. The project has also facilitated on-the-ground interaction between producers, UCCE, USFS, BLM, NRCS, and other staff, thus providing numerous valuable and informal two-way education opportunities.

Overall, 35 ranch families participated in this project. The allotment and pastures enrolled in the study represent ~1 ,000,000 acres of mountain grazing land, and ~11,000 head of range beef cattle. The results of this project have direct application to the 40 million acres of rangeland within California. The primary recommendation from this project is that enhanced riparian health in grazed systems can be achieved by traditional livestock management practices, particularly livestock distribution efforts. As with any management challenge, the key to success is the consistent exertion of management effort required to implement these practices successfully. Additional recommendations are detailed in the final report for project SW01-044.

**Areas Needing More Study**

This project serves as proof on concept that management solutions can be developed from management scale, cooperative research between scientists and managers. There are many topics (*e.g.*, endangered species, water quality) at the interface of agriculture and the environment that occur at a temporal and spatial scale ill-suited to plot-based research. We think that the scientific and management community would be well served to investigate the opportunity to integrate cross-sectional, longitudinal surveys with traditional plot-based research to address some of these topics.

With specific regard to meadow streams and grazing, there is need for additional study of these relationships with more specific quantification of annual grazing pressure on individual meadows (*e.g.*, utilization). Stocking rate data at the allotment or large pasture scale is not precise enough to clearly define meadow to meadow variation in grazing utilization.

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**Table 1. Description of physical characteristics of the meadow associated Rosgen[1] category C and E stream reaches surveyed in this study.**

| | Min. | Mean | Median | Max. |
|---|---|---|---|---|
| **Grazed** | | | | |
| Latitude (d.d°) | 37.0445 | 39.1086 | 39.4947 | 41.8915 |
| Longitude (d.d°) | 119.1167 | 120.1516 | 120.1749 | 121.5565 |
| Elevation (ft) | 3364 | 5961 | 5952 | 8562 |
| Solar Radiation (%)[1] | | | | |
| May | 28 | 74 | 76 | 99 |
| June | 27 | 77 | 80 | 100 |
| July | 27 | 76 | 78 | 100 |
| August | 21 | 71 | 74 | 99 |
| September | 15 | 65 | 66 | 99 |
| **Non-Grazed** | | | | |
| Latitude (d.d°) | 37.028 | 39.751 | 40.054 | 41.256 |
| Longitude (d.d°) | 119.122 | 120.829 | 120.944 | 121.991 |
| Elevation (ft) | 3549 | 6178 | 6200 | 9255 |
| Solar Radiation (%)[2] | | | | |
| May | 44 | 72 | 77 | 99 |
| June | 47 | 75 | 79 | 100 |
| July | 46 | 73 | 78 | 100 |
| August | 30 | 67 | 61 | 100 |
| September | 20 | 60 | 54 | 100 |
| **Streambed Substrate** | **Silt** | **Sand** | **Gravel** | **Cobble** |
| Grazed (% sites)[3] | 37 | 16 | 27 | 20 |
| Non-grazed (% sites)[3] | 21 | 19 | 28 | 32 |

[1] Rosgen, D. 1996.
[2] Percent of available solar radiation arriving at stream water surface per month, measured with a solar pathfinder.
[3] Percent of sites enrolled in the study with silt, sand, gravel, or cobble streambed substrate.

**Table 2. Description of livestock management practices and activity on the grazed meadow associated Rosgen[1] category C and E stream reaches surveyed in this study.**

