Bacterial Water Quality Responses to Four Grazing Strategies—Comparisons with Oregon Standards

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ABSTRACT

Concentrations of fecal coliform (FC) and fecal streptococcus (FS) were measured weekly during summer 1984 in streamwater of 13 wildland watersheds managed under four range management strategies. The strategies were (A) no grazing; (B) grazing without management for livestock distribution; (C) grazing with management for livestock distribution; and (D) grazing with management for livestock distribution and with cultural practices to increase forage. Counts of FC were compared to Oregon water quality standards. Data for FS were used for determining the FC/FS ratio to assess origin of FC organisms. Counts of FC were significantly lower under strategies A and C than under strategy D, but no significant differences were apparent among other strategy comparisons. Two strategy D watersheds violated the Oregon water quality 30-d $\log_{10}$ standard of no more than 2×10^3 FC L^{-1} (200 FC•100 mL^{-1}). One watershed was in violation for most of the sampling period. Ratios of FC to FS indicated that wildlife was the major source of FC bacteria in strategies A, B, and C watersheds. Cattle were the primary source of FC bacteria on strategy D watersheds.

Several studies have examined the effect of livestock grazing on bacteria in water (Coltharp and Darling, 1973; Doran and Linn, 1979; Gary et al., 1983; Kunkle and Meiman, 1968; Skinner et al., 1974). These authors agree that cattle (*Bos taurus*) noticeably increase fecal coliform (FC) counts—some counts show up to 10-fold increases over background counts. Tiedemann et al. (1987) found significant increases in streamwater FC counts with increased intensity of grazing management. The largest differences in FC concentrations (10X) occurred between control watersheds (no grazing) and watersheds managed for maximum livestock production. Counts of FC in excess of 2×10^4 L^{-1} (>2000•100 mL^{-1}) were observed by Tiedemann et al. (1987) when intensive management was used to maximize livestock production. Results suggested that Oregon water quality standards may have been violated, but sampling frequency was not adequate for comparison with Oregon standards. Bacterial counts were not compared to Oregon water quality standards in any of the studies we reviewed. In most instances, sampling was not of the proper frequency to allow the authors to make such comparisons. Also, some studies were conducted before State standards were established (about 5 to 10 yr ago). Oregon bacterial water quality standards for streamwater specify that the $\log_{10}$ mean FC concentration cannot exceed 2×10^3 L^{-1} (200•100 mL^{-1}) based on a minimum of five samples during a 30-d period (State of Oregon, 1984). Also, no more than 10% of the samples in a 30-d period can exceed 4×10^3 L^{-1} (400•100 mL^{-1}). The primary objective of this study was to determine the responses of FC indicator bacterial concentrations to increasing intensity of grazing management and to relate findings to Oregon standards.

Besides FC levels being elevated when livestock are pre-

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sent, they may remain high after cattle are removed (Jawson et al., 1982; Stephenson and Street, 1978; Tiedemann et al., 1987). Some viable FC bacteria remain in animal wastes for up to 1 yr (Clemm, 1977). Fecal coliforms may survive up to 2 wk in soil (Van Donsel et al., 1967) and up to 6 wk in surface waters (Clemm, 1977). A potential source of FC bacteria to streamwater, therefore, exists after the animals leave the watershed. The second objective of this study was to verify results of our longer-term study (Tiedemann et al. 1987), which showed that FC counts remained elevated even after livestock were removed under intensive management to maximize livestock production.

Another objective of the present study was to determine the source of bacterial contamination in streamwater. The ratio of FC to fecal streptococcus (FS) has been proposed as a way to determine the source of bacterial contamination in wildland streams and lakes (Geldreich, 1967). Geldreich introduces the concept by noting a FC/FS ratio of 4 in human and domestic waste and 0.7 in runoff and waste from livestock and poultry (chicken, *Gallus gallus domesticus*) in feedlots and stockyards. Geldreich and Kenner (1969), Van Donsel and Geldreich (1971), and Geldreich (1976) establish ranges of FC/FS in feces for humans, > 4; cattle, 1.2 to 0.08; cattle and wildlife, 0.08 to 0.04; and wildlife, < 0.04. Applying the ratios to pasture and wildland settings, however, has met with mixed results. Doran and Linn (1979) observed ratios of 0.04 to 1.2 in streamflow from grazed pastures compared with 0.001 to 0.08 from ungrazed pastures. On irrigated sites in Colorado, Kunkle and Meiman (1968) found ratios < 1.0 on ungrazed land and 1.7 to 5.5 on grazed land. Others have attempted to use the ratio concept on wildland streams but were unable to distinguish human contamination from nonhuman and cattle contamination from wildlife (Messley and Kingsbury, 1973; Skinner et al., 1974).