| | Min. | Mean | Median | Max. | S.E.[2] |
|---|---|---|---|---|---|
| **Stocking Variables** | | | | | |
| Stocking rate (AUM/acre/yr)[3] | 0.005 | 0.48 | 0.05 | 5.1 | 0.1 |
| Management unit area (ac) | 100 | 18,313 | 3,000 | 100,000 | 2,708 |
| Herd size (AU)[4] | 10 | 167 | 150 | 670 | 13 |
| Days grazed per year (d/yr) | 2 | 64 | 80 | 155 | 3.7 |
| Grazing events per year | 1 | 1.2 | 1 | 6 | 0.07 |
| Days per grazing event (d) | 2 | 63 | 80 | 155 | 3.8 |
| Days rest between grazing events each year (d/yr) | 30 | 275 | 285 | 363 | 7 |
| **Livestock Distribution**[5] | | | | | |
| Days herding livestock per year (person days/yr) | 0.0 | 10.2 | 6.0 | 30.0 | 1.0 |
| Days maintaining off-stream livestock attractants per year (person days/yr) | 0.0 | 3.2 | 1.5 | 33.5 | 0.5 |
| Total days herding livestock and maintaining off-stream livestock attractants (person days/yr) | 0.0 | 8.9 | 5.0 | 41.0 | 0.9 |

[1] Rosgen, D. 1996.
[2] One standard error of the mean.
[3] AUM = animal unit month. One animal unit month is equivalent to the amount of forage demand (lb dry wt) that a single animal unit consumes in a month (~900 lb dry wt).
[4] AU = animal unit. One animal unit is the equivalent of a single 1000 lb beef cow, with or without a nursing calf.
[5] Activities conducted specifically to control livestock distribution through space and time within the management unit, with the specific goal of achieving desired grazing pressure and utilization on meadow associated with study stream reach. Reported in units of effort (person days/year).

**Table 3. Mean values for macroinvertebrate indices at grazed and non-grazed meadow associated Rosgen[1] category C and E streams. Values in parenthesis are 1 standard error (s.e.) of the mean. P-Value represents the comparison of mean grazed and non-grazed, based upon negative binomial regression analysis.**

| Indice | Grazed (s.e.) | Non-Grazed (s.e.) | P-Value |
|---|---|---|---|
| **Richness** | | | |
| No. Taxa | 18.65 (0.67) | 22.34 (1.07) | 0.031 |
| No. Ephemeroptera Taxa | 3.93 (0.25) | 6.47 (0.38) | <0.001 |
| No. Plecoptera Taxa | 2.08 (0.178) | 3.91 (0.29) | <0.001 |
| No. Trichoptera Taxa | 3.18 (0.22) | 3.30 (0.43) | 0.872 |
| **Assemblage Composition** | | | |
| % EPT | 36.10 (2.05) | 61.80 (3.03) | <0.001 |
| % Ephemeroptera | 19.97 (1.56) | 41.92 (2.99) | <0.001 |
| % Plecoptera | 8.66 (1.03) | 12.00 (1.69) | 0.174 |
| % Trichoptera | 7.46 (0.84) | 7.86 (1.54) | 0.833 |
| % Diptera | 46.18 (2.37) | 30.00 (2.84) | 0.003 |
| % Chironomidae | 28.20 (1.83) | 20.41 (2.32) | 0.036 |
| % Elmidae | 9.60 (1.30) | 4.23 (1.23) | 0.093 |
| % Coleoptera | 11.60 (1.40) | 4.35 (1.24) | 0.038 |
| % Megaoptera | 0.16 (0.10) | 0.08 (0.08) | 0.239 |
| % Olicoptera | 1.00 (0.25) | 1.10 (0.65) | 0.899 |
| **Pollution Tolerance** | | | |
| % Dominant Taxa | 38.39 (1.77) | 30.37 (1.78) | 0.019 |
| % Intolerant (0,1,2) | 16.87 (1.51) | 29.44 (2.59) | <0.001 |
| % Tolerant (8,9,10) | 2.67 (0.67) | 0.69 (0.35) | 0.147 |
| No. Intolerant Taxa | 5.01 (0.37) | 8.12 (0.59) | <0.001 |
| No. Tolerant Taxa | 0.53 (0.07) | 0.23 (0.09) | 0.193 |
| No. Clinger Taxa | 7.66 (0.47) | 9.83 (0.79) | 0.103 |
| No. Long Lived Taxa (>2 yr) | 3.45 (0.22) | 2.40 (0.32) | 0.102 |
| **Functional Feeding Group** | | | |
| % Shredders | 5.44 (0.57) | 5.74 (1.27) | 0.395 |
| % Scrappers | 7.47 (1.04) | 17.47 (2.22) | 0.010 |
| % Collectors | 66.86 (1.79) | 60.40 (3.06) | 0.197 |
| % Predators | 10.89 (0.98) | 10.16 (1.28) | 0.543 |

[1] Rosgen, D. 1996.

**Table 4. Negative binomial regression analysis of associations between macroinvertebrate indices, livestock distribution effort (person days/yr) and streambed substrate (cobble=3, gravel=4, fines=5) for Rosgen[1] category C and E stream reaches surveyed in this study.**

| Macroinvertebrate Indice | Factor | Coefficient | S.E.[2] | P-Value[3] |
|---|---|---|---|---|
| No. EPT Taxa | Live. Dist. Effort | 0.020 | 0.008 | 0.012 |
| | Substrate | -0.146 | 0.079 | 0.067 |
| | Intercept | 2.615 | 0.341 | <0.001 |
| No. Ephemeroptera Taxa | Live. Dist. Effort | 0.017 | 0.008 | 0.051 |
| | Substrate | -- | -- | -- |
| | Intercept | 1.190 | 0.137 | <0.001 |
| No. Plecoptera Taxa | Live. Dist. Effort | 0.029 | 0.011 | 0.009 |
| | Substrate | -0.266 | 0.133 | 0.045 |
| | Intercept | 1.533 | 0.628 | 0.015 |
| No. Tricoptera Taxa | Live. Dist. Effort | 0.015 | 0.008 | 0.073 |
| | Substrate | -- | -- | -- |
| | Intercept | 0.995 | 0.128 | <0.001 |
| No. Total Taxa | Live. Dist. Effort | 0.011 | 0.004 | 0.009 |
| | Substrate | -0.098 | 0.043 | 0.023 |
| | Intercept | 3.227 | 0.182 | <0.001 |
| No. Coleoptera Taxa | Live. Dist. Effort | 0.017 | 0.007 | 0.017 |
| | Substrate | -0.158 | 0.096 | 0.095 |
| | Intercept | 1.375 | 0.424 | 0.001 |
| No. Intolerant Taxa | Live. Dist. Effort | 0.025 | 0.009 | 0.007 |
| | Substrate | -0.227 | 0.097 | 0.020 |
| | Intercept | 2.291 | 0.404 | <0.001 |
| % Intolerant Taxa[4] | Live. Dist. Effort | 0.016 | 0.009 | 0.060 |
| | Substrate | -0.232 | 0.122 | 0.058 |
| | Intercept | -0.991 | 0.444 | 0.026 |
| % Dominant[4] | Live. Dist. Effort | -0.013 | 0.006 | 0.027 |
| | Substrate | -- | -- | -- |
| | Intercept | -0.837 | 0.074 | <0.001 |
| % Diptera[4] | Live. Dist. Effort | -0.009 | 0.005 | 0.096 |
| | Substrate | 0.109 | 0.056 | 0.051 |
| | Intercept | -1.153 | 0.225 | <0.001 |
| % Chironomidae[4] | Live. Dist. Effort | -0.011 | 0.006 | 0.091 |
| | Substrate | 0.087 | 0.052 | 0.097 |
| | Intercept | -1.545 | 0.253 | <0.001 |

[1] Rosgen, D. 1996.
[2] Standard error of term (livestock distribution effort, streambed substrate, intercept) of each negative binomial regression model developed for each macroinvertebrate indice.
[3] P-Value for each model term, P<0.10 required for inclusion into final model, n.s. indicates P>0.10.
[4] Percent of total assemblage abundance composed of this taxa, calculated as taxa abundance/total sample abundance.

**Table 5. Negative binomial regression analysis of associations between macroinvertebrate indices and streambed substrate (cobble=3, gravel=4, fines=5) for non-grazed Rosgen[1] category C and E stream reaches surveyed in this study.**

| Macroinvertebrate Indice | Factor | Coefficient | S.E.[2] | P-Value[3] |
|---|---|---|---|---|
| No. Total Taxa | Substrate | -0.265 | 0.058 | <0.001 |
| | Intercept | 4.062 | 0.212 | <0.001 |
| No. EPT Taxa | Substrate | -0.505 | 0.096 | <0.001 |
| | Intercept | 4.373 | 0.343 | <0.001 |
| No. Intolerant Taxa | Substrate | -0.632 | 0.099 | <0.001 |
| | Intercept | 4.294 | 0.367 | <0.001 |

[1] Rosgen, D. 1996.
[2] Standard error of term (streambed substrate, intercept) of each negative binomial regression model developed for each macroinvertebrate indice.
[3] P-Value for each model term.