Several characteristics of streams may influence bacterial counts: discharge, turbidity, conductivity, pH, and temperature. Diurnal fluctuations of bacterial counts sometimes relate to discharge, but evidence is contradictory. McSwain and Swank (1977) report an inverse relation to flow, but Kunkle and Meiman (1968) and Kunkle (1970) relate peaks in bacterial counts to rises in stream stage height and attendant flushing of streambanks. Coliform counts seem to be inversely related to stream temperature (Clemm, 1977; Geldreich and Kenner, 1969; Kunkle and Meiman, 1968). Extremes of pH also influence coliform bacteria viability with 5.5 to 7.5 as a safe range (McFeters and Stuart, 1972). Apparently, no information is available on effects of turbidity on bacterial counts, although increased turbidity may correlate with higher counts because high turbidity is associated with stirring of bottom sediments (a protracted source of coliform bacteria). Concentrations in sediment may be 100 to 1000 times greater than those in overlying water (Hendricks and Morrison, 1967; Stephenson and Rychert, 1982; Van Donsel and Geldreich, 1971). Our fourth objective was to test for relations among FC concentrations and stream discharge, temperature, pH, conductivity, and turbidity.

This study is a companion to a 6-yr study of effects of increased intensity of grazing management, season, and watershed characteristics on bacterial water quality (Tiedemann et al., 1987). In that study, samples were collected monthly and only FC levels were measured. Increased sampling intensity (7-d intervals) and measurements of FS in this study let us compare FC counts to Oregon water quality standards and to examine the sources of contamination. Measuring stream characteristics when samples were collected allowed us to relate FC levels to environmental variables during summer.

STUDY AREA AND BACKGROUND

This study was part of the Oregon Range Evaluation (EVAL) Project, which was established in 1976 to implement known range management techniques and evaluate their impacts on range and associated resources (Sanderson et al., 1988).

Four intensities of range management formed the basis for evaluations in this study:

A. Control—no grazing.
B. Grazing with no attempt to attain uniform livestock distribution throughout a pasture.
C. Grazing management to attain uniform livestock distribution throughout a pasture with fencing and water developments.
D. Intensive grazing management to maximize livestock production. Includes practices to attain uniform livestock distribution and improve forage production with cultural practices such as seeding, fertilizing, and forest thinning.

The EVAL studies were located in eastern Oregon near John Day and included about 140 500 ha on 19 Forest Service, USDA, grazing allotments, and 21 private ranches. Study watersheds were in the northern part of the Malheur National Forest and were part of larger grazing allotments.

Watersheds ranged from 1.2 to 18.1 km^2 and from 1450 to 1992 m mean elevation (Table 1). Predominant habitats were mountain meadow, western larch (*Larix occidentalis* Nutt.)-Douglas-fir [*Pseudotsuga menziesii* (Mirbel) Franco], fir-spruce [*Abies lasiocarpa* (Hook.) Nutt.-*Picea engelmannii* Parry ex Engelm.], ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.).

Climatic data from the Austin, OR, station indicated that 70% of the average annual precipitation is received as snow between November and April (NOAA, 1984). Average annual temperature is 2 °C with monthly means of −9 °C in January and 14 °C in July. Daily maxima exceed 32 °C in summer. During winter, daily minima below −18 °C are common.

Runoff patterns are similar to those reported for other watersheds in the interior northwest (Fowler et al., 1979; Helvey et al., 1976). Snowmelt runoff begins in March in low-elevation watersheds and in mid-May in high-elevation watersheds. Peak discharge occurs from mid-April to early June, depending on elevation and aspect

Table 1. Range management strategy, ecosystem, and physical characteristics of the 13 study watersheds.

Watershed	Watershed code	Range management strategy	Ecosystem†	Drainage area, km²	Elevation, m (above MSL) Min.	Mean	Max.
Big Creek	BI	A	FS	5.2	1817	1992	2225
Blackey Creek	BL	A	L	2.3	1599	1932	2344
Caribou Creek	CA	C	PP	6.3	1238	1493	1905
East Donaldson Creek	ED	C	L	4.1	1235	1478	1732
East Little Butt Creek	EL	C	L	3.0	1199	1487	2004
Flood Meadow§	FL	D	LP/MM	18.1	1553	1678	1892
Keeney Meadow	KE	D	MM/PP	12.7	1638	1690	1862
Lake Creek	LA	A	L	1.2	1532	1611	1732
Little Boulder Creek	LB	C	L	6.0	1453	1786	2301
Ragged Creek	RA	A	L	8.8	1193	1559	1908
Tinker Creek	TI	D‡	L	4.4	1472	1611	1886
West Donaldson Creek	WD	C	L	3.9	1235	1450	1659
West Little Butte Creek	WL	B	L	4.6	1199	1532	2277

† FS = fir/spruce, L = larch/Douglas-fir, MM = mountain meadow, PP = ponderosa pine, LP = lodgepole pine.
‡ The D strategy at TI was attained in water year 1981; all other strategies were attained in water year 1979.
§ Flood Meadow was not grazed in 1984.

of watersheds. Flows diminish during summer with the lowest occurring in August and September. Peak flows on these watersheds range from 5.7 to 634 L s^{-1} km^{-2}. Late-summer minimum flows range from 0.03 to 4.8 L s^{-1} km^{-2}.

METHODS

Grab samples of streamflow were collected from each watershed at 7-d intervals from 3 July through 25 Sept. 1984 by using commerical, disposable, sterile, plastic containers. Samples were placed on ice in a cooler, transported to the laboratory, and analyzed within 8 h of collection.

During the 3 months, 13 samples were collected from each of the 13 watersheds. Stream temperature was measured with a hand-held thermometer at the time of sample collection. Measurements of stage height were recorded at the time of sample collection and used to determine instantaneous discharge from rating tables established for each stream. Rating tables were developed from current meter measurements of discharge and water depths above control structure (Wisler and Brater, 1959).

Samples were analyzed for FC and FS concentrations by using the membrane-filter technique with incubation on commercial (Millipore[1]) membrane-filter culture medium (Rand et al., 1976). Culturing was done in tight-fitting dishes on an aluminum-block incubator with temperature control to within 0.2 °C accuracy.

When high counts were anticipated, samples were diluted. Data for actual FC counts are strongly skewed toward lower counts (Tiedemann et al., 1987), but distribution can be improved by conversion to $\log_{10}$; therefore, counts of FC per liter (or per 100 milliliter) were transformed to $\log_{10}$. To account for values of zero in the analysis, the transformation was done using FC•100 mL^{-1} + 1. This value was then multiplied by 10 to express counts on a per-liter basis. Concentration data are presented as log (geometric) means. Hydrogen ion activity (pH) of each sample was measured with pH paper by using a wide-range, low-buffer strip for pH to within 1 unit and narrow-range paper for pH 0.2 unit within the range established by the wide-range paper. Turbidity was determined with a turbidity meter designed to read in nephelometric turbidity units (NTU) (Rand et al., 1976). Conductivity, dS m^{-1}, was measured using platinum electrodes and a solu-bridge (Rand et al., 1976).

Concentration data for FC were analyzed as a split-plot in time (sample dates) with strategies and watershed-within-strategy as the main plot factor and main plot error term (Steel and Torrie, 1960). Bartlett's test was used to determine homogeneity of variance among dates (Steel and Torrie, 1960). Where the *F*-test was significant in the analysis of variance for all dates, the least significant difference (LSD) test (Carmer and Swanson, 1971) was used to determine the significance of differences among means. No differences in homogeneity of variance were found among individual sample dates; the data were, therefore, combined into one analysis with dates as a factor.

Results were compared with the Oregon water quality standard for the John Day River basin by calculating 29-d rolling geometric means (five weekly samples). The 13 samples collected from 3 July through 25 September were used to establish mean FC levels for nine periods. Rolling means were determined by taking values for the first five sample dates referenced by the middle date of the 29-d period and by advancing one sample date to determine the mean of the next period. The nine rolling means provide a more intensive view of water quality on a week-by-week basis throughout the sample period than if we had used discrete 5-wk periods. The latter technique would have allowed us to compare results to Oregon standards for only two sample periods. Individual samples were also compared to the 4 × 10^3 L^{-1} (400•100 mL^{-1}) standard to determine if 10% of the samples exceeded this level.

Effect of cattle presence or their previous presence on FC concentrations was evaluated by establishing three criteria—cattle not present, cattle present, and cattle previously present. The category, cattle not present, was represented by samples collected from ungrazed strategy A watersheds and from watersheds prior to cattle entry for the current season. The cattle-present criterion was represented by those sample dates when animals were actually in the pasture. The last category, cattle previously present, was represented by samples collected after animals had been removed during the current grazing season. The cattle-not-present criterion for grazed watersheds is probably confounded to some degree by elevated FC levels from grazing the previous year, especially on strategy D watersheds (Tiedemann et al., 1987). These data were analyzed using a design similar to that described above with cattle presence as a main effect. The error term for this analysis was "watershed by cattle presence within strategy."