Figure 1. Box plot of stream macroinvertebrate indices from grazed and non-grazed Rosgen category C and E meadow associated stream reaches.

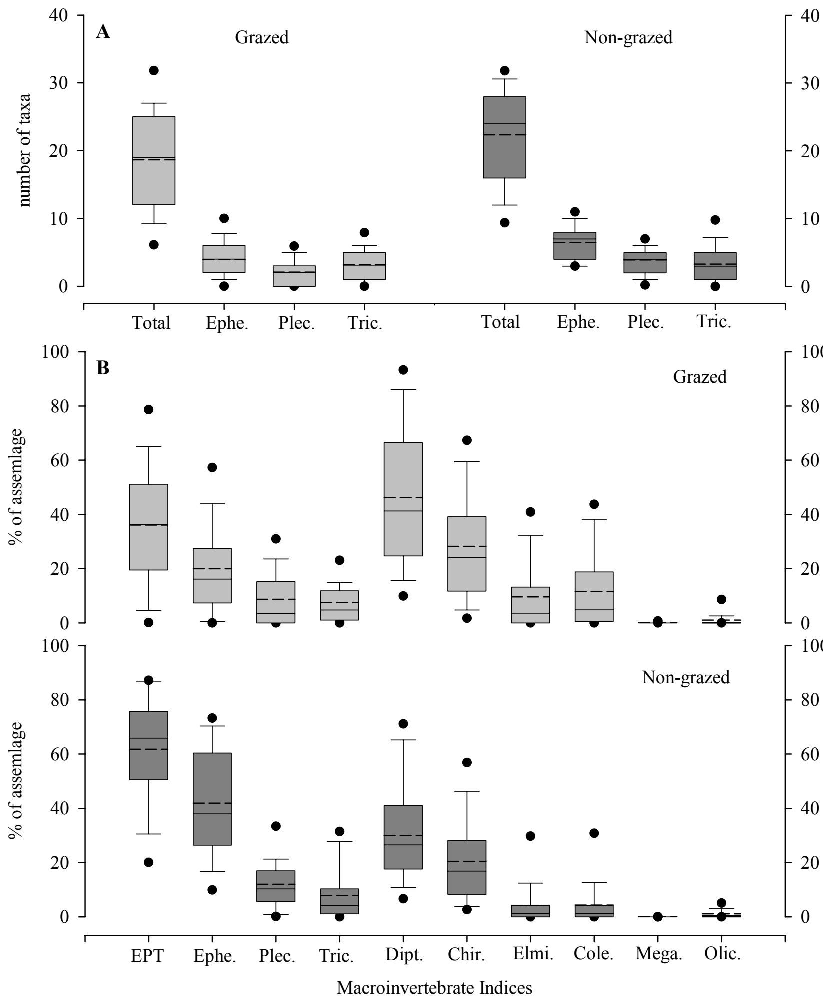

Figure 2. Box plot of stream macroinvertebrate indices from grazed and non-grazed Rosgen category C and E meadow associated stream reaches.