Concentrations of FS were used for calculating the FC/FS ratios to determine the source of bacterial contamination based on FC/FS ratios proposed in the literature. Because some watersheds were ungrazed, the FC/FS ratios were also used to assess the validity of the ratio concept for distinguishing wildlife from cattle pollution sources. The FC/FS ratios were calculated only for samples meeting the criteria established by Geldreich (1967), Geldreich and Kenner (1969), Geldreich (1970), and Greenberg et al. (1985): collected less than 24 h of stream travel from the pollution source; having FS counts greater than 1 × 10^3 L^{-1} (> 100•100 mL^{-1}); and collected when pH was between 4.0 and 9.0. Average low flow stream travel time from source to mouth of each stream was estimated by measuring actual travel time (m s^{-1}) in several short reaches (20–150 m) with dye and extrapolating to the entire stream. These measurements were taken in late summer 1983. Computation of FC/FS ratio was done using actual concentration values of both—not the $\log_{10}$ transformation. In addition to computing the FC/FS ratio, we plotted time trends of FS to determine if concentrations were related to presence of cattle. No statistical comparisons were made among grazing strategies for FS, nor were any comparisons made with environmental parameters.

The FC/FS ratios as indicators of sources of bacterial contamination were evaluated by determining the number of

[1] Mention of product name does not imply preference nor constitute endorsement by the USDA Forest Service.

samples from each watershed that fell into each of the following categories: 1.2 to 0.08, cattle; 0.08 to 0.04, cattle and wildlife; and < 0.04, wildlife.

Relations among FC counts and environmental variables were analyzed by partial correlation after effects of range management strategy were removed.

RESULTS AND DISCUSSION

Comparisons of Fecal Coliform Levels among Grazing Strategies

Analysis of variance indicated significant differences ($P < 0.01$) among strategies, watersheds within strategies, and dates for the 3-month sample period. The effect of strategy was also consistent among dates as indicated by the nonsignificant strategy × date interaction. Geometric mean FC counts for the 3 months were 40 L^{-1} (4•100 mL^{-1}) for strategy A, 90 L^{-1} (9•100 mL^{-1}) for strategy C, 150 L^{-1} (15•100 mL^{-1}) for strategy B, and 920 L^{-1} (92•100 mL^{-1}) for strategy D. Statistically, the only significant differences in strategies ($P < 0.05$ by the LSD test) were lower counts in strategies A and C than in strategy D. In the longer term study (Tiedemann et al., 1987) with monthly sampling from 1979 to 1984, summer FC counts were significantly different ($P < 0.05$) for each strategy and were arrayed A < C < B < D. Similarity of counts in watersheds in strategies A and C in 1984 may be because two of the five strategy C watersheds were not grazed until the last week of sampling. Similarity of FC counts in watersheds in strategies A and B in 1984 may be the result of decreasing cattle use and decreasing FC counts at West Little Butte (strategy B) between 1979 and 1984 as documented in the long-term study (Tiedemann et al., 1987). Figure 1 shows the array of FC counts among watersheds. Strategy A watersheds and all but one strategy C watershed had less than 100 FC L^{-1} (< 10 FC•100 mL^{-1}). Average FC counts on Caribou, a strategy C watershed, were similar to those on strategy D watersheds, (650 L^{-1}; 65 •100 mL-1). Average FC count for the single strategy B watershed, West Little Butte, was 150 L^{-1} (15•100 mL^{-1})—not substantially different from counts for watersheds in strategies A and C. On strategy D watersheds, FC counts ranged from 190 L^{-1} (19•100 mL^{-1}) at Flood (not grazed in 1984) to 2.27×10^3 L^{-1} (227•100 mL^{-1}) at Tinker Creek. Differences in physical and vegetation characteristics among watersheds played a major role in the degree of FC contamination that occurred. Strategy A watersheds were ungrazed, and low FC counts were expected. For strategy C watersheds, except Caribou Creek, attempts at achieving uniform livestock distribution and use were successful, partly because these watersheds did not have meadows next to the stream to attract livestock. Caribou Creek (strategy C) has a stringer meadow along the main channel that attracted cattle so that FC counts were similar to those for strategy D. Elevated FC levels associated with grazing were anticipated from Caribou Creek, because when cattle are on the pasture, they frequently concentrate in the meadow along the stream.

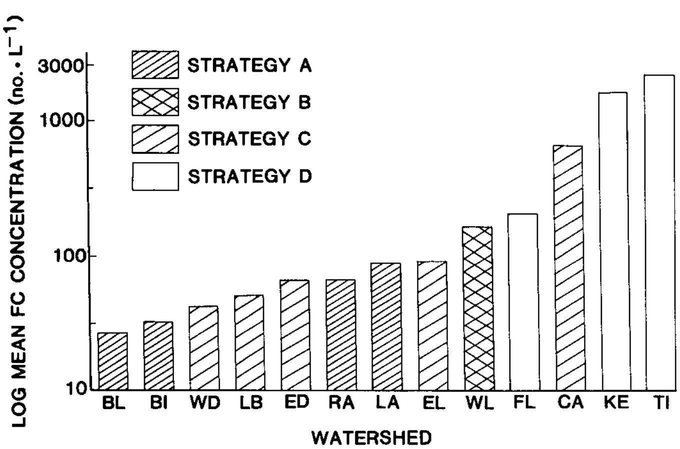

Fig. 1. Log mean fecal coliform concentration by watershed, July through September 1984.

Strategy D watersheds had different physical and vegetation characersitics than other watersheds. All three of these watersheds have prominent meadows where strategy D seeding and fertilization treatments could be installed. These meadows also attract livestock because of water, gentler terrain, and forage that is more abundant and succulent than that of upland areas. Average stocking rate of livestock was also a factor in higher FC counts in strategy D watersheds than in strategies B or C. Stocking rate in strategy D was 2.8 ha per animal unit month (AUM) compared to 8.2 and 7.7 ha AUM^{-1} for strategies B and C, respectively. The actual number of animals on a watershed is probably not as important as watershed characteristics, as indicated by FC levels in Caribou (strategy C) being comparable to those in strategy D watersheds despite a substantially lower stocking rate at Caribou (4.9 ha AUM^{-1}).

Comparison with Oregon Water Quality Standards

Two strategy D watersheds, Keeney Meadows and Tinker, violated the 30-d $\log_{10}$ Oregon standard of no more than 2×10^3 FC L^{-1} (200 FC•100 mL^{-1}). Keeney violated the standard for two periods, those measured 24 July to 21 August (mid-point 7 August) and 28 August to 25 September (mid-point 11 September) (Fig. 2A). Tinker was in violation for the major part of the sampling period, 3 July to 11 September (mid-points 17 July to 28 September) (Fig. 2B). The September decline in FC coincided with removal of cattle on 3 September. Flood Meadow, the other strategy D watershed, was not grazed in 1984 and FC counts remained below the standard. Caribou Creek, strategy C, approached the standard between July 24 and 31, but counts then declined rapidly (Fig. 2C). This decline coincided with removal of the cattle from the pasture (8 August). All other watersheds were well below the recommended standard during the 3-month sampling period.

Counts in excess of 4×10^3 FC L^{-1} (400 FC•100 mL^{-1}) were observed in more than 10% of the samples collected from Keeney Meadows and Tinker. The intensive grazing strategy D imposed on these watersheds resulted in violation of this standard. On Caribou (strategy C), one sample exceeded the 4×10^3 FC L^{-1} (400 FC•100 mL^{-1}) standard. This represented 20% of the samples for that period and a violation of the 10%, 4×10^3 FC L^{-1} (400 FC•100 mL^{-1}) standard.

Effects of Cattle or their Previous Presence on Fecal Coliform Levels

Cattle presence or their previous presence did not have a significant ($P = 0.101$) effect on FC concentrations. Comparisons among means were striking, though, with a ninefold greater FC count when cattle were present than when they were not [469 L^{-1} (46.9•100 mL^{-1}) compared with 56 L^{-1} (5.6 •100 mL^{-1})]. Average FC count after cattle were removed (cattle previously present category) was 185 L^{-1} (18.5•100 mL^{-1}). Differences were not significant because of large variability in counts among watersheds within a given category. For example, counts of FC in Keeney Meadows (strategy D) for the four sample dates prior to the time cattle grazing began (cattle not present) averaged 1.34×10^3 L^{-1} (134•100 mL^{-1}). For Lake Creek (strategy A, cattle not present), counts for the same period averaged 35 L^{-1} (3.5•100 mL^{-1}). This comparison also reinforces the conclusion from our long-term study (Tiedemann et al., 1987) that FC levels remain elevated up to 9 months after the animals have been removed from the watershed. Comparison among the three categories was most striking for strategy D. Average counts of FC were 270, 2.69×10^3, and 1.55×10^3 L^{-1} (27, 269, and 155•100 mL^{-1}) for cattle not present, cattle present, and cattle previously present, respectively.