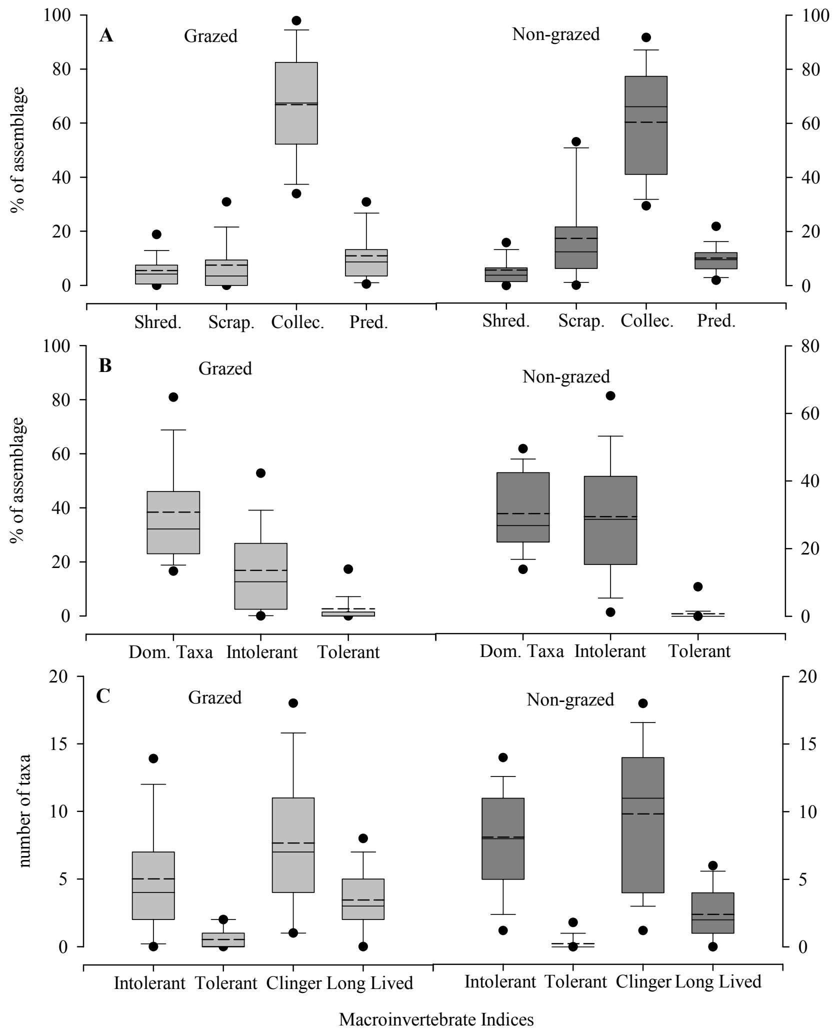

Figure 3. Overall mean (grazed and non-grazed reaches combined) values for 15 key indices for the 3 substrate size classes encountered in this study (cobble, gravel, fines).

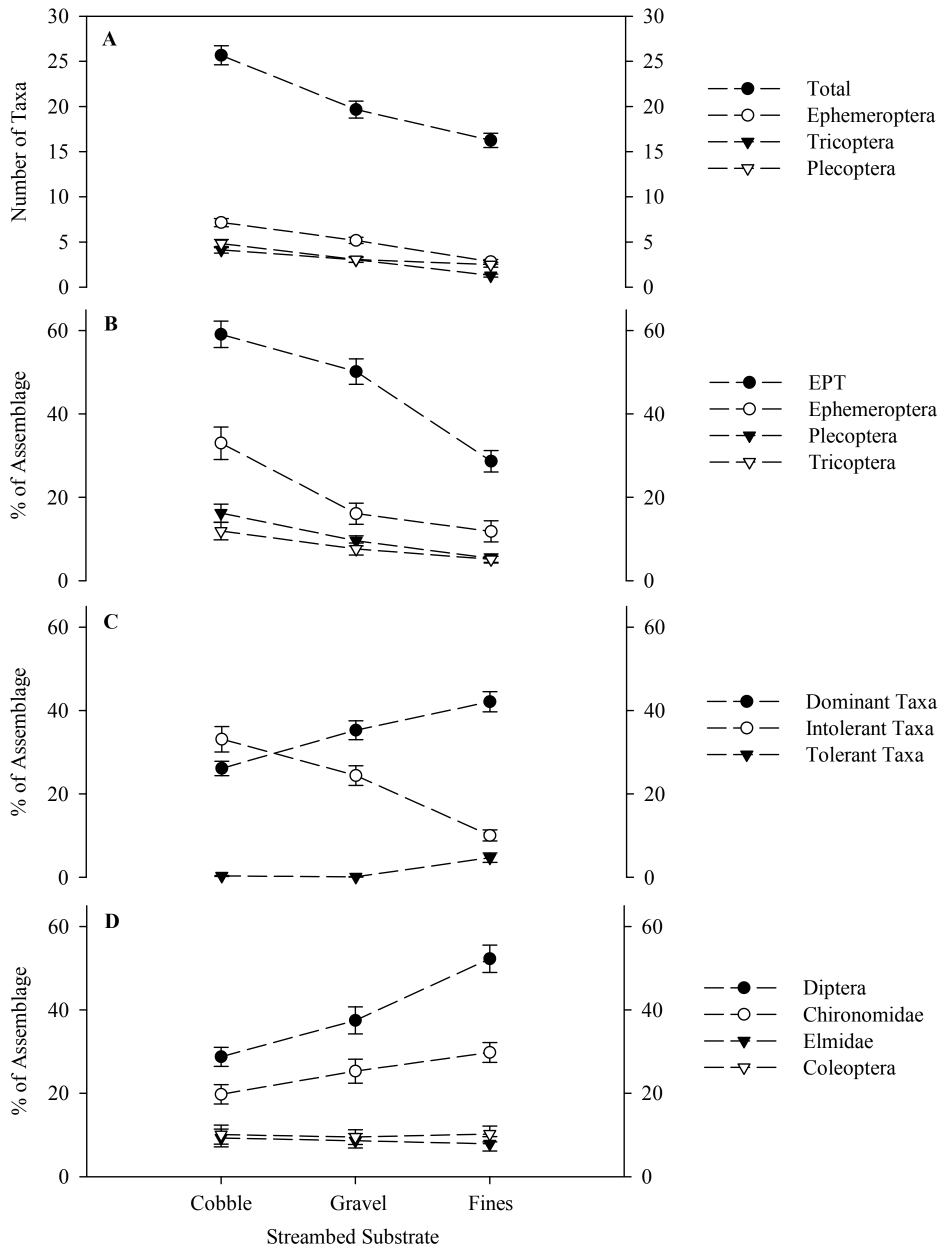

Figure 4. Negative binomial regression predicted relationships between livestock distribution effort, streambed substrate, and macroinvertebrate indices.