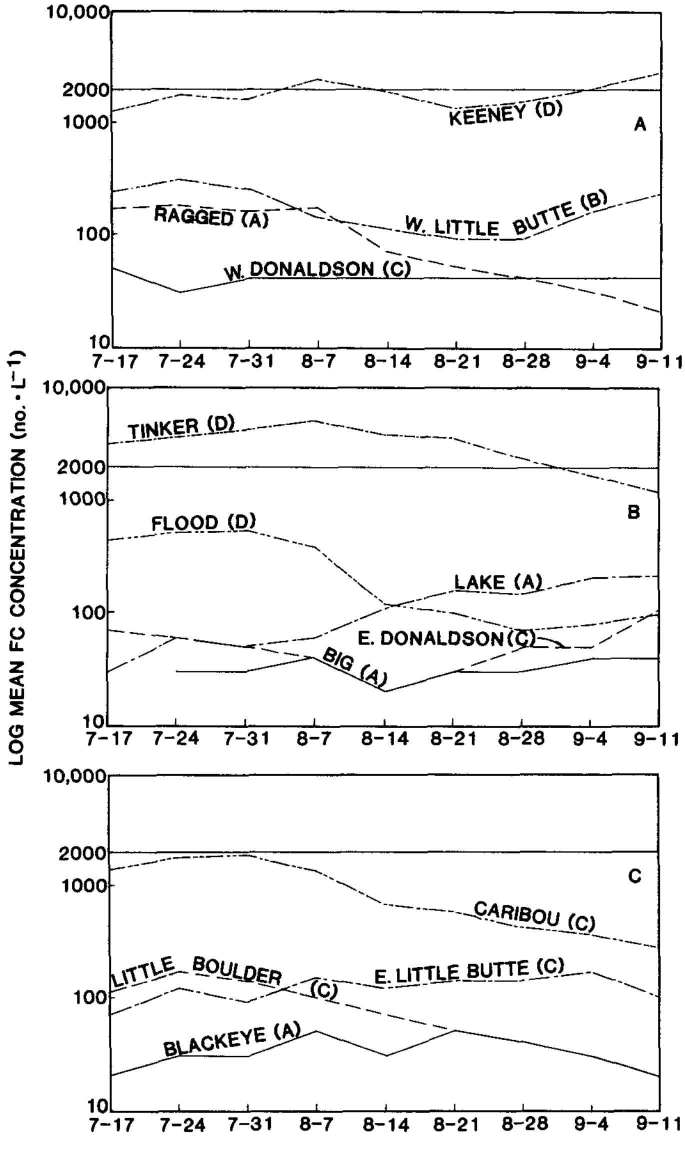

Fig. 2. Rolling 29-d log mean fecal coliform concentrations. Solid line at 2×10^3 FC L^{-1} (200 FC•100 mL^{-1}) represents the 30-d log_{10} Oregon standard. (*A*) W. Donaldson, Ragged, W. Little Butte, and Keeney Creeks; (*B*) Big, E. Donaldson, Lake, Flood, and Tinker Creeks; (*C*) Blackeye, Little Boulder, E. Little Butte, and Caribou Creeks.

Within a given strategy, large variations also occurred in response to cattle presence. For Little Boulder (strategy C), mean FC count was 150 L^{-1} (15•100 mL^{-1}) for the six sample dates when cattle were present. This contrasted with a mean FC count of 1.85×10^3 L^{-1} (185•100 mL^{-1}) on Caribou Creek (also strategy C within the same grazing unit) for the six sample dates when cattle were present. Watershed characteristics played a major role in this variability. Little Boulder is a relatively high-elevation watershed with a deep, steeply incised drainage that discourages cattle from using the channel bottom. Caribou, in contrast, is a low-elevation watershed with stringer meadows that increase the accessibility of the stream channel to livestock. These meadows also may attract cattle use because of forage that is more succulent than that of surrounding hillsides.

Fecal Coliform/Fecal Streptococcus Ratios as Indicators of Source of Bacterial Contamination

Time trends of FS bacteria for summer 1984 were distinct for nine of the watersheds with average counts increasing from less than 2×10^3 FS L^{-1} (200 FS•100 mL^{-1}) in early July to approximately 3×10^4 FS L^{-1} (3000 FS•100 mL^{-1}) by early to mid-August and declining by September to levels of early July (Fig. 3). These watersheds were in strategies A through C and had mostly western larch and Douglas-fir as forest overstory. The four watersheds that did not display this trend were Big Creek, strategy A; Caribou Creek, strategy C; and Flood and Keeney Meadows, strategy D (Fig. 3). Predominant vegetation on these watersheds was fir-spruce, ponderosa pine, and mountain meadow-lodgepole pine. Average counts of FS on western larch-Douglas-fir watersheds were significantly higher [1.081×10^4 L^{-1} (1081•100 mL^{-1}) $P < 0.10$] than they were on the watersheds dominated by other vegetation [4.26×10^3 L^{-1} (426•100 mL^{-1})]. We speculate that the increase in FS in mid to late summer on the western larch-Douglas-fir watersheds was the result of insect activity peculiar to this ecosystem. Douglas-fir trees on these watersheds were being defoliated by the spruce budworm (*Choristoneura occidentalis*) during 1984.

Calculation of the FC/FS ratio is valid only when more than 1×10^3 FS L^{-1} (100 FS•100 mL^{-1}) are present, pH is >4.0 and <9.0, and the sample point is <24 h stream travel time from the source (Geldreich, 1967, 1970; Greenberg et al., 1985). All samples met the criteria for travel time and pH levels. Nineteen of the 168 samples did not meet the 1×10^3 FS L^{-1} (100 FS•100 mL^{-1}) criterion, however, and were excluded from the analysis. On strategy A, B, and C watersheds, the majority (72–90%) of samples had an FC/FS ratio < 0.04 indicating that wildlife was the primary source of bacterial contamination (Fig. 4). Most of the samples (9) indicating cattle pollution in strategy C were from Caribou Creek. Cattle appear to be the main source of bacterial contamination on strategy D watersheds; most (76%) of samples had FC/FS ratios between 1.2 and 0.08.

The number of samples indicating cattle as the source of pollution (FC/FS ratio 1.2–0.08) was plotted as a function of the log mean of FC levels for all watersheds. The linear regression equation, log mean FC = 1.14 + 0.377 X (where X = number of samples with FC/FS ratio 1.2–0.08) describes the relation with $R^2 = 0.90$. The regression coefficient was highly significant ($P < 0.01$). This direct relation between FC counts and the FC/FS ratio indicating that cattle are the predominant source of contamination lends support to the ratios proposed for distinguishing bacterial contamination from wildlife and cattle.

Relation of Fecal Coliform Concentrations to Environmental Parameters

Partial correlation analysis of FC concentration with stream characteristics measured during sample collection were significant ($P < 0.05$) only for pH and turbidity, after the effect of range management strategy was removed (Table 2). Although the partial correlation coefficients for pH and turbidity were significantly different than zero, the relations were weak (Table 2).

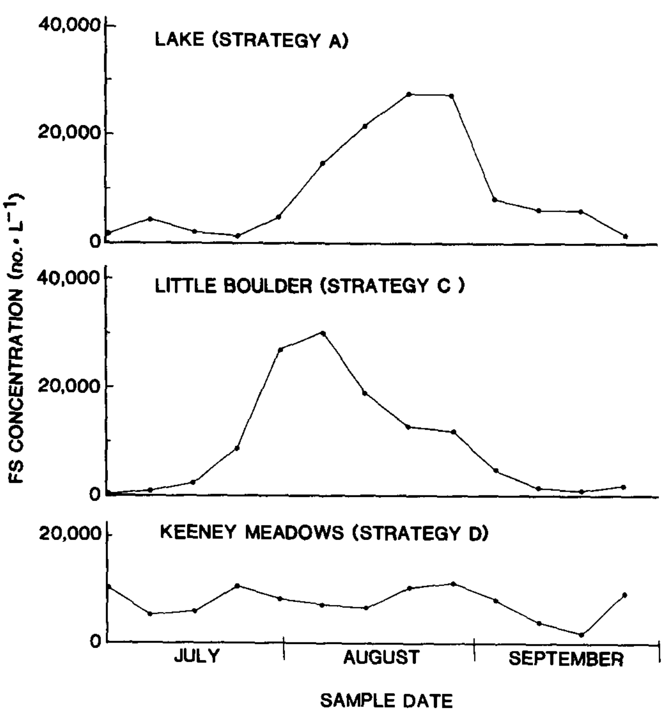

Fig. 3. Time trends of fecal streptococcus in streamwater, July through September 1984, for representative watersheds of western larch–Douglas-fir (Lake and Little Boulder Creeks) and other ecosystems (Keeney Meadows).

Table 2. Partial correlation coefficients for environmental parameters with log_{10} fecal coliform concentration after effects of range strategy was removed.