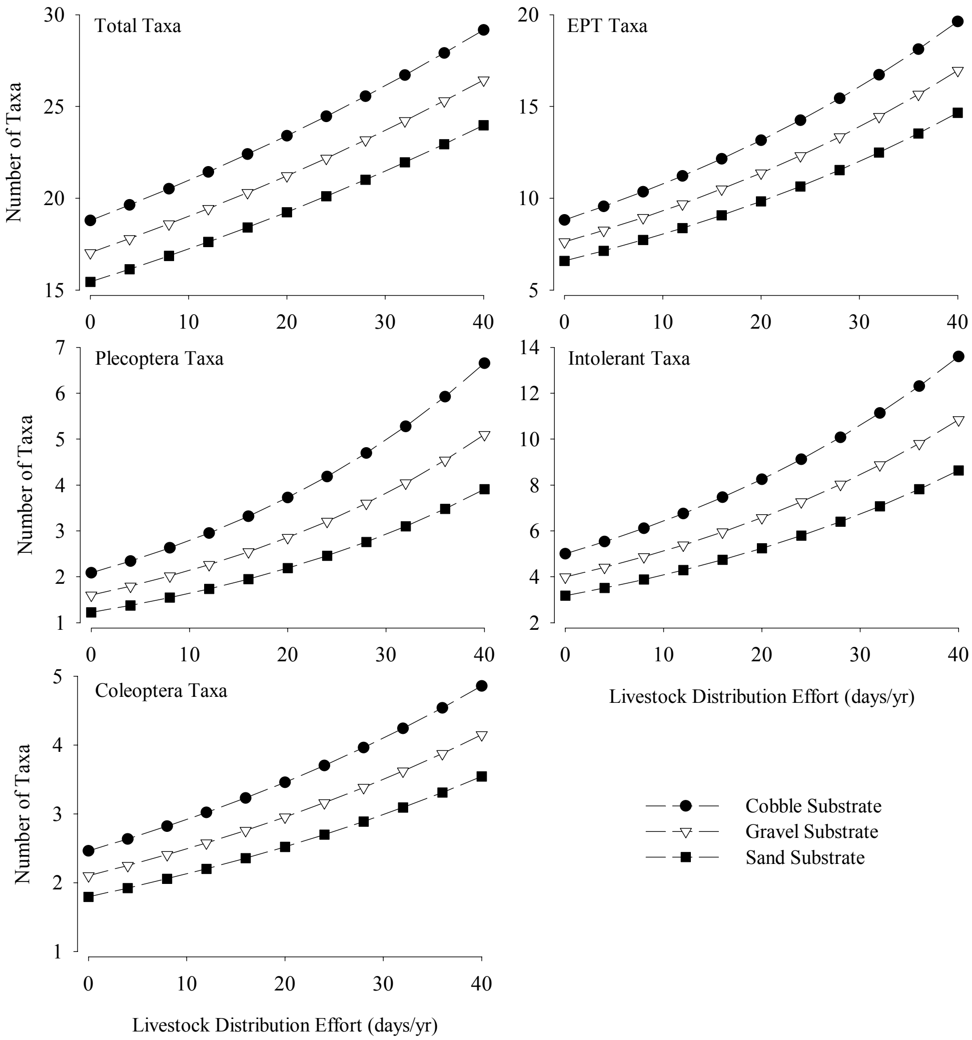

Figure 5. Negative binomial regression predicted relationships between livestock distribution effort, streambed substrate, and macroinvertebrate indices.

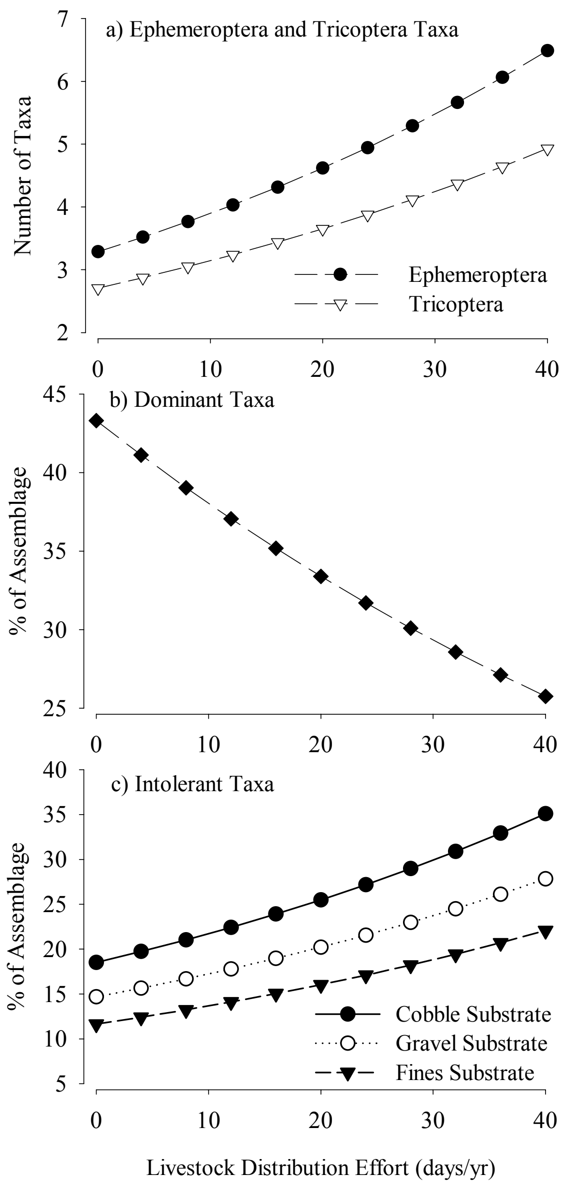

Figure 6. Negative binomial regression predicted relationships between livestock distribution effort, streambed substrate, and macroinvertebrate indices.