Parameter	Correlation coefficient	Significance level < P
Log discharge	0.0854	0.386
Water temperature	−0.0446	0.651
Stream pH	0.2376	0.014
Stream conductivity	−0.1084	0.271
Turbidity	0.4107	0.001

CONCLUSIONS

The primary intent of this research was to determine the effect of four different strategies for managing grazing on bacterial water quality and to compare the results to Oregon water quality standards. The Oregon standard for FC concentrations in streams within the John Day River basin is not greater than 2×10^3 L^{-1} (200•100 mL^{-1}) based on a log mean (geometric mean) of five samples collected within 30 d. Also, no more than 10% of the samples during the 30-d period can exceed 4×10^3 FC L^{-1} (400 FC•100 mL^{-1}). Two of the strategy D watersheds exceeded the 2×10^3 FC L^{-1} (200 FC•100 mL^{-1}) standard for several periods during summer 1984. On two strategy D watersheds, more than 10% of the samples also exceeded the standard of 4×10^3 FC L^{-1} (400 FC•100 mL^{-1}). Management under strategy D caused significantly greater concentrations of FC in streamwater than did management under strategies A and C. Although FC counts in strategy B did not differ significantly from strategy D, this comparison was based on only one strategy B watershed. The strategy B watershed showed continuous declines in FC levels between 1979 and 1984; this decline appeared to be related to changes in use patterns by livestock resulting from fencing (Tiedemann et al., 1987). Although stocking rate was higher on strategy

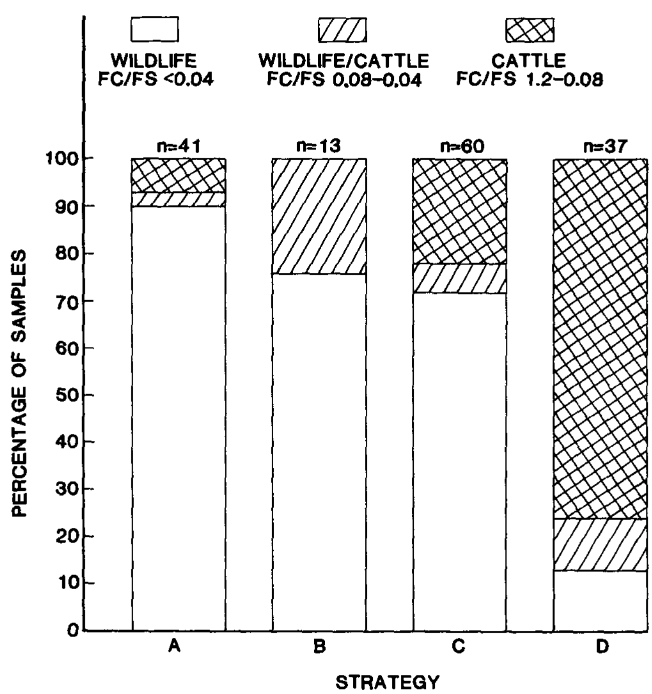

Fig. 4. Percentages of samples with FC/FS ratios indicative of wildlife, wildlife/cattle, and cattle pollution for each range management strategy.

D watersheds (2.8 ha AUM^{-1}) than on strategy B or C watersheds (8.2 and 7.7 ha AUM^{-1}, respectively), the major difference in FC levels among watersheds appeared to be related to differences in watershed characteristics. The strategy D watersheds all had meadow areas that attracted animals to the stream area. One strategy C watershed (Caribou) had FC levels comparable to those for strategy D, including one violation of the 10%, 4×10^3 FC L^{-1} (400 FC•100 mL^{-1}) 30-d standard. This watershed also had stringer meadows that attracted livestock to the riparian area.

Tests of the relation between cattle presence on the pasture and FC levels were inconclusive, primarily because of variation in response among watersheds within a given strategy. Comparison of FC levels for intensively managed strategy D watersheds before grazing [1.34×10^3 L^{-1} (134•100 mL^{-1})] with those of ungrazed strategy A watersheds [35 L^{-1} (3.5•100 mL^{-1})] reinforced the conclusion of our long-term study (Tiedemann et al., 1987) that FC levels may remain elevated for up to 9 months after the animals are removed.

The FC/FS ratio as an indicator of source of contamination showed that cattle were the primary contributors to elevated FC levels on strategy D watersheds and in one strategy C watershed. The ratio also suggested that wildlife may be the primary contributors to FC bacteria in watersheds managed under strategies A, B, and C (excluding Caribou Creek). Numbers of samples with FC/FS levels indicative of cattle as a source of contamination (1.2–0.08) was positively and significantly correlated with average FC concentrations. Our results lend support to the use of the FC/FS ratio (Geldreich, 1967) to distinguish cattle from wildlife sources of pollution.

Contrary to results from some other studies relating FC concentrations to stream characteristics, we found no correlations to stream characteristics (water temperature, stream discharge, or electrical conductivity) after we adjusted for effects of range management strategy. Fecal coliform levels were significantly related to stream pH and turbidity, but the correlations were weak.

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