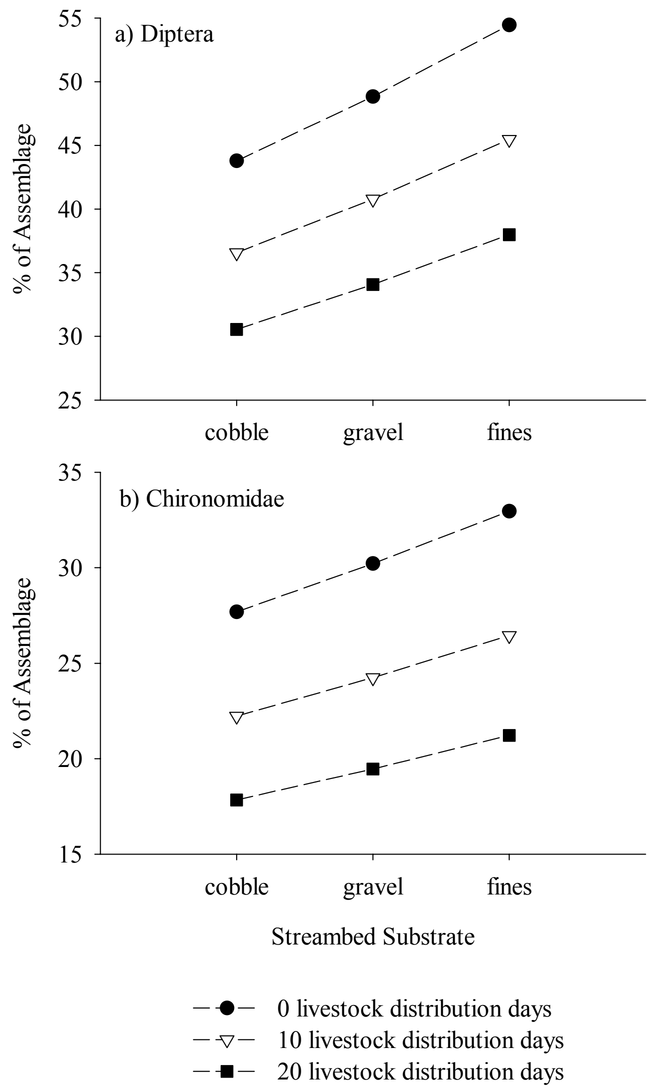

Figure 7. Negative binomial regression prediction (lines) of relationships between macroinvetrebrate indices (symbol = mean and 1 standard error) and streambed substrate.

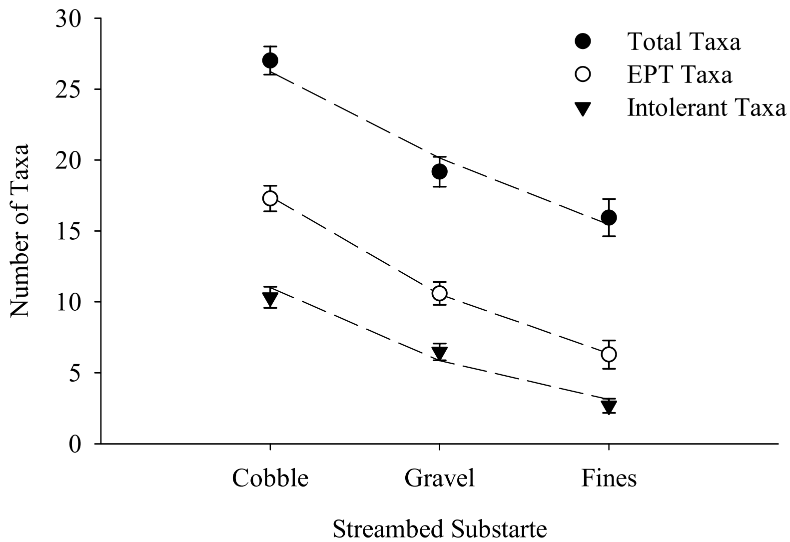

Figure 6. Negative binomial regression predicted relationships between livestock distribution effort, streambed substrate and macroinvertebrate indices for grazed stream reaches, and non-grazed means for these indices by substrate size class.